ENHANCING WATER SECURITY THROUGH RESTORATION AND MAINTENANCE OF ECOLOGICAL INFRASTRUCTURE: LESSONS FROM THE UMNGENI RIVER CATCHMENT, SOUTH AFRICA

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Water Research Commission

by

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EXECUTIVE SUMMARY

The uMngeni River Basin supports over six million people, providing water to South Africa's third largest regional economy, contributing approximately 11%, or about R460 billion, to national GDP (Hay, 2017). It is therefore a significant catchment that contributes to human wellbeing locally, regionally and nationally. It supports South Africa's third largest city, Durban, as well as an important secondary city and political and administrative centre, Pietermaritzburg. It covers an area of 4 440 km^2 and has an average annual rainfall of a little under 1000 mm. The catchment is dominated by agricultural activities in the upper reaches, including dairy, beef, poultry, timber and sugar cane. The middle and lower reaches are dominated by urban development, industry and mixed rural-urban land uses. The area under commercial plantation forestry in the basin ranges from 650 000 to 740 000 ha of eucalyptus/pine trees. These plantations are estimated to reduce streamflow by approximately 64 million cubic metres per annum. Alien invasive vegetation in the catchment is estimated to consume between 12 and 15 million cubic metres of water over and above what would have been consumed by natural vegetation. Despite a series of dams (Nagle, Midmar, Albert Falls, and Inanda) within the uMngeni River catchment, it remains a water stressed catchment, which is only just meeting the water demands of its inhabitants. The Spring Grove Dam on the Mooi River has recently been completed and the Smithfield Dam on the uMkhomazi River is in the planning phases. These dams are planned to meet water demands now and into the future. However, the catchment is considered to be a closed catchment, unless more water can be transferred in to it from other adjacent catchments. The water resources in the catchment are seriously threatened by point (WWTW) and diffuse sources of pollution, which causes eutrophication, very high microbial occurrence, health impacts on both people and ecosystems, reduction in water clarity and unpleasant odours. This poses a serious threat to a wide range of water users in the catchment, with a particular impact on recreation and tourism. Indications are that the Duzi canoe marathon numbers are declining, which impacts on revenue and employment in the catchment. Diffuse pollution varies across the catchment and, unlike point source pollution, it is a function of the topography, land use, land management, soil type, hydrology and climate. The anticipated urban and industrial development in the uMngeni system will increase the demand for water, which exceeds the presently available water resources.

However, even with these challenges the uMngeni River and its catchment continues to provide the resources required to sustain the economy of this growing region, supporting human wellbeing, economic development, social needs and ecosystem services. The critical question facing the catchment is how to sustain and enhance water security in the catchment. The role of ecological infrastructure (EI) in enhancing and sustaining water and sanitation delivery in the catchment has been recognised.

The overall aim of this project was to identify where and how investment into the protection and/or restoration of EI can be made to produce long-term and sustainable returns in terms of water security assurance. In short, the project aimed to guide catchment managers when deciding "what to do" in the catchment to secure a more sustainable water supply, and where it should be done. This seemingly simple question encompasses complexity in time and space, and reveals the connections between

different biophysical, social, political, economic and governance systems in the catchment. The project partnered with other research initiatives in the catchment, including projects funded through the Green Fund of the DEA/DBSA. The uMngeni River catchment has become a focus area and pilot study site through various initiatives, with research and social learning being consolidated through the uMngeni Ecological Infrastructure Partnership (UEIP). Through this initiative, more than 24 government departments, academic institutions, private companies and NGOs have signed a MoU which documents their commitment to investing in restoring, maintaining and managing EI for water security. In an attempt to ensure uptake of the research products, the project was aligned with UEIP restoration initiatives, including Mpophomeni (upper catchment), the Baynespruit in Pietermaritzburg (middle catchment), the Palmiet River catchment and Mzinyathi in eThekwini Municipality (lower catchment).

Over the past five years, the project has explored the conceptual and philosophical basis for investing in EI. This report demonstrates how EI can be utilised to secure water for the benefit of society through research focused on selected case studies in the uMngeni River catchment. This addresses a critical gap in moving from the many vague and broad conceptual ideas of how EI could form part of a catchment management strategy, to demonstrating how this can be an integral component of future water resource management plans in cities and urban areas, and ultimately, in a catchment management strategy, should a Catchment Management Agency be established.

Through the study, we highlight that there is an interdependent and co-constitutive relationship between EI, society, and water security. In particular, by working in spaces where EI investment is taking place, it is evident that socio-economic, environmental and political relations in the catchment play a critical role in making EI investment possible, or not possible. **In contrast to many projects which have identified this complexity, here, we move beyond identification and actively explore and explain these interactions and provide lessons based on these experiences and analyses.** The study inherently addresses aspects of water quantity and quality, economics, societal interactions, and the governance of natural resources. It highlights that ensuring the availability and sustainable management of water resources requires both transdisciplinary and detailed biophysical, economic, social and development studies of both formal and informal socio-ecological systems, and that investing in human resources capacity to support these studies, is critical. To this end, an Opportunities and Risks Framework for Investing in Ecological Infrastructure (ORF4Ei – Chapter 2) was created to guide future development plans. We have produced 10 Lessons for investment in EI that are critical in the uMngeni River catchment, which have emerged from this five-year research project. These lessons are also applicable wherever investments in EI are being considered. Ultimately, we identify opportunities in the uMngeni River catchment where investment into the maintenance and/or rehabilitation of EI can produce long-term and sustainable returns for the delivery of water-related ecosystem services, showing these spatially in an annotated map form.

Project Objectives

1. *To investigate and report on the status of catchment land-use and water resource quality in the selected sub-catchment(s).*

Through numerous project Deliverables and student-led papers and dissertations, we have thoroughly investigated the status of catchment land-use and water resource quality through the various case studies and also synthesised these findings at a catchment scale. Details of these papers and projects are provided in Chapter 6 and the Appendices to the report.

2. *Cost the impacts of the degradation of ecosystem infrastructure on water users from different stakeholder experiences using an evidence-based approach.*

We explored the economics of investing in EI through four case study assessments. We considered the costs and benefits of investing in wetland rehabilitation for improved water quality; identified and evaluated multiple options for water quality and stormwater management in a small urban catchment; explored water supply benefits that could be achieved through maintenance and rehabilitation of grasslands in the upper catchment; and investigated the relationship between raw water quality and treatment costs at two water treatment works within the catchment. We conclude that there are clear water quantity and quality benefits from investing in EI in the uMngeni River catchment and that these opportunities are optimised from a perspective that views water security investments along a continuum where built infrastructure (BI) and EI investment complement each other, rather than being considered as “one or the other”.

3. *Investigate how an intact EI could secure and enhance the benefits provided to society and economy in the catchment.*

These diverse case assessments generated several interesting findings, raised a number of questions and invoked much cross-disciplinary discussion. Interestingly, while each case focus was different, common themes and learnings emerged, from which we can draw several globally relevant lessons. Ultimately, an assessment of the benefits of investing in EI at a catchment level and the potential for reducing the core cost drivers of the local water utility, supporting water security in the catchment was highlighted.

4. *Investigate how investment in the protection and enhancement of the environmental asset base (or EI) of the uMngeni River catchment could contribute to resilient economic growth, greater social equity and justice and the reduction of environmental risks, thereby addressing the goals of the green economy.*

We have synthesized the findings from the various project Deliverables and used these to map the connections between them (See Objective 7). On the basis of this, we have developed the Opportunities and Risks Framework for EI (ORF4Ei), which can be used by decision makers in the catchment to identify appropriate strategies and types of EI interventions, entry points for EI interventions, and barriers, enablers, and levers of change aligned with the goals of the green economy.

5. *With the aid of the stakeholder water resource management framework produced in phase 1, develop a cost-effective conservation management strategy based on the principles of the green economy.*

The key elements of the framework developed in Phase I and II of the Shared Rivers initiative (Pollard et al., 2011; 2013) provided a basis for understanding the social phenomenon of collective action, but strongly focused on maintaining The Reserve and linked to the CMA in their study catchment(s). The ORF4Ei captures the elements of that framework and organises them in a context relevant to the uMngeni that can be used as a strategic tool to identify opportunities and risks for investment in EI as a component of any catchment management plan that is developed once a CMA is established.

6. *Develop and train actors in the catchment in an appropriate governance model/approach, which includes social learning, knowledge production (including spatial knowledge), participatory engagement and technical methods (models, guidelines, indicators, procedures) necessary to achieve a paradigm shift to transform society, and the economy towards a healthy relationship with the EI within the*

catchment, i.e. to change the socio-ecological relations in the catchment to ensure greater resilience through the development of a transformative governance approach.

In the uMngeni River catchment, we are learning and experimenting with how to apply teaching and learning and social transformation methodologies that genuinely support change (Chapter 4). Our approach can be described as co-engaged, action learning through which pathways for change to a more sustainable future becomes an enabling process; where participants are part of the processes of change rather than being acted upon through awareness raising or communicated messages. The co-engaged learning pathways, which support action learning, are helping to overcome the weaknesses of top-down awareness raising or communicated messages from those who believe they know, to those whom they would like to deliver their messages.

Furthermore, through the project, students registered for post-graduate studies ranging from Honours (4th year) and Masters to PhDs have contributed to the knowledge production process of the project. In total, 3 Postdocs, 9 PhDs, 15 MSc, and 7 Hons students have been affiliated with the project. Of these numbers, those that have graduated within the project scope include 2 PhDs, 9 MSc, and 7 Hons, while the remaining students continue their studies with most in the final stages and on track to graduate in 2019.

7. *Describe the catchment connectivity from both bio-physical and social aspects that are core to understanding drivers of the catchment processes and characteristics.*

During the course of the project, a detailed methodology was developed and tested to assess water resource connectivity and inter-dependency (between water quality, quantity and access) from a landscape perspective (Chapter 2). This methodology enabled the researchers to build a catchment-level understanding of water-society-space relations in the uMngeni River catchment through the construction of an emergent water-society-space trialectic which, ultimately, formed the basis of the ORF4Ei (Chapter 6).

8. *Recommend further research on the social and ecological interface critical to improve natural resources governance at the catchment scale.*

Particular aspects which need further research have been synthesised from the project and are presented in map form (Figure 5.5).

Methodology

Given the complexity of the uMngeni River catchment and the need to investigate the WRC 2354 research questions in depth over a longer period of time, both the uMngeni Ecological Infrastructure Partnership (UEIP) members and the research team supported a case study approach to exploring the multiple factors shaping water security and EI in the catchment. The project team adopted an approach where research undertaken for this project supported the activities for the UEIP. Three of the case studies (Mpophomeni area, Baynespruit, and Palmiet catchments) were selected by those leading the establishment of the UEIP as they were spaces that exemplified the issues being faced and represented the different conditions of the catchment. The research team added the Mzinyathi catchment, as previous research had indicated the importance of understanding the impact of the rapid densification of peri-urban areas under traditional authority on water governance. Under the UEIP, various service providers in the catchment agreed to undertake specific restoration activities in the case study areas where they had a mandate to do so. Research was then aligned with, and supported these activities. This required that the research team and students were actively engaged with service providers, their activities, as well as the communities who lived and engaged with them in each case study area. **This interaction, engagement and action research, is reflected throughout the project and was fundamental in informing the process, shaping the**

methodology and ultimately, the findings and recommendations from the study. Following a detailed analysis of each of the case studies, a detailed methodology was developed and tested to assess water resource connectivity and inter-dependency (between water quality, quantity and access) from a landscape perspective (Chapter 2). This enabled the researchers to build catchment-level understanding of water-society-space relations in the uMngeni River catchment through the construction of an emergent water-society-space trialectic, which ultimately, formed the basis of the ORF4Ei (Chapter 6).

Results

The results from this study have been synthesised as Ten Lessons for Investment in Ecological Infrastructure. These lessons are applicable to the uMngeni River catchment, but will find resonance wherever such interventions are being considered, both in South Africa and globally.

Lesson 1: People (human capital), the societies in which they live (societal capital), the constructed environment (built capital), and natural capital interact with, and shape each other

By working in spaces where EI investment is taking place, it is clear that the socio-economic-political-environmental relations play a critical role in making EI investment possible, or not possible. This is a major learning: only in implementing or trying to implement EI investments on the ground, can the institutional, governance, social and biophysical complexity, and challenges that arise, be recognised. If we do not find ways to understand these interlinkages and address these challenges, investments in EI will never be sustainable.

Lesson 2: Investing in Ecological Infrastructure enhances catchment water security

Our studies have clearly shown that there are both water quality and quantity benefits of investing in EI for the uMngeni River catchment. Clearing IAPs is a relatively quick solution to providing additional streamflow without the burden of extensive legislative and financial arrangements that affect BI projects. Without the proposed uMkhomazi transfer scheme, the water resources supply to the residents of the uMngeni River catchment are under pressure with an estimated shortfall of approximately 50 million m^3 per annum. Although EI alone cannot provide the additional 200 million m^3 per annum forecast to be needed by 2030, our analysis shows that clearing IAPs in the catchment headwaters alone would provide 15.6 million m^3 of water at a 90% assurance of supply – enough to fill 25-30% of the planning and construction gap between now and the completion of the uMkhomazi transfer scheme. An important aspect is that EI provides a natural buffer against disaster from both quality and quantity perspectives and that investing in EI through maintenance and restoration enhances and sustains these benefits. Examples include the role of natural systems in both mitigating toxic chemical spills as illustrated by the recent Willowton Oil disaster, and the opportunity for removal of invasive alien plants to enhance water supply to the reticulation system more rapidly than the planning and construction of a dam.

Lesson 3: Investing in Ecological Infrastructure or Built/Grey infrastructure is not a binary choice

A key message from this study is that investment in infrastructure is not a binary choice between EI and BI – rather, they are complementary. Achieving water security requires investment in both. It is the integration of BI and EI, which provides the most realistic opportunities to sustain and finance EI and to ensure water security.

The study has confirmed that ecosystem-based solutions are multifunctional relative to BI. This is a key difference between ecosystem-based solutions and BI and deserves meaningful consideration in urban planning and management. Urban systems should integrate a mix of BI, ecosystem-based solutions (ecological and green infrastructure) and social initiatives to improve the management of urban water and wastes.

This approach is evident in the design of the new wastewater treatment works (WWTW) for the rapidly urbanizing settlement of Mpophomeni upstream of Midmar Dam, a key water resource. The water quality enhancement potential of healthy wetlands is recognized in the design of the new WWTW, with rehabilitation of portions of wetland adjacent to the WWTW and wetland systems at the outflow of the works included as a legal requirement of the environmental authorization for the proposed works.

Related to this, it can be argued that creating an additional Strategic Integrated Project (SIP), directly focused on EI, could in fact continue the artificial separation between BI and EI. Rather, opportunities to leverage funding for EI through ongoing infrastructure development projects, which recognise its value and complementary role should be sought (as expanded upon in Chapter 3).

Lesson 4: To be sustainable, investments in infrastructure need a concomitant investment in social and human capital

'Investing in EI' typically refers to actions taken to improve the condition of EI, maintain/preserve the existing condition and/or halt further declines in condition and may include physical interventions such as ecosystem restoration, rehabilitation, conservation, and management activities, but a key message from this study is that it must also include investments related to developing human capacity, strengthening institutions and governance, and influencing social behaviour. There is a need to invest in social learning, and the building of governance platforms, particularly building of state-citizen relations, society or human-environment relations, and society-environmental relations. One of the key learnings from this project is the importance of developing human and social capital if EI interventions are to make a difference. Building social and human capital is therefore considered to be an EI intervention, which extends traditional approaches of EI interventions in to the socio-political realm.

In essence, maintaining and restoring EI requires investment in human and social capital as an integral component. Efforts which tend to focus on Natural Capital alone will fail.

Lesson 5: Investing in Ecological Infrastructure is financially beneficial

The economic case assessments (see Section 3.4) have demonstrated the value of EI and emphasised the interactive and interdependent relationship between EI and BI.

From a water quality perspective, the benefit provided by the Mthinzima Wetland complex in mitigating the impacts of polluted run-off from Mpophomeni upstream of Midmar Dam has been highlighted. Even in its degraded condition, the wetland complex provides a water quality enhancement service. A cost-benefit analysis of the rehabilitation of a portion of the wetland system demonstrates that the benefits of rehabilitating the wetland – based on the costs of replacing the water quality enhancement service of the wetland with a standard 1 ML wastewater treatment plant – exceed the costs of rehabilitating and maintaining the wetland (benefit-to-cost ratio of 1.25 under an 8% discount rate and 20 year timeframe).

In a second case assessment, a qualitative multi-criteria evaluation supported by a cost comparison was undertaken to identify suitable investment options for improved water quality and stormwater management in the Baynespruit, a small urban catchment. Revegetation of degraded riparian areas in the catchment provides the greatest range of benefits, contributing to improved water quality and stormwater control, as well as providing additional co-benefits (e.g. biodiversity, aesthetic, recreation benefits). This has a relatively low implementation cost (R822 919). The BI options, while effective at achieving their main objective, provide the least opportunity for additional benefits and are relatively more expensive to implement and maintain (i.e. stream canalisation at a cost of R11 000 000 for implementation).

Additional case assessments demonstrated:

- The benefits (importance) of catchment maintenance compared to rehabilitation: Based on the Unit Reference Value (URV) approach, our analysis demonstrated that the cost per unit volume of water supplied (m^3) by maintaining grasslands is considerably lower (R0.31/m^3) than for restoring degraded areas (R2.44/m^3).
  - Savings on energy costs: Over the past 5 years, the cost of energy associated with bulk water supply in the uMngeni system has almost doubled. A proportion of these costs are associated with pumping water through transfer schemes and, particularly in drought periods, pumping water from relatively fuller supply dams to water treatment works (e.g. at a cost of R32 million in 2017). The average cost of pumping this water (2018) was R0.46 per m^3; indicating that every m^3 produced by the catchment upstream of these treatment works saves the water utility at least R0.46c per m^3. Based on these rates and the extent of invasive alien plants (IAPs) in the catchment, it can be argued that clearing the upper uMngeni of IAPs could save Umgeni Water approximately R15 million per year in pumping costs (at 2017 rates).

Most restoration programmes are supported by secondary government initiatives (e.g. the expanded public works programmes in South Africa) or corporate social investment funds, rather than being mainstream in development and infrastructure planning. The approach in this project has been to consider the opportunity to invest in EI through identifying opportunities to do so from existing tariffs and where BI needs have been identified, to include aspects of EI in the financing plan. Our approach shows that this is practically and financially feasible.

Lesson 6: Understanding path dependencies is critical to shift thinking

The project has revealed that the main barriers or obstacles to the implementation of EI interventions to support water security in the uMngeni River catchment are social, financial, political, and institutional, rather than technical or a lack of scientific knowledge. The legacy and path-dependency of the hydro-modernist approach shapes how BI interacts with water and society (or relates to water and society) and the natural environment in the catchment, and is strongly entrenched and difficult to shift. Levers of change which can begin to shift these, particularly through the use of EI interventions, need to be identified and supported by legislation and policy. The ORF4Ei provides insight in to where the levers of change might be in each particular context in the catchment. The traces of history continue to play a major role in shaping water outcomes in the catchment. The legacy of both colonialism and apartheid is a major challenge and barrier to improving water security. This coupled with lock-in to hydro-modernist approaches, creates a water security context that can only be shifted by working within the current system, recognizing its socio-economic, political and environmental context and relations, and using innovation through EI interventions, to slowly, patiently and wisely shift the catchment to a more sustainable, just, and socio-ecological-centred set of practices and way of being.

Lesson 7: Understanding the governance system is fundamental

The complexity of balancing competing demands and expectations is not to be underestimated. Despite the best efforts of water utilities, water service providers, catchment management forums, and other entities, the uncertainty over the future role of the Department of Water and Sanitation (DWS), who has the mandate for catchment management under the National Water Act (NWA), and the complexity of rural and urban land management in areas under Traditional

Authority, complicate efforts beyond the purely local.

Legislation and policy are important and form a critical part of governance. However, in the absence of clear directives about how to implement good legislation and policy, informal institutions through multi-actor governance arrangements evolve, emerge, and currently play a critical role. The Palmiet Catchment Rehabilitation Project provides an example, where innovation in governance and the creation of a multi actor governance platform, with a strong focus on state-citizen relations, is opening up opportunities for EI interventions, including social learning, reducing risk in the catchment.

Lesson 8: Meaningful participatory processes are the key to transformation

There are multiple state- and non-state actors (including civil society, academia, and citizens) who create the catchment governance system, effectively "governing with and beyond the state". Whilst there has been much research on natural capital, human and social capital is poorly researched and poorly understood. This project brings this aspect to the fore, particularly in that it highlights the need for an approach that is grounded in practice and understanding of local conditions through the case studies and moves well beyond the typically theoretical limitations of many academic frameworks. In this project, we recognize the theoretical developments, but ground our outcomes in meaningful participatory processes. Ultimately, these should be supported by the development of a vision and strategic plan for the uMngeni River catchment which is aligned with sustainability goals and principles of the green economy, rather than being reactive and being driven by a neo-liberal agenda which emphasises expansion of BI. Our approach can be described as co-engaged, action learning through which pathways for change to a more sustainable future become an enabling process; where participants are part of the processes of knowledge production and change, rather than being acted upon through awareness raising or communicated messages.

Lesson 9: Social learning, building transdisciplinarity and transformation takes time and effort

The uMngeni Ecological Infrastructure Partnership recently celebrated its fifth anniversary. This project has evolved in parallel with the UEIP. The long-term nature of the project has allowed consistent engagement with the UEIP as well as allowing for a sustained and committed action research partnership with communities in the case study catchments, to evolve. This could not have been achieved in a shorter time span, despite the long history many researchers have had with the communities they are engaging with.
Furthermore, the five-year time span has allowed the graduation of both MSc and PhD students. The value of a self-energising team of longer term PhD students supported by aligned input from shorter term PostDocs, MSc and Honours students is immeasurable. Together with the project leaders, PhD students provide stability and a core of research around which ideas evolve and develop.

Lesson 10: Students provide new insights, bring energy and are multipliers

Students involved in the project ranged from Honours (4th year) and Masters to PhDs. In total, 3 Postdocs, 9 PhDs, 15 MSc, and 7 Hons students have been affiliated with the project. Of these numbers, those that have graduated within the project scope include 2 PhDs, 9 MSc, and 7 Hons students, while the remaining students continue their studies with most in the final stages and on track to graduate this year (2019). In addition to the capacity building that occurred on an individual basis for each thesis or dissertation, students gained valuable insight regarding placement of their research within the broader framework of a research project framed to address key societal challenges in a catchment that effectively forms a "living laboratory".

A programmatic approach provides opportunities for the continuation of the research project, providing greater momentum, e.g. project cycles do not always coincide with degree timelines. Therefore, many students' research concluded prior to the five-year project cycle and students progressed towards employment with other organisations. Students take the knowledge of the research and the concept of EI forward to these new endeavours and enable a multiplier effect through which the lessons from this project can be shared and expanded. These PhD students will become leaders in water governance and EI in the future, as a result of the capacity they have built and the experience they have developed as emerging researchers engaged in action research in the uMngeni River catchment.

Discussion

These lessons have emerged from and inform the development of the ORF4Ei framework which can be applied to determine where, how, and by whom, EI interventions in the uMngeni River catchment, can be made (see Tables 2-1, 2-2 and 2-3). This framework of opportunities and risks in the catchment is then moderated in relation to the range of water security interventions that are possible (the BI-EI continuum), the governance and institutional arrangements in each context, as well as the cost-benefits and financial decisions (see Figure 2-9). All of these elements are connected in the catchment and hence are not independent. It is useful, however, to conceptualise them as components of a universal decision-making framework for EI interventions in catchments, both in South Africa and globally.

Finally, the interactive development of the framework in the uMngeni River catchment is captured in both an interactive online map (https://arcg.is/9CC5X) and illustrative map which shows specific risks and opportunities for investment in EI in the uMngeni River catchment (Figure 5.4).

Conclusions and Recommendations for further research

Through this project, the potential water quality and quantity benefits on investing in EI have been quantified and the costs and benefits analysed. We conclude that there are great opportunities to enhance water security in the uMngeni River catchment through investments in EI. However, in order for these to be sustainable, any investment in the catchment's Natural Capital requires a concomitant investment in its Human and Social Capital. Based on experiences from the catchment, we have provided an Opportunities and Risks for Investment in Ecological Infrastructure framework to guide future EI investments (ORF4Ei).

Future research areas for consideration are explained below.

- Maintenance/conservation of EI is 'cheaper' than restoration. Responding to this reality requires a shift to a perspective of investing in EI as proactive/preventative measure, rather than as an impact mitigation response (receiving system). However, who is to bear the cost of maintenance and restoration? Should this be the landowner, the public, a water utility, business, or water users? This is an implementation aspect that needs further investigation.
- Through this study, it became clear that knowledge of the internal biological and chemical functioning of the impoundments is lacking. Further research to understand the limnology of the impoundments is needed.
- Ensuring good governance requires an understanding of the opportunities for collaboration between scientists, society and state officials. A key question for the future where Citizen Science is likely to complement formal monitoring and law enforcement is to better understand what meaningful public participation looks like in the future and from an EI perspective,

what indicators and related actions will form part of such a governance system.

- Finding ways to draw the private sector in to innovative and participatory governance platforms, which this research has identified as being critical for water security, and to understand the way the private sector values and hence is willing to invest in EI interventions, requires urgent research as this remains a major gap in water governance and EI investment currently.
- Related to this is a question around appropriate forms of monitoring of EI interventions to support evaluation from ecological, social, and economic perspectives.
- As the population grows and densifies, a better understanding of the value and presence of EI in urban ecology and the opportunities this provides is needed
- Is economic value an appropriate and useful tool for evaluating EI and social capital investments? Are these forms of capital amenable to economic evaluation? There is a strong argument for resisting the allure of single value metrics and equating the importance (value) of EI with economic value which needs further exploration. There is great importance in making EI and social capital investment visible in water resource management and urban planning. Ongoing engagement across the water sector in support the National Water and Sanitation Master Plan is needed to support this. Engagement with the private sector remains a critical gap.

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Ms. Silindile Mtshali</td><td>Mr. Semeshan Naidoo
Mr. Theolin Naidoo
Dr. Jean Namugize
Mr. Simphiwe Ngcobo
Ms. Hlengiwe Ndlovu
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Ms. Susan Risko
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Ms. Nokulinga ZweZwe</td></tr>
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CONTENTS

FIGURES

TABLES

BOXES

ABBREVIATIONS

ACRU	Agricultural Catchments Research Unit
ARC-PHP	Agricultural Research Council's Plant Health and Protection
AWARD	Association for Water and Rural Development
BEDS	School of Built Environment and Development Studies
BI	Built Infrastructure
BN-RRM	Bayesian Network Relative Risk Model
BRICS	Brazil, Russia, India, China, and South Africa
CARA	Conservation of Agricultural Resources Act
CBA	Cost-Benefit Analysis
CBO	Community-based Organisation
CMA	Catchment Management Agency
CMF	Catchment Management Forum
CoGTA	Cooperative Governance and Traditional Affairs
CoP	Communities of Practice
CPB	Climate Protection Branch
CRI	Climate Risk Index
CSAs	Critical Source Areas
CWRR	Centre for Water Resources Research
DBSA	Development Bank of Southern Africa
DEA	National Department of Environmental Affairs
DIN	Dissolved Inorganic Nitrogen
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
DUCT	Duzi Umgeni Conservation Trust
EI	Ecological Infrastructure
EIA	Environmental Impact Assessment
EPCPD	Environmental Planning and Climate Protection Department
ERA	Ecological Risk Assessment
EWS	eThekwini Water and Sanitation
EWT	Endangered Wildlife Trust
GI	Green Infrastructure
GIS	Geographic Information System
HIV-AIDS	Human Immunodeficiency Virus Infection and Acquired Immune Deficiency Syndrome
HYPE	Hydrological Predictions for the Environment
IAHS	International Association of the Hydrologic Sciences
IAP	Invasive Alien Plant
ICP-OES	Inductively Coupled Plasma – Optical Emission Spectrometry
ICWQ	International Commission on Water Quality
IDP	Integrated Development Plans
IHE (Delft)	Institute for Water Education
INR	Institute of Natural Resources
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IUCN	International Union for the Conservation of the Nature

IUGG	Union of Geodesy and Geophysics
IWRM	Integrated Water Resource Management
JG (Afrika)	Jeffares and Green Afrika
KPA	Key Performance Areas
KZN	KwaZulu-Natal
LULC	Land Use Land Change
MCMF	Msunduzi Catchment Management Forum
MMTS	Mooi-Mgeni transfer scheme
MoU	Memorandum of Understanding
MSEP	Mpophomeni Sanitation Education Programme
MTSF	Medium Term Strategic Framework
NSE	Nash-Sutcliffe efficiency
NEMA	National Environmental Management Act
NGO	Non-Government Organisation
NPV	Net Present Value
NRM	Natural Resources Management
NW & SMP	National Water and Sanitation Masterplan
NWA	National Water Act
OLI	Operational Land Imager
ORF4Ei	Opportunities and Risk Framework for EI
PBIAS	Percentage of Bias
PCRP	Palmiet Catchment Rehabilitation Project
PPP	Public-Private Partnership
QMRA	Quantitative Microbial Risk Assessment
QRI	Quarry Road Informal (settlement)
RIOS	Resource Investment Optimization System
RS	Remote Sensing
RWFA	Rwanda Water and forestry Authority
SANBI	South African National Biodiversity Institute
SAPPI	South African Pulp and Paper Industries
SASS	South African Scoring System
SCIMAP	Sensitive Catchment Integrated Modelling and Analysis Platform
SDF	Spatial Development Framework
SDGs	Sustainable Development Goals
SEBEI	Socio-Economic Benefits of Ecological Infrastructure
SES	Social Ecological Systems
SIP	Strategic Integrated Projects
SKSE	Seasonal Kendall Slope Estimator
SNV	Netherlands Development Organization
SOE	State-owned Enterprise
SPOT (7)	Système Pour l'Observation de la Terre
SRP	Soluble Reactive Phosphorus
TLGFA	Traditional Leadership and Governance Framework Act
TP	Total Phosphorus
TSS	Total Suspended Solids
UEIP	uMngeni Ecological Infrastructure Partnership

UKZN	University of KwaZulu-Natal
UMDM	uMgungundlovu District Municipality
UMFULA	Uncertainty reduction in Models for Understanding development Applications
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
URV	Unit Reference Value
UW	Umgeni Water
WASH	Water, Sanitation and Hygiene
WESSA	Wildlife and Environment Society of South Africa
WHO	World Health Organization
WQIs	Water Quality Indices
WRC	Water Research Commission
WRMC	Water Resources Management Charge
WTW	Water Treatment Works
WULA	Water Use License Agreement
WWF-SA	World Wide Fund for Nature South Africa
WWTW	Wastewater Treatment Works

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CHAPTER 1. INTRODUCTION

This document forms the final report and recommendations from a five-year Water Research Commission of South Africa funded project entitled:

"Demonstration of how healthy ecological infrastructure can be utilized to secure water for the benefit of society and the green economy through a programmatic research approach based on selected landscapes".

Over the past five years, the project has explored the conceptual and philosophical basis for investing in Ecological Infrastructure (EI) and through this report, demonstrates how EI can be utilised to secure water for the benefit of society through research focused on selected case studies in the uMngeni River catchment.

There is an interdependent and co-constitutive relationship between EI, society and water security. Through the study, we identify approaches in the uMngeni River catchment where investment into the maintenance and/or rehabilitation of EI can produce long-term and sustainable returns for the delivery of water-related ecosystem services. The study inherently addresses aspects of water quantity and quality, economics, societal interactions, environmental systems and the governance of natural resources. It highlights that ensuring availability and sustainable management of water resources requires both transdisciplinary and detailed biophysical, economic, social and development studies of both formal and informal socio-ecological systems. It also argues that the human resources capacity to support these studies is critical to sustainable and transformative outcomes.

1.1 Background to "Ecological Infrastructure" – A South African approach to support an emerging Green Economy

Over the past two decades, many authors have highlighted the fundamental role of the natural environment in underpinning societal well-being. Rockstrom and Sukdev (2016) highlight how the Sustainable Development Goals (SDGs) supported by the sustainable functioning of the "Biosphere" underpin all aspects of society. Associated with this recognition, Green Economy initiatives are highlighted as one of the National Presidential Outcomes in South Africa. The Water Research Commission has therefore developed The Green Village And Economy Lighthouse as one of its flagship initiatives. Through this initiative, the WRC funds research intended to support development that results in improved human well-being, social equity and access to resources, while significantly reducing environmental risks (Water Research Commission, 2014). It aims to uplift living conditions by transforming impoverished rural, peri-urban and urban communities through development that is sustainable and informed by the integration of science and technology. Lessons from this project also highlight that state-citizen partnerships facilitate this approach, allowing for the acknowledgement and adoption of local community practices and knowledge for *meaningful collaboration* of the state, private sector and citizens in decision making.

In South Africa, natural resources which deliver ecosystem services, such as water supply, water purification, flood attenuation and recreational services, are known as EI, as opposed to built infrastructure (BI) (such as concrete, bricks and pipes). Thus, EI is defined as "*functioning ecosystems that produce and deliver valuable services to people*" (Jewitt et al., 2015), and has, until now, been understood as an alternative or complementary intervention that provides similar benefits to conventional BI (SANBI, 2013) (Box 1). There are some similarities with the established "ecosystem goods and services" concept and the broader concepts of Natural Capital, Nature-Based Solutions, etc. In South Africa, there is now an increasing understanding and acceptance of the term, EI, and its significance and value in a country where a pro-growth economic development agenda threatens to compromise sustainability of natural resources. Through this project, we demonstrate that investment in EI forms part of a continuum of interventions in catchment investment opportunities.

BOX 1.1 A Continuum from Built to Ecological Infrastructure

An emerging discourse on the management of water resources argues that nature-based solutions provide alternatives or support to 'built infrastructure', which can be more cost-effective and provide additional co-benefits. The conventional perspective advocates BI, arguing that the links between built water infrastructure and economic development are well established; where BI is insufficient to manage water, socio-economic development is curtailed. Both perspectives attempt to balance social, economic and environmental considerations; one by placing emphasis on BI, and the other on ecological infrastructure (EI). In reality, it is unlikely to be a case of either-or; rather an approach is needed that recognizes that, while more BI may be required, it is not necessarily the best or only option in any given situation. Alternative or complementary solutions using EI should be given equal consideration in planning. The reality of many successful projects highlights that there is a continuum from BI to EI, and optimal solutions lie within a range of options across the BI-EI continuum. Approaches and tools that promote the integration of a range of knowledge systems – engineering, hydrology, sociology, geography, development studies, ecology, economics – into planning processes are needed

Evaluating options and finding an appropriate balance between development needs and safeguarding ecosystems and nature is complex. Often, planning and decision-making processes isolate water management issues within the context of engineering or hydrology or waste management; insufficient attention is given to the role of socio-ecological systems. This poses both a challenge and opportunity to water resource management.

1.2 The Argument for SIP 19 vs Integrating EI in SIPs

In South Africa, Strategic Integrated Projects (SIPs), have, for some time, been the focus of development through the National Infrastructure Plan (https://www.gov.za/sites/default/files/PICC_Final.pdf). SIP 18 titled "Water and sanitation infrastructure" is described as a "10-year plan to address the estimated backlog of adequate water to supply 1.4 M households and 2.1 M households with basic sanitation. The SIPs will involve the provision of sustainable water supply to meet social needs and support economic growth. Projects will provide for new infrastructure, rehabilitation and upgrading of existing infrastructure, as well as improve management of water infrastructure". This is depicted in Figure 1-1.

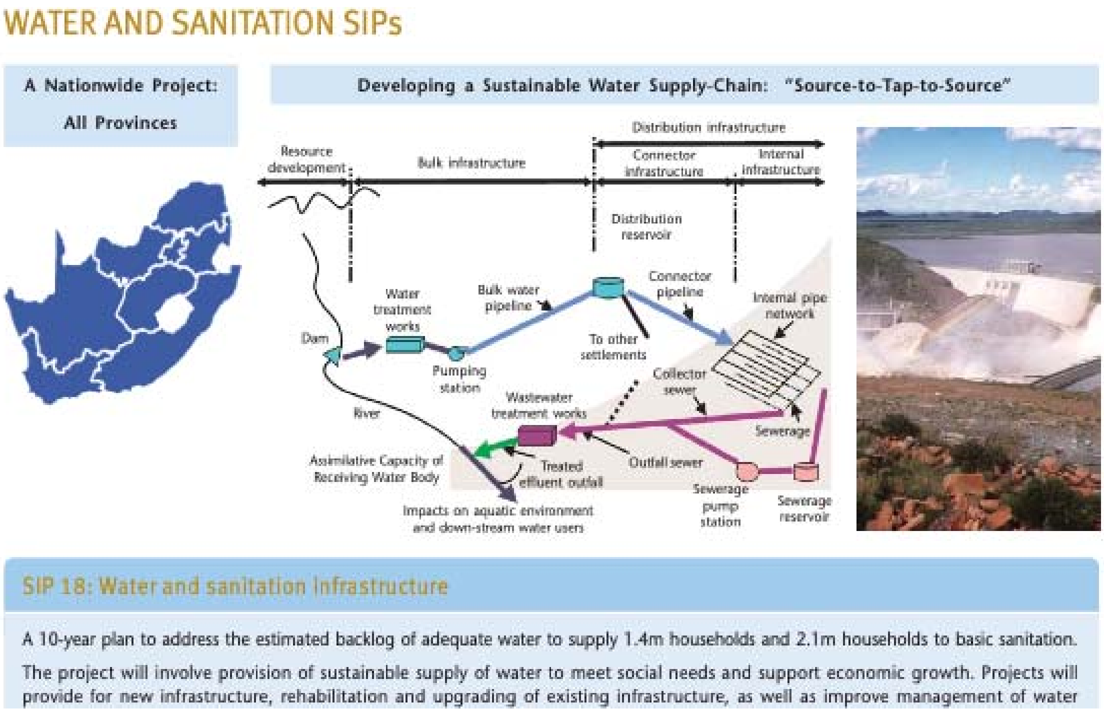

Figure 1-1 SIP 18 Water and Sanitation Infrastructure

Absent in SIP 18, and many other infrastructural projects, is any consideration of the value of the natural environment in providing these services. SIP 19 on EI (Figure 1-2) has been proposed to fill this gap.

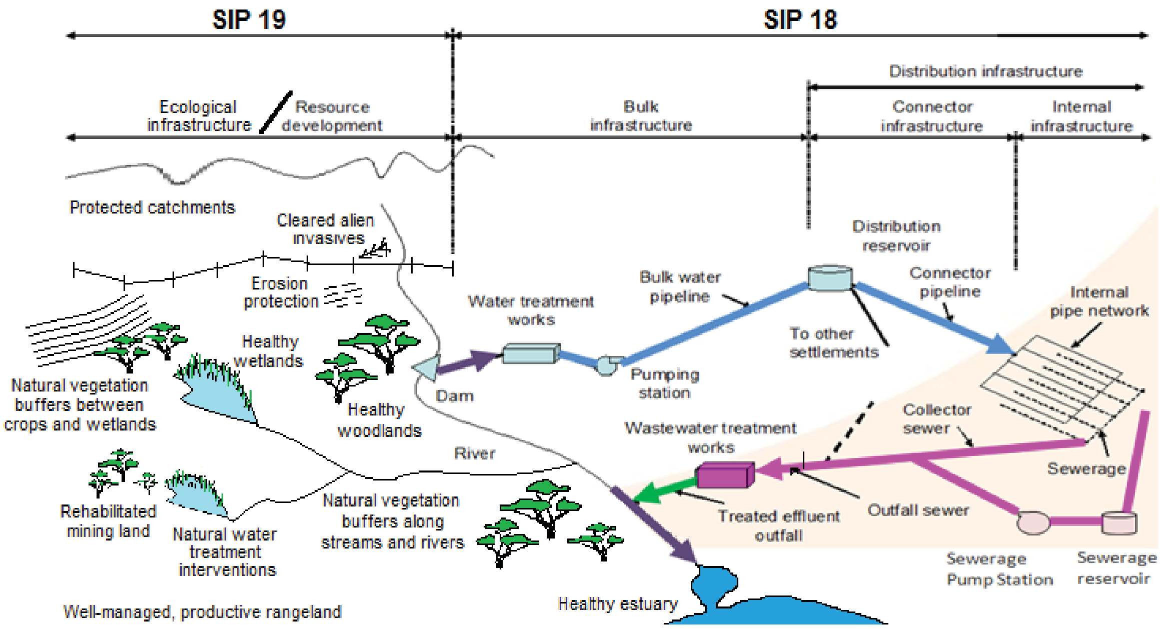

Figure 1-2 SIP 19 Ecological Infrastructure and its relationship with built infrastructure (SANBI, 2016)

This reflects an understanding of the importance of the integration of EI and built (grey) infrastructure (BI) to provide water services to society. These include water for agriculture (both dryland and integrated), recreation, as well as being the core supply for human consumption through to constructed reservoirs, irrigation schemes, interbasin transfers etc. In addition, the catchment (with its associated EI) is also the recipient of waste generated by society through its use of water, providing the final stage of good wastewater management – or in the case of poor wastewater and solid waste management, IS the only treatment system available!

This forms a key message from this study, i.e. that investment in infrastructure is not a binary choice between BI and EI – rather, they are complementary. Achieving water security requires investment in both. It is the integration of BI and EI which provides the most realistic opportunities to sustain and finance EI and to ensure water security. It can be argued that creating an additional SIP directly focused on EI could in fact continue the artificial separation between BI and EI. Rather opportunities to leverage funding for EI through ongoing infrastructure development projects, which recognise its value and complementary role should be sought (as expanded upon in Chapter 3).

Figure 1-3 illustrates the concept of enhanced benefits from a natural system. Benefits to society derived from EI can be enhanced by investment in infrastructure – both public and private. However, at some stage the ability of EI to continue to deliver services is compromised by over exploitation/degradation. Therefore a need exists to find a balance between development and its associated impacts on the environment, taking into consideration the limitations of the environment to absorb negative consequences of development. In South Africa, this is reflected in the catchment classification system associated with the setting of Resource Quality Objectives, and ultimately the Reserve. Rehabilitation and restoration efforts aim to improve the ability of EI to produce ecosystem services, however this requires initial investment (capital costs) and, depending on development impacts, continual investment to mitigate detrimental impacts on the environment to restore the socio-ecological balance that can sustain the level of benefits desired. Maintaining infrastructure, both EI and BI, is critical to sustaining the provision of benefits and avoiding costly rehabilitation.

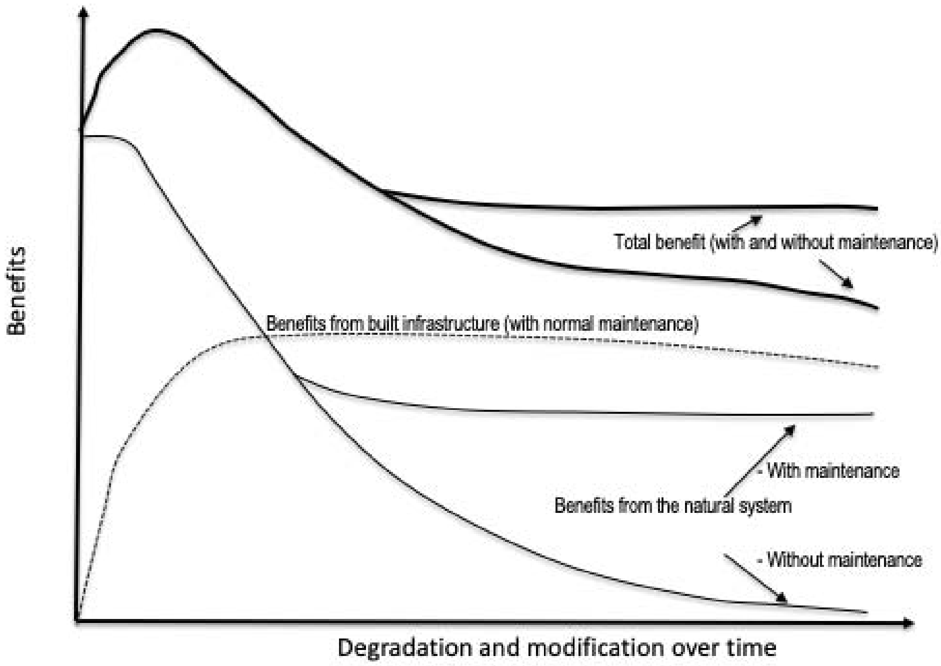

Figure 1-3 Maximising and maintaining goods provided by Ecological Infrastructure (after McCartney et al., 1999)

1.3 A Social-Ecological Relations Approach to Interaction of Human, Social, Natural and Built Capital

Many have highlighted that human well-being is inextricably linked to the health of the environment, or the health of the connected socio-ecological (human-natural) system. This principle, in effect, underpins all of the SDGs (see for, e.g. Rockstrom and Sukdev, (2016)). Turner et al. (2016) highlight that to ensure human well-being requires that there are interactions between built, social, human and natural capital. Built (incl. the economy) and human capital are embedded in society, which is embedded in the rest of nature. Natural capital can be considered as the stock of renewable and non-renewable resources (e.g. plants, animals, air, water, soils, minerals), that when combined with other capitals, yields a flow of benefits to people. Following this approach, ecosystem services can be considered as the relative contribution of natural capital to human well-being – they do not flow directly to create well-being. **Rather, the existence of people (human capital), the societies in which they live (societal capital), a constructed environment (built capital) and natural capital all interact with and shape each other, to provide services** (Figure 1-4)**.** This formulation is aligned with socio-ecological relations theory which argues that in order to understand nature-society relations, it is critical to understand these relations as being dialectical (Asaduzzaman and Virtanen, 2016), in other words environment and society shape each other; are socially constructed and co-produced (Bassett and Peimer, 2015). Society has choices as to how it values, utilizes and invests (or not) in the catchment. These choices are dependent upon societal values and goals and its capacity to recognize and understand the importance and consequences of decisions (choices) it makes regarding biophysical opportunities and constraints, financial and governance systems, and existing built, economic and social systems, which in turn produce path dependencies. This report argues that while socio-ecological relations are socially constructed (and hence it focuses on dominant discourses and the power of actors), there is also a materiality, a set of contingent conditions, or objective reality, which exists beyond the human construction of nature or environmental issues. Thus, the interactions between these multiple capitals both increases and decreases each other, but with understanding and respect for each form of capital's contribution, the overall effect can be positive. Building from this, we adopt an approach where ecosystem services are delivered to society through the interaction of, and relations between, these different capitals.

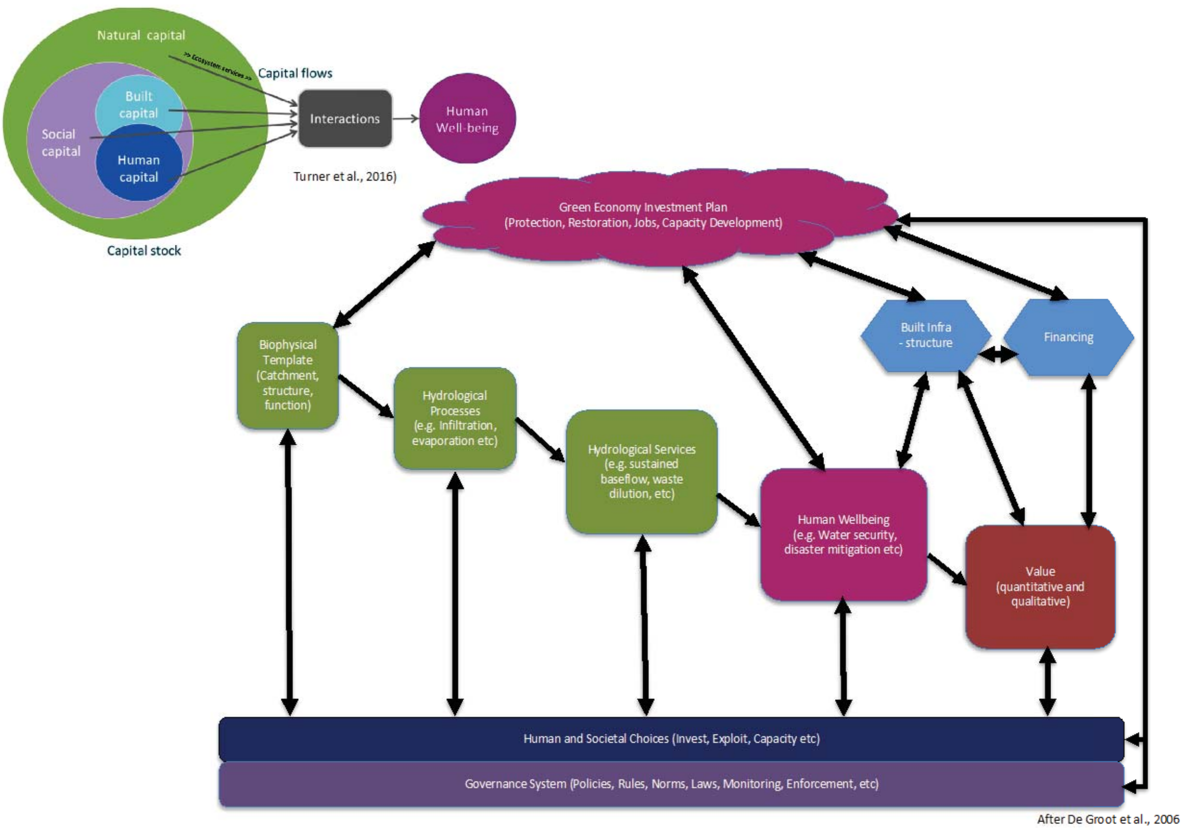

Figure 1-4 Interaction and relationships between different capitals: Interactions between built, social, human and natural capital required to produce human well-being. Built (incl. the economy) and human capital are embedded in society which is embedded in the rest of nature. Ecosystem services are the relative contribution of natural capital to human well-being, they do not flow directly to create well-being and need the other capitals to be able to contribute. It is therefore essential to adopt a broad, transdisciplinary perspective in order to address ecosystem services (Turner et al., 2016)

Path dependencies, discussed in greater detail in Chapter 2, are trajectories of momentum that society has developed and continues to maintain, knowingly or subconsciously. Deeply rooted in the historical and geographical context, path dependencies continue to promote particular ways of knowing, understanding and doing that enforce specific approaches. Momentum for a particular path, once established, tends to influence social norms and values in a way that reinforces and reproduces the trajectory and these social norms and values therefore become dependent on that particular path. This is considered a reinforcing feedback loop, which involves a set of societal patterns. Often such cyclical behaviour and the patterns created are difficult to break, and therefore patterns, whether helpful or harmful, continue to influence society and its choices. Through this study, detrimental path dependencies are recognized and highlighted in an attempt to shift these path dependencies or halt them all together, using levers of change to build greater sustainability within the uMngeni River catchment (Chapter 6).

Understanding such path dependencies requires an investigation of the historical, social, economic, political and biophysical context within which they develop. It is therefore essential to adopt a broad, transdisciplinary perspective in order to address the question of how and where to invest in the ecosystem for the return of services (Turner et al., 2016). Typically, evaluation approaches have emphasised the biophysical component or materialities of a system and research has focused on these. In this context, human and social capital are poorly researched and poorly understood. **This project brings this aspect to the fore, particularly in that it provides an approach from a developing country perspective, that is grounded in practice and understanding of local conditions through the case studies, and moves well beyond the typically theoretical limitations of many academic frameworks. In this project we recognize the theoretical developments, but ground our outcomes in meaningful participatory processes.** Thus, we adopt an approach where the different capitals provide an entry point for the interaction with our partners in the case studies. In the case of potential funders and government, municipalities etc., this could be through financial, built, social or human capital or where development partners are typically perceived to be ‘poor’ and lacking skills and competencies; we rather acknowledge their *economic* poverty and seek to build on their human and social capital, their agency and other strengths.

1.4 Investing in Ecological Infrastructure

The question of how EI can be utilized to secure water for society is challenging to address. It is difficult not only because of the variances produced through different histories of relationships within a certain ecological context (in this case, in the context of a river that flows across a dynamic and diverse region over time), but also because of the challenges involved in the translation of elements of ecology into infrastructure and governance and institutional systems. In order for EI to function and perform a particular role critical to humans, namely to produce and deliver services to people in the uMngeni River catchment, it needs to be maintained, and in places where it has been degraded, it must be restored or rehabilitated. However, this perspective is still limited as it considers only portions of the system, i.e. it only considers some of the capitals. In investing in EI, we seek to guide a process where investment is regenerative and has a positive impact on all forms of capital, not which depletes some forms of capital at the expense of others.

Considering the various forms of capital, investment in EI should prioritize critical areas identified as having the greatest potential return on investment towards the end goal of securing water resources. Restoration of the entire degraded area is not possible. According to SANBI (2014:4), investing in EI involves “maintaining functioning ecological infrastructure, as well as restoring degraded ecological infrastructure” where ‘Investment’ refers to “devoting time, effort, finances and/or making decisions in support of a particular undertaking with the expectation of a worthwhile result”. This project therefore attempts to address the question: “What to do and where to do it” and extends this to suggest “for and by whom” and argues that maintaining and restoring EI requires investment in human and social capital as an integral component, as opposed to many efforts which tend to focus on Natural Capital alone.

In this report, 'investing in EI' refers to actions taken to improve the condition of EI, maintain/preserve the existing condition and/or halt further declines in condition and may include physical interventions such as ecosystem restoration, rehabilitation, conservation and management activities. However, a key message from this study is that it **must also include investments related to developing human capacity and strengthening institutions, governance and influencing social behaviour. Thus, there is a need to invest in social learning, and the building of governance platforms, particularly building of state-citizen relations. One of the key learnings from this project is the importance of developing human and social capital if EI interventions are to make a difference. Building social and human capital is therefore considered to be an EI intervention, which therefore extends traditional approaches to EI interventions.**

1.5 Ecological Infrastructure and Water Resources Governance

Since 1994, South Africa has enabled numerous Acts and policies which are generally supportive of the natural environment. These include the National Water Act and the National Environmental Management Act, to name a couple. These have been detailed in various WRC 2354 project Deliverables. In other cases, legislation predating 1994, e.g. the Conservation of Agricultural Resources Act (CARA, 1983), remain key in the legislative environment in which investments in EI are considered. In addition, South Africa has signed and ratified all major international conventions pertaining to biodiversity conservation, including the Convention on Biological Diversity (1992), the Ramsar Convention (1971), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1973), World Heritage Convention (1972), as well as the United Nations Framework Convention on Climate Change (UNFCCC) (1992) and the Convention to Combat Desertification (1994), and ratified the Biosafety Protocol (2000). Most recently, South Africa has become the 12th country globally to ratify the international Nagoya Protocol (2014) to protect the country's biological diversity and associated traditional knowledge.

More recently, drawing from the National Infrastructure Plan, the National Planning Commission (https://www.gov.za/issues/national-development-plan-2030) highlighted the importance of biodiversity, conservation, and ecosystem rehabilitation. The Commission recommended that there needs to be a strategy that considers the environmental impact of any new developments and stated that investment in the protection and rehabilitation of biodiversity and ecosystems is required, in effect confirming the importance of the existing Environmental Impact Assessment legislation and processes. However, their approach considers only situations where there is a likelihood of loss of natural assets as a consequence of other forms of development, rather than any intent for restoration or rehabilitation of environmental assets that have been lost or damaged.

This position is considered in the Medium Term Strategic Framework (MTSF) which forms the governments' strategic plan for 2014 to 2019 (see https://www.poa.gov.za/Pages/MTSF.aspx). This highlights relevant legislation and important policies and allocates responsibilities to different government departments, suggesting indicators and targets. Outcome 10 is focused on the environment and it is here that EI is considered, and linkages to other aspects of environmental legislation and planning, which are related to EI are specified. The degradation of natural resources and depletion of EI is recognized, as is the particular role of EI in contributing to water security. EI contributes to all of the strategic plan outcomes to a greater or lesser degree. The National Water and Sanitation Master Plan continues this approach and recognises EI in its philosophy (Figure 1-5). However, apart from recognition of the country's Strategic Water Source Areas, there is little substance on how this should be achieved.

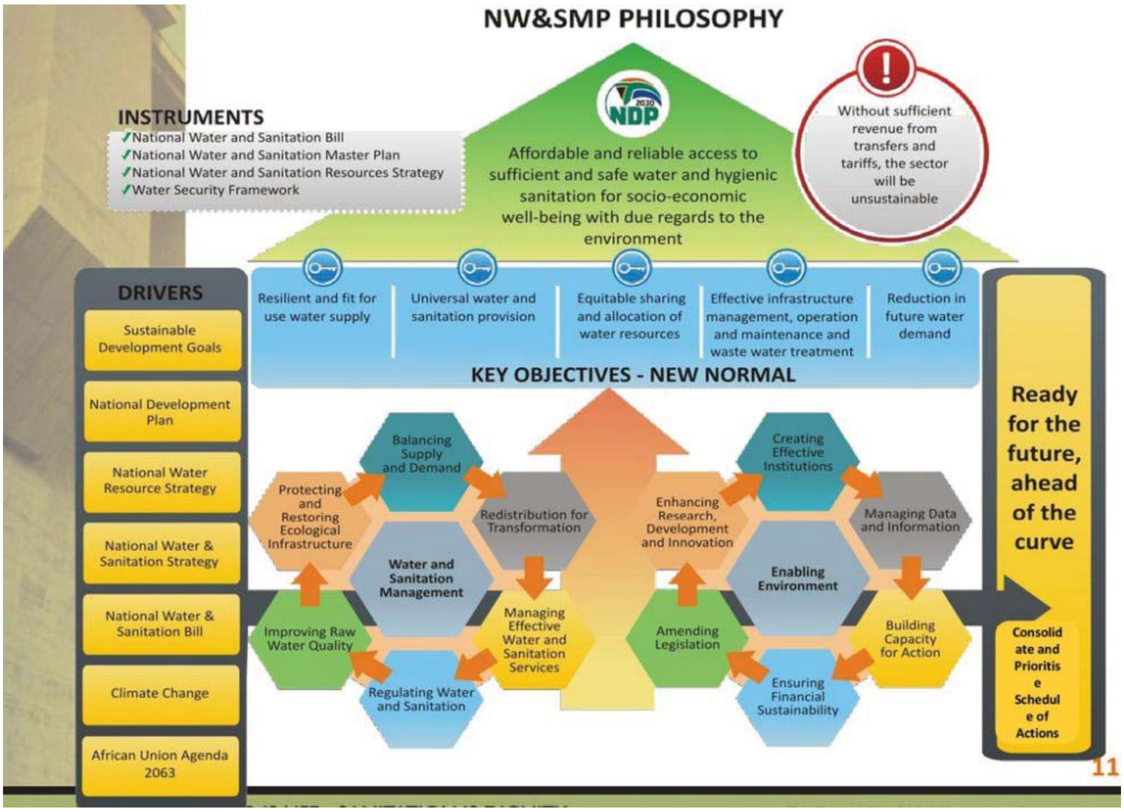

Figure 1-5 Context for National Water and Sanitation Masterplan including investment in EI

Previous work aligned to this study, i.e. Colvin et al. (2015), and Pringle et al. (2015) have outlined the social and institutional contexts under which investing in EI in the uMngeni River catchment must be considered. There are numerous other studies which detail this (see for example Stuart-Hill, Schulze et al. (2010), Rowlands, Taylor et al. (2013), Jewitt, Zunckel et al. (2015), Pringle, Bredin et al. (2015), Cilliers and Cilliers (2016)).

The complexity of balancing competing demands and expectations is not to be underestimated. Despite the best efforts of water utilities, water service providers, catchment management forums and other entities, the uncertainty created by a dysfunctional DWS, who still claim the mandate for catchment management under the NWA, and the complexity of rural and urban land management in areas under Traditional Authority, undermine efforts beyond the purely local. Despite the intentions of the NWA, implementation has essentially become a top-down process. There has been consideration of this in various projects and many role players have expressed frustration with the experience that efforts on the ground are hamstrung or could be completely undone by uncertainty at the National level (Pollard et al., (2014); Graham et al., (2016)). In the most recently available version of the National Water and Sanitation Master Plan (October 2018) (http://www.dwa.gov.za/National%20Water%20and%20Sanitation%20Master%20Plan/Documents/NWSMP%20Call%20to%20Action%20v10.1.pdf) the role of local water resource management institutions are still under consideration and the lack of yet to be established CMAs is highlighted, leaving an implementation vacuum in most of the country's catchments.

Legislation and policy are important and form a critical part of governance. However, in the absence of clear directives about how to implement good legislation and policy and govern water, informal institutions, evolve, emerge and currently play a critical role, through multi-actor governance arrangements, both within and beyond the state, in implementation.

1.6 Financing of Water Resources Management and Opportunities for Ecological Infrastructure Investment

Since the introduction of the NWA of 1998, South Africa has been developing a pricing strategy, tariff regulations and norms and standards for water services tariffs. Water services tariffs are the basis of funding for water resources management in the country. However, these funds are generally not ring-fenced and thus limit their use as a financial instrument for improved water resources management. Figure 1-6 reflects the components of South Africa's National Water Pricing Strategy. Water resources charges are collected at different stages of the water resources management cycle. The cycle starts with the water resources management charge. In the case of the uMngeni River catchment, this is collected from bulk water sales by the water utility, i.e. Umgeni Water and paid to DWS. The water resources development charge and bulk water tariff are costs incurred by the bulk water utility and handed over to DWS. Water is then treated and distributed to the bulk water buyers who are the municipalities and some other clients. The retail water tariff is the price that the consumer pays to the municipality, and similar to the case with electricity, this is often loaded as an income generation stream by those service providers. The municipality also charges both individual and industry consumers for sanitation disposal. In theory, the water discharge charge is levied against all water returning to the stream (based on the "polluter pays" principle.), but this has not been implemented.

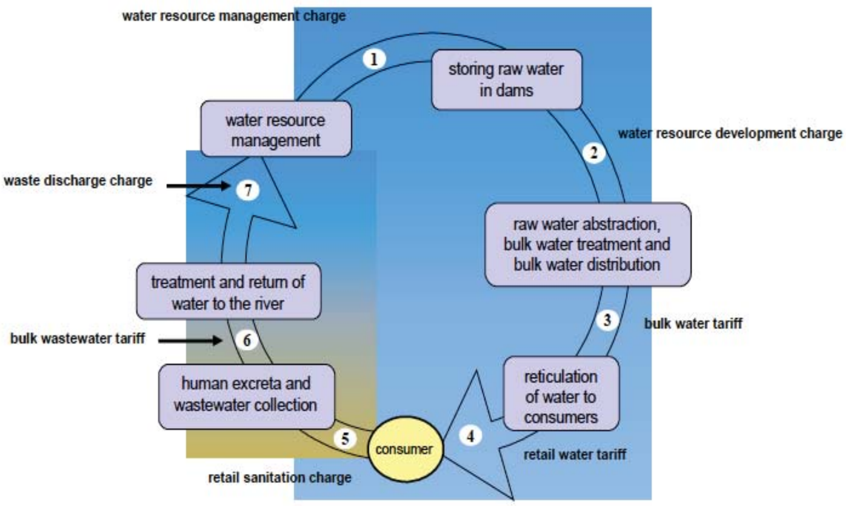

Figure 1-6 Context for National Water and Sanitation Masterplan including investment in EI (Ralf, 1998)

The Water Resources Management Charge includes ensuring ecological sustainability and is intended to include aspects such as:

- Safeguarding the Reserve,
- Management of the catchment,
- Water quality protection, and
- Water conservation and demand management.

However, as yet, this has been poorly implemented. Arguably, the focus has been on aspects of the Reserve which is largely reduced to being considered a demand on the system by water resources managers and planners. Some catchments have Invasive Alien Plants Clearing Programmes that are partially supported by these charges.

A key point is that the vast majority of the money is generated through various charges and tariffs associated with the built infrastructure components of the cycle. The World Water Development Report (2018) highlighted that globally, less than 5% of financial flows in water resources management are spent on supporting the natural catchment functions (EI). In the uMngeni River catchment, this value is less than 1% (see Chapter 3).

Over the past ten years, there has been a strong effort to establish alternative forms of financing for investments in EI. These include green bonds as explored by Cartwright et al. (2015) and water funds such as those established for Cape Town, and which are under consideration for the uMngeni. In particular, leveraging of available funds to attract input from corporate and other potential funders is an area which the Nature Conservancy has had much success. However, despite years of effort across the globe, it remains difficult to justify expenditure on EI maintenance and restoration for a variety of reasons. These include the reality that methods of quantifying both costs and benefits are limited, uncertainties are high, there is a lack of tools through which to evaluate "success" and there are few success stories in the form that will attract traditional investors. Consequently, most restoration programmes are supported by secondary government initiatives (e.g. the expanded public works programmes in South Africa) or corporate social investment funds, rather than being mainstreamed in development and infrastructure planning.

The approach in this project has been to consider the opportunity to invest in EI through identifying opportunities to do so from existing tariffs and where BI needs have been identified, to include aspects of EI in the financing plan.

In the same way that BI requires capital investment and funds for maintenance, so too does EI (Cartwright and Oelofse, 2016). We provide evidence through a series of assessments from an economic perspective, using economic methods which consider aspects of both water quantity and quality as detailed in Chapter 3. This includes assessments of the operational benefits that Umgeni Water (or any other) bulk water utility could gain through investment in EI focused on core business costs, i.e. raw water, chemical, energy and associated benefits.

1.7 The uMngeni River catchment

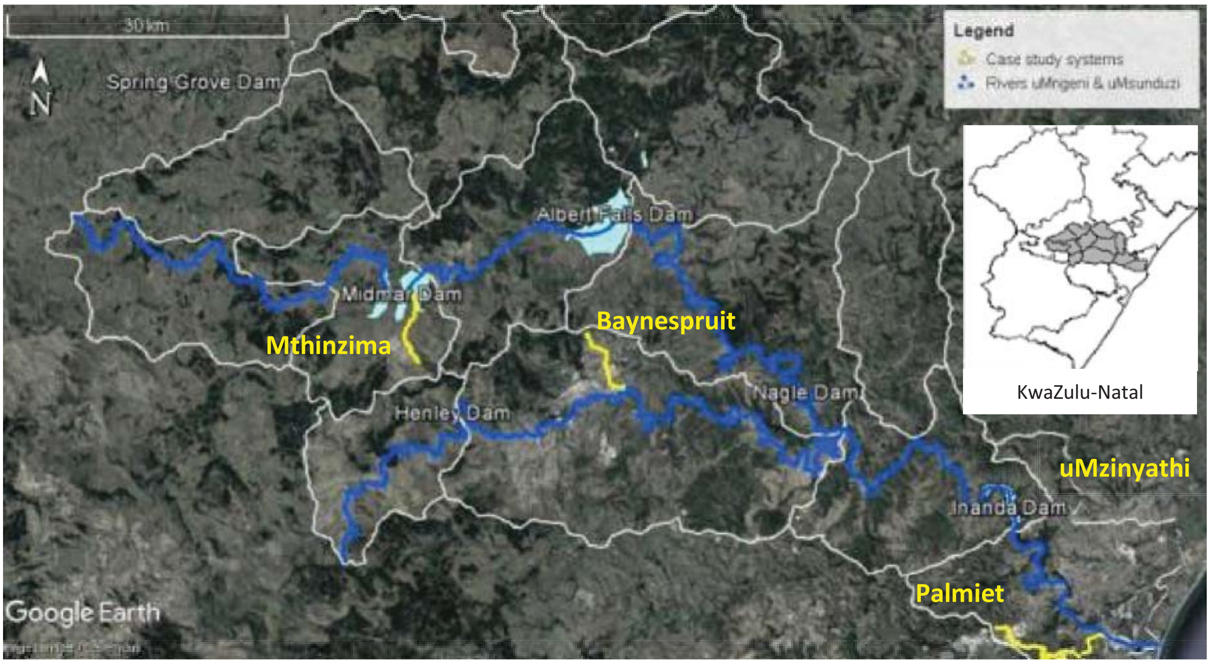

Figure 1-7 Overview of the study area showing the pilot study sites, Mthinzima Stream, Baynespruit Stream, Palmiet River and Mzinyathi, KwaZulu-Natal

The characteristics of the uMngeni River catchment are well-known. These have been reported extensively elsewhere and a short summary is presented here. The catchment is home to approximately 6 million people with the cities of Durban and Pietermaritzburg having the largest concentrations. The urban population is growing as a result of natural population increase, as well as the in-migration of people from predominantly KwaZulu-Natal, Eastern Cape Province, and other parts of southern Africa. Water resources are provided to the cities and some rural users by the bulk water facility, i.e. Umgeni Water (UW). This is achieved through a series of four major reservoirs in the catchment and transfers from the adjacent Mooi River basin where water is pumped to the uMngeni through an inter-basin transfer, with additional transfers planned from the adjacent uMkhomazi catchment. Bulk water is treated at a series of treatment works and wastewater is treated by several treatment works by the local municipalities, or UW on their behalf. This is depicted in Figure 1-7.

Land use in the headwaters consists of grasslands, commercial agriculture, small pockets of indigenous forest, and fairly extensive agricultural cropping. Increasing urbanisation and industry is found as one moves downstream, with urban sprawl dominating as one gets closer to the urban areas of Durban and the Indian Ocean. In the headwaters, water is of good quality. However, as one moves downstream through the catchment, water quality deteriorates through the influx of agricultural nutrients from fertilisers and effluent from livestock production and then through waste and pollution from the cities of Pietermaritzburg and Durban and their peri-urban surrounds.

1.7.1 Water Resources Management

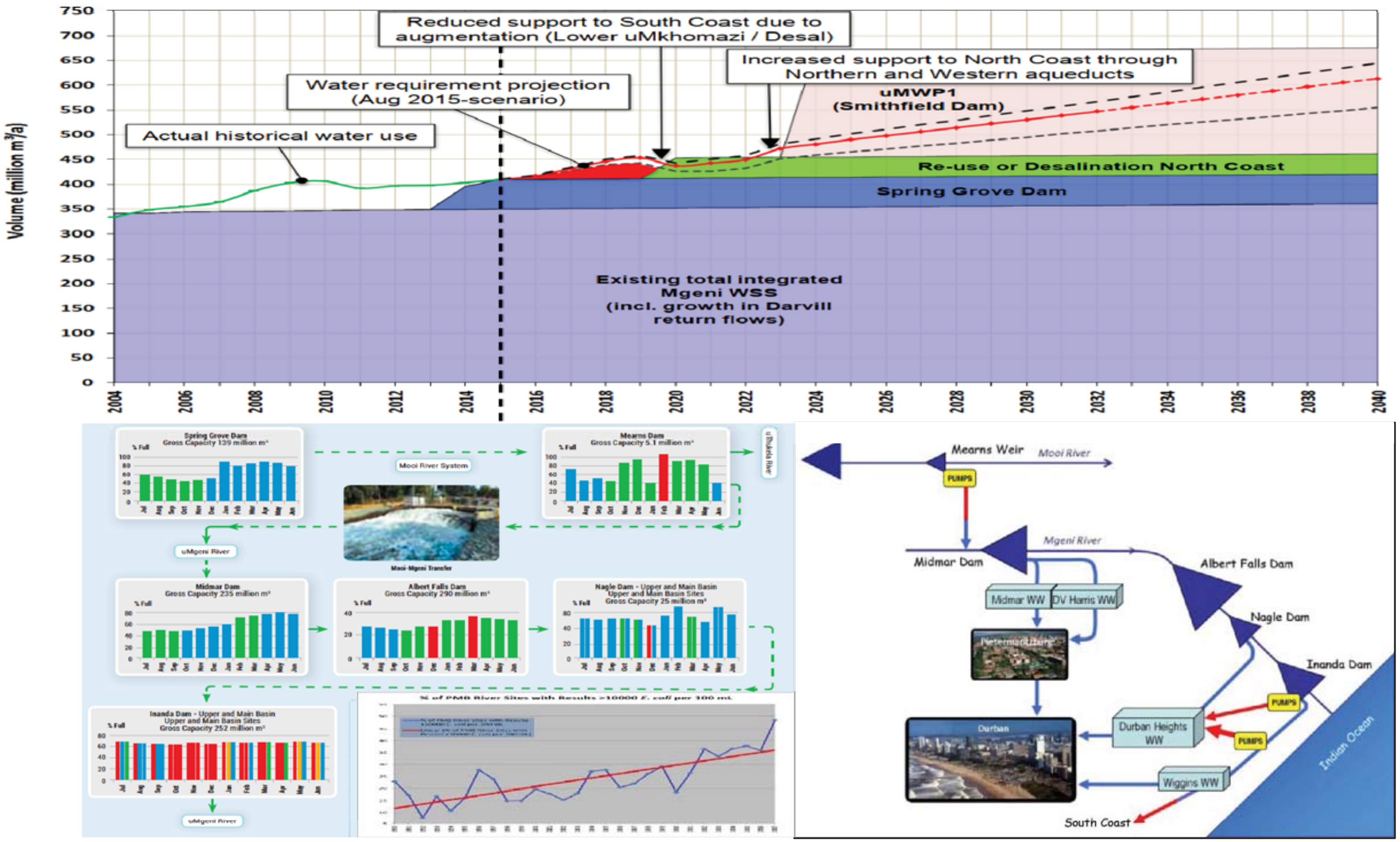

Figure 1-8 Projected demand, reticulation and storage systems and water quality in the uMngeni System

Source: Reproduced from Umgeni Water (2014:135)

As the population has grown and the catchment has developed, the demand for water has increased. The catchment reconciliation strategy has highlighted future risks to the catchment water supply. The focus on addressing this has been through the construction of new built infrastructure, i.e. Spring Grove Dam on the Mooi River and the soon to be under construction Smithfield Dam, as part of the uMkhomazi scheme, thereby adopting a hydro-modernist approach to water security (Chapter 2). Water demand management is also applied and has been successful in reducing water demand in the recent drought period (2015-2017). However, the potential contribution of EI and restoration of EI has not been considered in the reconciliation strategy, nor in the updated reconciliation strategy released in 2017. Although highlighting the potential of EI to contribute to water resources security, the report concludes *“It should be noted, however, that while catchment care would likely improve water resources, specifically in the maintenance of water yield and quality, there is currently a lack of quantifiable data in this regard. Catchment care was therefore not explicitly accounted for in the reconciliation scenarios and water balances developed as part of this Reconciliation Strategy Update”,* highlighting the reluctance of traditional water resource planners to engage with EI and to move beyond current ”business as usual” approaches. This is a reluctance that is borne of the dominance of a well-established hydro-modernist[1] discourse in South Africa and the catchment, a conservative approach to water management, the difficulties of considering anything beyond the norm within the Terms of Reference and budget provided, as well as the profit motivation of the consultants who undertake such studies in the context of a neo-liberal economy, who choose to reduce project risk or cost by avoiding innovation, even when newer more experimental designs have potential to offer more sustainable long-term solutions.

The importance of the reconciliation strategy and Figure 1-8 should not be underestimated. It drives most of the water resources planning decisions made in the catchment and its future financing is a major consideration in water pricing negotiations. Consumers in the catchment are already paying a levy of approximately R0.10 per cubic metre to finance the future construction of uMkhomazi Scheme.

1.7.2 Water Resources Governance in the uMngeni River catchment

In this project, the hydrosocial cycle and governmentality are applied as theoretical lenses to examine the main ‘water moments’ in the city of Durban and beyond into the uMngeni River catchment. ‘Water moments’ relate the history of water and sanitation in the city to its geographical (social, economic, political and environmental) context. ‘Water moments’ have impacts at the local scale, but have been shaped in the course of time by different paradigms, conceptualisations and approaches at a far greater scale. These framings are then used to develop a representation of the ‘water moments’ and water governance in the uMngeni River catchment. The overall approach can be classified within the philosophy of political ecology and political economy, and is linked to socio-ecological relations theory, focusing on the ecological, social and economic dimensions of the catchment, within a particular political context.

In this regard, governance considers not only the relations between society and water, but also considers the political governance structures or institutions that are involved in shaping water governance within the catchment.

A Catchment Management Agency (CMA) does not yet exist for the uMngeni River catchment (as of September 2019). Though a stakeholder engagement process to develop such an institution has begun, the decision to establish the CMA has hung in the balance since October 1999 (Meissner et al., 2016). The power to establish a CMA resides with the DWS Minister and the delegated legal functions proposed for the CMA still fall under the mandate of the DWS. Therefore, while the decision to move forward with the CMA is debated, DWS has recently taken a decision to proceed with developing a Catchment Management Strategy for the Pongola-Umzimkulu Water Management Area, which contains the uMngeni River catchment. During March of 2019,

[1] Hydro-modernism refers to hard engineering approaches to water which rely on built infrastructure, including dams, treatment works and pipes with a focus on technical and economic efficiency using top down governance approaches (Martel, 2019).

the DWS held various stakeholder meetings to elicit comments on the first draft of this strategy, which is envisaged to be finalized in November 2019.

In the absence of a CMA, this gap has been filled by various local organisations. The Umgeni Ecological Infrastructure Partnership (UEIP) was formed to establish a catchment-based community of practice, emphasising the EI aspects of water resources management in the catchment (Box 1.2).

BOX 1.2 The uMngeni Ecological Infrastructure Partnership (UEIP)

The uMngeni Ecological Infrastructure Partnership (UEIP) is a partnership that was formally established in November 2013 upon signing of a Memorandum of Understanding (MoU) by key organisations that are committed to finding ways of integrating ecological infrastructure (EI) solutions to support built infrastructure investments in addressing challenges of water security in the uMngeni River catchment. The partnership currently comprises over 24 organisations from national, provincial and local government departments, business and academic institutions as well as civil society. The South African National Biodiversity Institute (SANBI), as a co-founder of the UEIP, has been the centre of coordination for the partnership since its inception. The primary focus of the UEIP is to explore the role that EI can play in improving water security in the catchment.

The objectives of the UEIP are as follows:

- Strategic investment in EI contributing to enhanced water security in the uMngeni River catchment
- Improved governance that is contributing to slowing the rate of degradation of EI
- Strengthened institutional capacity for the rehabilitation, maintenance and protection of EI
- An enabling policy environment for investment in the rehabilitation and management of EI in the catchment
- An improved knowledge base on EI that informs policy and practice
- Effective collaboration, coordination and co-learning that enables the UEIP to consolidate, grow and demonstrate its value

From: http://biodiversityadvisor.sanbi.org/participation/umngeni-ecological-infrastructure-partnership/

The UEIP aimed to integrate activities across sectoral mandates, providing a platform for multiple perspectives from government, academia, and private business towards a collaborative approach. Umgeni Water plays a critical role in managing water resources in the catchment. It has been successfully operating as a bulk water supplier since 1974 under the Water Services Act (Act 108 of 1997) and the Public Finance Management Act (Act 1 of 1999) (Umgeni Water, n.d.). The organisation is therefore specifically mandated to focus on water, rather than incorporate a diverse ecological focus.

1.7.3 Financial Flows in the Catchment

Financial flows form part of the governance framework as they tend to influence the what, where, and how aspects. As the project aims to identify potential investment opportunities, financial flows form a substantial portion of this study.

Table 1-1 provides a breakdown of the funding generated through Umgeni Water, the bulk water supplier in the catchment. Based on sales from 2014-2018, the water resources management charge (WRMC) of R0.018 per m^3 in the uMngeni generates approximately R7 million per annum. This represents less than 0.5% of the financial flows associated with water sales in the catchment, assuming only bulk water supplied by Umgeni Water. Based on the analysis undertaken by Jewitt et al. (2015), R225 million was needed to rehabilitate and maintain critical parts of the catchment, but there is no obvious source from where this funding could be obtained. Based on 2018 sales, if the WRMC were to be increased to R0.10 per m^3, it would generate approximately R43 million per year. Thus, over five years, this amount could easily be obtained. This would reflect a cost increase of less than 1.5% to the consumers in the catchment.

Table 1-1 Cash flows generated in the uMngeni River catchment and 2020+ examples of different Water Resources Management Charges.

	UW bulk sales (1000 m^3)	Bulk water tariff (R/m^3)	WRMC (Total ZAR)	UW Total income	Water Resources Management Charge	WRCMC as % of Sales
2014	440000	R4.16	R7,040,000.00	R1,830,400,000.00	R0.02	0.38%
2015	447000	R4.53	R7,152,000.00	R2,024,910,000.00	R0.02	0.35%
2016	436000	R4.89	R6,976,000.00	R2,132,040,000.00	R0.02	0.33%
2017	409887	R5.40	R6,558,192.00	R2,212,160,139.00	R0.02	0.30%
2018	434568	R6.21	R6,953,088.00	R2,698,667,280.00	R0.02	0.26%
2020+	434568	R7.06	R43,456,800.00	R3,066,746,376.00	R0.10	1.42%

1.8 Project Approach/Case Studies

Given the complexity of the uMngeni River catchment and the need to investigate the project research questions in depth over a longer period of time, both the UEIP members and the research team supported a case study approach to exploring the multiple factors shaping water security and EI in the catchment. The project team has adopted an approach where research undertaken for WRC 2354 has been geared to support the activities for the UEIP. Three of the case studies (Mpophomeni area and the Baynespruit and Palmiet catchments) were selected by those leading the establishment of the UEIP (Sutherland and Roberts, 2014), as they were spaces that exemplified the issues being faced in the catchment and they represented the different conditions of the catchment. The WRC 2354 research team added the Mzinyathi catchment, as previous research had indicated the importance of understanding the impact of the rapid densification of peri-urban areas under traditional authority on water governance (Sutherland et al., 2014). Under the UEIP, various service providers in the catchment agreed to undertake specific restoration activities in the case study areas where they had a mandate to do so. Research for WRC 2354 was then aligned with and supported these activities. This required that the research team and students were actively engaged with service providers, their activities, as well as the communities who lived and engaged with them in each case study area. **This interaction, engagement and action research is reflected throughout the project and was fundamental in informing the process, shaping the methodology and ultimately, the findings and recommendations from the study**.

A brief description of each case study follows:

1.8.1 The Upper Catchment/Mpophomeni

The Upper catchment contains land uses that differ from the middle and lower catchment, as they are more rural in nature. The climate in the area is characterised by warm, wet summers and cool, dry winters, with a mean rainfall of 992 mm per annum, which influences the type of agricultural activities that are practiced in the catchment. Large scale commercial agriculture (cattle, diary, piggeries, poultry and forestry), subsistence farming, peri-urban settlements, a large township (Mpophomeni) and environmental conservation areas are the dominant land uses in the Upper catchment. The Upper catchment is critical to the water supply in the uMngeni system as it contains valuable EI, including grasslands, multiple rivers, streams and wetlands, which support water production in the catchment, as well as two important water storage facilities: Midmar Dam and Albert Falls Dam. The upper catchment also receives water from the adjacent Mooi River through an inter-basin transfer scheme. The Upper catchment is located in uMgungundlovu District Municipality, where 50% of the land has been transformed. This indicates a relatively high level of development in the rural landscape (Hay, 2017). This also means that critical EI in the form of grasslands, wetlands, riverine areas and indigenous forests are under pressure or have been lost to development.

For many years, contributions to poor water quality exceeded the limitations of existing infrastructure, resulting in heavy pollutant loads to the natural system. These pollutants are a combined result of agricultural activities and domestic waste. The township of Mpophomeni, which was established on a dairy farm in 1963, is currently composed of both formal and informal housing (Rivers-Moore, 2016) which does not have adequate sanitation measures and in some instances the sanitation system that does exist is not used as it is intended or maintained (Kolbe, 2014). For over 20 years, sewerage from Mpophomeni flowed into Midmar Dam (Taylor and Taylor, 2016). Being a more rural case study means that there is less focus on economic resources being provided to the area, placing constraints on the provision of BI, therefore EI could offer supportive solutions. Investing in EI can help to reduce these costs (Browne, et al., 2018; Hughes, 2018; WESSA, 2017).

A wide range of organisations, notably the Department of Environment Affairs (National Government), through its Natural Resource Management Programme (which includes the Working For Water programme), and NGOs such as Duzi Umgeni Conservation Trust (DUCT), through its alien clearing and Ecochamps programmes, are investing in addressing this challenge, with some success. A UEIP member from the KZN Department of Economic Development, Tourism & Environmental Affairs agreed to champion this case study through a rehabilitation effort titled 'Save Midmar'. The 'Save Midmar' initiative linked community activities with research, NGOs, and various tiers of government, both provincial and local. Additionally, Citizen Science has grown considerably in the Upper catchment, particularly in Mpophomeni through the efforts of environmental organisations, NGOs and civil society organisations, particularly the Wildlife and Environment Society of South Africa (WESSA) and DUCT. According to Taylor (2019, p 1) "through action research processes in the uMngeni River catchment, 24 'Stories of Change' about effective EI implementation have been published (Dambuza, 2017c; and Taylor and Cenerizio, 2018). In these case studies tangible and effective action has been taken to strengthen EI and the Stories of Change have been co-published with the participants, who are leaders in their local communities, and who led the change processes. It is particularly encouraging to see how many political leaders, including Councillors and Traditional leaders have taken up this work".

1.8.2 The Middle Catchment/Baynespruit

The Middle catchment is defined as the area from below Midmar Dam to Nagle Dam. It includes the Msunduzi Municipality and the city of Pietermaritzburg. This case study focuses on the Baynespruit tributary, which flows through the east of Pietermaritzburg, traversing townships, middle income residential areas, an industrial area and informal settlement to join the Msunduzi River just below the township of Sobantu before joining the Umgeni River. This case study is therefore very similar to the Palmiet River, with its relatively small catchment, which also flows through a range of land uses typical of the different city zones, and passing through an informal settlement before it joins the larger uMngeni River. The Baynespruit catchment has experienced rapid population growth, which has increased development pressure and led to degradation of the landscape. The municipality has limited resources and capacity to adequately address this growth and provide services in high-density settlements (Govender 2016). This has impacted on water quality due to the development deficits present in the catchment.

Msunduzi Municipality, as a member of the UEIP, proved a key leader in the Baynespruit case study, supporting small, short-term environmental projects and recently implementing experimental floating wetlands. The Municipality has also partnered with a local NGO, specifically DUCT. In recent years the Msunduzi Green Corridor Pilot Project has been established which is affiliated with the Durban Green Corridor Project. The project envisaged the establishment of "Green Hubs" to inspire a sport-friendly environment and enable canoeing, biking, and trail walks, as well as offering opportunities for supporting the green economy through the building of eco-furniture, township trails, and community gardens. Activities undertaken through this initiative included alien invasive removal (continued through the River Health Programme), solid waste management and recycling, river custodians, and eco-champions (DUCT, 2015). Msunduzi Municipality participated in the EI workshops facilitated by WESSA. The Msunduzi Municipality reached out to the National Department of Environmental Affairs (DEA) through the Natural Resource Management Programme regarding the Baynespruit Rehabilitation Project and received support after a site visit in 2017 (MLM, 2017). Much of the work performed by the DEA involves the clearing of alien invasive species, as alien species tend to place additional pressure on the already limited water supply. This highlights the integrated approach of catchment management, considering the environment's role in water security.

1.8.3 Lower Catchment: The Palmiet Catchment

The Palmiet catchment is a small sub-catchment of the uMngeni River catchment. It is located in the urban core of Durban in Ward 23. The Palmiet River flows through a range of land uses including upper and middle income suburbs, an industrial area, a nature reserve and informal settlements, and as such is similar to the Baynespruit catchment. The river is 26 km long and flows through a small, steep highly urbanised catchment. It enters the uMngeni River approximately 7 kilometres from the sea. It is therefore an unusual case study choice as it does not impact on water security of the uMngeni River catchment directly. However, it has proven to be a very wisely chosen case study by the UEIP, as the small catchment exemplifies all the major challenges associated with urbanised catchments with a wide range of land uses, which makes it possible to study these in relation to the river, and each other, in detail. It is a river that floods very quickly due to its steep, urbanised catchment. It has a major impact on the lower uMngeni River, the beaches and the sea after floods, due to its high levels of pollution and the material washed out of formal urban areas and informal settlements that are located on its banks. It flows through a nature reserve and suburbs that have active conservancies and it provides examples of the value of ecosystem services in highly vulnerable and stressed environments, including Quarry Road West informal settlement. The catchment is located within the eThekwini Municipality and is therefore subject to its formal administration (legislation, policy, systems and practices). In terms of river rehabilitation, the catchment is currently governed by eThekwini Municipality, as well as a number of organisations that govern 'beyond the state' (Swyngedouw, 2005), but which work in partnership with the state, forming the Palmiet Catchment Rehabilitation Project. This includes local environmental forums, including River Watch (which has now become the Palmiet River Valley Conservancy), Ratepayers Associations and Conservancies, researchers from the School of Built Environment and Development Studies (BEDS, UKZN) and sub-ward committees and civil society organisations within informal settlements in the catchment. This governance arena has been in existence since 2014 when the Palmiet Catchment Rehabilitation Project was established and it has contributed to improved water and climate governance in the catchment, through social learning, the co-production of knowledge and partnerships between different departments within the municipality and between different state and non-state actors, as this case study has revealed (Vogel et al., 2016; Martel and Sutherland, 2019; Sutherland et al., 2019; Williams et al., 2019; Sutherland, 2019).

1.8.4 The Lower Catchment: Mzinyathi Catchment

Mzinyathi is located in the north-west of eThekwini Municipality in an area that is under both municipal and traditional authority governance. Unlike most metropolitan municipalities in South Africa, governance in the eThekwini Municipality is made more complex by the existence of a dual governance system where 34.8% of the municipal area (comprising 79 913 hectares of Ingonyama Trust land) is governed by both the municipality and traditional councils (eThekwini Municipality, 2013). The governance environment shifted in 2000 when the municipal area of the previous Durban Metropolitan Council was expanded by 68% to include previously rural and Ingonyama Trust areas, which originally formed part of the homeland of KwaZulu under apartheid. A single metropolitan municipality or Unicity was created, the eThekwini Municipality, through the national municipal demarcation process (Durban Metropolitan Council, 2000) which created an urban periphery that was more rural than urban in character. The EI and ecosystem services of the municipality are predominantly located in this peripheral 'rural' zone, which has formed an ecological buffer for the city. However, the rapid densification of these areas has led to the degradation of the city's natural environmental assets and the environmental services they provide (World Bank, 2016).

The ongoing urbanisation of eThekwini Municipality, the decompression of people from crowded townships within the city, the desire for a 'rural lifestyle' and the availability of land through the communal land system, has led to the rapid densification of the Mzinyathi catchment, which has become a densification hotspot in the municipality (Sutherland et al., 2016). It therefore reflects the pressure on ecosystem services as the demand for land and housing increases, and the impacts of the loss of EI on water governance in these rapidly transforming peri-urban areas (Sutherland et al., 2016). The Mzinyathi case study also illuminates the challenges and opportunities for water governance, and the value of EI in improving water security in areas under dual governance and hence it was selected by the WRC 2354 research team for inclusion in the project.

1.9 Goals of this project

The project had an extensive list of aims and objectives provided through the Terms of Reference for the call, to which the team responded. These were hugely ambitious given the budget and time available for the project. However, the partnership with the UEIP and related projects such as the SBSA-GreenFund, SANCOOP CLIMWays Project and the relationship with Umgeni Water provided a good platform for this project. Consequently, most of the aims and objectives were addressed, but perhaps not in the way first intended. As with any large and ambitious project, approaches, methodologies and project results and outcomes evolve and emerge over time. Consequently, there were many surprises and learnings in outcomes and methodology and these shifted somewhat during the course of the project. However, as a consequence of this approach, we believe that the findings are grounded in reality and have great value.

The original Project Aims are listed below:

- Investigate and report on the status of catchment land-use and water resource quality
- Cost the impacts of the degradation of ecosystem infrastructure on water users from different stakeholders experiences using an evidence-based approach
- Develop a cost effective conservation management strategy based on the principles of the green economy
- Investigate and report on the status of catchment land-use and water resource quality
- Cost the impacts of the degradation of ecosystem infrastructure on water users from different stakeholders experiences using an evidence-based approach
- Investigate how investment in the protection and enhancement of the environmental asset base (or EI) of the uMngeni River catchment could contribute to resilient economic growth, greater social equity and justice and the reduction of environmental risks, thereby addressing the goals of the green economy
- Develop a cost effective conservation management strategy based on the principles of the green economy

These have all been addressed through the various scientific papers and student dissertations and are captured in the various Deliverables of this project.

However, the main messages have emerged outside of these technical reports and form the basis of this document. In particular, we address:

- A different approach to understanding interrelationships between space, water and society describing catchment connectivity, the importance of history and resulting path dependencies.
- Quantifying the economic benefits that society can gain from investments in EI in terms of both water quantity and water quality and investigation of appropriate funding options.

- How these can be combined to identify levers of change to guide "what to do, where to do it and by whom it should be done" for EI investments.
- A transformative approach, which emphasizes sustained and meaningful human capacity development, relevant to society as a whole including leaders, business and industry, community members and researchers.
- The benefit of strong student cohort ranging from final year to PhD and Post-Doctoral fellows and the multiplier effects of such investments in capacity development.

CHAPTER 2. CATCHMENT CONNECTIVITIES

Patrick Martel, Catherine Sutherland, Graham Jewitt, Susan Risko, Michelle Browne, Mathew Varghese, Jim Taylor, Sabine Stuart-Hill and Duncan Hay

2.1 Introduction

Chapter Two describes the range of approaches and methodologies adopted to identify the connectivities[2] between water, society and space in the uMngeni River catchment. By developing an understanding of the relations that constitute, produce and are embedded within the uMngeni River catchment, points of entry for ecological infrastructure (EI) investment and levers of change can be identified. WRC 2354 has adopted a project approach which recognises, illuminates and analyses the connections and relations between natural, social, human and built capitals. These connections and relations need to be identified and understood if the potential for EI to change water security outcomes, and consequently support a more resilient and sustainable future for the catchment, is to be realised.

During the course of the project, a detailed methodology was developed and tested to assess water resource connectivity and inter-dependency (between water quality, quantity and access) from a landscape perspective (Sutherland et al., 2016). This methodology enabled the researchers to build a catchment-level understanding of water-society-space relations in the uMngeni River catchment through the construction of an emergent water-society-space trialectic, which was applied to provide the findings reported here. Trialectic thinking moves away from the well-established binaries employed in modernist epistemology and ontology (Sutherland, 2016). It explores the multiplicity of relations between 'things', which Lefebvre argues can most often be conceptualised in threes, or in trialectics (Lefebvre, 1980; Soja, 1996; Massey, 2005). Trialectics are disorderly, unfixed, and constantly evolving, revealing the complexity of life (Soja, 1996). They are assembled to produce a "thirdspace", a composite of all spaces and things, a "knowable and unknowable, real and imagined lifeworld of experiences, emotional events, and political choices … and action in the field of unevenly developed (spatial) power" (Soja, 1996, p 31). This makes alternative ways of seeing and doing things possible, as it shifts away from narrow dualistic thinking. The trialectic is adapted in the third section of this chapter to create a framework, the Opportunities and Risks Framework for EI (OR4Ei), for determining where, how and by whom, EI interventions in the uMngeni River catchment, can be made (see Tables 2-1, 2-2 and 2-3). This framework of opportunities and risks in the catchment is then set in relation to the range of water security interventions that are possible, the governance and institutional arrangements in each context, as well as the cost benefits and financial decisions (see Figure 2-9). All of these elements are connected in the catchment and hence are not independent. It is useful, however, to conceptualise them as components of a universal decision making framework for EI interventions in catchments, both in South Africa and globally, which would translate uniquely in every context.

[2] Connectivity is defined as the state or extent of being connected or linked to another person or thing. Connection is where people and/or things have a relationship. It is often about the act of being in a relationship with something else, i.e. being connected. Relations are defined as the condition of being connected or the way in which people and or things are related, and hence how they shape each other. Relations are therefore revealing of power and agency.

2.2 An Approach to Understanding Water-Society-Space Relations

The main research problem, aim and objectives required a transdisciplinary approach for the study. The composition of the research team for the WRC 2354 project therefore ensured that both natural and social scientists were included, with an interest in developing transdisciplinary expertise through the project. Transdisciplinary research has emerged as a response to the need for research (and science) to: be relevant and help to resolve 'real' world problems, most especially 'wicked problems' (Bhaskar et al., 2010; Vogel et al., 2016); address complex socio-ecological problems in open systems by drawing on multiple ways of knowing (Max-Neef, 2005; Bhaskar et al., 2010; Vogel et al., 2016); and to be able to integrate and synthesise knowledge about these problems in ways that leads to socio-ecological transformation (Max-Neef, 2005; Hirsh Hadorn et al., 2008; Bhaskar et al., 2010; Vogel et al., 2016). Epistemological transdisciplinarity requires drawing knowledge from already existing disciplinary fields, leading to creative interdisciplinary work (Bhaskar et al., 2010), as this WRC 2354 project has attempted to do.

The methodology was developed so as to better understand the connectivities in the catchment (see Sutherland et al., 2016; Sutherland et al., 2019). This included identifying relevant theoretical frameworks to analyse relations in the catchment, the adoption of a case study approach, as well as constructing water configurations for the case studies. A qualitative system dynamics modelling exercise based on the water configurations was also undertaken and this included expert responses to the systems map created. An analysis of 'water moments' identified in the uMngeni River catchment from 1854 to the present[3] was conducted. Research on the economic value of EI was also included in the analysis of the connectivities (Brown et al., 2018). These research activities all contributed to the overall thematic analysis, so as to develop a water-society-space trialectic (Figure 2-1).

In summary, the approach adopted was transdisciplinary and was grounded in action research and participatory methods (see Chapter 4; as well as Taylor,, et al., 2018)).

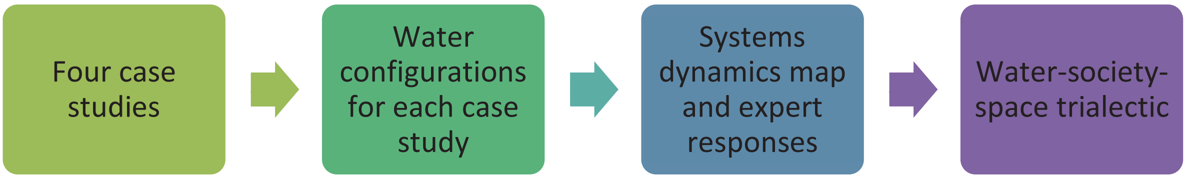

Figure 2-1 The approach used to develop a catchment-level understanding of water-society-space relations in the uMngeni River catchment

Two theoretical frameworks, namely socio-ecological relations theory and socio-ecological systems thinking, were used to consider the relationships between society, economy, environment and governance within the uMngeni River catchment. Importantly, these theories emerge from different philosophies and paradigms and hence analyse relations from different epistemological and ontological perspectives (or ways of knowing the world). Traditionally, natural scientists have favoured a socio-ecological systems approach to understand the *connections* between water and society. In contrast, social scientists construct water-society *relations* through the frames of political ecology and political economy, drawing on conceptualisations such as the hydrosocial cycle (Linton and Budds, 2014). Hydrosocial cycle thinking argues that society and water shape each other. It focuses particularly on the politics and power that produces the relationships between water and society, which are assembled to create particular society-water outcomes in different contexts (Linton and Budds, 2014). As the project evolved, theories and methods pertaining to socio-ecological relations theory emerged as the preferred way of framing and understanding the relations in the uMngeni River catchment, particularly when constructing a water-society-space trialectic.

[3] The 'water moments' in the uMngeni River catchment have been identified by using the 'water moments' in eThekwini Municipality from 1854 to the present as a proxy (see Martel, 2019).

Given the complexity and size of the uMngeni River catchment, the four case studies described in Chapter 1, and selected as pilot studies of the UEIP, were used to explore the relations between natural, human, social and built capitals and governance systems (Figure 2-2). This includes the Mthinzima/Mpophomeni case study in the upper catchment, the Baynespruit catchment in the middle reaches, and the Palmiet and Mzinyathi catchments in the lower reaches (see Section 1.8 in Chapter 1). Interaction and, in some cases, collaboration and the co-production of knowledge between the research team, municipalities, communities, and to a limited extent the private sector, has formed part of the knowledge building process through the co-engaged action research methodology adopted in each case study.

Different yet complementary methodologies were used in each of the four case studies to collect and analyse data. This was necessitated by the different issues and challenges faced in the upper, middle and lower catchment, as well as the reality and influence of conducting situated action research in the different parts of the catchment. With the central aim of developing a relational understanding of the catchment, water configurations[4] were used as an organising framework to reveal the critical elements that shape and reflect water security in each of these case studies. The water configurations approach provided an analytical frame, which ensured that there was uniformity in data presentation and analysis for each case study. Within each case study configuration, emphasis was placed on understanding the context, the actors engaged in the catchment, the dominant discourses shaping water governance in each case study, the critical issues and risks, as well as the materiality of and knowledge produced in each locality. These configurations reveal common and unique characteristics of each water security assemblage in each case study.

Comparative analysis of the configurations highlighted that both the history and geography of the uMngeni River catchment shape and structure water-society-space relationships. Water quality is a critical concern throughout the upper, middle and lower reaches of the uMngeni River. Path dependencies that have been created continue to impact on water security in the catchment. Development deficits, increasing population growth and demands on the catchment, weak governance, and a lack of monitoring, enforcement and compliance are critical issues that need to be addressed. Building relations between the state, citizens and industry, is considered to be essential to improving water quality. Two case studies reveal that where this has been achieved to a certain level, governance has improved, which then provides a platform for water security interventions. The willingness of communities to engage in EI interventions and rehabilitation efforts is significant, as is their knowledge of their environment. Environmental education and social learning processes are essential in building human and social capital to bring about changes to water security, with communities being able to draw on their own resources and capabilities to shift their relationships and engagements with water challenges. This becomes even more powerful when it occurs through participatory processes, in partnership with the state.

[4] A configuration, which consists of the actors, discourses, materialities (biophysical realities and contingent conditions), the issues and critical risks, the knowledge produced and the spatial expressions of society-water relationships, is a heuristic device employed to analyse water connectivities through the lens of the four case studies in the catchment (Sutherland et al., 2019).

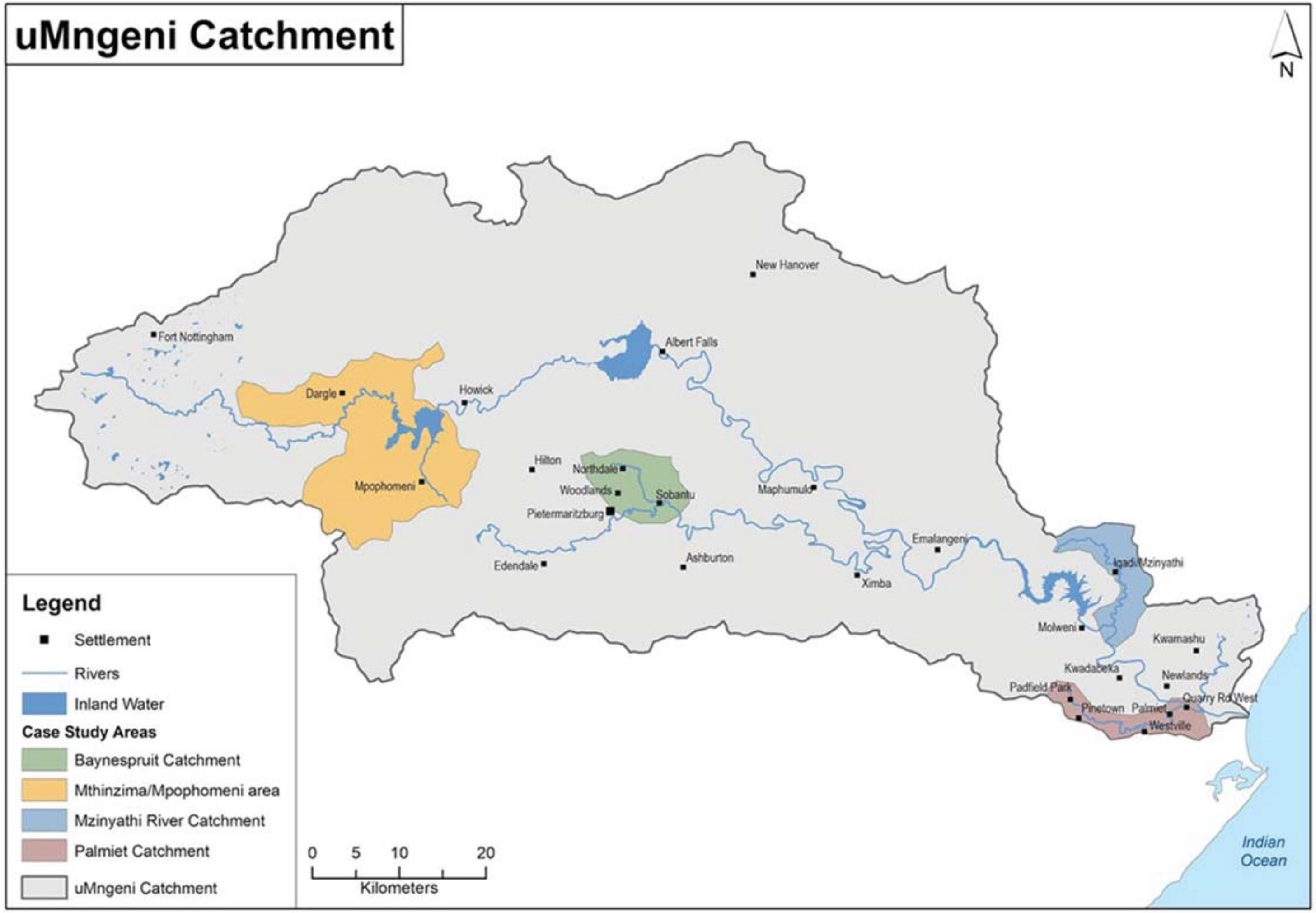

Figure 2-2 The four case studies selected within the uMngeni River catchment

The absence of business and industry in most collaborative governance forums, is of serious concern in all case studies, as are the challenges that arise from a dual governance system, which includes democratic and traditional leadership. This is evident in two case studies. The recent ecological disaster of the Willowton oil and caustic soda spill on 7 August, 2019, which has impacted significantly on the Msunduzi River, the uMngeni River and Inanda Dam, re-iterates just how critical it is that industry and the private sector engage in water governance forums in the uMngeni River catchment.

The relational understandings developed through the configurations were used to provide knowledge for the development of a conceptual, qualitative and participatory system dynamics model (the third step in Figure 2-1). This systems dynamics model or map was constructed by researchers in the WRC 2354 project team. The process for developing the systems map was as interesting as the outcomes of the model. It provided significant learning on transdisciplinary research and the challenges of finding a common platform and language with which to interact and share knowledge. This form of co-engaged research was one of the highlights of the research process.

Once finalised, the qualitative systems map was ground-truthed by experts with knowledge on the uMngeni River catchment, particularly from the water, climate change and environmental fields. The value of the system dynamics modelling exercise was revealed when experts reflected on the map produced, and thereafter revealed what they thought the critical structuring elements in the uMngeni River catchment are. Through their interactions with the map, a second diagram representing the critical opportunities and risks in the uMngeni River catchment was produced (Figure 2-3). An analysis of this data revealed the critical variables or elements of the catchment that are shaping water security. These are the development of a strategic plan for the uMngeni River catchment which is aligned with sustainability goals and principles; the governance of the catchment; water management by the state; social engagement and education; and the building of state/citizen and state/industry relations. The path dependencies and potentially positive role of agriculture and forestry; the critical value of the environmental asset base and concerns about its degradation; the risk and impact of poor water quality; and the need for knowledge development which can influence policy and practice, further influenced the catchment configurations (Refer to Figure 2-3).

The analysis of the configurations, the system dynamics modelling process, the commentary on the systems map, identification of the dominant water moments shaping water security over time, as well as a review of the other WRC 2354 deliverables, including the economic evaluations, was then used to generate the water-society-space trialectic. The trialectic reveals the relations that constitute and produce the uMngeni River catchment and which are embedded within it, enabling levers of change and points of entry for EI investment, to be identified (see Chapter 6). This research further signals what the enablers and barriers to successful EI interventions might be. Findings were confirmed and validated through triangulation of the data used (Cohen et al., 2018). Consistency and convergence in the structures were identified, which means that the elements of the trialectic can be accepted with high levels of confidence. These structural elements also reflect the status quo (2014-2019) or the 'where we are now' in the catchment, based on the findings of detailed research across four case studies undertaken over five years.

Figure 2-3 The systems dynamics model triggered responses from experts which revealed the critical structuring elements in the uMngeni River catchment

2.2.1 The Water-Society-Space Trialectic of the uMngeni River catchment

The water-society-space trialectic encapsulates the relations that are currently shaping water security and EI investment (both realised and potential) in the uMngeni River catchment (see Figure 2-4). This framework therefore moves away from the use of binary logic and dualisms and rather engages with concepts that reveal the connections and relations between water, society and space. The uMngeni River catchment assembles, contains, reflects, is shaped by, produces and reproduces the multiple relations of its particular water, society, space trialectic[5]. In this research, the concept of a trialectic is adapted to include the multiple water, society, space relations that come together in varying combinations in the uMngeni River catchment, at a particular time, shaped by historical and geographical traces, as well as envisioned futures. It captures how conceptualisations of the present system provide the building blocks to shape and drive the catchment into a new future and trajectory, using EI as a lever of change (see Chapter 6). A trialectical approach represents a move from dualistic to relational ontologies and from a disciplinary focus to transdisciplinarity.

This approach considers how society influences water (and vice versa), how society influences space (in relation to water) (and vice versa), and how water and space influence one another. It also reveals the interconnectivities between these three sets of relations. This analytical approach enables water connectivities that are embedded in society, to be revealed. Importantly, the relations comprise of both structural elements and processes (factors that structure how society, water and space 'work'). These appear on the sides of the trialectic depicted in Figure 2-4. These relations are produced, and shaped by meta-structures (much larger elements that shape society and determine relationships in it), epistemic notions (broad framing ideas that are well accepted, such as sustainable development) and global frameworks, including global and national institutions. When unravelling the water-society-space relations, time and space matter. The trialectic reveals traces of history, which in the case of water security in the uMngeni River catchment, have created path dependencies which make the shift towards improved water security and investment in EI challenging. The current time-space context of a transforming South African society, an emerging economy in the global south, a country with high levels of poverty and inequality and development deficits, weak governance, and environmental risk and environmental change, including climate change, shapes water security outcomes. Nature also has agency. Water acts back on society-space relations, as does the materiality of the uMngeni River catchment. Rather than the environment being the stage upon which and through which society creates its relations, water and space together create these relations (Braun, 2008; Hinchcliffe, 2008; Lefebvre, 1991; Massey, 2005). Massey (2005; 2006) calls for nature to be brought back into place and space, where both nature and space cannot be held still, and where nature (in this case water), society and space produce and construct each other (Sutherland, 2016). It is this 'co-constitutive space' that the trialectic reveals. In this project, this argument is extended to reflect the approach that sustainable investment in water security and human wellbeing must recognise the interactions between natural, built, human and societal capitals.

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[5] Lefebvre (1980, 1991) and Soja (1996) have written about the trialectics of spatiality, where the three moments of space, spatial practices, representations of space and representational space, come together in fluid, constantly evolving combinations. This echoes Massey's (2005) conception, that space is produced through multiple interrelations that are always under construction.

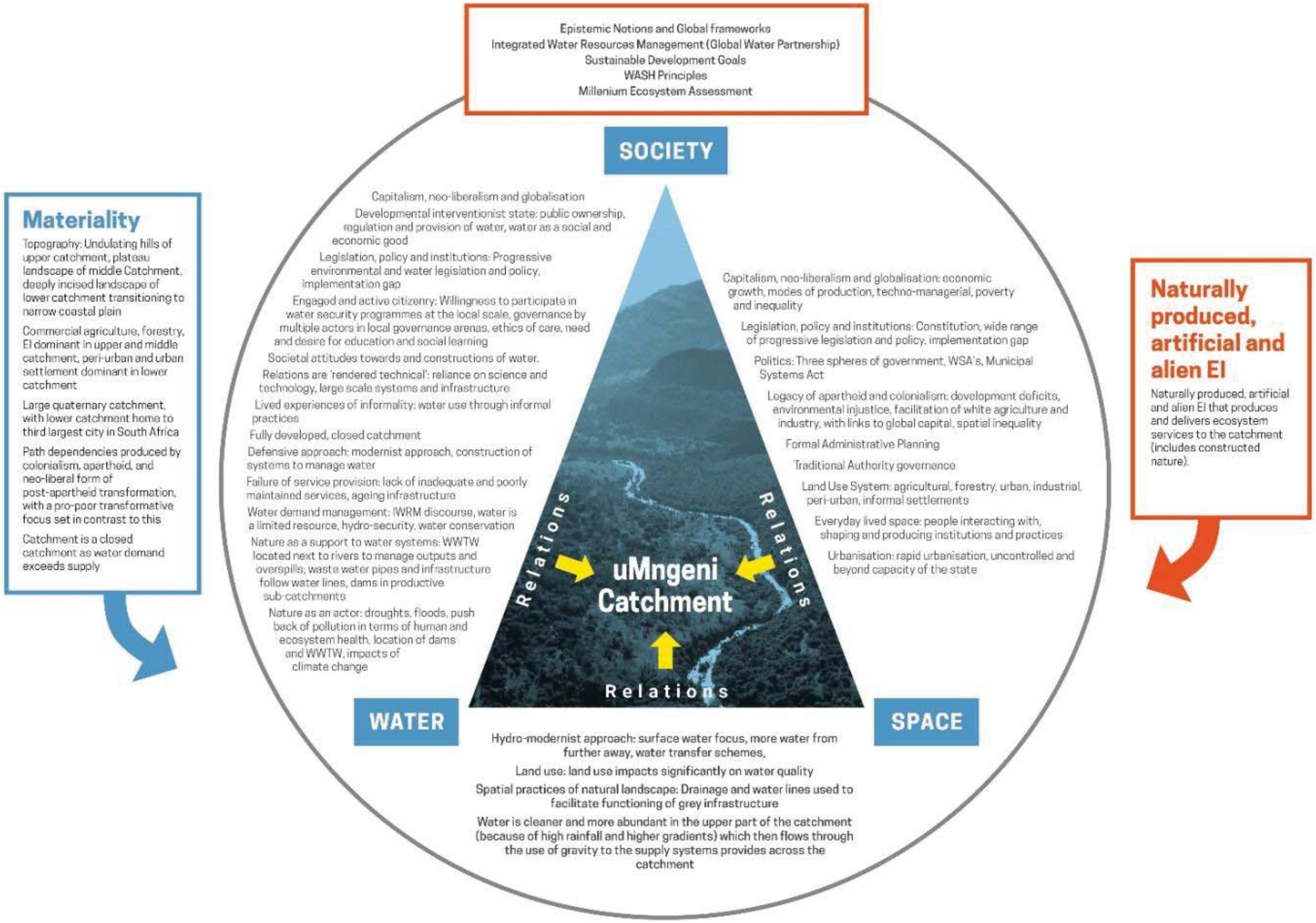

Figure 2-4 The water-society-space trialectic for the uMngeni River catchment

The research undertaken in WRC 2354 has revealed the meta-structuring elements (the broader structures of society, which are global and national), as shown in Figure 2-5, and structuring elements (local level structures which are shaped and produced by meta-structures and by internal relations in the catchment), as presented in Figures 2-6, 2-7 and 2-8 that define the catchment. These meta-structuring elements produce and shape the opportunities and risks for EI interventions in the catchment. The three sets of relations, society-space, society-water and water-space, as presented in Figure 2-4, are explained in more detail below. By revealing the relations between water, society and space and their inherent connectivities, we have created a reality congruent framework for the uMngeni River catchment. This framework can now be used to determine where EI, as an intervention to rehabilitate and maintain the natural environment to produce and deliver ecosystem services and hence support water security, can be inserted, and re-inserted, into the catchment

2.2.1.1 Epistemic notions and meta-structures shaping the uMngeni River catchment

When explaining the water-society-space trialectic in the uMngeni River catchment, we start with two broader framing concepts known as epistemic notions and meta-structures, which also shape global and national institutions. Epistemic notions are “rules of formation that underpin theories and policies, but are not formulated in their own right” (Hajer, 2003, p 106). Actors are not necessarily aware of epistemic notions, but their understandings of reality and behaviours are structured by them. These extensive framing concepts refer to the conformity in thinking and understanding during a specific period of time, which influences an actor’s interpretation of reality (Hajer, 2003). Epistemic notions identified include discourses of: Integrated Water Resource Management; Sustainable Development; universal and equitable access to water, sanitation and hygiene through the WASH principles; as well as commitments to protect the world’s environmental asset base, which is essential because of its value to humanity in a time of global and local environmental risk.

Meta-structures are the broader structures of society. Such structures may be global and national, yet they interact with local structures. These meta-structures have acted in the past, and now in the present, and have produced path dependencies, which continue to shape the outcomes of relations in the uMngeni River catchment (see Figure 2-5). Interestingly, although the meta-structures have always been present and have had marked effects in influencing the catchment dynamics, catchment management, including researchers, have not been able to understand or adequately describe them. The configurations and relations becoming increasingly evident through this research process are thus a major step forward in building the understanding of the complexity of the catchment management processes and concomitant shaping forces.

Colonial modernity imposed British planning systems and racialized conceptualisations of spatial ordering and ways of governing onto the uMngeni River catchment. This meta-structure has created a legacy of spatial relationships, for example, the location of sewerage works, as shown in the Baynespruit case study, on a river in close proximity to a poor, colonial-constructed black settlement, which provided labour to adjacent industry. This legacy has been reproduced in the same location under the apartheid era, in the case of the Darvill Wastewater Works and the Sobantu township, and under the neo-liberal post-apartheid economy, in the form of informal settlements that have expanded in the area adjacent to Sobantu.

Starting from the colonial era, drainage and control of surface water was considered as a challenge to urban settlement, and consequently water has been drained and moved away. This path dependency has become entrenched as a dominant, modernist approach to surface water, but is being challenged through EI interventions, such as through the value of wetlands and the introduction of sustainable urban drainage systems.

Colonial modernity	Imposition of British planning systems, conceptualisations of spatial ordering and ways of governing in the uMngeni River catchment Legacy of spatial relationships, e.g. location of sewerage works along a river in close proximity to low income African settlements Under-valuing and denigrating indigenous knowledge processes
Hydro-modernism	Mass roll-out of built infrastructure to secure water from further and further away The "taming of nature" by large scale interventions Coincides with the use of science and technology to de-politicise water Failing to respect and build on indigenous wisdom and tried and tested practice wisdom of the past
Apartheid ideology	Entrenchment of separatist development spatial patterns Reproduced the legacy of colonial spatial relationships Unequal access to water resources and differentiated provision of services based on race Production of development deficits, racial segregation and disrupted environmental relations Creation of Homelands and Bantustans
Post-Apartheid Transformation	Transformation of post-apartheid society: pro-growth and pro-poor agendas Addressing inequality and development deficits of apartheid era Democratisation of society
Neoliberalism and globalisation	Entrenching of inequality through water as an economic good Reproduces the legacy of spatial relationships of colonialism and apartheid using class as the main instrument of differentiation Water-society relations are structured within a neoliberal and materialistic logic, as water consumers are conceived of as clients and citizens who pay for water services Neoliberalism pushes that which capital does not value to the periphery, for example EI, indigenous knowledge, economically poor as well as unskilled labour
Recognition of global environmental change and environmental limits	Sustainability comes into ascendency A global movement to protect, rehabilitate and enhance biodiversity and ecosystem services Global agendas and frameworks, e.g. Sustainable Development Goals, New Urban Agenda, Paris Agreement on Climate Change, Sendai Framework for Disaster Risk Reduction (post 2015), Integrated Water Resources Management and WASH principles Call to include multiple actors and conserve environmental assets which underpin human well being

Figure 2-5 The meta-structures shaping water-society-space relations in the uMngeni River catchment

Hydro-modernism refers to the engineering approach which involves the mass roll-out of built infrastructure to secure water within a system, through dams, pipes, pumps and wastewater works, and from further and further away, as nature is tamed by large scale interventions. Significant path dependencies are created as this approach to water 'locks-in' and secures water from a wider spatial reach. Hydro-modernism coincided with the development and use of science in the water sector, as water solutions are engineered and 'rendered technical'. According to Li (2007, p 7), the practice of 'rendering technical' "confirms expertise and constitutes the boundary between those who are positioned as trustees, with the capacity to diagnose deficiencies in others, and those who are subject to expert direction". Li (2007) asserts that as challenges are 'rendered technical', they become non-political, as typically experts tasked with improvement interventions do not question or alter the underlying structure of political-economic relations in their analyses and recommendations. Consequently, underlying power relations and hence path dependencies remain unchallenged, as a boundary is established between experts and citizens in knowledge production processes. Water and environmental issues in the uMngeni River catchment have been 'rendered technical' by officials and engineers through managerial governance, in an attempt to govern and control the conduct of citizens and the political struggles that water rights and security evokes. Water interventions always reflect a particular political project (Martel, 2019; Hellberg, 2017; Swyngedouw, 2015; Sutherland et al., 2014), and they reveal dominant power relations, which in the case of hydro-modernism, become reinforced by rendering water management technical, thereby subduing opposing public interests and alternative approaches.

Such modernising processes have little time or respect for indigenous knowledge practices or 'ways of knowing' about water that have enabled indigenous people, across southern Africa to cope with health challenges, such as cholera, as well as weather events and locally based decision making options relating to village-based risk avoidance. Such has been the realisation of how indigenous knowledge practices and indeed natural and cultural heritage has been denigrated, that the Southern African Journal of Environmental Education has produced a dedicated edition, Volume 35, on this topic (Pesanayi et al., 2019).

Apartheid has had a major impact on water-society-environment relations in the uMngeni River catchment producing water inequality and social and environmental injustice. The impact of apartheid through its segregation of communities based on race, and its uneven and unequal development, is still evident in the catchment and undermines water security. After 1994, the post-apartheid government began to address the inequalities and development deficits created by apartheid through the South African Constitution and its Bill of Rights, which affirm the democratic values of human dignity, equality and freedom. The Constitution of South Africa (Chapter 2) provides that: "*Everyone has the right to have access to sufficient water*", ensuring the right to basic water supply and sanitation services. These rights are addressed through the pro-poor agenda in South Africa which defines national government's social transformative programme and the nature of its developmental state.

Neoliberalism is the dominant global economic system with its market-oriented policies, the privatisation of resource utilisation and service provision, and the reduction of state influence in the economy. It is evident in South Africa in the particular form of its developmental state, with its pro-growth agenda and neo-liberal macro-economic policies. South Africa represents an interesting case in terms of water and sanitation provision, as this is a responsibility of the state, with free basic water and sanitation being provided to the poor. However, water is also considered to be an economic good and hence it is shaped by competitive, market-orientated policies and pricing structures (Sutherland et al., 2014).

The value of the environmental asset base, and the EI and ecosystem services it provides, which underpins and sustains development in South Africa, is well recognised. Sustainable Development is a powerful discourse which frames national legislation and policy and South African environmental legislation is progressive and strongly supports the protection and maintenance of the country's valuable environmental resources. However, while the value of the environment is recognised at a rhetorical and institutional level, the politics and practice of environmental management and the ongoing degradation of South Africa's valuable environmental resources reveals that in reality, economic and development pressure is the priority, with the conservation of environmental resources being considered as an impediment to development or as a costly practice that does not support economic growth, job creation and poverty alleviation. This pro-growth discourse is challenged by a wide range of sectors and actors in the country, but it remains pervasive in politics. Global environmental change, including climate change, which is being experienced in South Africa, is beginning to shift thinking and practice towards a more sustainable and environmentally transformative approach to development.

The meta-structures described above shape water-society-space relations in the uMngeni River catchment and interact with, and often subjugate, structural elements and processes at a local level.

2.2.1.2 Structural elements shaping the uMngeni River catchment

Local level structures in the uMngeni River catchment are shaped and produced by meta-structures and by internal relations and materialities or contingent conditions in the catchment. These structures and processes form the relations between society and space, water and society and water and space in this catchment.

2.2.2 Society-Space Relations

Society-space relations emerged as being critical in producing and undermining water security in the uMngeni River catchment (Figure 2-6). By taking cognisance of the structures influencing society-space relations identified within Figure 2-6, planners of EI interventions in the catchment can be made aware of the potential opportunities and risks produced by these relations or structuring elements.

2.2.3 Water-Society Relations

The following society-water relations emerged as being critical in producing and undermining water security in the uMngeni River catchment (Figure 2-7). These relations interact with one another, as well as the relations identified on the society-space and water-society axes of the trialectic.

Figure 2-6.../

Capitalism, neoliberalism and globalisation	Prioritises particular modes of production and focuses on economic growth and the market Commercial agriculture, the growth and development of two large cities and the conceptualisation of water as an economic good, capturing and engineering flow of water from far away to meet the demands of the market - reflects capitalist and neo-liberal logic Poverty and inequality are the outcomes of the current economic system.
Legislation, policy and institutions	Legislation shapes what citizens can and cannot do in and with space Legislation impacts how economic, social and biophysical aspects of society interact with one another The legacy of past legislation Legislation is required to promote societal value changes Establishment of mandates and responsibilities for different spheres of government, as well as the re-construction political and administrative space
Governance	Refers to the way in which social, economic, environmental and political systems, as well as their interactions, are steered or governed Process of steering or governing societal relations through the interactions of actors in different combinations and alliances Legislation and policies are foundational to governance
Politics	Politics establishes who has the power to shape water-society-space relations, and through which means and mechanisms There is a culture of community participation in post-apartheid South Africa Ward Committee system can support or undermine state-citizen relationships Shifting of water-society-space relations when communities participate and engage in environmental governance through building state-citizen relations that are not solely reliant on the mediation of the councillor Party politics and local political dynamics are associated with the administration of wards
Legacy of apartheid and colonialism	This has produced and continues to produce development deficits and inequalities (inadequate access to water and sanitation, waste management services, environmental injustices) The relationship between townships and water resources Ageing and poor infrastructure Creation of parastatals (Umgeni Water - initially as a water board) and the development of large scale commercial agriculture and forestry in the catchment (created a high demand for water)
Failure of the state and poor governance	State is not fulfilling its mandates, implementing legislation and policy or ensuring compliance, enforcement and monitoring Attributed to a lack of capacity and skills, a lack of finance, corruption and the local state being overwhelmed by complex challenges
Formal administrative planning	Planning systems evolved from the British administrative systems first implemented during the colonial era IDPs, SDFs and LUMS provide the normative and legal framework for land use in the catchment Land use plays a significant role in shaping water outcomes and water security in the uMngeni River catchment uMngeni Catchment not aligned with formal administrative boundaries, which creates challenges of co-operation between different administrative entities
Traditional authority governance	TLGFA guides the allocation and use of land in traditional authority areas; provides for the establishment of traditional councils and the recognition of traditional communities and traditional leaders Legally, Ingonyama Trust land is state land. It is governed by the traditional authority, who has the power to allocate land, and the municipality, who is mandated to implement planning legislation and policy, provide services and protect the environment Traditional authority land is rapidly densifying leading to the development of residential neighbourhoods outside formal planning processes and building regulations
Land use systems	Land use plays a significant role in determining water quality in the uMngeni River catchment Land use system is embedded in and has emerged from the colonial and apartheid history of the catchment, and this continues to shape contemporary patterns Land restitution processes have attempted to transform land use and access Restructuring of land uses through municipal demarcation processes, creating 'wall to wall' municipalities Increasing levels of informality due to increasing urbanisation and the inability of the state to address urban poverty, housing and other services Rapid densification in traditional authority areas
Everyday lived experiences and practices of ordinary people	Citizens interact with legislation, policy and practices of the state, re-shaping these practices through different modalities of social mobilisation Ongoing negotiations over and the construction of state-citizen relations Interacts with the governing approach of the local government - managerial governance State response to social mobilisation, actions and protest through participatory processes
Urbanisation	Urbanisation shapes where and how people live, work and play Rural urban migration places pressure on water resources, built infrastructure and basic services Urbanisation processes in the uMngeni River catchment are formal and informal, and this restructures and challenges traditional water-society-space relations

Figure 2-6 Structures and processes constituting society-space relations in the uMngeni River catchment

Capitalism, neoliberalism and globalisation	Neo-liberal project places demand on water for economic growth With continued economic growth, water resources are drawn from a wider spatial reach Water is conceived of as an economic good, and payments are required for water
Water as a public good	Constitution of South Africa places a legal obligation on the government to realise people's right to sufficient water National Water Act (No. 36 of 1998) ensures that water has remained a public good National state regulates water resources Provision of water and sanitation services is delegated to the local state or municipality State regulates the relationship between water use and the environment Ecological reserve has three components: Basic Human Needs (25 litres per person per day), environmental requirements (achieved through reserve determination and resource quality objectives), and strategic / international water requirements
Balancing water as an economic and social good	The local state is required to balance water as an economic and social good Challenging in municipalities that lack capacity and finance An example is the spatially differentiated service provision model in eThekwini Municipality Free Basic Water policy which was pioneered in Durban The state mediates the relations between water and capital The state is both a regulator and provider of water services
Progressive environmental and water legislation	The challenge of the implementation gap, which undermines water security Catchment Management Forums (CMF) play a key role, particularly in the upper and middle catchment The absence of a catchment Management Agency in the uMngeni River catchment is a major challenge, as CMFs have limited powers The uMngeni Ecological Infrastructure Partnership (UEIP) performs a key role in creating an integrated city-region approach to improving water security The role of Umgeni Water in the catchment
Engaged and active citizenry	Civil society is playing an important role in shifting the way citizens interact with water and participate in programmes to support and enhance ecosystems There is a willingness to participate in water security programmes at the local scale Growth in civic science at the local level Development of an ethics of care, signifying the need and desire for education and social learning Participatory governance and the co-production of knowledge on water
Societal attitudes towards water	Significant shift in attitudes towards water. Citizens across socio-economic classes acknowledge that water is scarce Drought, as well as social learning through the media, has played a role in shifting these attitudes Disconnect between people and water in terms of where and how water is produced The spiritual value of water to communities Citizens are aware of the impacts of polluted water, but ways of addressing this challenge is complex Connected to development deficits, attitudes and behaviours. Especially in situations where water has become the only means of removing sewage, solid waste and wastewater in the absence of services
Relations are rendered technical	The reliance on science and technology, large scale systems and infrastructure, bulk water supply, institutionalisation of engineering, a science and technology approach Experts make decisions about water governance, and they are influenced by dominant paradigms, approaches and ways of thinking that are powerful and prevailing
Lived experiences of informality	Lived experiences of informality 're-orders' interactions with formal water systems Water is abstracted and used through informal practices and networks, including illegal connections, sanitation and solid waste disposal systems, and it is diverted and re-categorised as being free Occurs for a range of reasons: the absence of formal systems to support informal life; citizen's lack of understanding of the costs of water; or their unwillingness to pay
Reality of a fully developed, closed catchment	Water resources in the uMngeni River catchment have been captured and fully utilised to support 6 million people living and working in the catchment uMngeni catchment is no longer open to stream flow reduction activities such as afforestation, expansion of irrigated agriculture or the construction of storage dams
Modernist and defensive approach	This approach has results in the construction of engineered and built infrastructure to manage surface water Built infrastructure is used for drainage and for moving water in all of its forms through the system, collecting and storing water through the logic of a large-scale bulk supply system Approach has ensured the supply of water to the third largest economic hub of South Africa, but it is under stress and there is a need to consider alternative approaches to enhance water security in the uMngeni River catchment
Failure of service provision	The lack of adequate and poorly maintained services and ageing infrastructure shapes water-society relations Access to water across the catchment is good, with only 4% of the population having to walk more than 200 metres to obtain water Adequate sanitation and solid waste services are poor, which adversely affects water quality Failure to maintain sewerage systems, resulting in overflows and leaks of sewage into rivers, adversely affects water quality Industries bypass grey systems for managing pollution, wastewater and stormwater, releasing effluent directly into rivers Non-point source pollution is challenging to manage as it is produced through a combination of topography, land use, soil type, hydrology and climate
Water demand management	Water demand management and water conservation emerge from a hydro-security discourse, and coincides with the privatisation of water and has a techno-managerial approach Reflects a neo-liberal or business approach to water Droughts and other natural disasters have played a role in supporting water demand management due to water restrictions
Nature as a support to hydro-modernist water systems	Nature acts as a buffer or facilitator for built infrastructure Water resources management financing in South Africa goes through a cycle from catchment management charges through to bulk water costs to water supply costs, sewerage costs and then a wastewater discharge In the uMngeni River catchment, 98% of finances flow through the built infrastructure charges, with very little finance going to support nature's services or ecological infrastructure Ecological infrastructure is currently undervalued in South Africa's water resources management financing cycle
Nature as an actor	Droughts, floods and other natural disasters recalibrate water-society relations Alteration of practices - e.g. water conservation and water demand management interventions during periods of drought Solid waste pollution along rivers and the coastline following flood events

Figure 2-7 Structures and processes constituting water-society relations in the uMngeni River catchment

2.2.4 Water-Space Relations

The following society-water relations emerged as being critical in producing and undermining water security in the uMngeni River catchment (Figure 2-8).

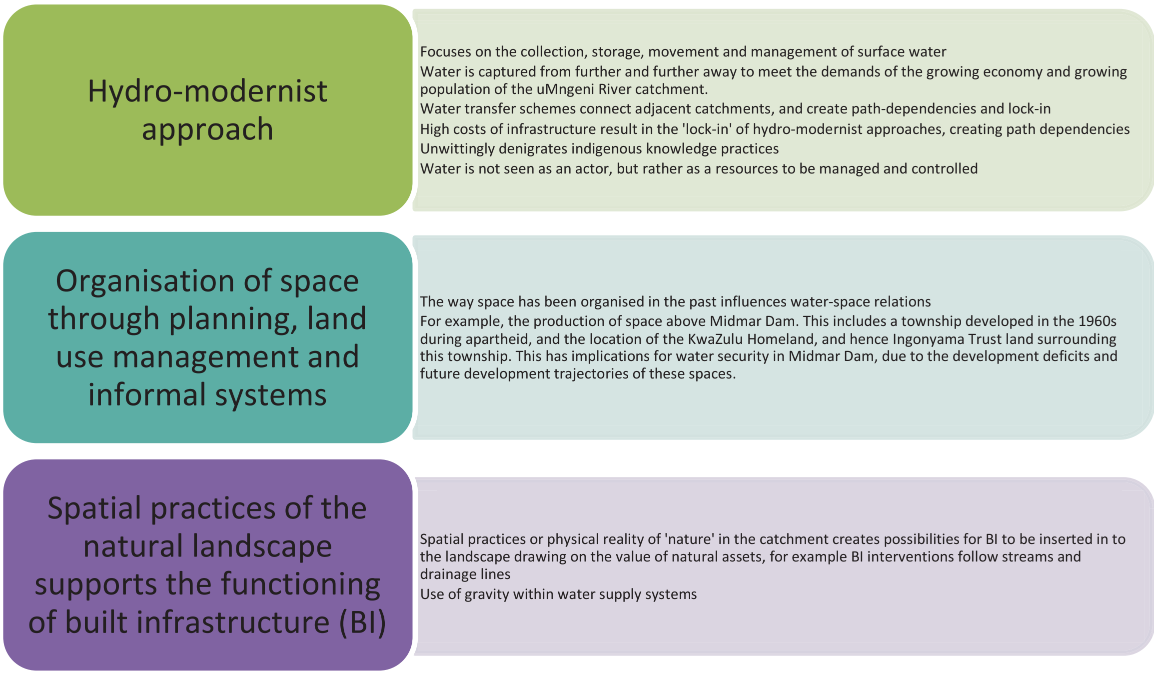

Figure 2-8 Structures and processes constituting water-space relations in the uMngeni River catchment)

The epistemic notions, meta-structures and structural elements of the uMngeni River catchment have been outlined and set in relation to each other in the water-society-space trialectic of the catchment. WRC 2354 argues that these relations are critical in determining where, how, by whom and when to use EI to improve water security in the catchment. The trialectic is therefore a useful tool for decision makers. So as to make it more accessible and user friendly, the trialectic has been adapted to form the Opportunities and Risks Framework for EI interventions in the uMngeni River catchment (ORF4Ei)[6]. This framework is presented in the next section of this chapter, and is applied to the water security interventions continuum, that is introduced in Chapter 1 and further developed in Chapter 6, and which forms the focus of this research.

2.3 The Opportunities and Risks Framework for EI Interventions in the uMngeni River catchment (ORF4Ei)

The trialectic is converted in to the Opportunities and Risks Framework for EI (ORF4Ei[7]), which can be used by decision makers in the catchment to identify appropriate strategies and types of EI interventions, entry points for EI interventions, and barriers, enablers and levers of change. The ORF4Ei presents the society-space, society-water and water-space relations that have emerged as being critical in shaping BI and EI interventions in the uMngeni River catchment. These interventions, which are expanded on in Chapter 6, where they are reflected as a continuum of BI, EI and hybrid BI/EI interventions, are shaped by the epistemic notions of water security, the meta-structures of South African society and the social, economic, environmental and political context in which they are embedded in the catchment, as well its material reality or physicality. They are both enabled (opportunities) and constrained (risks) by the structures of the water-society-space trialectic.

[6] This can be referred to as the Or-for-EI
[7] This can be pronounced as OR-for-EI

The ORF4Ei consists of the epistemic notions and the meta-structures which must be reviewed at the outset of any evaluation of EI interventions, and the opportunities and risks which are presented in Tables 2-1 to 2-3 below.

2.3.1 Epistemic Notions and Meta-Structures in The ORF4Ei

The first step in the decision making process is to take cognizance of the epistemic notions and meta-structures shaping water security in the catchment. Epistemic notions frame ways of thinking about water security that are embedded in global, national and local discourses. The meta-structures inform the framework as they are the broader structures of South African society, which are informed by global and national processes and they interact with local structures. These meta-structures have acted in the past, and act in the present, as they have produced path dependencies, which continue to shape the outcomes of relations in the uMngeni River catchment. These meta-structures shape all South Africa catchments, as they reflect the broader structures shaping South African society. The meta-structures shaping water security, decision making and practice in the uMngeni River catchment were presented in Figure 2-5 above.

2.3.2 Opportunities and Risks in the uMngeni River catchment

The structures of the water-society-space trialectic form the opportunities and risks in the ORF4Ei. These are presented in sets of relations: society-water, society-space (in relation to water) and water-space in Tables 2-1, 2-2 and 2-3. These tables are a useful decision making tool for EI interventions in the uMngeni River catchment and can be completed for each intervention in a particular place.

Table 2-1 Society-water Opportunities and Risks in relation to water security interventions continuum

Intervention:	**Particularities/Characteristics of Place:**
SOCIETY-WATER	**Water security interventions, including EI**
South African Constitution (principles and rights)	
Legislation and policy	
Neo-liberalism	
Developmental, interventionist state	
Engaged and Active Citizenry	
Governance arena with active and engaged state-citizen-private sector-research actors	
Societal constructions and attitudes towards water	
Integrated Water Resource Management Discourse and institutions	
Hydro-modernist (science and technology)	
Informality and its lived experience	
Closed catchment; fully developed	
Failure of service provision, failing infrastructure	
Environment as a buffer	
Environment as an actor: shapes what is possible and produces risk and uncertainty (climate change, droughts and floods and pushing back from pollution)	

Table 2-2 Society-space Opportunities and Risks in relation to water security interventions continuum

Intervention:	Particularities/Characteristics of Place:
SOCIETY-SPACE	
South African Constitution (principles and rights)	
Legislation and policy	
Political organisation: three spheres of government	
Legacy of colonialism and apartheid	
Formal administrative planning	
Traditional Authority Governance	
Land Use System: Agriculture, Forestry, Industry, peri-urban, urban, informal	
Interaction between people and institutions and practices	
Rapid Urbanisation	
Poverty and inequality	

Table 2-3 Water-space Opportunities and Risks in relation to water security interventions continuum

Intervention:	Particularities/Characteristics of Place:
WATER-SPACE	
Hydro-modernist: water from further away	
Impact of land use on water quality and quantity	
Natural landscape supports design of built infrastructure (nature as facilitator and buffer)	
Water more clean and more abundant in upper catchment	
Water demand highest in lower catchment	

The ORF4Ei enables decision makers to consider the opportunities and risks for EI interventions in a catchment. In this chapter, the ORF4Ei for the uMngeni River catchment has been presented. However, the knowledge and social learning from this research can be applied to other catchments in South Africa and globally. The methodology for conducting this research can be repeated in other places, enabling decision makers to produce a trialectic or ORF4Ei for their own catchment. This would require a transdisciplinary research approach being adopted; the selection of a range of case studies that represent the diversity of conditions in the catchment; the development of water configurations for each case study; a systems dynamics modelling exercise; a response to the systems map produced by the main stakeholders in the catchment, a study of economic cost benefits and financial flows and reflections on the water moments evident in each particular country (see Sutherland et al., 2016; Sutherland et al., 2019). The ORF4Ei is then set in relation to the BI/EI water security interventions continuum, the governance and institutional arrangements in the catchment and the financial considerations of investing in EI to produce a decision making framework for investing in EI.

2.4 Investing in Ecological Infrastructure in Catchments across South Africa and Globally: A Decision Making Framework

WRC 2354 has revealed the structuring elements that shape water security in the uMngeni River catchment. These structuring elements are particular to this catchment, although some of them are applicable to other catchments in South Africa, Africa and globally. Investing in EI in catchments across South Africa and globally requires a context specific approach which recognizes the epistemic notions, meta-structures and structures that shape water governance in each particular catchment. The water security interventions continuum can be developed and applied with both universal and context specific interventions being identified. The governance and institutional arrangements of national, regional and provincial governments need to be identified and engaged with in decision making, and cost benefit analyses of each intervention need to be considered. This universal decision making framework is outlined in Figure 2-9.

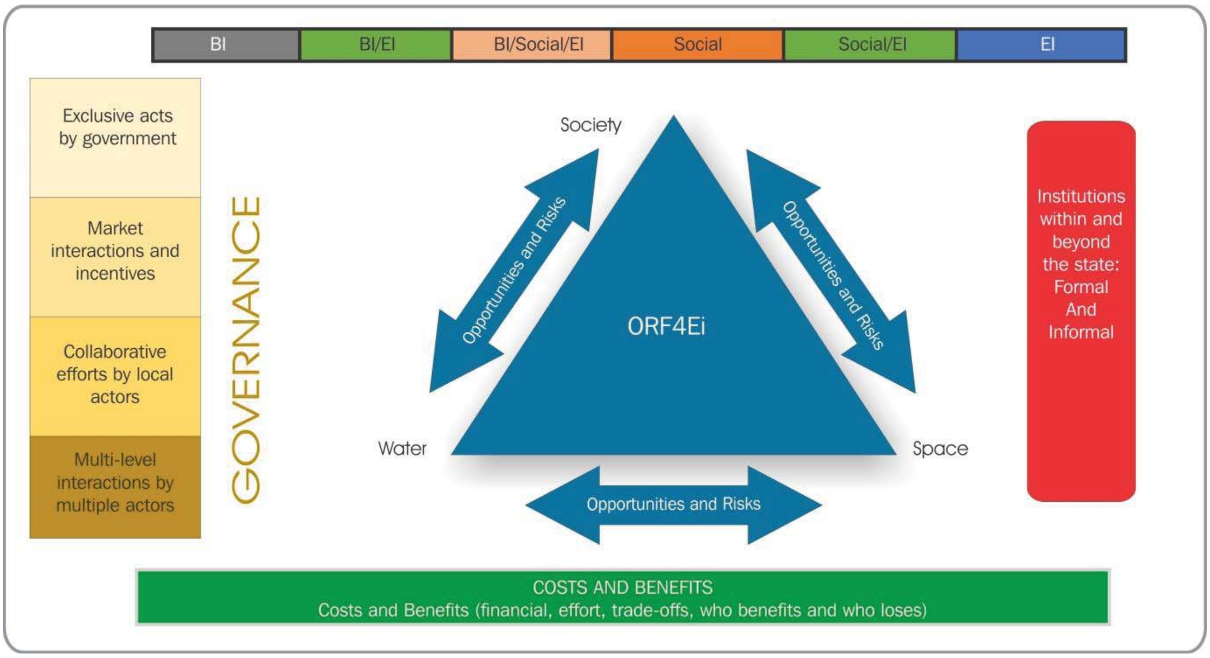

Figure 2-9 Decision making framework for EI interventions in South African and global catchments

EI interventions need to be considered and evaluated in terms of the governance arrangements in the catchment, the formal and informal institutions which govern and shape the catchment and the specific society-water-space relations of the catchment as represented in the ORF4Ei. The costs and benefits of the interventions will also shape the decisions being made. This process is not linear, as the ORF4Ei can shape the development of the water security interventions, and it can also influence the governance arrangements, institutions and costs and benefits.

2.5 Conclusion

This chapter has presented the water resource connectivity, inter-dependency and society-water relations from a landscape perspective (space) in the uMngeni River catchment. A transdisciplinary methodology was required in order to reveal the water-society-space relations. The approach adopted is a combination of socio-ecological systems and socio-ecological relations thinking, which enabled the exploration of the relationships between the social, economic, environmental, political and governance dimensions of the uMngeni River catchment. In addition, a transdisciplinary research approach was conducted by researchers from different disciplines, with the goal of creating new understandings of the relations of the uMngeni River catchment, which go beyond discipline-specific conceptions. The trialectic presented in this chapter, with its materiality, epistemic notions, meta-structures and structural elements, which shape the catchment and which emerge out of it, is adapted to develop an Opportunities and Risks Framework for EI interventions (ORF4Ei). This can be used as a framework to evaluate where, how and by whom, EI and other water security interventions can be made in the uMngeni River catchment. This decision making framework was expanded further to include the governance and institutional arrangements in a catchment as well as cost benefit decisions, all set in relation to the continuum of BI/EI water security intervention continuum.

CHAPTER 3. INVESTING IN ECOLOGICAL INFRASTRUCTURE – SNAPSHOTS FROM AN ECONOMIC PERSPECTIVE

Michelle Browne, Graham Jewitt, Nothando Buthelezi, Lutendo Mugwedi, Stuart Ferrer

3.1 Introduction

We explored the economics of investing in Ecological Infrastructure through four case study assessments. We considered the costs and benefits of investing in wetland rehabilitation for improved water quality; identified and evaluated multiple options for water quality and stormwater management in a small urban catchment; explored water supply benefits that could be achieved through maintenance and rehabilitation of grasslands in the upper catchment; and investigated the relationship between raw water quality and treatment costs at two water treatment works within the catchment. These diverse case assessments generated several interesting findings, raised a number of questions, and invoked much cross-disciplinary discussion. Interestingly, while each case focus was different, common themes and learnings emerged from which we can draw several globally relevant lessons.

3.2 Emerging Themes and Lessons

The economic case assessments (see Section 3.4) have demonstrated the interactive and interdependent relationship between ecological infrastructure and built infrastructure and the value of ecological infrastructure as a complement to built infrastructure. This was evident in the role of a degraded wetland (ecological infrastructure) in improving the water quality of a stream contaminated with raw sewage; rehabilitation of the wetland would further enhance this service. In this case, the wetland, especially if rehabilitated, plays an important role as a buffer between a rapidly expanding settlement, characterised by informal planning and design, and a major water storage dam (built infrastructure).

The design of a new wastewater treatment works (WWTW) for the settlement is a further example of an integrated built-ecological infrastructure approach. As a condition of the approval for the WWTW the design for the works includes the rehabilitation of degraded wetland areas surrounding the WWTW as a risk mitigation strategy. Further, given the location of the WWTW upstream of a major water storage dam, the design includes piping the treated wastewater away from the catchment of the dam and discharging it to another rehabilitated wetland to further improve the quality of the water. In addition to this integrated built-ecological infrastructure approach, the long-running Mpophomeni Sanitation Education Programme (MSEP)[8] which has been effective in improving the water quality within the settlement through the actions of the EnviroChamps, demonstrates the importance of both citizens and governments (and the relationships between them) in water and waste management (see Chapter 4).

The evaluation of options for improved water quality and stormwater management in a small urban catchment highlighted that ecosystem-based solutions are often multifunctional relative to many built infrastructures. A

[8] The MESP programme was initially established as a joint initiative of the uMgungundlovu District Municipality (UMDM) and the Dusi uMngeni Conservation Trust (DUCT) with a view to enhancing the environment, particularly the water quality, within Mpophomeni through supporting the development of Enviro Champs (Ward, 2016).

wetland, for example, can enhance water quality while also providing co-benefits such as recreation and aesthetic opportunities and biodiversity conservation (especially if part of an ecological infrastructure 'corridor').

In many instances, built infrastructure, while being an effective solution in one location, doesn't address the root cause and often 'relocates' an issue or risk downstream. For example, in the Baynespruit catchment, damage to property from stormwater flows is a challenge. Canalisation of the Stream can mitigate the flooding issue in the immediate surroundings, but it creates a problem of dealing with the high velocity outflows of the canalized portion, which then requires additional built infrastructure. In this case, ecological infrastructure in the form of intact riparian edges, healthy wetland systems and reintroducing a meandering flow path where possible could reduce the velocity of storm flows and mitigate the flood damage risk.

An integrated approach – one that considers built infrastructure, ecosystem-based solutions and social initiatives together – can be an effective strategy for water management. Such an approach broadens the spectrum of options available for water management and provides a greater range of benefits in a multifunctional approach to urban water management. Fundamental to the effectiveness of an integrated approach is an understanding of the context, local conditions and ideologies to ensure that the strategy is relevant and responsive to the local context.

The case evaluations highlighted challenges of uncertainty and data availability in evaluating ecological infrastructure options, both in 'understanding the biophysical science' and predicting the outcomes of investing in ecological infrastructure and ecosystem-based solutions, and in 'understanding the economics' and assigning appropriate 'value estimates' to articulate the role and importance of EI. The 'evidence base' of approaches to water management that integrate ecological and built infrastructures and social initiatives remains small. To build this 'evidence base' we need to invest in these types of approaches and innovations across a range of contexts to deepen our understanding and generate new lessons and knowledge. Importantly, this should be supported through long-term, multi-perspective, monitoring and evaluation to provide the contextual knowledge and evidence base from which general principles can emerge.

Even if the biophysical science involved no uncertainty, the evaluation of ecological infrastructure is challenged by value complexity and uncertainty. Ecosystems and their attributes matter to us in different ways, at different times, in different contexts. We 'live from', 'live in' and 'live with' our environment (O'Neill et al., 2008); it shapes us and we shape it; these various kinds of human-nature relations give rise to different sources and types of value. Economic value is based on a very specific theory of value and model of human behaviour and reflects only one way in which humans interact with the non-human world and one 'type' of value. While the economic value perspective can be a useful framework for considering the value of ecological infrastructure, it is a partial one. It is one "of the many metaphors necessary to comprehend the complexities of environmental changes and their impacts on humans" Norton and Noonan (2007:665).

3.3 Limitations of Valuation Approaches

Economic valuation is limited in articulating the value of ecological infrastructure, both conceptually in that the perspective reflects only one theory of value and model of human behaviour, and practically through data limitations and method uncertainty. This means that economic value metrics cannot be used alone to evaluate the role of ecological infrastructure, nor are they always the most relevant or feasible methods. Economic value should be viewed as one source of information on ecological infrastructure, and economic valuation considered as one of the tools available for evaluating a particular investment action. However, when economic methods are applied, the concepts and principles of the methods must be followed and the limitations and assumptions communicated with the results.

BOX 3.1 Discount Rates and the Tragedy of the Horizon: Favouring the Present and Compromising the Future?

There is a major challenge in comparing the cost of securing water through different mechanisms for example from a dam, borehole, desalination plant or investment in EI and nature-based solutions. Typically these options are assessed through a Net Present Value (NPV) approach based on a specific discounting procedure and discount rate. Discounting is a fundamental component of economic evaluation, and small changes in the discounting procedure and rate, can have a significant influence on the result of an economic evaluation. The choice to 'discount', the selection of a discount rate, and the time frame over which a project should be assessed are ethical decisions based on a judgement on inter-generational equity and the obligation of the current generation to the wellbeing of future humans and non-human entities.

Discounting accounts for time preference – the assumption that people value current consumption / benefit over future consumption / benefit. The discount rate is a weighting applied in the NPV analysis to bring the monetary value of future costs and benefits to a common time dimension, based on the assumption that benefits have lower value the further into the future they are realized, while deferred costs are more attractive than immediate payment. Risk is an additional component of the discount rate. Generally, discounting assumes a "risk adjusted" discount rate which accounts for future investment risks. The higher the risk, the higher the discount rate, and therefore, a lower present value of future benefits. Future liabilities seem less expensive and future revenues less valuable which favours investments with higher immediate benefits over investments with lower immediate, but sustained benefits over time.

Discounting concepts and practices are intertwined with the planning horizon/timeframe and assumptions about future conditions (the future wealth of individuals and technological advancements). Many argue that discounting practices and expectations of a "return on investment" lead to short termism and inherently undervalue nature for future generations. This has been termed the "tragedy of the horizon" as, effectively, costs are transferred to future generations. These assumptions and implications need to be recognized and considered when applying economic evaluation to ecological investment decisions, especially, given the uncertainty associated with ecological thresholds and regime changes and the risk of irreversible effects (Wesley and Peterson, 1993). There are many arguments for, and against, conventional discounting practices and questions about discounting should continue to be debated in the policy arena.

Single value metrics and formal algorithms are appealing to decision-makers – as a way to simplify complex decisions and distance decision-makers from taking 'difficult' decisions. Favouring a single approach, such as economic valuation, however, displaces other values and ways in which humans and ecosystems interact, and promotes a single way of thinking about ecosystems and their importance. In this way, the 'value' of ecological infrastructure is at risk of being equated with economic value. When economic value cannot be measured, or when the role of ecological infrastructure is not conducive to economic valuation (e.g. many of the ways we interact with ecosystems and in maintaining the cycles that support life on earth), we risk attributing zero value to ecological infrastructure.

An important learning from the application of economic approaches in the case studies of this project is that the *process* of economic valuation generates a deeper understanding and awareness of the local context – the system interactions and interdependencies, the many social objectives, the risks and opportunities – and stimulates discussion, debate and interaction across disciplines and stakeholders. It is the awareness of the local context gained through the process that is meaningful to decision-making. The more people involved in the process, the greater the shared understanding.

The diverse relationships and interdependencies between ecosystems, society and technology (built infrastructure) mean that we need a rich framework for evaluating the role of ecological infrastructure in ensuring water security. A framework that guides us to consider issues of sustainability, equity, irreversibility and uncertainty and value ecological infrastructure in all its social, cultural, economic and ecological dimensions. Thus, the research reported in this chapter draws on the water-society-space trialectic and is framed within the ORF4Ei framework described in Chapter 2.

3.4 The Economic Assessment Case Studies

The reflection and lessons discussed in the previous section draws from our experience in applying an economic lens to evaluating investments in EI for water security through a case study approach. Each of the case study assessments is discussed briefly in the following sections.

3.4.1 A Cost-Benefit Assessment of Wetland Rehabilitation

The upper uMngeni River catchment, draining into Midmar Dam, is a strategically significant water resource, supplying drinking water to several municipalities and major urban centres. Midmar Dam is considered at risk of eutrophication from continued inputs of nutrients form the catchment and management actions to reduce nutrient loads to Midmar Dam are a priority. The Mthinzima Stream, one of several systems flowing into Midmar Dam, drains part of the Mpophomeni Settlement located roughly 2.5 km upstream of the Dam. The sanitation infrastructure of the settlement is inadequate. Wastewater collected through the formal sanitation system is 'stored' and pumped to a wastewater treatment works in a nearby town; due to natural seepage, pump station failure and excess flows, wastewater enters the Mthinzima system during this process. Blockages and surcharging man-holes are a frequent occurrence due to the poor design of the wast water conveyance system along with improper use of the system (disposal of solid waste). The Mpophomeni Settlement, which contains both formal and informal housing, is experiencing rapid expansion, both planned and unplanned, and commercial development.

The Mthinzima Stream flows through several degraded wetland areas before reaching Midmar Dam, Figure 3-1. The potential of wetlands, even in a degraded condition, to enhance the quality of water is evident in this case from an improvement in water quality across a portion of degraded wetland[9]. Rehabilitation of the wetland could further enhance this service. A new wastewater treatment works (WWTW) is planned for the settlement. The 'water treatment' potential of healthy wetlands is recognized in the design of the new WWTW, with rehabilitation of portions of wetland adjacent to the WWTW included as a legal requirement of the environmental authorisation[10] for the proposed WWTW.

[9] This has been shown through several water quality analyses (e.g. van Deventer, 2012).
[10] As governed by the South African National Environmental Management Act, 1998.

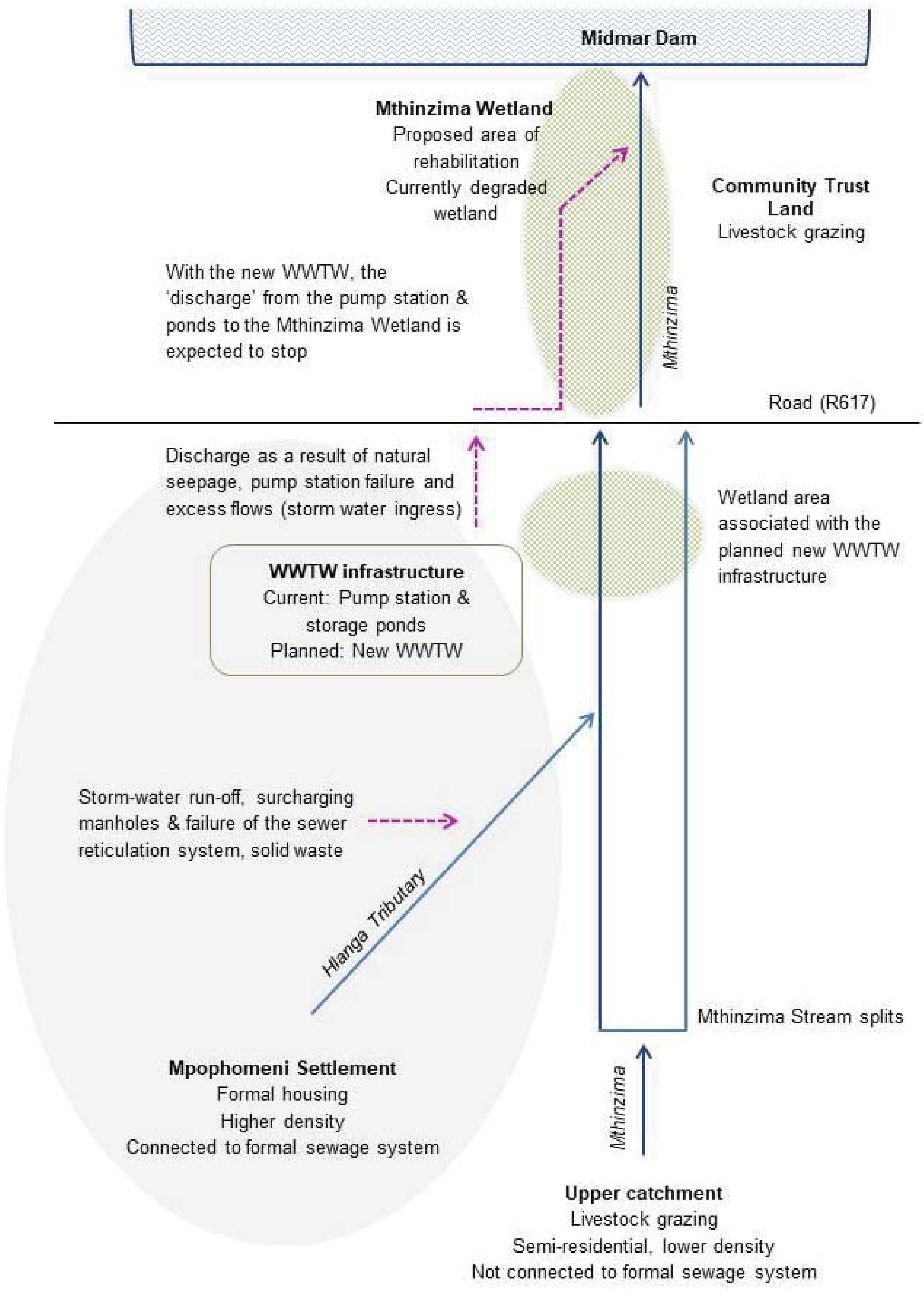

Figure 3-1 Schematic orientation of the Mthinzima-Mpophomeni system highlighting the relevant infrastructures, pollution inputs and water flows

An economic cost-benefit assessment (CBA) was undertaken to evaluate the rehabilitation of the degraded wetland. The potential increase in nutrient removal capacity of the wetland area with rehabilitation[11] was taken as the primary benefit and the implementation of the rehabilitation and annual wetland maintenance as the costs. The increase in nutrient removal capacity was estimated based on the anticipated gain in functional wetland area as a result of the rehabilitation[12] and per hectare nutrient removal rates of wetlands from the literature[13]. This additional nutrient removal benefit was valued using the 'replacement cost' method, which equates the value of the benefit with the value of the next best option of achieving the same outcome, in this case, the fixed and maintenance costs associated with a standard, low volume wastewater treatment plant. The benefits and costs were compared through a net present value (NPV) analysis which showed the benefits to exceed the costs (positive NPVs) over the life of the investment for all discount rates and time periods considered *ceteris paribus*[14], Table 3-1. The benefit-cost ratio was stable at 1.3 across the analysis.

Table 3-1 Net present value analysis of wetland rehabilitation

	Net present values (B-C ratio)		
	Life of investment (number of years)		
Discount Rate	20	30	40
3%	+ (1.26)	+ (1.26)	+ (1.26)
5%	+ (1.25)	+ (1.26)	+ (1.25)
8%	+ (1.25)	+ (1.25)	+ (1.25)

The economic analysis indicated that investing in the rehabilitation of the wetland is economically worthwhile, even though only one potential benefit, enhanced water treatment, was considered. However, there were several assumptions and uncertainties in the analysis. There is an established base of evidence indicating the water quality enhancement potential of wetland systems; however, much of this evidence, including the nutrient removal rates used in this case study, stems from the international literature. Studies of South African wetland rehabilitation projects, supported by long-term, comprehensive monitoring from multiple perspectives (ecological, social and economic), are needed to build a local evidence base.

Using the costs to build and operate a standard, low volume wastewater treatment plant as an alternative to the wetland rehabilitation likely over-estimates the value of the water quality enhancement benefit, and from an economic theory perspective is not a true reflection of value in that there is no indication that someone would be willing to pay to implement and operate such a plant. However, the benefit of the wetland rehabilitation is undervalued in that only one potential benefit was considered, and further, the risk to Midmar Dam of eutrophication through continued, and arguably increasing, nutrient loads, and the associated costs of eutrophication (water treatment cost increases, loss in recreational value) were not considered in the valuation.

It was a challenge to identify a realistic alternative to the wetland rehabilitation that could provide the same benefits, which suggests that there is, in fact, no alternative. This highlights a key controversy in applying economic valuation methods in the context of ecological restoration. Economic valuation assumes at least

[11] That is, the difference between the 'without rehabilitation' and the 'with rehabilitation' scenarios. The 'without rehabilitation' scenario was taken as the current state, however it is likely that without rehabilitation the wetland area would continue to degrade.

[12] As part of the rehabilitation planning, a gain in functional wetland area of 10.78 ha was estimated (GroundTruth, 2015).

[13] Drawn from the database of Land et al. (2016) and filtered based on wetland type (free water surface), wetland history (restored) and climate zone (Cfb which corresponds to Howick (Conradie, 2012)).

[14] Meaning that all other variables, or contextual conditions, were assumed not to have changed.

some degree of substitutability between alternatives: in this case, there appears to be no realistic substitute to the wetland and its rehabilitation.

3.4.2 Evaluating Investment Options for Improved Water Quality in a Small Urban Catchment

The Baynespruit Stream is a small, urban, highly degraded tributary of the uMsunduzi-uMngeni River. The Baynespruit catchment consists of high-density formal and informal residential development (both rapidly expanding) and numerous trade effluent regulated industries. Water pollution, characterised by sewage spills, solid waste (litter) and industry effluents (oils), and stormwater management are key water-related issues in the Baynespruit system.

Attempts to address urban water and waste management issues typically focus on built infrastructure options and overlook the potential contribution of ecological functions and social processes. Shifting the evaluation approach to a social-ecological-built (technological) systems perspective[15] broadens the spectrum of potential options and creates opportunities to realise additional benefits. This case study explored ecological infrastructure[16], social initiatives and built infrastructure options for improved water quality and stormwater management in the Baynespruit catchment. A qualitative multi-criteria evaluation supported by a cost comparison was undertaken as a first step towards identifying suitable options. The following criteria were evaluated in the context of the Baynespruit catchment:

- **Reliability** – the effectiveness of the measure in addressing water quality and stormwater management issues;
- **Long-term durability or resilience** – the extent to which the option is durable and resilient overtime and to likely threats;
- **Reversibility and flexibility** – the ease with which the option can be reversed/removed and its flexibility in terms of opportunity to integrate with 'other' infrastructures;
- **Feasibility** in the urban context – the extent the option is realistic and practical for implementation in the Baynespruit catchment;
- **Costs** –implementation and maintenance costs;
- **Co-benefits** – the extent of additional positive impacts associated with the option;
- **Dis-benefits** – the extent of negative impacts associated with the option.

Based on the multi-criteria evaluation, eight potential options were prioritized for further assessment to explore how they could be implemented in the Baynespruit catchment, their potential impact on water quality and stormwater runoff, and the associated implementation costs (financial estimate), benefits (identified) and threats and constraints. Table 3-2 highlights the main conclusions for each of the options.

[15] This perspective draws on the social-ecological-technological systems framework, Depietri and McPhearson (2017), which emphasises the interactions between social, ecological and technological domains.
[16] Here, both ecological infrastructure in terms of naturally functioning ecosystems as well as green or hybrid approaches – which blend ecosystem functions and engineered infrastructures/technology – were considered.

Table 3-2 Evaluation of potential options to support water quality and stormwater management in the Baynespruit catchment, ranked in order of least to highest cost[17]

Option		Conclusion
Green/hybrid	Floating wetlands (FW)	Least cost; impact constrained by small size and limited suitable sites to locate FW; water quality benefits, no stormwater control benefits, provides some co-benefits; medium risk (from high stream flows) to long-term durability.
Social	Environmental advocacy	Relatively low cost; impact over the long-term; provides both water quality and stormwater benefits and high potential co-benefits; complements other options (e.g. extending durability of other options). Volunteer / citizen science approaches can reduce costs.
Ecological	Revegetation of riparian zone	Relatively low cost; potential to provide water quality, stormwater and co-benefits (ecological and social benefits); medium risk (from e.g. competition for land, illegal dumping) to long-term durability could be eased through environmental advocacy initiatives.
Ecological	Wetland rehabilitation	Medium relative cost; provides water quality benefits, high potential for co-benefits; some risk of vandalism and threats from illegal dumping and competition for space; long lifespan with regular, low maintenance, but additional maintenance likely required in the Baynespruit context (e.g. solid waste management).
Green/hybrid	Waterless sanitation	Medium relative cost; potential water quality benefits (depending on scale of implementation), addresses only point source pollution; additional significant benefit of water conservation and associated low operation cost; social acceptance a key challenge, likely acceptance in the short-term only where the alternatives are pit latrines or no sanitation (i.e. in informal, rural or peri-urban areas).
Built	Rehabilitate waterborne sanitation	Medium relative cost; water quality benefit, no significant stormwater or co-benefits; long lifespan if continuously maintained, effectiveness could be improved through environmental advocacy initiatives (e.g. on solid waste disposal) and improved waste management services; only direct alternative to this option is waterless sanitation.
Built	Stream canalisation	High relative cost; effective at addressing streambank erosion and property damage issues where they are currently experienced, but transfers the issue/damage downstream, therefor requires significant infrastructure (gabions, weirs) at the downstream 'exit' point; no significant water quality benefits or co-benefits; political pressure from affected residents to implement this option.
Green/hybrid	Rooftop rainwater harvesting	High relative cost; ability to reduce flow velocity depends on associated water storage capacity and effective use of collected water, generally limited in attenuating high flows, but effectiveness enhanced if used in conjunction with sustainable urban drainage systems, can significantly reduce rooftop runoff, but this is only a small proportion of catchment runoff; potential to provide co-benefits to households and commercial sector and save costs on purchased municipal water.

The evaluation suggests that revegetation of degraded riparian areas in the Baynespruit catchment provides the greatest range of benefits, contributing to improved water quality and stormwater control, as well as providing additional co-benefits (e.g. biodiversity, aesthetic, recreation benefits). This comes at a relatively low cost. The main threats to this option are competition for land and the need for regular, but low cost,

[17] The different options were not assumed to be equivalent in effectiveness (outcomes) and therefore the costs couldn't be compared directly, but do provide an indication of 'order of magnitude'.

maintenance. The built infrastructure options, while effective at achieving their main objective, provide the least opportunity for additional benefits and are relatively more expensive to implement and maintain.

This assessment highlighted that many of the options considered, rather than being alternatives, complement one another. For example, environmental advocacy initiatives can reduce the threats to wetland and riparian area rehabilitation. Ecosystem-based options that slow stormwater flows before they enter a stormwater drain can reduce the pressure on wastewater treatment works during high rainfall events. The different 'infrastructure domains' (social, ecological and built) are interconnected. Opportunities to improve urban water and waste management lie in recognising these connections. Rather than relying solely on built infrastructures, integrating ecosystem-based options and social initiatives into urban planning can provide a greater range of benefits in a multifunctional approach to urban water and waste management.

Selected potential options towards addressing water quality and stormwater challenges in the Baynespruit catchment.

Action	Details of action	Description of action in BS
ECOLOGICAL INFRASTRUCTURE		
Rehabilitate wetlands	Rehabilitate wetlands to improve ecological function and enhance water quality.	Rehabilitate two wetlands identified to have water quality enhancement capacity.
Revegetation of riparian areas	Revegetation of the riparian area to restore biodiversity and ecosystem function to improve water quality and quantity and flood attenuation (infiltration).	Clearing of alien invasive plants and revegetation along the stream (14 ha).
BUILT INFRASTRUCTURE		
Rehabilitate waterborne sanitation network	Repairs to the sanitation network to reduce wastewater pollution of the stream and improve water quality.	Repairs to selected sections of the sanitation network.
Stream canalization	Straightening and lining of the stream with concrete to mitigate flooding and stream bank erosion to protect properties and homes.	Concrete encasement of sections of the stream.
HYBRID / GREEN INFRASTRUCTURE		
Floating wetlands	Buoyant mats planted with wetland plants anchored on the stream surface to improve water quality, reinstate species habitat, maintain habitat corridors and enhance the ecosystems services.	Seven potential sites, 2 selected to pilot the approach. Each floating wetland is 4 m^2.
Rooftop rainwater harvesting	Collection of rainwater from rooftops and stored in tanks to reduce stormwater flows and provide water for non-potable purposes.	Harvesting of rainwater from a portion of the 197 ha of rooftop in the catchment (> 10x10 m).
Waterless sanitation	Installing waterless toilets to provide sanitation in informal settlements and reduce wastewater production and water use.	Install urine diversion dry toilets in 408 households in informal settlements.
SOCIAL INITIATIVE		
Environmental advocacy (residential)	Initiatives to build civic awareness of the value of the environment to improve environmental quality.	20 EnviroChamps undertake door to door environmental awareness, engage local schools and communities in stream clean up and monitoring campaigns.

3.4.3 Contribution of EI to Reducing Bulk Water Supply Costs

Core business costs for bulk water utilities typically include raw water, chemicals (used for water treatment) and energy costs as well less direct costs such as maintenance and capital repayment costs. In the case of Umgeni Water, costs of bulk water, chemicals and energy have been subject to high increases and make up a much bigger proportion of costs in comparison to ten years ago, i.e. 2006 (Table 3-3). In the 2018 annual report, UW reported that the “reason for this increase was due to the treatment of high volumes of raw water with unsatisfactory quality associated with drought, catchment activities and the operation of additional plants”. In this section, we assessed, using a variety of approaches, the benefits that could be obtained by investing in EI relative to the bulk water utility cost drivers.

Table 3-3 UW-Statement of Profit and Loss (2017/18)

	2018		2017		2006
	R’000	%	R’000	%	%
Revenue	2 903 723		2 509 520		
Cost of sales	-1 191 532		-1 178 925		
Changes in water inventory	438	0%	823	0%	
Chemicals	65 453	5%	62 516	5%	**2,9%**
Depreciation	166 858	14%	133 698	11%	
Energy	257 361	22%	226 894	19%	**3,2%**
Maintenance	192 480	16%	174 586	15%	n/a
Raw water	209 126	18%	180 160	15%	9,8%
Section 30 activities	41 602	3%	150 942	13%	
Staff costs	220 675	19%	205 421	17%	28,5%
Other direct OC	38 415	3%	45 531	4%	
	1 192 408	100%	1 180 571	100%	

Combining efforts with a Green Fund Project (Jewitt at al., 2015), the ACRUHydrological Model was applied to the entire uMngeni River catchment to assess the hydrological benefits that could be achieved through rehabilitation of grasslands by removing Invasive Alien Plants and rehabilitating poorly managed areas (Hughes et al., 2019). This included consideration of baseflow, annual streamflow and sediment reduction. Aligned to this, an assessment of ongoing rehabilitation programmes resulted in the quantification of costs as depicted in Table 3-4. In this project, a more thorough investigation of the benefits reported by Jewitt et al. (2015) could be undertaken, in particular through a focused study on the upper-uMngeni on the importance of maintenance (rather than rehabilitation) of existing grasslands and the associated costs and benefits, the important role that EI plays in avoiding pumping costs and its potential role as a buffer to delay planned built infrastructure costs.

To assess the costs and benefits of water generated through different forms of EI, we applied the Unit Reference Value approach. This is a single, static measure of cost-benefit. It accounts for the benefits of an increase in water supply or reduced sedimentation, but NOT other positive benefits such as biodiversity improvements. The URV is defined as the “the ratio of the present value of all costs incurred over the economic life span of the project divided by the present value of the total benefits over the economic life span of the project” (Blignaut et al., 2010; Marais and Wannenburg, 2007; Van Niekerk, 2013). Thus, the URV is calculated by dividing the present value of the total cost (construction, operation and maintenance) of the project (typically built infrastructure) by the projected total volume of water supplied over its economic life. Just as an economic discount rate is applied in calculating the present value of total costs, the same discount rate is applied to derive the ‘present value’ of the volume of water, in cubic metres (Van Niekerk and Du Plessis, 2013). When applied to EI projects, it provides a comparable approach to that used in typical built infrastructure development projects, i.e. What is the cost of 1 m^3 of water from an investment in EI vs other water supply systems?

$$URV\ (cost\ per\ m^3) = \frac{PV\ of\ lifecycle\ costs}{PV\ of\ quantity\ of\ water\ supplied\ (m^3)}$$

However, it should be noted that this differs from many similar assessments where no discount rates are applied to water benefits provided, as these are assumed to continue in perpetuity. This is the crux of a methodological dilemma where many argue that typical economic analysis are compromised by the “Tragedy of the Horizon” and overly sensitive to the discount rates applied in the analyses as explained in Box 3.3.

Table 3-4 Invasive alien plant clearing and grassland restoration costs at 2016 equivalent prices

Category	Average rehabilitation costs (R/ha) for each category
Grassland/woodland categories	
Severely degraded grassland	7 836
Moderately degraded grassland	237
Untransformed management/Maintenance	20
Alien plant clearing categories	
>70% Canopy cover	14 566
30-70% Canopy cover	6 450
<30% Canopy cover	2 000
Restored management/Maintenance	150

3.4.3.1 The Importance of Maintenance

On every hectare of land in the catchment a portion of rain falling on it runs off and eventually joins a river to form streamflow which is utilized downstream. A large portion of the rainfall evaporates and some remains in the soil and is eventually used by plants or percolates down to form groundwater. However, as that land degrades, the relative contributions of rainfall to these other portions changes and its ability to deliver optimal benefits is compromised, affecting both water quantity, soil erosion and water quality. As highlighted in Table 3-4, rehabilitation is expensive, incurring both capital costs in the initial phases as well as longer-term maintenance costs to ensure the benefits achieved through rehabilitation are sustained. However, despite the recognition of follow up or maintenance costs in rehabilitation projects these are rarely considered in basic management (maintenance) of the catchment landscape. There are numerous guidelines for grassland management related to grazing and burning, managing indigenous forests and wetlands etc., but the real costs of these activities are not visible. Effectively, they are left to the landowner to absorb with no real recognition of the benefits that such maintenance provides in terms of water supply benefits associated with both water quantity and quality.

In Table 3-5, in addition to costs of providing additional streamflow estimated in the previous Green Fund supported project, we have estimated the URV for grasslands in good condition in the catchment assuming the costs for maintenance described in Table 3-1, I.e. if the area of grassland which was invaded by invasive plants had been maintained in accordance with CARA and so did not become invaded, what would the cost of this maintenance be, and what are the water quantity benefits. The derived URV of R0.31 per m^3 (6% discount rate) of water generated highlights the importance of maintenance of EI. It is by far the cheapest of all other water related infrastructure options. Typically, this land is held by private farmers, rural communities and the state (including nature reserve). All of these struggle to effectively cover the costs of this maintenance and associated adherence with CARA. In addition, the CARA requirements are rarely enforced. Support for these landowners and custodians to maintain their land has been mooted and occasionally, been effective through

Payment for Ecosystem Services type schemes such as (ref). Framed in the context of maintenance of EI and the clear cost benefits associated with this, the argument becomes even more compelling. This raises several questions around existing legislation, for example, should private land-owners be obligated to adhere to CARA without financial support?

Table 3-5 Unit Reference Values for rehabilitation and maintenance in the upper-uMngeni River catchment. The maintenance scenario reflects the costs of maintenance to prevent an equivalent area of grassland from becoming invaded.

	Total additional yield *	**Total additional baseflow**	**Total avoided sediment**	**NPV of total project cost**	**Water Cost (total cost: yield over 50 years – 6% discount rate to both costs and benefits – URV equiv**
	m^3	**m^3**	**m^3**	**R**	**R/ m^3**
Midmar catchment – restoration through IAP removal	107 679 991	15 552 401	4 970 930	R63 863 301	R2.44
Midmar – grassland maintenance only for equivalent area	107 679 991	15 552 401	-	R9 747 214	R0.31
Additional benefits not quantified	▪ Meet provincial and national biodiversity objectives ▪ Maintenance and elevation of recreation values ▪ Maintenance of food security services ▪ Maintenance and elevation of visual, smells and sense of place values ▪ E-flows ▪ Create long term jobs * Additional annual streamflow over 50 years at 50% assurance of supply, weighted average.				

3.4.3.2 Saving on Energy costs

Umgeni Water in their recent annual reports, have highlighted rising energy costs as being a major cost factor in their operations (Table 3-3) . Over the past 5 years, the cost of energy associated with bulk water supply has almost doubled from R0.28 per m^3 in 2014 to R0.54 in 2018, Figure 3-2. In 2017, UW spent R23 million on electricity used to pump water from the Mearns/Spring Grove transfer scheme to the uMngeni River catchment. Furthermore, because of the low levels of storage at Albert Falls Dam, it was not able to fully supply parts of Durban, so additional water had to be pumped from Inanda Dam to Durban Heights treatment works – at a cost of R32 million. The average cost of pumping this water was R0.46 per m^3 of water pumped for the three pump stations. Therefore, it can be argued that every m^3 produced by the catchment upstream of those two dams means that that water does not have to be pumped, so saves UW at least R0.46c per m^3.

Based on the modelling exercise, on average, 1 ha of invasive wattle in the catchment uses about 200 m^3 per hectare per month more than grassland, i.e. 2400 m^3 per hectare per year. So at a pumping cost of 50c per m^3, each hectare cleared and maintained – or prevented from being invaded saves UW R1200 per year. Based on mapping of invasive alien plants undertaken by Mtshali (2017) for the Lions and uMngeni River catchments upstream of Midmar Dam, there are 125 km^2 or 12 500 ha of invasive wattle. In contrast, in 2007, mapping suggested that this area was only 30 km^2. It can therefore be argued, that clearing the upper uMngeni of IAPS could save Umgeni Water approximately R15 million per year in pumping costs (at 2017 rates).

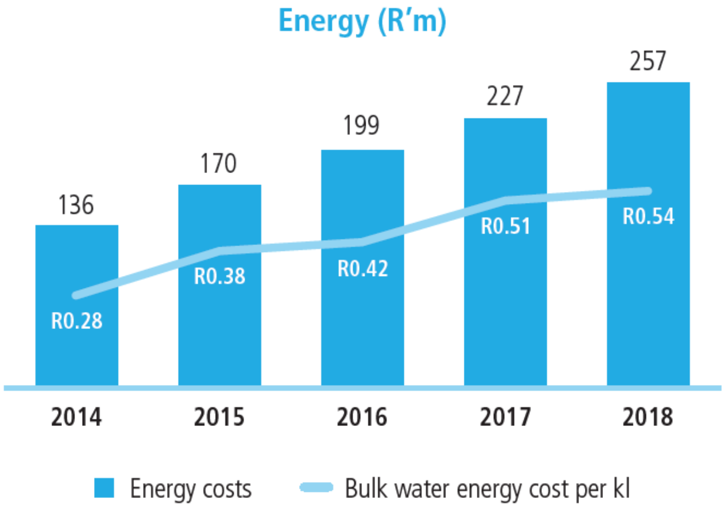

Figure 3-2 Energy costs per cubic metre of water supplied by Umgeni Water (Umgeni Water, 2019)

3.4.3.3 A Water Resources Planning Buffer

Clearing IAPS is a relatively quick solution to providing additional streamflow without the burden of extensive legislative and financial arrangements that affect built infrastructure projects. Investments in EI can take place relatively quickly and, in the case of clearing IAPS, produce fairly quick benefits. As such, it provides an interim solution to reduce the pressure on water resources during the planning and construction of built infrastructure. Without the uMkhomazi transfer scheme, the water resources supply to the residents of the uMngeni River catchment are under pressure (Figure 1-8) with an estimated shortfall of approximately 50 million m^3 per annum. Although EI cannot provide the additional 200 million m^3 per annum forecast to be needed by 2030, our analysis shows that clearing IAPs in the catchment headwaters would provide at least 15.6 million m^3 of water at a 90% assurance of supply – enough to fill a significant portion of the planning and construction gap between now and the completion of the uMkhomazi transfer scheme (Red section of Figure 1-8). This supports previous work by Gillham and Haynes (2001) who estimated that the removal of IAPs upstream of Midmar Dam could provide a firm yield of approximately 12 million m^3 and postpone the future requirement for costly built infrastructure. The value of such a postponement is indicated by the savings from deferring capital expenditure[18].

3.4.3.4 Exploring water quality and water treatment cost relationships

In addition to analyses to assess the water quantity benefits of investing in EI, this assessment explored water quality and water treatment cost relationships, *based on the use and costs of treatment chemicals,* for selected Water Treatment Works (WTW) in the uMngeni River catchment. Water quality contaminant data and chemical dosage and cost records for a five-year period (2013-2018) were statistically examined for the DV Harris water treatment work which draws water from Midmar Dam (in the upper uMngeni River catchment) and Wiggins WTW which draws water from Inanda Dam (in the lower uMngeni River catchment).

The assessment generated several interesting findings. The average cost of treating water per cubic metre is higher for the DV Harris WTW (R0.16/m^3) than for the Wiggins WTW (R0.08/m^3). The higher cost appears to be driven by higher chlorine, polymer and lime brown use per unit of water treated (kg/Ml) at DV Harris, Figure 3-3. Along with bentonite, these are the main chemicals used in the treatment process, and, in the short-run, their dosage is primarily driven by a few key water quality constituents (pH, turbidity and *E.coli*[19]). At the

[18] For example, Turvey (1976) who illustrated the approach in analysing demand management to postpone the commissioning of a new water supply scheme.
[19] *E.coli* is used as an indicator of faecal contamination of water.

Wiggins WTW, small quantities of potassium permanganate are added during the winter period to address higher levels of manganese in the raw water which results from the mixing of water within the dam due to surface cooling. The average cost of chemical treatment has not increased significantly at either WTW over the five years examined, and, compared to cost estimates from a similar study in the 1990s (Graham et al. 1998), the (real) treatment cost at Wiggins has remained stable. The real treatment cost at DV Harris, however, appears to have increased.

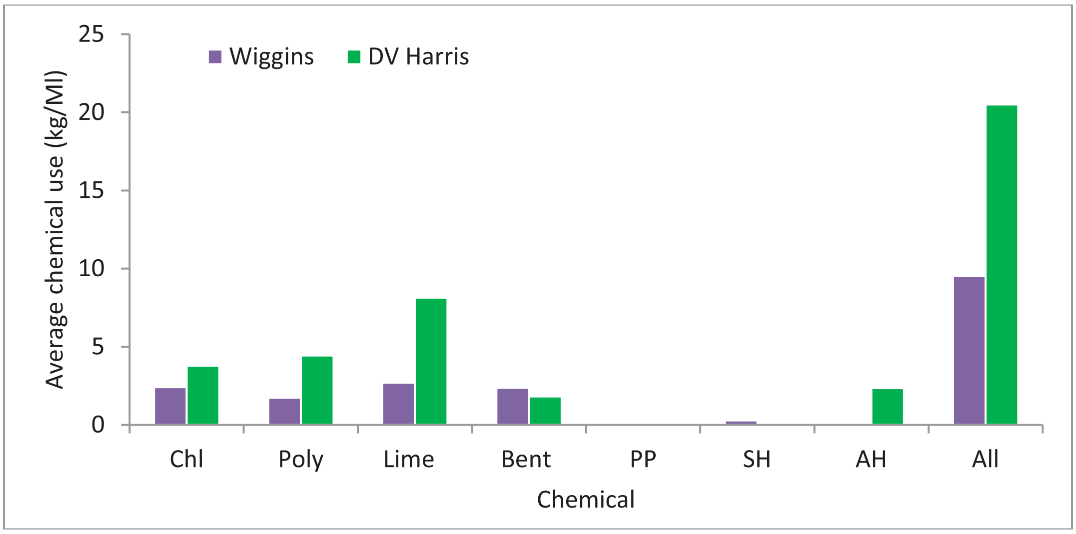

Figure 3-3 Average (2013-2018) chemical use at the Wiggins and DV Harris water treatment works.

Note: Chl – Chlorine, Poly – Polymer; Lime – Lime Brown; Bent – Bentonite; PP – Potassium Permanganate; SH – Sodium Hypochlorite; AH – Ammonium Hydroxide; All – All chemicals.

The water quality data for the inflows to the WTWs showed higher levels of turbidity, pH and E.coli on average at DV Harris than Wiggins, Table 3-6. The treatment process at the two plants differs in terms of the pre-oxidation type: chlorination is used at the DV Harris plant, while ozone is used at Wiggins. Ozone is formed from oxygen and no additional chemicals are added, however the process requires specialized equipment and energy. The DV Harris plant is a much smaller WTW, with a capacity of 110 Ml/day and an average flow of 83 Ml/day compared to Wiggins which has a capacity of 350 Ml/day and an average flow of 280 Ml/day.

Table 3-6 Average concentrations of key water quality constituents for raw water abstracted from Midmar and Inanda Dams for treatment at DV Harris and Wiggins water treatment plants (respectively)

	Ave. concentration		Correlation with cost		Chemical
Constituent	**DV Harris**	**Wiggins**	**DV Harris**	**Wiggins**	
pH	7.90	7.77	-0.02	0.14	Lime
Turbidity (NTU)	6.47	1.17	0.15	0.14	Polymer
E.coli (counts/100 ml)	4.41	1.57	0.14	0.12	Chlorine
Manganese (S) (mg/l)	0.01	0.02	0.10	0.26	Potassium permanganate
Iron (S) (mg/l)	0.13	0.02	-0.03	0.21	

The quality of the water at the inflows to the two WTWs was largely stable over the study period; alkalinity and conductivity show some increasing trend at Wiggins. Seasonal trends are apparent in the data for many of the water quality constituents. For both WTWs, the quality of the water abstracted from the dams is relatively constant, meaning that the amounts of chemicals added during the treatment process are seldom adjusted. Raw water for potable water treatment is abstracted near the dam wall, possible negative impacts on the quality of this raw water from contaminants entering the dams through river flows are generally reduced through a combination of dam length and shape and 'natural' assimilative capacity (Umgeni Water, 2019). The degree of contamination and accumulation overtime through which the natural refining capacity of the dams can persist is uncertain; once these 'thresholds' are reached impacts on raw water quality may become significant, occur abruptly and be irreversible. During the recent drought conditions in the uMngeni River catchment, a drop in the level of Inanda Dam reduced the natural refining capacity of the dam which was evident in a deterioration of the quality of the abstracted water (Umgeni Water, 2019). A better understanding of the limnology of the dams would help reduce these uncertainties.

The relationship between the quality of water abstracted from the dams and treatment costs, *based on the use and costs of treatment chemicals,* is statistically weak in the short-run as there is minimal variation in the water quality data and chemical use. This is evident in the weak correlations[20] observed between the water quality constituents and the estimated treatment cost. Longer time series data would contribute to a better understanding of trends in water treatment costs and to potentially identify key events of higher / lower treatment costs which can then be further investigated to relate them to possible events having an impact on water quality (e.g. drought, algae bloom events, etc.). In this case, chemical cost data were only available on a monthly basis, which may have 'masked' some of the variation in the data, similarly for the water quality data. There was some uncertainty on how the chemical costs had been estimated, additional attention should be given to this aspect in future similar studies; using chemical dosage records rather than monthly cost estimates could reduce this uncertainty.

In the long-term, water quality trends and anticipated future water quality influence the design of WTWs, as in the case of the Wiggins WTW. At the time of being designed (pre-1984), the quality of the water in the lower uMngeni River catchment was already considered to be poor and it was anticipated that water from the planned Inanda Dam (not then yet built) would be highly eutrophic. The Wiggins WTW was designed with this in mind and ozone was selected as the primary disinfection medium to cope with pollution problems and to reduce the amount of chlorine required (Pryor et al., 2002).

[20] Correlation analysis is used to determine whether two variables tend to move together — that is, whether large values of one variable tend to be associated with large values of the other (positive correlation), whether small values of one variable tend to be associated with large values of the other (negative correlation), or whether values of both variables tend to be unrelated (correlation near zero). Correlation coefficients range between -1 and +1, with values nearer 0 indicating weaker relationships.

Table 3-7 Opportunities to reduce bulk water utility cost drivers through investment in Ecological Infrastructure.

Bulk Water Utility Cost Drivers	**EI Benefit and/or Perspective**
Raw Water	Enhance supply Provide planning buffer
Energy (pumping and treatment)	Sustained supplies result in lower inter-basin transfer costs and better opportunities to transfer water under gravity.
Chemicals	Not proven
Maintenance	Not assessed
Human Resources	n/a
Capital repayment	Opportunity to delay capital expenditure.

3.5 Conclusions

In this Chapter, we have assessed the economic and financial benefits of investing in EI from several perspectives. We can conclude that there are clear water quantity and quality benefits in investing in EI in the uMngeni River catchment and that these opportunities are optimised from a perspective that views water security investments along a continuum where BI and EI investment complement each other, rather than being considered as “one or the other”.

CHAPTER 4. LANDUSE, LANDCOVER AND ITS INFLUENCE ON WATER QUALITY AND QUANTITY IN The uMngeni River catchment

Graham Jewitt, Nantale Nsibirwa, Shaeden Gokool

4.1 Introduction

Catchment rainfall, soil, topography and landuse and land cover (LULC) and other biophysical conditions control both water quantity and quality in its rivers. The declining runoff and deteriorating water quality in the rivers of the uMngeni River catchment has been well documented. Several studies report diffuse pollution as a major contributor to the degradation of rivers and streams in the catchment, and they have raised concerns that the impoundments of the catchment could become eutrophic (Breen, 1983; Pillay and Buckley, 2001; Matthews and Bernard, 2015). From a water quantity perspective, changes in forest and agricultural practices and large areas of Invasive Alien Plants (IAPS) coupled with a higher domestic and industrial demands decrease streamflow (Hughes et al., 2019a,b). These connections within the hydrological cycle along various corridors and between various components of EI are particularly important as they contribute to the flow of energy, matter and organisms in an ecosystem. Analysis of this functioning and connectivity can indicate potential sites where protection or restoration could be most effective.

Through the course of this project, we have progressed through purely hydrological quantity hydrological modelling to water quality and economic analyses to identify optimal sites in the catchment when investments in EI would be most effective. This has resulted in four peer reviewed publications and another in preparation. This aspect of the work has progressed through the work of Hughes (2019a,b) who identified that the key sub-catchments where hydrological and Namugize who focussed on water quality responses to LULC in the upper-uMngeni River catchment, to the more recent publications by Gokool and Jewitt (2019) and the MSc of Nsibirwa (2019).

Through these studies, we emphasize the need for systematic rehabilitation planning which takes connectivity between biophysical and non-biophysical components of the catchment into account. Resources need to be directed towards specific actions and locations that can produce the maximum benefit, taking into account the scale of planning and the scale of the intervention, particularly because ecosystem responses to land use changes vary over space and time (Newson, 2010). However, optimising potential sites from a hydrological connectivity and biophysical perspective is only one component of a far more complex decision making process as considered in the integrating framework provided by the ORF4Ei.

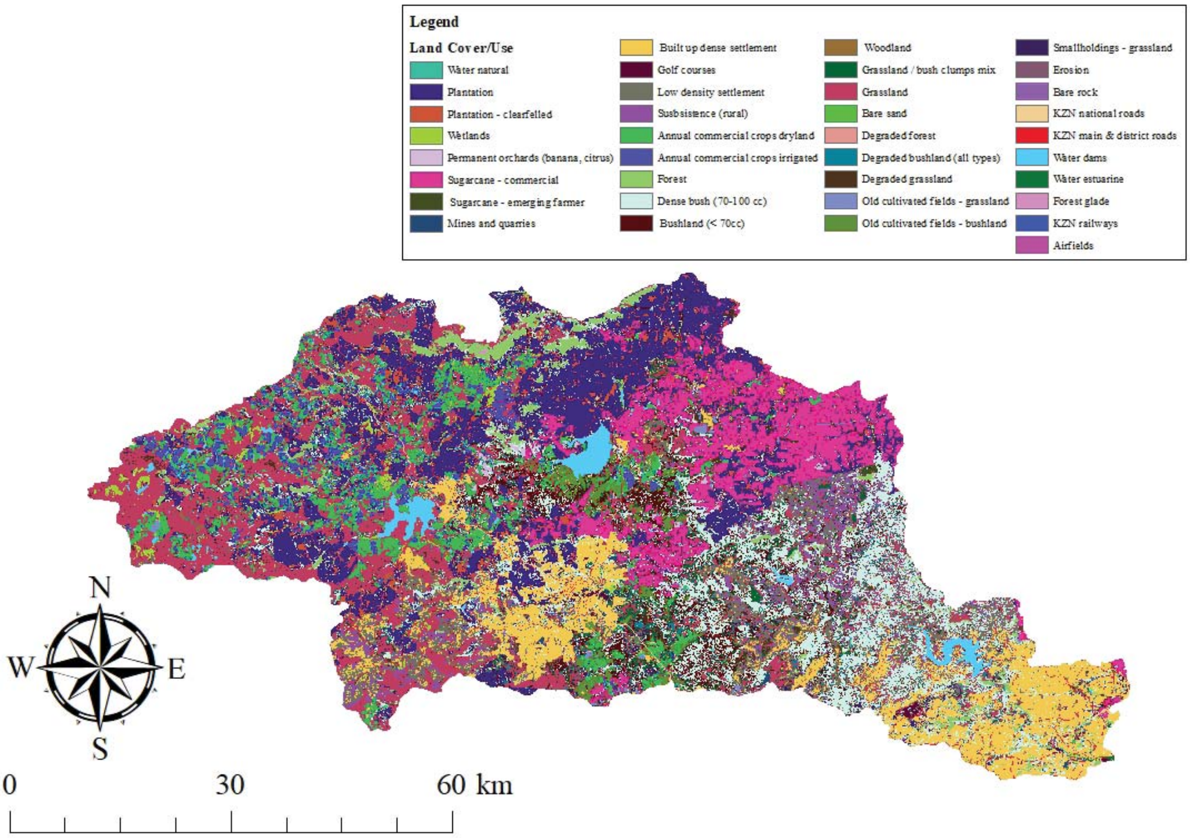

Figure 4-1 Land cover and land use in the uMngeni River catchment

4.2 Catchment Land Use and Land Cover

A 2011 land cover dataset was supplied by Ezemvelo KZN Wildlife for use this project (Figure 4-1). The dataset contains 47 land cover classes which were derived from 2011 SPOT5 multispectral single date imagery. The map has a reliable level of confidence, scoring an overall land cover mapping accuracy of 83.51% (Ezemvelo KZN Wildlife and GeoTerraImage, 2013). The map grid has a resolution of 20 m × 20 m, which matches the highest resolution DEM available. The data was clipped to the catchment boundary and converted to the ASCII format, using the ArcMap toolset. The predominant LULC characterising the upper reaches of the catchment include; intensive commercial afforestation, agricultural land (predominantly livestock farming) and wetlands. The urban concentrations around Pietermaritzburg and Durban are clear and the lower reaches of the catchment are characterized by densely-populated urban areas and industrial zones. IAPS are extensively distributed within the catchment, particularly infestations of wattle (Acacia spp).

4.3 Mapping Water Quality Risks

The deteriorating water quality in the river systems of the uMngeni River catchment, KwaZulu-Natal, South Africa, has been documented over 40 years (Hemens et al., 1977; Namugize et al., 2019). This decline has been ascribed to the rapid land use and land cover changes that have occurred in the catchment since the arrival of European settlers in 1850 (Moll, 1965). Several studies report diffuse pollution as a major contributor to the degradation of rivers and streams in the catchment, and they have raised concerns that the impoundments of the catchment could become eutrophic (Breen, 1983; Pillay and Buckley, 2001; Matthews and Bernard, 2015). There is a great need to identify the Critical Source Areas (CSAs) in the catchment landscape, i.e. areas that produce and transport pollutant material to the drainage network (Pionke et al., 2000).

To locate CSAs, a risk-based modelling framework, called the Sensitive Catchment Integrated Modelling and Analysis Platform (SCIMAP) Model, was used to provide a calculation of diffuse pollution risk (Milledge *et al.*, 2012). The SCIMAP Model is based upon the notion that catchments can be conceptualised as a set of flow paths that connect the distributed sources of possible pollutants across a landscape, to receiving rivers (Lane *et al.*, 2006). Fundamentally, the model focuses on the environmental degradation associated with diffuse pollutant losses, from the land to the water, where source areas combine with the high probability of connection to the river network (Milledge *et al.*, 2012). The outputs of SCIMAP are a series of maps that identify land units that are most likely to be causing an observed downstream pollution problem (Lane *et al.*, 2006). The maps give an indication of where to prioritise diffuse pollution mitigation activities. This links well with the efforts that are being made to invest in EI, as they identify the areas in which the protection, control and rehabilitation of EI should be prioritised from a hydrological connectivity perspective.

The primary aim of this study was to identify the CSAs and transport pathways of nutrients in the uMngeni River catchment, using the SCIMAP Model. The intention is that the generated outputs will be used to guide the future efforts and investments in the protection of the EI. Despite having readily-available input datasets for the application of SCIMAP in the uMngeni, deriving input land cover weightings. SCIMAP requires three main data layers to compute the diffuse pollution risk, namely, a DEM, land cover and rainfall raster data.

4.3.1 Mapping Diffuse Pollution Risk

Figure 4-2 shows a network index map that represents the hydrological connectivity risk for the uMngeni River catchment. This map is an intermediate layer that is generated during the SCIMAP modelling process. The network index map indicates the modelled spatial pattern of soil moisture, hence identifying areas that are most likely to drain by saturated excess flow. Areas with a relatively high and low likelihood of connecting to the river network are depicted in red (with a risk value of 1) and blue (with a risk value of 0) respectively.

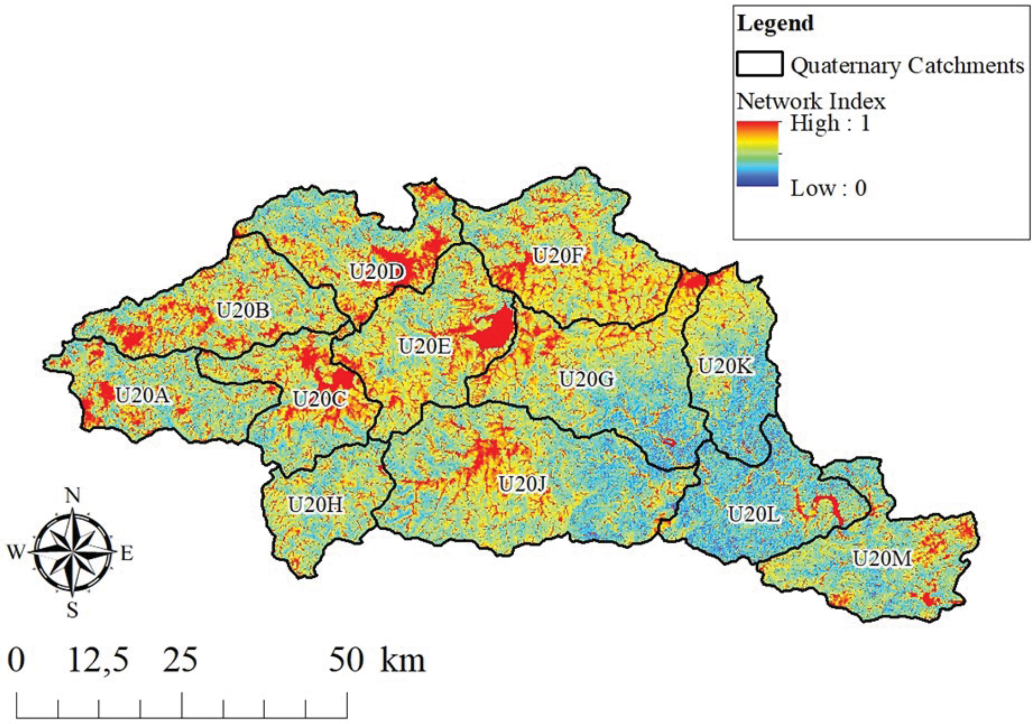

Figure 4-2 Network index map representing hydrological connectivity in the uMngeni River catchment (Step 2 of the SCIMAP processing structure)

The map illustrates that the areas with a higher risk of connectivity are found in the higher-lying western region of the catchment. Areas with the least risk of connectivity are found in the central-eastern region of the catchment. U20B, U20C, U20D, U20E and U20F have the highest connectivity risk and U20L has the lowest connectivity risk. Overall, 36% of the entire catchment area has been assigned a risk of between 0.80 and 1, and 10% of the catchment area has been assigned a risk of between 0 and 0.20.

The diffuse pollution risk map is also an intermediate layer that is generated during the modelling process. SCIMAP combines the hydrological connectivity risk and the land use export potentials to locate the CSAs. The diffuse pollution risk map of the CSAs of nutrients in the uMngeni River catchment is shown in Figure 4-3. High risk areas are depicted in red (with a risk value of 1) and low risk areas in green (with a risk value of 0).

The final map output produced by the model is shown in Figure 4-4. The map indicates the expected in-stream diffuse pollution risk and considers the effect of rainfall dilution. The layer is a combination of the connectivity, the land use export potentials and the rainfall dilution potentials of the catchment area. With this layer, one can identify the transport pathways of diffuse pollutants into the main channels. Risk is depicted in multiples of the standard deviation from the mean, to identify areas where the diffuse pollution risk is greater than the dilution potential. High risk areas are depicted in red (indicating that the risk is greater than the dilution potential) and low risk areas in green (indicating that the risk can be alleviated by the dilution potential).

Figure 4-3 and Figure 4-4 illustrate that the important areas for the generation and transfer of nutrients are found in the central regions of the uMngeni River catchment. Regions with the least CSAs of nutrients are located mostly in the western headwaters of the catchment. Quaternary catchments U20F, U20G, U20H, U20J, U20K and U20M have the highest diffuse pollution risk, and U20A and U20D have the lowest diffuse pollution risk. Overall, 0.56% of the entire catchment area has been assigned a diffuse pollution risk of between 0.70 and 1, and 92% of the catchment area has been assigned a diffuse pollution risk of between 0 and 0.20.

A close-up view of the Midmar sub-catchment (U20C) results is shown in Figure 4-5. The map depicts a combination of the intermediate and final diffuse pollution risk layers. Key areas for the generation and transfer of nutrients are found in the central and eastern parts of the sub-catchment. The areas that are least at risk for transferring nutrients into the river network and impoundment are found in the southern-most reaches of the sub-catchment. It was found that 0.82% of the sub-catchment area has been assigned a diffuse pollution risk of between 0.70 and 1, and 94% of the sub-catchment area has been assigned a diffuse pollution risk of between 0 and 0.20.

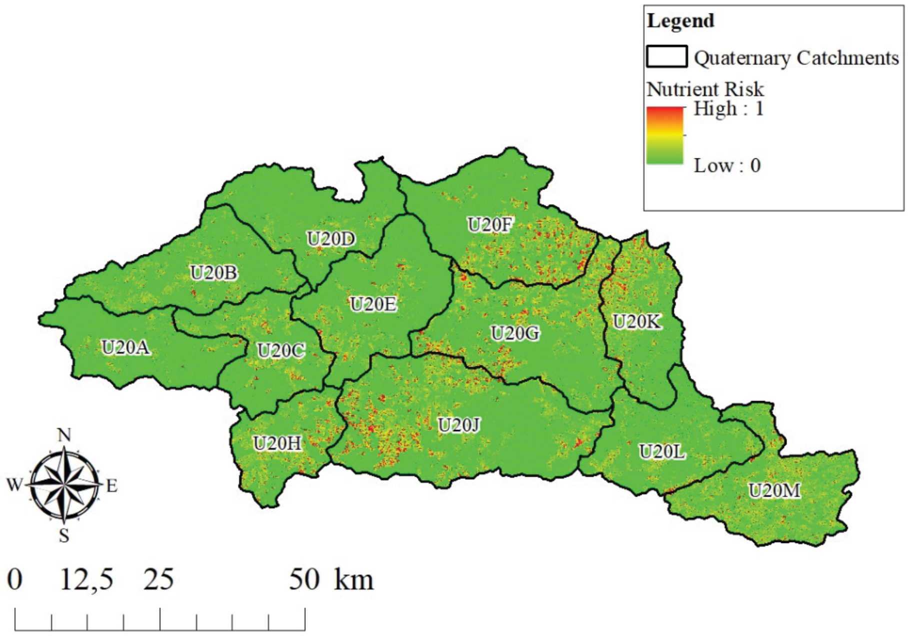

Figure 4-3 Diffuse pollution risk map of the Critical Source Areas (CSAs) of nutrients in the uMngeni River catchment (Step 3 of the SCIMAP processing structure)

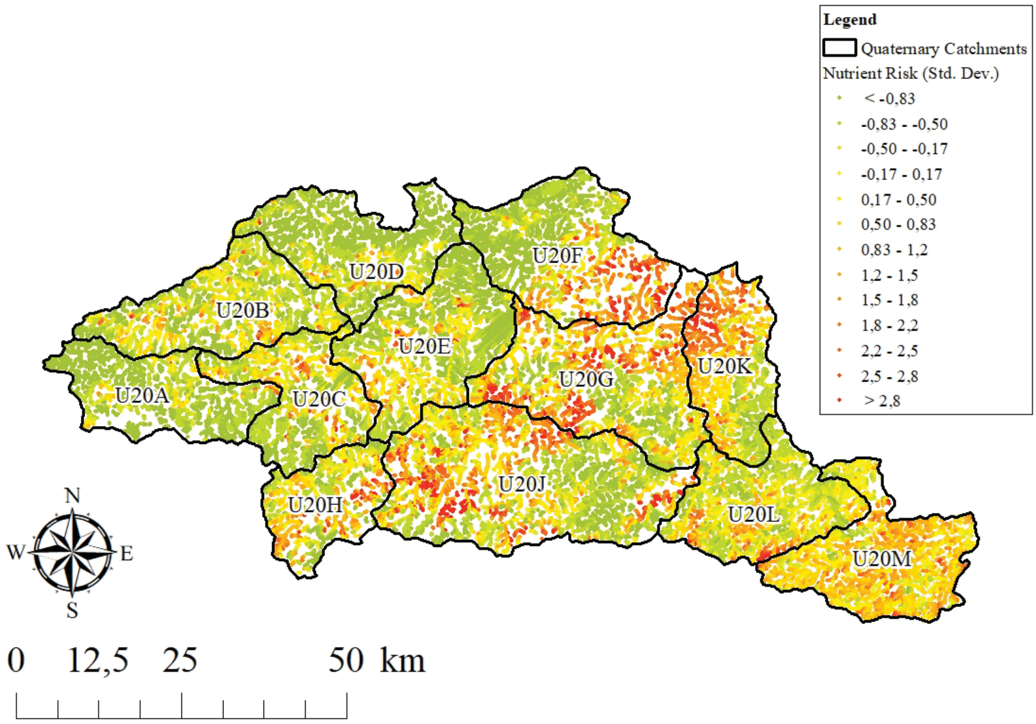

Figure 4-4 In-stream diffuse pollution risk map of the Critical Source Areas (CSAs) of nutrients in the uMngeni River catchment (Step 5 of the SCIMAP processing structure)

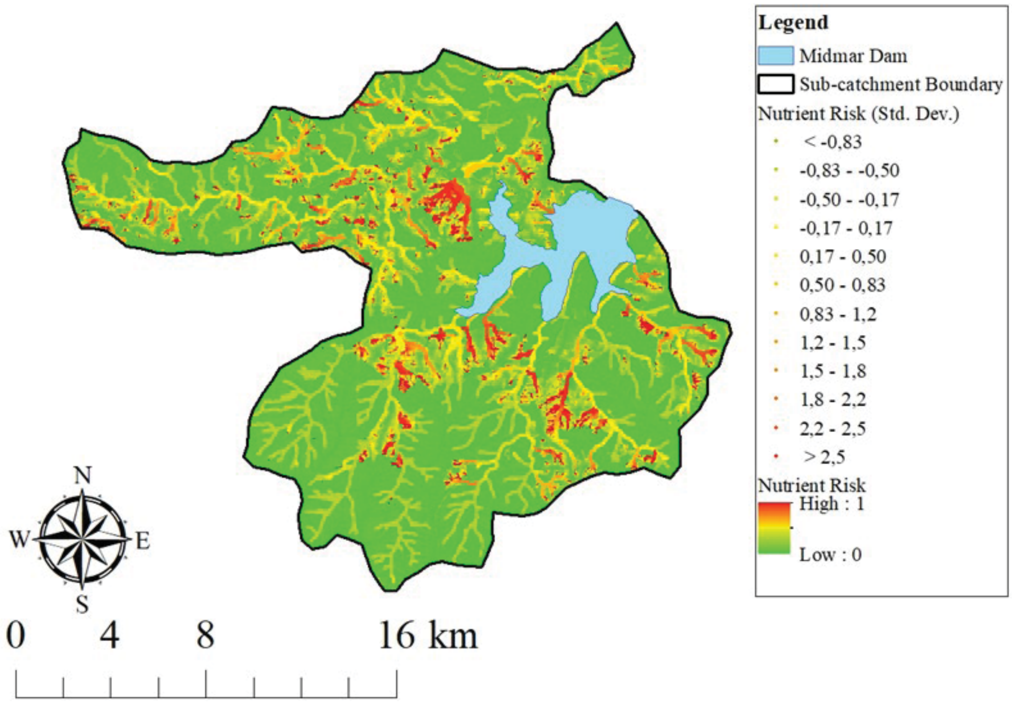

Figure 4-5 Diffuse pollution risk map of the Critical Source Areas (CSAs) of nutrients in the Midmar sub-catchment

4.4 Ecosystem Services Modelling

Traditionally, sophisticated hydrological models have been used to demonstrate how the execution of particular management activities can improve the delivery of hydrological ecosystem services (HES) across large geographic scales (Goldstein et al., 2017; Luke and Hack 2018). However, these approaches are constrained by factors such as; application effort, limited data availability for model implementation or validation and their inability to identify priority areas within a catchment for investment in EI (Goldstein et al., 2017).

In recent years the development and advancement of specialized ecosystem services (ES) models have facilitated landscape screening to identify priority areas for investment in EI, as well as to provide a quick overview of the potential benefits a particular management activity may have on HES within the catchment (Bagstad et al., 2013a, 2013b; Luke and Hack, 2018). These models are predicated on simplified hydrological process representations, differing from the more traditional hydrological simulation models. However, the focus of their development has been to enable decision makers to make more well-informed planning and management decisions over a large geographic extent, through the use of tools that require minimal data and application effort (Luke and Hack, 2018).

As a complement to hydrological analysis by Hughes et al. (2019a,b), we set out to explore how the state-of-the-art in ES modelling can be implemented to guide decision making, regarding investments in EI within the uMngeni River catchment to improve the delivery of particular HES. This involves an iterative process of identifying priority areas for investment in EI and evaluating the potential biophysical benefits these activities may have on HES within the uMngeni River catchment.

4.4.1 The RIOS and INVEST Models

There are various decision-support tools that have been designed specifically for the purpose of ES assessments as detailed by Bagstad et al. (2013a; 2013b). In this particular study, the Resource Investment Optimization System (RIOS) and the Integrated Valuation of Ecosystem Services and Tradeoffs model (InVEST), developed by the Natural Capital Project were selected for application to model HES within the uMngeni River catchment. This decision was largely predicated upon their extensive application internationally, relatively minimal data requirements and practical application effort. According to Luke and Hack (2018), these models can be jointly implemented as they utilize similar requisite data sets. Furthermore, some of the RIOS model outputs can be used as direct inputs to the InVEST suite of models (Vogl et al., 2016). Subsequently, the combined application of these models can prove to be expedient, as it can allow for the rapid determination of activity priority areas and assessment of the impacts these activities will potentially have on HES delivery (Guswa et al., 2014; Vogl et al., 2016). A schematic of this process for the uMngeni River catchment is depicted in Figure 4-6.

The first step in implementing the RIOS Investment Portfolio Advisor was to define the objectives of the study and provide the requisite data for these specific objectives. The model will then determine priority areas within the catchment to meet a particular objective. Additionally, objective weights, activity preference areas, and relative cost effectiveness are taken into consideration to determine priority areas so that multiple objectives can be addressed simultaneously (Vogl et al., 2016).

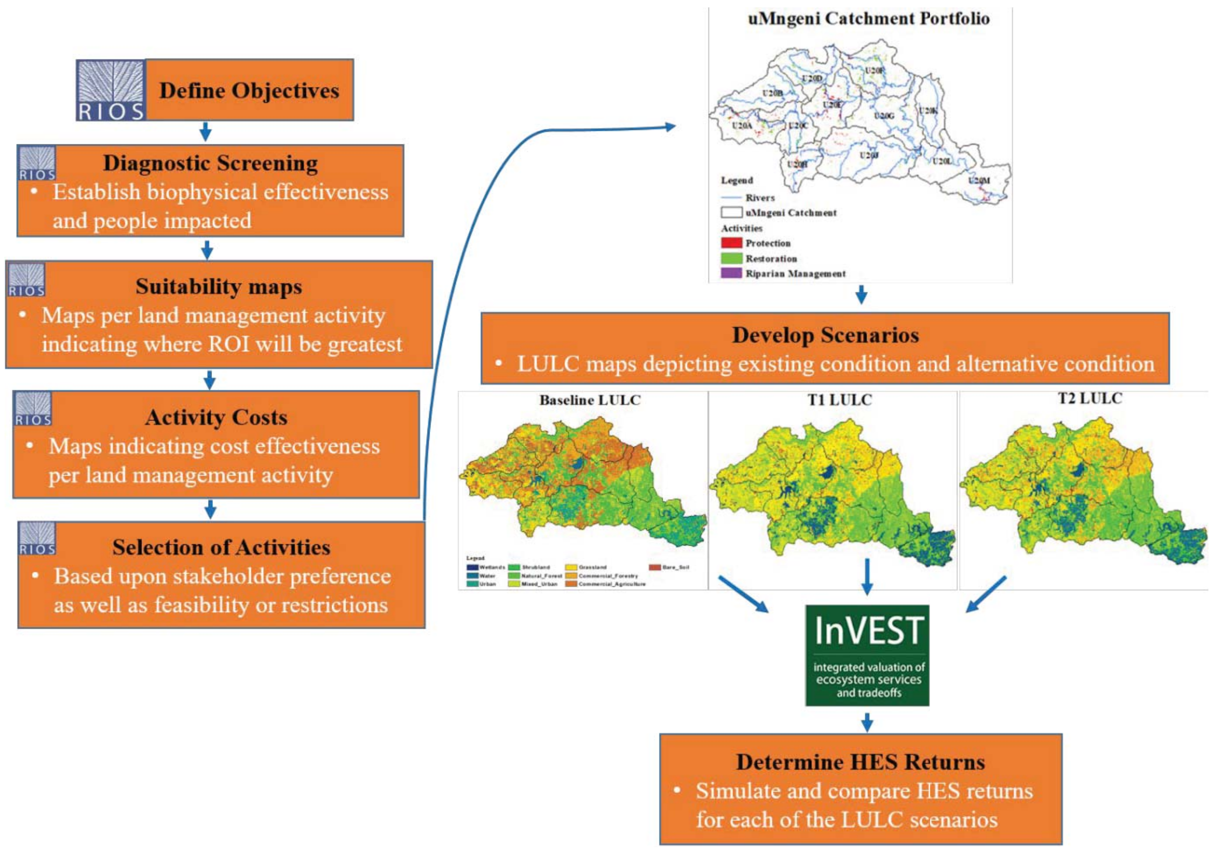

Figure 4-6 A conceptual representation of the combined implementation of RIOS and InVEST (adapted from Vogl et al., 2016)

The selected objectives for the presented study were informed by the research undertaken by Hughes et al. (2019 a,b) and include; i) water yield enhancement, ii) dry-season baseflow enhancement, iii) erosion control, iv) flood mitigation and v) water quality enhancement. To achieve these objectives, changes in LULC or management activities are required, which will ultimately influence ES delivery within the catchment. Different activities may elicit the same desired outcome, however the cost and location of these activities will differ. Subsequently, RIOS determines where these particular activities should be undertaken to provide the greatest ROI. Although, several transition activities are included in RIOS, only the keep native vegetation, revegetation (assisted) and riparian management options were selected.

RIOS utilizes a ranking model to determine the priority areas for investment. This approach is based on the premise, that a narrow set of biophysical and ecological factors will influence the efficacy of a transition achieving the designated objective, with much of this impact dependent on the conditions of the surrounding landscape. As such, it reflects a narrow aspect of catchment possibilities which are then further analysed through the ORF4Ei. Subsequently, ranking scores which designate the potential effectiveness of a particular activity are assigned contingent to the condition of a particular pixel and its adjacent pixels (Vogl et al., 2016). Although RIOS allows for modelling objectives and transitions to be weighted relative to each other, default weighting values available in RIOS were selected for our model simulations. The selection of these values ensures all objectives are considered equally when determining the transition scores and all transitions contribute equally to fulfilling the specified objectives (Vogl et al., 2016). During this phase the following information is captured in the Portfolio Translator module (Vogl et al., 2016); the time taken for the change in LULC or management practice to occur, associated changes to the biophysical response of a particular area resulting from the implementation of a particular transition activity and the degree of transition. For example, during our simulations it was assumed that natural vegetation would be replaced by bare soils if left unprotected and areas identified for restoration would elicit the biophysical response of the closest and most abundant natural LULC (determined within the model) if assisted revegetation activities were undertaken.

Furthermore, it was assumed that 50% of the original LULC would be transitioned to the new LULC in a year. During our analysis three LULC scenario maps were developed, these included; i) a baseline scenario depicting the current LULC, ii) transitioned scenario (T1) depicting new LULC combinations resulting from the implementation of management activities and iii) transitioned scenario which demonstrates new LULC combinations, with former protected areas being allowed to degrade (T2) (Vogl et al., 2016). The resultant LULC maps, as well as the associated biophysical coefficient tables were then used as direct inputs to the InVEST suite of models to evaluate the influence of the potential changes in LULC on HES delivery.

4.4.2 Results

The results of the RIOS modelling simulations (Figure 4-7), illustrates the most suitable locations for investment across this range of objectives. Furthermore, RIOS outputs a budget report indicating the expenditure and the total area that has been converted for a particular activity. This information can then be further summarized to determine the total area converted and costs associated with the recommended management activities by LULC type.

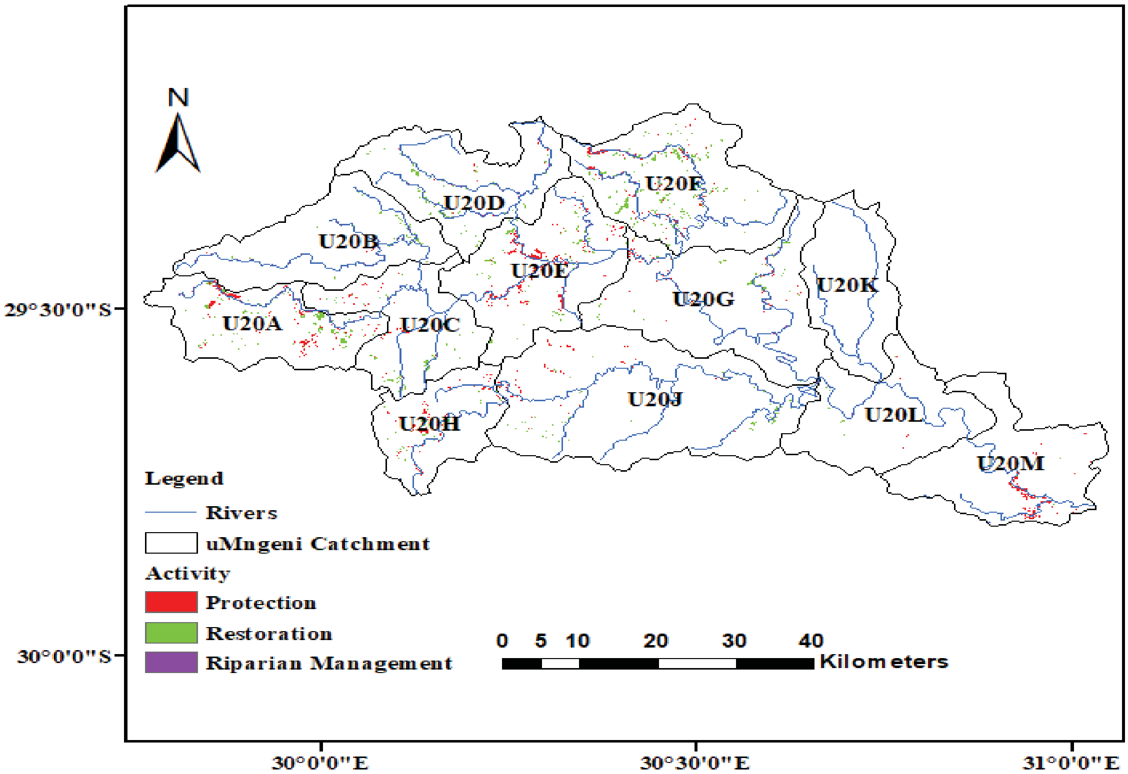

Figure 4-7 Modelling results of the RIOS Investment Portfolio Advisor, indicating activity preference areas for investment in EI within the uMngeni River catchment

The results of our RIOS modelling simulations show that the proposed management activities are primarily located in six sub-catchments, with the distribution of recommended management activities varying considerably between the various LULC types. Full details are available in Gokool and Jewitt, 2019.

4.5 Interactive Web Map

It is necessary that the information that has been generated to support sustainable water resources management be made more accessible to water resources decision-makers and stakeholders in the uMngeni River catchment (Mitchell et al., 2014). In addition, the information that is shared should be readily accessible and it should be presented in a manner that is simple enough for decision-makers and stakeholders to comprehend (Liu et al., 2008). For this reason, an interactive web map of the diffuse pollution risk in the uMngeni River catchment was created as a part of this study.

Using the ArcGIS Online platform, the map consists of an aerial photography-base map, with a layer depicting hydrological connectivity, as well as a layer for each nutrient diffuse pollution risk model output. In relative terms, the map allows for the identification of the quaternary catchments that need to be prioritised, followed by the sub-catchments, and finally, the associated land units or fields. In terms of protecting EI, the purpose of the web map is for users to concentrate on identifying the plots of land or fields that are highly likely to contribute to the diffuse pollution problem. This action has the potential to support the development of site-specific mitigation measures for prioritised areas. Furthermore, the web map provides a platform for stakeholders to discuss and investigate the results being produced by the SCIMAP Model.

The maps in this section depict the uMngeni River catchment that has been subdivided into the 12 quaternary catchments delineated by the Department of Water and Sanitation (DWS) in South Africa. The interactive web map of the results can be located, using the following web address: https://arcg.is/9CC5X.

CHAPTER 5. THE PROCESS OF LEARNING AND MOVING TOWARDS TRANSDISCPLINARITY

Sabine Stuart-Hill, Jim Taylor, Susan Risko, Graham Jewitt and Catherine Sutherland

5.1 Introduction

The call for research approaches, which both develop knowledge and implement research findings, is being recognised with a transition to co-engaged action research (O'Donoghue, Taylor and Venter, 2018). This is important, as research which does not engage with, nor takes action to solve problems in society, runs the risk of reinforcing the science-policy-implementation gap. Typically, recommendations are made through scientific knowledge production processes, but these are not always acted upon nor implemented, because the people who are expected to act on the findings were not part of the research processes developed to address the issues. For challenges as complex as catchment management and EI interventions, it is essential to conduct research within the social, economic, environmental and political context within which the intended outcomes are to be implemented and to recognise the importance of this context both to those implementing the research outcomes in policy and practice, and those that will be the beneficiaries of its outcomes. Many of the issues and problems that catchment management has to address in the uMngeni River catchment are considered 'wicked problems' as there is rarely a single solution that can be implemented. As Bhaskar (2010) states, "exemplifying the triangular relationship of critical realism, interdisciplinarity and complex (open-systemic) phenomena" is needed for the investigation of wicked problems such as water resources management.

This project aimed to develop knowledge that could inform both policy and practice and which could become embedded as solutions in spaces in the catchment at different scales through action research. Critical Realism developed by Bhaskar[21] , the transdisciplinarity theory expounded by Max-Neef, socio-hydrology and socio-ecological relations theory, including concepts from the hydro-social cycle, formed the background for our research journey. Waddock et al. (2015) discuss large scale change as being more than incremental change, which only seeks to know how to continue on current trajectories. Waddock et al. (2015) also pointed out that large scale change requires transformative pathways and defined transdisciplinarity as moving from 'what is' at an empirical level, to a value level, which constitutes 'what could be done'. Focused research, within particular disciplines was undertaken, but knowledge and methods were shared, learnt and integrated between disciplines as we considered Max-Neef's (2005) transdisciplinary pyramid. Transdisciplinarity is defined here, as moving from 'what is' at an empirical level, to a value level, which constitutes 'what should be done'. A transdisciplinary intent shaped the research design, which took the team from empirical research framed by our disciplines, including the case studies and other joint research activities, to a new form of knowledge. A new set of solutions were therefore co-created through a process of joint sense making.

Our research team followed a research design that was participatory, embedded and which included action research, with each case study being investigated using similar research methods, i.e. quantitative and qualitative, to then form a narrative for the overall catchment. It needs to be emphasised here that the research team consisted of experienced senior researchers with a long-standing history of engagement in the catchment, but also included a number of emerging academics, as well postgraduate students engaged in our diverse research endeavours (*cf.* CHAPTER 7).

[21] For a useful overview of the work of Bhaskar, see Bhaskar, R. and Scott, D. (2015). *A Theory of Education*. Springer International Publishing, New York, NY.

Building collective capacity in the context of resource-based risks and uncertainty points towards the broad field of social learning as a useful component of organisational learning and social change. Wals (2007:18) describes social learning as:

> *"[…] learning that takes place when divergent interests, norms, values and constructions of reality meet in an environment that is conducive to learning. This learning takes place at multiple levels, i.e. at the level of the individual, at the level of a group or organisation or at the level of networks of actors and stakeholders."*

These ideas and concepts form the basis of the approach adopted by the project team and is best described as a social learning approach which advocates an 'enabling' orientation – rather than a traditional 'causal' approach (i.e. seeking to understand and from that knowledge to cause change in others through top-down methodologies) (Taylor, 2014).

The research, over time, became a journey for the research team. At times this was in isolation of each other, be it at the level of the individual or as a disciplinary team, while at others it was interactive through informal as well as structured engagements. These included moments of connecting such as through regular field trips to get a feel and understanding of the different case studies that were core to the study. In addition, there were team research meetings as well as the Reference Group meetings that grounded the research still further and enabled us to engage more fully. Set activities, such as training on discourse analysis (November 2nd, 2017 and March 15th, 2018) as well as a group modelling and capacity building exercise (July 4th, 2018), further strengthened the research endeavour. Supervision of students followed a group approach with regular meetings (on average fortnightly) and an approach where junior students were paired with more senior students.

The journey of the team was complemented periodically through engagements with other relevant stakeholders and citizens. This was effectively a relational engagement, which grew deeper as levels of trust grew over time. It has to be noted here, that several researchers has been active in the catchment for some years and had well established networks from the onset. However, the project intensified the connection between researchers and citizens, but also of these to government, NGOs and decision-makers. The longer run-time of the project assisted immensely in this crucial aspect of understanding and trust building.

Key stakeholders included:

- Individuals applying citizen science tools, engaging with Ecological Infrastructure (EI) and informing more traditional research (Graham and Taylor, 2019). Such stakeholders included unemployed citizens, living in township areas and informal settlements, as well as civic science forums and conservancies, who developed a strong connection with EI and the importance of caring for life-supporting natural resources such as water, healthy food and clean air.
- Street theatre groups, such as Mpophomeni Youth Productions who developed a range of EI related drama productions which were performed to leadership groups including Councillors, Traditional Leaders, Municipal authorities, community gatherings as well as through schools and youth groups. Such events were popular and engaging and resulted in rich dialogue around EI topics of concern in the townships.
- EnviroChamps (Ward, 2016), were also a stakeholder group that our research team engaged with from time to time. EnviroChamps are effectively local community members who represent the environment and effectively become the eyes-and-ears of the community and convey issues and risks to the authorities. EnviroChamps also engage with community members, often through door-to-door education campaigns and help inform their respective communities (Taylor and Taylor, 2016).
- Other engagements included Leadership Seminars. These seminars engaged with decision-makers at a political level as well as with local authorities.
- The Umgeni Ecological Infrastructure Partnership (UEIP) has a collaboration and coordination objective. Here, experts and higher-level decision-makers work together at a catchment scale.

- Umgeni Water (UW) which is the bulk water utility for the cities of Pietermaritzburg and Durban. Many of its staff are actively engaged and committed to addressing problems in the catchment. UW also sponsor a Research Chair at the University of KwaZulu-Natal.
- Officials from state departments in provincial and local government, as well as leaders from the various traditional authorities.

5.2 Philosophy and Approach: Beyond Communicating Solutions

In the uMngeni River catchment we have been learning how to apply teaching and social transformation methodologies that genuinely support change. By applying co-engaged, action learning pathways (O'Donoghue, Taylor and Venter, 2018) change for a more sustainable future becomes enabling where participants are part of the processes of change rather than being acted upon through awareness raising or communicated messages. The co-engaged learning pathways, which support action learning, are helping to overcome the weaknesses of top-down awareness raising or communicated messages from those who believe they know, to those whom they would like to deliver their messages. Indeed communicated processes are not proving very effective in bringing about change for a more sustainable future (Kemmis and Mutton, 2012). Kemmis and Mutton continue to point out that 'practice architecture' or learning processes that are based on real-life practices are more likely to be effective than learning that is of a more theoretical nature. In this sense practice architecture is mutually supported within action learning processes, as we discovered through the course of the project. As we have learned in this project this not only relates well to impoverished citizen groups, but also to decision-makers in other communities, e.g. local government, the UEIP, researchers and postgraduate students.

In the past, and still in some situations today, technologies are researched and developed in order to solve biophysical, social and health problems. The assumption is made, as in the case of cholera outbreaks and the HIV-AIDS pandemic, that one can discover what is going wrong, develop a more informed response and then 'communicate' this response to all concerned. Unfortunately, meaningful learning and enduring social change does not come about through such simplistic, 'cause and effect' orientations to learning and change (Taylor, 2014). For enduring social change to occur, we need to build and enhance human and social capital by ensuring that people become actively involved, and co-engaged, in their own learning.

Co-Engaged Action Learning (Taylor and Venter, 2017; and O'Donoghue, Taylor and Venter 2018) is an applied and practical orientation to learning in which inter-linking features of; 'tuning in' or preparation, 'field-work,' 'information seeking,' 'reporting' and 'action taking' are applied. These processes become useful orientations to support learning that is engaging, co-engaging, meaningful and longer lasting. During the cholera outbreak at Eshowe, KwaZulu-Natal in the year 2000, for example, advice on how to avoid the disease was communicated to members of the public. Although helpful, it was only when more engaged learning processes were used, during which bacteria could be identified using a simple community health kit, proved more meaningful than simply the communication of clear messages (O'Donoghue, 2005). Similar findings were revealed in the cholera outbreak in Harare in 2011 (Mandikonza, Musindo and Taylor, 2011).

5.2.1 Problematic Assumptions of Deficit Development and How to Work Towards Addressing Them

A major challenge faced in a development context, such as in the uMngeni River catchment, is the unintended effect of 'deficit development.' Deficit development may be described as an outlook that assumes that people 'lack' resources and skills, and that these inadequacies must be overcome in order to 'develop.' As such, it is an outlook on development that tends to have a blind spot towards the inherent potential or opportunities that people in resource-poor contexts have. Research and experience have shown that if one works with people from a deficit perspective one may, inadvertently, perpetuate a 'power-gradient' from those who assume they know (the development agency and facilitators) to those who appear to lack capacity (the intended target group of the development processes). An enduring belief may persist, where 'those who have' are perceived to have a recipe or methodology for sharing or imparting their expertise and apparent competence (Rahnema, 1992). Such an outlook may perpetuate the very inequalities it seeks to address.

Instead of an outlook where the development partners are perceived to be 'poor' and lacking skills and competencies, one could rather acknowledge their *economic* poverty and seek to build on their social capital, their sense of agency and other strengths. In a development context it is important to recognize mutual strengths, without neglecting weaknesses, and seek to engage with and address both strengths and weaknesses. The approach of building different capitals (including human and social capitals) adopted in this project has been strongly influenced by this perspective.

While aiming for greater sustainability, one should build on this strength instead of focusing on the negative lack of skills and technology. An example of this is the way the Centre for Environmental Education in India, has developed the 'hand-print' (https://www.handprint.in) concept where people seek to do something positive to overcome or alleviate their environmental impact, rather than focusing on their negative impact or environmental 'foot-print.' An example of a hand-print action is the way the EnviroChamps of Mpophomeni, in 2018, through fixing fresh-water leaks, saved 10 million litres of treated water in just six-months. This amount of water saving equates to a financial saving in the region of R180 000!

There are many communities living in economic poverty in the uMngeni River catchment. A closer look at the social fabric may reveal a more complex situation, however. Communities and societies may be economically poor and suffering great hardships but the ability of people to work together and support each other in challenging times is unprecedented. The Nguni[22] tradition where people of a similar age are considered to be brothers and sisters, the elderly are considered to be the parents of all people younger than they are, and young people are regarded as the children of older people is an example of this. Where such traditions are respected, the social capital remains strong since no one would wish to harm others who are considered members of one's family. The tradition that it takes a village to raise a child is one outcome of this indigenous knowledge. It is important, in the uMngeni River catchment, that helpful indigenous knowledge practices, or the wisdom of the past, is fore-grounded and applied. We need to use the best approaches that modern times offer, along-side the best practices from the past.

5.2.2 Case Studies

The case studies which formed the focus for the project activities formed the basis of our engagement. A short description of this aspect for each case study area follows:

Mpophomeni/Mthinzima
Emphasis in the Mpophomeni community was placed on environmental education. Various teaching techniques were explored such as theatre in combination with scientific tools such as clarity tubes and miniSASS that uses invertebrates to determine river health. This bridged the divide between local communities and scientific practices to facilitate the exchange of knowledge, as well as embracing it in a fun way involving theatrics that inspire behavioural change for a positive environmental outlook. This as well as the rehabilitation plans of the Mthinzima in relation to the local wastewater treatment works and the 'Save Midmar' initiative linked many of the activities and research between the community, academia with different projects (including international academics/collaborators), provincial government, local government and NGOs. The UEIP also has this topic on its agenda in most meetings.

One particular experience that was shared amongst the Mpophomeni community involved a day visit from high-level delegates from Sudan. The delegates travelled to South Africa to learn more about water resource management and found themselves learning from the Mpophomeni community how water resources are monitored by community members themselves! Through such interactions and many others, Mpophomeni Envirochamps begin to see the immense value their work provides, not only locally, but across the African

[22] isiZulu, the most widely spoken language in KwaZulu-Natal, is a language in the Nguni cluster of languages.

continent! This part of the catchment was the focus of much of the biophysical related research. However, as the project developed, community members became more involved with the related postgraduates studies, both biophysical and a societal focus emerged. Consequently, the outcome was that the Envirochamps co-designed research questions and methods of data collection.

Sobantu / Baynespruit

The Sobantu community that lives in the Baynespruit catchment worked closely with field researchers on issues of relevance such as community gardens and health impacts due to contaminants in the river and soils. Results were shared with the community in order to facilitate understanding of results and in turn increase the community's own knowledge base. In another intervention in the same catchment, the local municipality explored the idea of implementing floating wetlands. This was an experimental design as well as an opportunity to explore the local effectiveness of the intervention. More recently, local NGOs are continuing the initiative, working with community members to explore the use of removed alien vegetation in craft work. MiniSASS is also being performed in this location. Further, this catchment has been much discussed in the UEIP, as well as a close collaboration exists between the local municipality and academia. Members of the Sobantu community have also raised their voices in the Msunduzi catchment Management Forum and thus, are developing a relationship with the regional Department of Water Affair and Sanitation office in Durban. Postgraduate research and the associated students started to become embedded in the communities as they informed them of their research outcomes and through their studies established a strong relationship with government departments for themselves as well as their supervisors and other team members.

Mzinyathi

The Mzinyathi River, and the communities that live within its catchment, are located within the Qadi Traditional Council, headed by *Inkosi* Mqoqi Ngcobo, on land under the control of the Ingonyama Trust Board (I.T.B.), in the north west of eThekwini Municipality. Mzinayathi is therefore governed by both the traditional authority and eThekwini Municipality. The dual governance system impacts on catchment management and the potential for EI interventions, as the traditional authority is responsible for allocating land in the area, while the municipality is mandated to provide services and protect the environment, as per NEMA (1998). The Mzinyathi catchment is located on the periphery of the municipality, in an area which contains valuable ecosystem services, and which is rapidly densifying due to the availability of land, the lack of implementation of municipal planning and building regulations, the lower cost of services and no rates and taxes on land, and the attractive peri-urban environment, which offers both rural and urban lifestyles.

Research conducted in the project therefore focused on understanding both the relationships between, and responsibilities of different actors, including the state (both administrative and traditional), community members and 'newcomers' in Mzinyathi, in shaping human-environment and hence water relations. This included understanding different actors' constructions of ecosystem services in the area, and how their governance impacts on water security. Ongoing follow up studies will attempt to build a governance arena between the different actors to address the impact of rapid densification on the environment and the services it provides and to create a platform upon which EI interventions can be implemented.

The Palmiet Catchment Rehabilitation Project (PCRP)

The Palmiet Catchment Rehabilitation Project (PCRP) was initiated in 2014 as a pilot project in the UEIP and WRC 2354 (Vogel et al., 2016). The PCRP has evolved into an innovative governance arena that has been established between officials from eThekwini Municipality, researchers from Development Studies, School of Built Environment and Development Studies (BEDS), UKZN, and civil society (including civic science) organizations, including the Palmiet River Valley Conservancy, River Watch ((a local NGO), eThekwini Conservancies Forum and the Quarry Road West informal settlement 'mapmakers'. The PCRP has adopted a participatory governance approach, which focuses on the co-production of knowledge. An Action Plan for the catchment was drawn up in 2015 by all the stakeholders in the PCRP and this continues to inform action in the catchment. The PCRP members meet on a quarterly basis and the meeting is chaired by officials from the Climate Protection Branch (CPB), Environmental Planning and Climate Protection Department (EPCPD). The PCRP is led by the Community of Innovation, a core team of the PCRP, which includes CPB officials, BEDS researchers, representatives of River Watch and representatives from the Quarry Road West informal settlement. The project has focused on improved water and climate governance in the catchment, with a particular emphasis on how to use EI to enhance water security and to reduce environmental risk.

The project reveals the value of building a participatory governance arena that creates a platform upon which to initiate EI interventions in the catchment. The first five years of the project, i.e. that covered by WRC 2354, has focused on understanding the relations between the multiple 'communities', who live, work and recreate in the Palmiet River and its catchment. The PCRP has produced a wide range of data, reports and academic journal articles and book chapters as well numerous meeting minutes, social media posts and press articles. These form a valuable resource and set of data to shape decision making in the catchment, thereby supporting 'datafication' for just and sustainable development (Sutherland et al., 2019). The PCRP has also built relationships across the catchment, and over the past 18 months has been able to begin to influence critical departments, such as the Human Settlements Unit and eThekwini Water and Sanitation, which can operationalize EI interventions. CPB in EPCPD, as a state agency, facilitates change, rather than implementing projects on the ground, and hence it is important that the major implementing departments have been drawn in to the project. The implementation of EI interventions in the PCRP received a major boost in June 2019 when a service provider, GroundTruth, was appointed by EPCPD in eThekwini Municipality, to implement EI interventions in the catchment. This is part of third stream funding from the Development Bank of South Africa, as part of the Western Aqueduct project. The CPB was able to motivate for the project based on the governance arena and knowledge base that had been built as part of the PCRP.

A community of practice has therefore been established in the catchment which includes hybrid EI interventions, social learning through participatory practices, the co-production of knowledge and data, community-based practices for water and climate governance and climate adaptation, experimentation with EI interventions in the catchment, and an action plan which is guiding the PCRP.

5.3 Developing Agency and the Emergence of Communities of Practice

As our research project progressed we found that a number of Communities of Practice (CoP) developed. Such groups shared a common concern and vision for Ecological Infrastructure. Wenger, Trayner and de Laat, M. (2011) define a Community of Practice (CoP) as a learning partnership among people who find it useful to learn from, and with each other about a particular domain. They use each other's experience of practice as a learning resource. Wenger (1998) highlights three dimensions in a community of practice: joint enterprise (wise catchment management), mutual engagement (between members), shared repertoire (that members develop over time through experience, knowledge, and developing vocabulary) (Wenger, 1998). Wenger (2009) argues that learning is contextual and occurs through engaging in experiences and participating in the world around us; it is "a fundamentally social phenomenon, reflecting our own deeply social nature as beings capable of knowing" (p.210). He continues to argue that CoPs are social learning systems which exhibit characteristics that arise out of learning, such as "complex relationships, self-organisation, dynamic boundaries, ongoing negotiation and cultural meaning" (p.1). In some cases, CoPs started to merge in their endeavours, especially in the case study areas and thus join forces in making sense of and addressing challenges they face individually or collectively.

The following section of our research report outlines how changes towards more sustainable EI practices came about and how such work could be taken further.

5.3.1 Connecting Catchment Leadership with Wise Catchment Management Practices

Finding ways of inspiring local leaders[23], government and especially local government to become meaningfully involved in wise catchment management processes remains a challenge in the uMngeni River catchment. During field-work in the catchment it became apparent that local government has a strong interest in protecting the resource base of the catchment. It is not often clear, however, how this interest can translate into local government commitment and support and how this could best be implemented. A critical lesson learnt across all case studies is that in order to build water security in the catchment through EI interventions, state citizen relations need to be built and strengthened.

An early study in the uMngeni River catchment in KwaZulu-Natal conducted a power-mapping exercise which revealed how people with influence, such as those in local government or even political councillors and traditional leaders, acknowledged that they had considerable power and influence in terms of catchment related actions, but were quick to point out that their knowledge of ecological infrastructure, or catchment management processes, was not adequately developed (Rowlands, et.al., 2013). As the power-mapping proceeded it became increasingly clear that people with influence (or power) often had little understanding of wise catchment management processes or how they should respond to these. To address these weaknesses a Leadership Seminar programme was developed and although it had very limited resources a great deal was achieved as is noted below. In essence, the Leadership Seminar concept was developed to meet these challenges and overcome the knowledge and action competence gaps (Dambuza, 2017a).

"Leadership Seminars," involve those stakeholders who have been identified as highly influential and whose work mandate requires a high level of understanding of the environment and ecological infrastructure, catchments (the natural water factories of the nation), and climate change risks and opportunities. Most notably, the Leadership Seminars seek to inspire and enable leaders to meet their mandated responsibilities, or Key Performance Areas, as these relate to catchment management processes.

A number of Leadership Seminars have been conducted in the wider uMngeni River catchment and key findings are that the building of relationships that promote trust is crucial, as is the manner (ideology), through which the workshops are conducted. It is noteworthy that at each Leadership Seminar, a practical field-work activity is undertaken, and all participants have a hands-on experience in basic environmental analysis, data collection and synthesis. This activity needs to be relevant to the context in which the participants are situated. In many instances the miniSASS (Stream Assessment Scoring System; www.minisass.org) proved appropriate to the leadership seminar objectives.

Enviro-Picture Building activities, such as the *Puzzling Climate Change* resource or *Catchments to Coast*, helped support the learning by situating the issues in the local realities of the leadership groups. The *Capacity4Catchments* website (https://capacityforcatchments.org/community) carries these tools (Graham and Taylor, 2019).

A number of Leadership Seminars have been facilitated, some with the support of CoGTA and we are encouraged by the levels of enthusiasm, commitment, and follow-up activity. In 2017, Tembeka Dambuza of WESSA, with the support of WWF-SA, developed three Ecological Infrastructure booklets to support the Leadership Seminars.

These booklets[24] are:

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[23] This includes elected local leaders (Councillors), traditional leaders, as well as leaders in local or district government.

[24] These three booklets are effectively works in progress as we continually update the materials. We appreciate input and suggestions for future issues. Researchers who would like to take this concept further can source digital copies of these booklets from Jim Taylor at jimtaylor835@gmail.com.

i. *"Key Performance areas and responsibilities within the local authorities that enable environmental projects."* This booklet outlines the KPAs of officials as well as links to legislation and compliance (Dambuza, 2017a).
ii. *"Tools and Teaching Resources for enhancing water care in catchments".* This booklet describes the tools that can be used in support of wise catchment management (Dambuza, 2017b). A WRC report by Graham and Taylor (2019) has a more recent and comprehensive overview of citizen science tools and how they may best be applied.
iii. *"Our Stories of Change"* is the third booklet in the EI series of booklets on EI in the uMngeni River catchment. *"Our stories of Change"* overviews how people are changing their lives, those they represent and other community members towards more sustainable EI practices. This booklet is effectively an evaluative account of how the Leadership Seminars are supporting positive changes in the catchment (Dambuza, 2017c). For a further 11 mini-case studies of positive EI changes in the catchment, with particular reference to the uMsunduzi region, please refer to Taylor and Cenerizio (2018). The uMsunduzi river flows through Pietermaritzburg and is a tributary of the uMngeni River.

The following quote is from one of the *Stories of Change*. It is a reflection from an iNduna who lives near Impendhle and it illustrates how people in leadership positions are, following the Leadership seminar process, addressing Ecological Infrastructure issues in their neighbouring community:

> *"I am Mrs. Doris Molefe, one of the iziNduna of the Isiminza Traditional Council. After ecological infrastructure training presented by the Wildlife and Environment Society of South Africa (WESSA) in partnership with the Traditional Institutional Support section of the Department of Co-operative Governance & Traditional Affairs (CoGTA), I became concerned by some of the issues in my community. To prevent soil from ending up in local streams, I decided to start a project to slow down soil erosion in a dongas close to my home……. Then, later, we began working on another section. This time we used 2 litre cool-drink bottles filled with water. By May 2017, soil had started piling up behind the structures we had constructed and grass had started growing on the soil. To share the work, I asked my children to make a short video clip of the project. We are also encouraging our neighbours to do similar projects….. Where was this training when I was younger? I could have done so many things"* (Dambuza, 2017c pg8).
>
> Otto Mbelu, also from the Isiminza Traditional Council, alludes to the style of training:
>
> *"What was unusual about the training was that we were not there only to listen—we all were given an opportunity to share what we know. I learnt a lot of knew things and had new points of view on some of the things I knew. Learning about the impacts of litter on our rivers, I returned to my community and decided what to do"* (Dambuza, 2017c pg4).

5.3.2 Coordination of Decision-Makers with Agency: The Policy-Research Interface

The uMngeni Ecological Infrastructure Partnership (UEIP) officially came into being in November 2013. Here partner organisations signed a five-year Memorandum of Understanding (MoU), committing themselves to find ways of protecting and restoring the natural water resources to ensure that people of the uMngeni River catchment have access to good quality water of adequate supply. In the first five years of its existence, the UEIP grew into a vibrant partnership of 24 organisations from government, business, academia and civil society committed to finding ways of better integrating EI solutions into water resource management in the Greater uMngeni River catchment.

These organisations used interdisciplinary and transdisciplinary approaches to harness the potential of intact, functioning ecosystems to supplement and in some cases substitute for BI as a component of water resources management in the catchment. The protection, restoration and rehabilitation of EI to enhance water security in the uMngeni has been the point of departure for the UEIP.

The first five years of the partnership was focused on streamlining governance and institutional arrangements to support integrated water resource management in a collaborated and coordinated manner in the catchment. The South African National Biodiversity Institute (SANBI) has been responsible for the coordination of the partnership since the inception; providing strategic, management and administrative support to the UEIP. The Institute of Natural Resources (INR) have provided office-space and management input to the UEIP.

Over the past five years, the UEIP has become a quality “learning organisation” with partner organisations developing the ability to co-learn and trust each other, to co-create solutions to challenges and issues around protection of ecological infrastructure in the catchment. To celebrate the successes and reflect on the progress and challenges of the partnership, SANBI, as the centre for coordination hosted the UEIP’s 5th Year Anniversary celebration on the 28-29 November 2018 at the Ascot Conference Centre in Scottsville, Pietermaritzburg. The celebratory event was attended by over 50 delegates representing the organisations signatory to the UEIP MoU. The delegates included researchers, implementers, students and young graduates living within the uMngeni River catchment and other parts of South Africa. The discussions also covered issues around each partner organizations’ expectations as well as contributions and benefits of organizations from the UEIP. Celebrations included the launch of the UEIP logo which was co-designed by partners as part of establishing a presence and identity for the partnership.

The UEIP has been very active in the research-policy interface, and effectively enhancing collaboration and coordination of activities in the catchment. With local governments supported by provincial government units and the local water board – being the implementers of 3 of 4 case studies (i.e. Mpophomeni community/ uMthinzima River, Sobantu community / Baynespruit river; Palmiet Catchment Rehabilitation Project), the engagements and learnings were multiplied. These hotspots of water quality and continuous relational engagements combined with public and political pressure created windows of opportunity for the different CoPs to engage with each other and sometimes merge within each case study. As several individuals were members of multiple or even all these case studies, these CoPs enhanced their effectiveness again and contributed to a catchment wide CoP around EI. It needs to be noted here, that the UEIP functioned as a key enabler for this catchment wide CoP, but does not represent it or may be used to formalise it. The different CoPs effectiveness is often enhanced by this informality and flexibility.

5.3.3 Umgeni Water

Umgeni Water (UW) is well established as one of the better organized and high performing SOEs in South Africa. Over the past eight years, it has supported the activities of a research Chair in Water Resources Management at the University of KwaZulu-Natal. UW is well established as a leading organisation in innovative water resources management approaches and the Chair, as a key knowledge holder in the catchment could take on multiple roles and contribute to different CoPs. The resultant multiplier effect and intensification of debate and innovation that has occurred provides another form of ‘learning from research for practice’.

Reflection from the chair holder highlights five key benefits in learning and contributing to the EI discourse:

1. Additional and, in general, flexible funding could be utilised to support activities of ongoing projects. This was particularly important for student bursaries as student projects could be prefunded and their costs lowered as UW made laboratory and analytical facilities available to researchers in the project.
2. Reporting at quarterly internal UW research meetings meant that engineers and scientists across divisions were exposed to EI type thinking and the importance of the catchment in UW day-to-day operations.
3. Lobbying/engagement became possible with key UW role-players who were also active in the UEIP, and as well as this specific research project. Their involvement and interest came through day-to-day activities, but was enhanced by the aforementioned support of student laboratory analyses, engagement with the student projects and participation on the project Steering Committee and membership of, and engagement with the UEIP.
4. Working through the UW financial reports and the different tariffs and bulk water costs of sales provided a means of engaging with staff. This created a lot of interest and useful feedback and better

knowledge of specific UW activities and cost drivers which could better inform the team of where EI investments would be most beneficial. These discussions evolved into the idea of an internal catchment levy to support EI investments from funds generated in addition to ongoing Section 30 activities.

5. Many aspects evolved from discussions, and gained emphasis at unexpected times. Examples include UW work on floating wetlands, detailed energy and pumping cost analyses and activities associated with the expansion of built infrastructure."

The above provided a useful element of an overall development towards research results being able to inform decision-making; and further, initiating implementation on the ground.

5.3.4 Reflection by the Members of the Project Team

As the project progressed, a COP began to take shape within the project itself. Increasing trust and the wide-ranging input from researchers with varying knowledge sets contributed to greater depth in these engagements. Of most significance was how the researchers with a strong natural science training and culture were able to learn from a wider repertoire of language and social skills enabling greater reality congruence with partner communities. Social science researchers too, experienced deeper insights from the natural and economic science data and this knowledge complemented their research and life experiences. In this regard, engaged action oriented research with stakeholders in the case studies was a critical enabler. It has not been an easy and smooth journey, but all members made significant efforts, for example, to bridge hydrological perspectives and those of social constructivism or critique. Here one can highlight the example of the natural sciences-based work struggling with the step by step 'emergence' of design in the social sciences mode. For example, the use of software to perform the discourse analysis was a comfortable way to analyse and draw lessons for some team members, while others preferred physical colour coding and used smaller data samples.

The reflection of the senior team members under four themes as shown in Table 5-1:

Table 5-1 Reflections of the project team on experiences over the course of the project

Key moments of surprise	Comforts and discomforts	Induces changes in knowledge and practice	Where to from here
Individual experiences within the project team varied significantly.	Discomforts arise when engaging in methods or activities envisaged by other group members.	Local context can provide insight for a meta scale.	The continuation of action research by putting practices first is critical.
Internal perception of the individual's connection to the project team influenced the overall output of the individual and or vice versa output influenced the connection to the team positively.	Though different disciplines have different areas of strength, it is possible to draw on each strength with resulting cohesion.	Using different lenses and perspectives during research offers valuable insight.	Consolidation and synthesis for reapplication of research is important.
Creating an enabling environment for members to share their perspectives builds trust and understanding.	People are very complex; the larger the group, the more complexity exists and must be managed.	How people are structured – such as in an organised group, or having delegated tasks – is important for different types of interventions that create change.	Financing offers an avenue for industry to engage.
Students and young researchers become highly influential beyond the academic space and beyond the project time.	Understanding methods across different epistemologies is challenging.	Knowledge was widened and deepened for all.	The "breakthrough"/ transformation lies in the residual impact of the project in the near future.
Co-engaged action research provides an interface for innovation.	Most tension was experienced when research / theory met practice. Reality and practice only started to change through an innovation change agent in each case study.	Changes are starting to take place with regard to research practice. This also seems to influence the individual worldview of the respective researcher / postgraduate.	More implementation and practice is needed, not more knowledge.

Working as part of such a diverse but enthusiastic and committed team of researchers has indeed been a privilege and as such been highlighted by all members. Most notably the ability of the researchers to co-engage with and involve community members in the research processes as partners, rather than as research subjects, was greatly encouraging. It was illuminating to see how enthusiastic community members, and local leadership, were to engage with and apply more informed EI processes. These forms of engagement, or indeed co-engagement, auger well for the future of the uMngeni River catchment and the people who live there.

5.4 Concluding Thoughts

Transdisciplinarity projects provide opportunities for learning that transcend disciplinary boundaries lines, yet, prove challenging due the broad spectrum of theory that each discipline brings to the table. In addition, this project embedded its activities in practice beyond the boundaries of pure academia. The variety of stakeholders at various levels and jurisdictions increased the project's complexity. These aspects over a time span of a five-year period provided a continuum of learning activities for all parties. While the overall focus of academia is on learning, to produce change from the learning creates purpose and the positive change intended. The project intended that knowledge generation would initiate system change at the uMngeni River catchment level, which we are gradually starting to see. It was also noted that learning occurred beyond the project team and was experienced within the various communities of practice as a result of the significant focus on how social interventions are just as critical as technological for creating change.

In effect, there are multiple CoPs which play a role in the catchment. They may not be called that and are often informal. Because multiple actors operate in multiple spaces, there is some overlap between them. Some of the interaction is across CoPs at the same "level", e.g. between the case studies, but some at a "higher" level – e.g. the UEIP – which may then become a new CoP which includes those actors, but also others. Actors will bring their experiences from different case studies, and through their interactions, new perspectives will "emerge" and may "merge" to create a higher level of knowledge – arguably a new CoP. As alluded to above, individuals seem to have played a key role in the connection between these spaces, i.e. the individual CoPs, investment into activities, linking to government and connecting with academia.

In reflecting on the project's trajectory, it can be noticed that an awareness transgressed along the well-known Neef transdisciplinarity pyramid, moving from the academic bases around disciplinary knowledge (empirical) towards values, ethics, and philosophies (value level) following a purposive, pragmatic, and normative pathway. The transformative approach is purpose driven and a new set of solutions were therefore co-designed by joint sense making (cf. 5.3, see Chapter 2).

Through the understanding obtained through this project, we expanded the ''Types of Change'' developed by Waddell (2011) and adapted by Waddock (2015), to include a more practical component as shown in Table 4-2. This addresses the question of *what is the point of research if it isn't to create chan*ge? Through the research approach as outlined in this chapter, research is situated in a specific case study context and applies practicable action to transform the situation for the better. It is also useful to consider Pierre Bourdieu's notion of "practical reason" (Robbins, 1991), where one starts from current actions and practices and seeks to make these more sustainable, rather than relying on the conventional wisdom and assumption that 'theory or awareness' will lead to more informed actions. Understanding that transdiciplinarity moves beyond knowledge integration and is rather more pragmatic around operationalisation as highlighted by Cundill et al. (2019) was an experience of this team.

In line with this rationale, additional types of change may be considered. Through a slight adaptation of the power and relationship 'Type of Change" in the original table, one can focus more on the practicality of the context beyond notions of power. While similarity does exist for the types of change described as "Purpose", this addition emphasises the extension of scope beyond *just research* towards *implementation*, working closely with stakeholders and implementing bodies. This approach strengthens the link between research and implementation for greater application opportunities that create effective societal change.

This concept of research-meets-implementation has been supported through collaborative efforts and facilitated and supported by entities such as the UEIP and UW. However, as the CoPs demonstrate, there are numerous actors involved in any co-engaged action research effort. It is encouraging to report that following these efforts in the uMngeni River catchment, 24 *Stories of Change* about effective EI implementation have been published (Dambuza, 2017c; and Taylor and Cenerizio, 2018). The *Stories of Change* may be described as case vignettes, or simple snap-shots of community engagements rather than as detailed case studies. In these *Stories of Change* tangible and effective action has been taken to strengthen Ecological Infrastructure (EI) and the *Stories of Change* have been co-published with the participants, who are leaders in their local communities, and led the change processes. It is particularly encouraging to see how many political leaders, including Councillors and Traditional leaders have taken up this work.

Furthermore, EnviroChamps have proved to be an effective way of mobilising communities in support of wise water management practices (Dent and Taylor, 2016 and Ward, 2016). Indeed, when the State President convened the Jobs Summit in 2018, the Framework Agreement, which came out of the summit, specifically mentioned the EnviroChamps of Mpophomeni as an example of community-based water management processes that will, in turn, support the economy through securing EI and thereby help to secure jobs.

Table 5-2 Types of change Waddell (2011), adapted by Waddock (2015), with further adaptations through this study (below the break and in purple).

ASPECT	**TYPE OF CHANGE**		
	INCREMENTAL	REFORM	TRANSFORMATION
Core questions	How can we do more of the same? Are we doing things right?	What rules shall we create? Who should do what? What are the rewards?	How do I make sense of this? What is the purpose? How do we know what is best?
Purpose	To improve performance	To understand and change the system and its parts	To innovate and create previously unimagined possibilities
Power and relationships	Confirms existing rules. Preserves the established power structure and relationships among actors in the system	Opens rules to revision. Suspends established power relationships; promotes authentic interactions; creates a space for genuine reform of the system	Opens issue to creation of new ways of thinking and action. Promotes transformation of relationships with whole-system awareness and identity; promotes examining deep structures that sustain the system Visioning
Action frames	Mediation	Negotiation	Visioning
Practical orientation	'Tuning in' or preparation	'Field-work'; 'information seeking'; 'reporting'	'Action taking' that initiates and follows through on the change envisioned
Social and technical innovation	Consideration of new social systems or technologies	Development of new social systems or technologies	Implementation, testing, and revision
Solution development	Fixing 'what is' scale dependent	Incorporating 'causes' from a wider-ranging scale than just local	Co-designing solutions that transcend scales, and departmental as well as disciplinary responsibilities

In conclusion, the reflection in this chapter shows that in order to achieve 'practice' from research it needs 'embeddedness in society' on a horizontally and vertically very wide scales. Furthermore, in accordance with Waddock et al.'s types of change (2015; 995) the team, as well as the numerous CoPs, both existing and those that have merged over time into bigger, sometimes more inclusive CoPs, show significant signs of reform with some of the individuals crossing over into the transformative space. It may be hypothesized here that transformative change needs further momentum through more individuals joining into this space of embedded action within the case studies and asking more pertinent questions about what is (How do I make sense of this?); and also visioning different actions (How do we know what is best?) going hand in hand with an implementation plan (new ways of thinking and action, unimagined possibilities, examining deep structures). The project's case studies now provide co-constructed learning environments and windows of opportunity for this bigger CoP in EI in the uMngeni River catchment.

CHAPTER 6. UTILIZING HEALTHY ECOLOGICAL INFRASTRUCTURE TO SECURE WATER FOR THE BENEFIT OF SOCIETY

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6.1 Introduction

This project has explored and demonstrated how healthy ecological infrastructure (EI) can be used to secure water for the benefit of society and the environment, supporting green economy principles and practices. It further reveals how approaches for investing in EI, can support the WRC's strategic water security goals of:

- good and well maintained water infrastructure (which includes built and ecological infrastructure);
- smart, highly aware water users (through training, awareness raising, education, capacity building, social learning and drawing on already existing water knowledges, in relation to water, society and the environment);
- a sustainable and talented group of people managing and maintaining the system (building water governance at multiple scales, drawing on multiple actors, experts and local actors);
- good partnerships with academic and research institutions (building state-citizen-research relations);
- and high investment in knowledge-based solutions (evidence-based policy making on the value of EI in securing water, supported by the use of the Opportunities and Risks Framework for EI (ORF4Ei).

Investing in EI in the uMngeni River catchment is not about the polarization of EI and built infrastructure (BI), or about EI simply replacing BI to support and enhance water security in the catchment. Rather, it is about making wise and sustainable decisions in each particular context. This includes using EI, BI and social processes, or a combination in a hybrid system, to ensure value for investment in terms of benefits, costs, effort and sustainable outcomes for water security. EI and BI can, indeed, be complementary. They are always implemented and practiced in relation to each other, even when they are perceived to be 'stand-alone' or binary interventions. BI is developed to exploit the resources of and manage the challenges and risks produced in the environment, securing and controlling water and distributing it in ways that aim to be efficient, risk averse and safe. On its own, EI cannot provide water at the scale and efficiency required by society, and so BI has predominantly been the approach used to provide water to society, through hydro-modernist approaches which rely on science and technology. BI systems are designed with their 'buffer for failure' which is usually the environment. When BI systems fail, EI, or the environment, acts as the sink, absorbing and dealing with the outflows of failed BI to the best of the environments ability. EI absorbs and has to deal with wastewater treatment plant failures, ageing infrastructure and where rivers become the discharge points of pollution. At other times the rivers become a solid waste and greywater storage and transfer system especially when waste management systems fail[25]. And grathey often do. This is a reactive rather than proactive approach. As

[25] The following statement by an environmental scientist about the catastrophic toxic spill from the Willowton factory in August 2019, shows how EI is the buffer for BI failures and hence needs to be well maintained, to ensure it can provide a high level of services at all times, particularly during a water pollution crisis: "What we are probably seeing here quite dramatically is the impact of the loss of much of the upstream aquatic ecosystem/biota (from the Willowton spill), that would have previously processed and provided a buffer and amelioration against the sewage from the lower reaches of the Duzi/Baynespruit. With the loss of most of the aquatic biota (not just fish, but also phyto and zooplankton, invertebrates, etc.) from the spill, their ability to process and degrade the sewage spill inputs is significantly reduced. Another reason that we need to be looking

pressure and failures in the socio-ecological system of the catchment intensify, so this approach becomes unsustainable, with dire long-term consequences for people and the environment (see Martel, 2019; Sutherland et al., 2019; Browne et al., 2018). EI and BI are therefore connected, relational and dialectical, with political, social, economic and environmental processes mediating the sustainability of their interactions.

The hydro-modernist approach, with its dominance of BI, is increasingly under pressure to meet water security goals. This, coupled with the ongoing degradation of the environment; increasing water demand; environmental risk and climate change exacerbates the challenges. As knowledge about sustainability and the importance of a safe operating space for humanity under conditions of environmental risk grows, the value of EI (and its associated ecosystem services), means that it has become necessary, desirable and morally responsible to explore how EI interventions can be strengthened and enhanced to support BI in securing water in the uMngeni River catchment.

6.2 A Continuum of Water Security Interventions

EI, BI and social processes form a continuum of water security interventions (see Table 6-1) from solely BI to solely EI interventions, including social practices of learning and change, and various combinations of BI, EI and social processes.

Table 6-1 Continuum of water security interventions present in the uMngeni River catchment

BI	BI/EI	BI/Social/EI	Social	Social/EI	EI
Wastewater treatment works with piped systems for inflow and outflow	Dam in a catchment with ecological restoration programmes	Wastewater treatment works, rehabilitating a wetland and training of EnviroChamps	Social learning and environmental education, developing sustainable practices and ethics of care	Alien invasive plant clearing through EnviroChamps (DUCT)	Installation of a wetland, rehabilitation of grasslands

Traditionally, investing in EI has focused on 'green' interventions with a strong ecosystem services rehabilitation focus, such as grassland rehabilitation to support water flow in a catchment, or the upgrading of wetlands, or the rehabilitation of riverine indigenous vegetation or the clearing of alien plant species. Indeed, the original definitions of EI were focused on "naturally functioning ecosystems" with the goal of "mainstreaming biodiversity". Due to its transdisciplinary nature, this project has revealed a broader spectrum of EI interventions. These include EI interventions that are predominantly political and social in nature, such as the building of governance arenas for river rehabilitation projects, the training of EnviroChamps or the development of social learning programmes to fore-ground practices about the value of a well-functioning environment for water security (Martel and Sutherland, 2019). These types of EI interventions are closely linked to the local development context, and acknowledge that 'softer' interventions are required to build stronger human environment relations and reduce water security risks. It also includes EI interventions, which include ecosystem services provided, for example, by vegetation that is not indigenous, and EI that is present or implemented at the micro-scale, such as the value and risk associated with a 'few' alien trees providing services in an informal settlement (Sim et al., 2019).

to get our aquatic ecosystems in as robust shape as possible, and building on the conservancy idea that DUCT is mooting, to buffer these sorts of events into the future" (Graham, 28/08/2019).

6.3 Case Studies of Ecological Infrastructure interventions in the uMngeni River catchment

Case studies of EI interventions in the catchment are presented across the deliverables of WRC 2354 (see Browne et al., 2018; Sutherland et al., 2019a). Multiple actors (state and non-state) were involved in each of the case studies, as collaboration was required to promote innovation through EI interventions. The following exemplars from the four case studies have been selected for the final report, as they reflect different forms of EI interventions on the water security intervention continuum. These interventions have been proposed or implemented and shaped by the particular context within which they are embedded (the structuring elements of the ORF4Ei). Within each case study, innovation was encouraged as well as collaboration between the range of state and non-state actors. The case studies reveal that EI is a valuable intervention for securing water in the catchment at different scales. The issues that need to be addressed include the context of the sub-catchments and rivers, the readiness for EI interventions and the champions that are driving each intervention as they shape their form, practices and outcomes. For example, the government official leading the Mthinzima wetland rehabilitation adopts a 'learning by doing approach', is focused on the tangible delivery of EI interventions and is an environmental scientist. This has driven the rehabilitation of wetland areas between Mpophomeni and Midmar Dam. The work is supported by the influence and presence of DUCT and WESSA in Mpophomeni, who are leading the development of social learning and environmental education through training EnviroChamps, facilitating Leadership Seminars, creating *Stories of Change,* and developing *Capacity4Catchments* activities (see Chapter 4).

In the Palmiet Catchment Rehabilitation Project (PCRP), the municipal officials who lead the Community of Innovation of the PCRP, are located in the Climate Protection Branch of the Environmental Planning and Climate Protection Department (EPCPD), which is a facilitating, rather than an operational department in eThekwini Municipality, as reflected in the approach of the National Environmental Management Act (Act 107, 1998). A governance arena for EI interventions has therefore been created. The implementation of possible physical EI projects is only now being considered, given that the Human Settlements Unit and Coastal Stormwater and Catchment Management Department of the eThekwini Municipality have recently entered the arena. This is as a result of the iQhaza Lethu project and the knowledge production processes in Quarry Road West informal settlement under the PCRP (Sutherland et al., 2019b). Different departments within the state have different mandates, capacity and funding to act, and hence in some cases, platforms which support EI interventions have been created (PCRP), while in others physical interventions are taking place (Mthinzima Stream).

The case studies reveal how the opportunities and risks contained in the ORF4Ei have shaped the particular EI responses in each sub-catchment. In Mzinyathi, for example, the WRC 2354 research team has been engaging in water governance for five years, but have not initiated the building of a governance arena, as they did in the Palmiet catchment. This is because the research exploring the value of EI in the Mzinyathi catchment had to begin with developing a good understanding of the relations between the two forms of governance, the eThekwini Municipality and the Qadi Traditional Authority and their role and responsibilities in terms of water governance (Sim et al., 2016; Sutherland et al., 2016). They also needed to understand the drivers and processes of rapid urban densification in the area and how this was impacting on ecosystem services and water security (Sutherland et al., 2016; Sutherland and Mazeka, 2019).

Given the social and cultural context of the catchment, local residents' constructions of the value of water and ecosystem services needed to be mapped before consideration could be given to EI interventions at the local scale. eThekwini Municipality, through the Ecological Restoration Branch in EPCPD, is investing in community ecosystem-based adaptation in the periphery and peri-urban areas of the city, with these interventions being relatively successful (World Bank, 2016). However, they are largely being implemented to protect large swathes of protected or open spaces, rather than securing ecosystem services within human settlements that are rapidly changing (Boon et al., 2016; Roberts et al., 2011; eThekwini Municipality, 2013).The EI intervention in Mzinyathi, through the co-engaged action research of WRC 2354, was therefore to understand human-environment relations and how these were being shaped by the dual governance system. This process led to a deepening of understanding in the area. However, given the complexities and sensitivities of the dual governance system, it is challenging to implement physical EI interventions, given the different mandates and responsibility of the traditional authority and eThekwini Municipality (Sim et al., 2019). The critical issue in Mzinyathi is to address the rapid loss of EI and ecosystem services, which is politically challenging as this is so deeply connected to the issue of land allocations. This learning is invaluable to future prospects for EI intervention or conservation in dual governance areas in the catchment, and hence the dual governance system, where present, is one of the major structuring, and shaping, elements in the ORF4Ei.

The Baynespruit case study, which reviewed various potential and actual interventions on the water security intervention continuum, revealed that EI interventions (including green/hybrid infrastructure) were among the lower cost intervention options and offered multiple benefits. The EI interventions were designed to address the particular context of the Baynespruit. For example, floating wetlands were proposed and tested given that they avoided the complexity of acquiring land for an intervention[26] (see Taylor et al., 2019). Regulatory requirements often stifle innovation in local government, because a by-law or regulation trying to control one problem, often prevents innovation and solutions for another, different problem. The rehabilitation of the Msunduzi River through planting natural vegetation along its edge and stabilizing its banks, cannot be a 'fast' and early gains intervention, as any significant structure introduced in to, or activity near, the river requires a Water Use Licence Authorisation in terms of the National Water Act which is a lengthy process. However, smaller areas of replanted vegetation are permissible, and so small pockets of vegetation, which recognized regulatory controls, but legally found a way to work around them, were planted up. The relevant structures of the ORF4Ei, namely the control of legislation and policy, and the spatial practices of nature as a support to hydro-modernism, were identified by the actors involved in this case study, and thereafter solutions were found, particularly by understanding the context and working with, and at times beyond it.

[26] However, the level of their impact (on water quality) in this case is lower relative to rehabilitated wetlands given the modest (pilot) size of the floating wetlands.

Mthinzima-Midmar interactions

Upper Catchment

- Mthinzima River flows through Mpophomeni, which has inadequate sanitation and waste services, into Midmar Dam
- Overflow and seepage from sewers flow into Mthinzima Stream
- New WWTW planned to address the risk
- Rehabilitation of wetland areas adjacent to proposed WWTW, which will act as a buffer for pollution, is a legal requirement for wetland rehabilitation as part of the environmental approval for new WWTW
- Rehabilitation of wetland area adjacent to Mthinzima Stream will act as a buffer for pollution from run-off from Mpophomeni (not addressed by new WWTW)
- Economic evaluation of wetland rehabilitation reveals that benefits outweigh the costs
- Enviro-Champs who promote social learning and environmental education in Mpophomeni support the reduction of pollution going into the Mthinzima stream by developing an 'ethics of care' and sustainability practices.

Baynespruit River

Middle Catchment

- Baynespruit is a small, urban, highly degraded tributary of the uMsunduzi-uMngeni River
- Proposed interventions include EI and social learning, as BI has been dominant and is failing
- Proposals adopt a focus on socio-ecological-technical interventions in combination with each other.
- These include green hybrid interventions such as floating wetlands, waterless sanitation systems, rooftop rainwater harvesting. Social interventions include environmental education and advocacy, BI interventions of upgrading sanitation systems and canalisation of the river, ecological interventions of riparian and wetland rehabilitation
- BI interventions are most expensive
- Revegetation of degraded riparian areas has the best outcome in terms of comparatively lower cost and multiple benefits
- Case study reveals the inter-connectedness and complementarity of different interventions along the water security continuum

Palmiet Catchment Rehabilitation Project

Lower Catchment

- Palmiet Catchment has a wide range of land uses that shape water security and flooding in the catchment
- Small urban catchment with a relatively small river which rises very rapidly during storm events and can result in devastating flooding of Quarry Road West informal settlement located on the floodplain of the Palmiet River in its lower course
- Governance arena has been built which includes actors from the local state, citizens, university researchers and civil society organisations
- Engaged in participatory action research and the co-production of knowledge
- Knowledge on relations between people, the catchment and the river has developed.
- Long process building relations particularly between citizens and the state, through bridges (university researchers)
- EI and BI interventions are now being considered particularly in terms of housing and risk for informal settlers, which has been made possible because of the governance arena and the co-production of knowledge

Mzinyathi Ethics of Care

Lower Catchment

- Mzinyathi River is a small river impacted upon by the building of Inanda Dam which affected its water flow.
- It flows through the Qadi Traditional Authority and is located in an area of dual governance between the traditional authority and eThekwini Municipality
- The river and its catchment provides valuable ecosystem services to residents who live peri-urban and rural lifestyles
- The area is rapidly densifying due to the accessibility of land, limited regulation and low cost of urban/rural life under traditional governance
- Due to the lack of planning and building controls and adequate formal service provision, urban densification is having a significant impact on the environment, as environmental systems are absorbing the costs of rapid, unserviced development
- The social constructions of ecosystem services reveal a recognition of the value of the environment to quality of life and as a buffer.
- Concerns about environmental degradation due to rapid development: the need for ethics of care and sustainability practices, as part of the governance agenda, is crucially important.

Figure 6-1 Case studies of EI interventions in the uMngeni River catchment

Figure 6-2 A visual representation of EI interventions in the uMngeni River catchment

The brevity of the final narrative report means that the significant amount of learning from the case studies cannot be presented in detail here (see the WRC 2354 deliverables for more detail). However, the examples presented above provide insight in to how EI can be implemented in the catchment. What the research has shown, is that EI interventions are emerging in multiple forms, at different stages of implementation in the uMngeni River catchment. These findings are providing useful lessons for where and how to intervene in the catchment.

The value of using EI, and its associated ecosystem services, for societal development and transformation, is well-established in a wide body of literature. This is particularly true in South Africa where EI and ecosystem services are protected and maintained due to their developmental co-benefits (Sutherland and Mazeka, 2019; Roberts, et al., 2012). The value of EI is contained and reflected in legislation and policy in South Africa, due to a well-recognized body of research, which supports its 'proof of concept'. It is also evident in multiple public and private interventions and practices across the country, which show its value to society (Sutherland and Mazeka, 2019; Buscher, 2012; Cartwright and Oelofse, 2016; Mander et al., 2017; Constanza et al., 2011).

The point of departure of WRC 2354, is therefore that EI provides benefits to society in terms of both enhancing water quantity and quality. However, the critical decision in terms of EI investments and interventions in the uMngeni River catchment, which WRC 2354 focuses on, is 'what to do where, how, when and by whom'. The following section presents an example of the application of the ORF4Ei developed as part of this research to guide decision-making around EI interventions in the uMngeni River catchment (see Chapter 2, Section 3). The Baynespruit case study water security interventions are evaluated in relation to the ORF4Ei, to show how it can be applied and to reveal the value of its application.

6.4 The Opportunities and Risks Framework for Ecological Infrastructure in the uMngeni River catchment (ORF4Ei) as applied to the Baynespruit case study

Interventions from the BI, social processes and the EI continuum, are implemented in a particular socio-economic, political and environmental context. This context has its own path dependencies, opportunities and risks. This context both enables and constrains the choices and possibilities for what kind of EI intervention to make, where, when, how and by whom, to enhance water security. This context is defined, understood and applied in WRC 2354 through the ORF4Ei. It outlines the opportunities and risks to EI interventions in the catchment drawing on the broad framing ideas (epistemic notions), structures (both meta-structures and local structures), and physical reality (materiality) which emerged as shaping water-society-space relationships in the uMngeni River catchment through the WRC 2354 project (see Chapter 2). Investing in EI in the uMngeni River catchment therefore requires a choice of which EI intervention is most suited to shifting path dependencies, maximizing opportunities and addressing the risks identified through ORF4Ei, to increase water security in particular places in the catchment.

The interventions being assessed in the Baynespruit catchment are used as examples to show how the framework can be applied as a decision making tool. The use of the framework is not comprehensive, in other words not all EI/BI continuum interventions are evaluated in the table, as they were not all evident in the Baynespruit case study. However, the example provides evidence of the way in which the framework aids in decision making around EI interventions. Each set of relations is briefly explained and colour coded to aid in the assessment of the various options. A green code represents a set of relations with positive outcomes that are achievable, an orange code represents a set of relations with potential, or which may be challenging to achieve due to significant barriers, and a red code represents a set of relations that have negative consequences, or which may be very difficult to achieve.

Table 6-2 Society-water Opportunities and Risks in relation to water security interventions continuum.

Intervention	**Particularities of Place**
Baynespruit Stream Catchment	Small, urban, highly degraded tributary of the uMsunduzi-uMngeni River. Consists of high-density formal and informal residential development (both rapidly expanding) and numerous trade effluent regulated industries. Water pollution, characterised by sewage spills, solid waste (litter) and industry effluents (oils), and stormwater management

SOCIETY-WATER	**BI**	**EI/BI: hybrid**	**EI**	**Social**	**Social/EI: socio-ecological**	**Social/EI/BI: hybrid**
	Canalisation of the river		**Rehabilitated wetlands and stream banks**	**Environmental Advocacy**		**Floating wetlands**
South African Constitution (principles and rights)	May protect citizens rights to protection from environmental hazards		Right to a healthy environment	Right to a healthy environment Human dignity		Right to a healthy environment
Legislation and policy	Will need to meet strict legislative requirements for significantly altering natural course of river		There is supportive legislation, but WULA is required	Not constrained by legislation and policy		Not constrained by legislation and policy due to scale and flexibility of system
Neo-liberalism	High cost, effective at addressing streambank erosion and property damage issues where they are currently experienced, but transfers the issue/damage downstream, therefor requires significant infrastructure (gabions, weirs) at the downstream 'exit' point		Medium cost which provides water quality benefits	Low cost for high social and environmental benefits, challenges neo-liberal separation of people and nature		Low cost
Developmental, interventionist state	Act by state alone to 'control the river and its impacts' as an interventionist state, using science and technology as a support for an state		High potential for co-benefits, intervention by state leads to broader developmental gains	Creates an informed, engaged and responsive public which can provide support to the developmental state		

SOCIETY-WATER	BI	EI/BI: hybrid	EI	Social	Social/EI: socio-ecological	Social/EI/BI: hybrid
	Canalisation of the river		**Rehabilitated wetlands and stream banks**	**Environmental Advocacy**		**Floating wetlands**
	intervening in nature and ensuring development, political gains for the state as seen as responsive to citizens needs in short term					
Engaged and Active Citizenry	Limited engagement by citizens		Need an informed citizenry to protect the wetland against vandalism and as a dumping site and in terms of competition for land	Creates an informed, engaged and responsive public which can provide support to the developmental state Empowers citizens to act in their own local spaces to improve water security through wetlands on private properties, food gardens and alien removal		Limited citizen engagement
Governance arena with active and engaged state-citizen-private sector-research actors	Exclusive act of the state in governing in the risk of the river, but supported by demands of citizens who have called for this type of intervention, so state is responding to citizens using managerial governance		Partnerships can be formed for the maintenance of the wetland, rehabilitation would be an act of the state with support from environmental organisations	Develops an informed and active citizenry that can engage in multi-actor governance arenas for social and environmental transformation Empower citizens to act. However, citizens often need to engage with the state to ensure implementation of EI practices. It is often difficult to draw in other actors.		Partnership between local state and NGO (WESSA) supports innovation

SOCIETY-WATER	**BI**	**EI/BI: hybrid**	**EI**	**Social**	**Social/EI: socio-ecological**	**Social/EI/BI: hybrid**
	Canalisation of the river		**Rehabilitated wetlands and stream banks**	**Environmental Advocacy**		**Floating wetlands**
Societal constructions and attitudes towards water	Reflects societal constructions of water that echoes the ideology and practices of hydro-modernism		Supports positive societal attitudes towards nature's role in securing water if supported by social learning and education	Leads to greater understanding of the multiple social constructions of water and shifts attitudes towards water conservation, ownership and stewardship		Creates awareness around using 'constructed' nature to clean water
Integrated Water Resource Management Discourse and institutions	Limited support of IWRM principles as return to 'hard' interventions of BI, rather than 'softer' and more integrated solutions offered by EI, but may be necessary in this case to manage the river		Supports principles of IWRM	Supports principles of IWRM		Supports improvement of water quality using environment
Hydro-modernist (science and technology)	Strongly embedded in and reflective of hydro-modernism		EI that can be linked to support BI	Enables citizens to critically engage with opportunities and costs of hydro-modernist paradigm and report failures in this system		N/A
Informality	Does not connect well with informality as this is a highly formal and structured intervention. May protect people living under conditions of informality		Well adapted to addressing conditions of informality	Well adapted to addressing conditions of informality		Functions well in conditions of informality
Closed catchment; fully developed	Control of 'high risk' river systems in a closed catchment		Supports water purification in a closed catchment which is essential	Builds an understanding that water is a limited and scarce resource		N/A

SOCIETY-WATER	BI	EI/BI: hybrid	EI	Social	Social/EI: socio-ecological	Social/EI/BI: hybrid
	Canalisation of the river		**Rehabilitated wetlands and stream banks**	**Environmental Advocacy**		**Floating wetlands**
Failure of service provision, failing infrastructure	Does not address failure of service provision and canals typically run the risk of becoming spaces of increased concentration of the impacts of failed service systems		Good intervention to address failure of BI and lack of service provision but should not be used as a reason to: not develop services, as pollution is being mitigated to a certain level, nor for upstream 'polluters' to not be responsible for managing their wastewater	Empowers citizens to find solutions to challenges associated with poor service provision and to mobilise and act against poor service provision which impacts on their communities and on water security. Builds capacity or people to act responsibly and reveal an 'ethics of care' toward the environment		Addresses failure of service provision at small scale without placing increasing demands on land to solve the problem
Environment as a buffer	Not recognising the value of using the environment as a buffer, rather controlling and limiting the ability of the environment to act		Acts as a buffer	N/A		Constructed EI as a buffer to water pollution
Environment as an actor: shapes what is possible and produces risk and uncertainty (climate change, droughts and floods and pushing back from pollution)	Environment may act back on this engineered solution, resulting in a reduction of its effectiveness, if it cannot control floods adequately and if pollution concentrates in the canal with limited environmental resources to ameliorate it		Acts to clean the environment and to regulate flood water	Enables communities to understand how the environment acts in both positive and negative ways to shape their quality of life		Environment as a response to help address pollution in the river. Hybrid constructed EI acts to clean up river and develop a no-regrets approach in relation to climate change

Table 6-3 Society-space Opportunities and Risks in relation to water security interventions continuum

SOCIETY-SPACE	BI	EI/BI: hybrid	EI	Social	Social/EI: socio-ecological	Social/EI/Grey: hybrid
	Stream canalisation		Rehabilitated wetlands and stream banks	Environmental Advocacy		Floating wetlands
South African Constitution (principles and rights)	May protect citizens rights to protection from environmental hazards		Right to a healthy environment	Right to a healthy environment Participation of citizens in South Africa's transformation		Right to a healthy environment
Legislation and policy	Will need to meet strict legislative requirements for significantly altering natural course of river		Supportive legislation for rehabilitation of wetlands	Not constrained by legislation but rather supported by NEMA (1998)		Not constrained by legislation and policy due to scale and flexibility of system
Political organisation: three spheres of government	Will require co-operation and co-funding across three spheres of government		Supported by all three spheres of government as an approach to improving water security	Supported by all three spheres of government as an approach to improving water security		Requires intervention from local government, no concerns about mis-alignment with other spheres of government
Legacy of colonialism and apartheid	Protects citizens who are located on the river due to the legacy and path dependencies of apartheid from the 'dangers' of the river, but in this case mitigation is predominantly for middle to higher income residents and sports fields		Addresses inequality by cleaning water and acting as a sponge after rainfall which helps to address challenges and path dependencies created by colonialism and apartheid	Addresses impact of colonialism and apartheid through education empowerment, and shifting attitudes that taking care of the environment only benefits the elite (and in the past, the white population), develops understanding that protecting the environment is critical to the vulnerable,		Partially addresses inequality by being used as a 'turning point' in stream and river management to begin cleaning water adjacent to informal settlements and reducing impact of informality and lack of services at a micro scale

SOCIETY-SPACE	BI	EI/BI: hybrid	EI	Social	Social/EI: socio-ecological	Social/EI/Grey: hybrid
	Stream canalisation		**Rehabilitated wetlands and stream banks**	**Environmental Advocacy**		**Floating wetlands**
				marginalised and economically poor people		
Formal administrative planning	Would need planning approval and EIA approval Would need to be aligned with and support planning and land use zones of the surrounding area, in other words does it contribute, given high cost to future land use plans and development of the area		Wetlands need to be protected by formal planning processes and land use systems, frameworks and plans Demarcation of wetland will need to align with planning and land use controls	Develops citizen science and local knowledge which can be used to support formal planning processes		Aligned with formal planning as floating wetlands placed in stream, rather than on land
Traditional Authority Governance	N/A		N/A	N/A		N/A
Land Use System: Agriculture, Forestry, Industry, peri-urban, urban, informal	Urban, urban informal which produced high loading of pollution on river and which is exposed to flooding (formal and informal residential areas). Impact of industry on pollution levels and failing BI (leaking pipes, blocked manholes)		Urban, urban informal which produced high loading of pollution on river and which is exposed to flooding	Urban, urban informal which produced high loading of pollution on river and which is exposed to flooding. Urban setting means that Baynespruit has more mini-SASS, citizen science activities than any other river due to activism of schools and church groups in the catchment.		Urban, urban informal which produced high loading of pollution on river
Interaction between people and institutions and practices	Limited interaction as this would be an exclusively state intervention with state institutions and practices. Political pressure from affected residents to implement this option so they will draw on state		Can lead to development of partnerships to maintain the wetland, can support green economy activities, can support development of informal institutions and	Leads to building of state-citizen relations which is critical to strengthening relationships between institutions and practices of the state and local		Relatively easy to establish through partnerships, may require third stream funding and support for the state as

SOCIETY-SPACE	BI	EI/BI: hybrid	EI	Social	Social/EI: socio-ecological	Social/EI/Grey: hybrid
	Stream canalisation		**Rehabilitated wetlands and stream banks**	**Environmental Advocacy**		**Floating wetlands**
	institutions to support their demands for canalisation of the river. Public participation as part of approval process for proposed canalisation so will trigger public engagement process		practices to protect the wetland once its value is recognised	communities and finding ways to connect and integrate them		intervention is experimental and innovative
Rapid Urbanisation	Attempts to address impact of rapid urbanisation and hence increased surface water flow and its impacts on river banks while at the same time, canalises the river to protect spaces of urbanisation		Attempts to address consequences of rapid un-serviced urbanisation and informality, and serviced urban areas with failing infrastructure at the medium scale	Addresses challenges of rapid urbanisation by supporting the development of environmental citizens who are aware of their rights and responsibilities in terms of water management and environmental degradation (illegal dumping, mis-use of sanitation systems, illegal connections to sewers) and the rights of the environment. Also targets industry who contribute to pollution and other environmental degradation		Attempts to address consequences of rapid un-serviced urbanisation and informality at a small scale
Poverty and inequality	May reduce direct impact and risk to communities of the flooding river and its pollution so can build resilience. However, canalisation is		Could be linked to green economy with ongoing maintenance of wetland	Addresses poverty and inequality through a capacitated, empowered and active citizenry		Could be linked in to green economy with local entrepreneurs producing and

SOCIETY-SPACE	BI	EI/BI: hybrid	EI	Social	Social/EI: socio-ecological	Social/EI/Grey: hybrid
	Stream canalisation		**Rehabilitated wetlands and stream banks**	**Environmental Advocacy**		**Floating wetlands**
	mainly aimed at protecting middle to upper income residential areas and sports fields		supported by public works programme			maintaining floating wetlands Addressed inequality by dealing with pollution where the urban poor live

Table 6-4 Water-space Opportunities and Risks in relation to water security interventions continuum

WATER-SPACE	BI	EI/BI: hybrid	EI	Social	Social/EI: socio-ecological	Social/EI/BI: hybrid
	Canalisation of the river		Rehabilitated wetlands and stream banks	Environmental Advocacy		Floating wetlands
Hydro-modernist: water from further away	Hydro-modernist approach of controlling the river and managing it in a contained space produced by science and technology		Addresses water issues in the local context where they are present and matter	Development of a citizenry that can challenge the dominance of hydro-modernism		Deals with problem where it is, so spatially a good solution
Impact of land use on water quality and quantity	Causes downstream impacts as it effectively 'relocates' the flood risk downstream (moves the water even more quickly through the system), unless addressed with additional BI downstream. The proposed canalisation is already an extension to an existing canal, which is causing scour in the stream and the current informal stabilising structures are starting to collapse		Addresses impact of land use on water quality at a medium scale at medium cost	Active citizenry that can play a role in shaping land use in their area		Partially addresses impact of land use on water quality at a small scale at medium cost
Natural landscape supports design of grey infrastructure (nature as facilitator and buffer)	N/A		Wetland provides good support to BI in managing pollution and stormwater from urbanisation	Citizenry that understands and can act and monitor the relationship between nature and BI and report failures in the BI system		River supports failure of BI as it accommodates floating wetlands under normal conditions which address pollution. Floating wetlands are washed away in heavy rainfall and storm events even though they are anchored with steel cables

WATER-SPACE	BI	EI/BI: hybrid	EI	Social	Social/EI: socio-ecological	Social/EI/BI: hybrid
	Canalisation of the river		**Rehabilitated wetlands and stream banks**	**Environmental Advocacy**		**Floating wetlands**
Water cleaner and more abundant in upper catchment	N/A		N/A		N/A	
Water demand highest in lower catchment	N/A		Helps to address water security by holding water in the system and releasing it more slowly	N/A	N/A	

Table 6-2 to Table 6-4 reveal how the ORF4Ei can be used to evaluate different water security interventions in different contexts. The research undertaken on the four case studies in WRC 2354 (see Chapter 2 and Sutherland et al., 2019), as well as the economic assessment of the value of EI (see Browne et al., 2018), reveal how different EI interventions (from across the water security intervention continuum) are being proposed, implemented and practiced in different contexts across the catchment through multiple governance arrangements, supported by formal and informal institutions (see Figure 2.9). It is therefore useful to provide a brief summary of how governance arrangements and institutions shape EI interventions in the uMngeni River catchment.

6.5 Governance and EI interventions in the uMngeni River catchment

Governance is critical to the implementation of EI in the catchment to support water security. According to Prakash et al., (2019, p 1) governance refers to the governing or 'steering' of social, economic, environmental and political systems and their relations or interactions, "by establishing and altering institutional and organizational arrangements, which regulate processes, mitigate conflicts and realise mutual gains (Paavola, 2007; Pierre and Peters, 2000; Lockwood, et al., 2010; Paavola, 2007; North, 1991). Institutions, in turn, provide the rules by which the systems are governed. Prakash et al. (2019, p 1) state that "institutions are the formal and informal rules and norms, constructed and held in common by social actors, that guide, constrain and shape human interactions (North, 1990; Ostrom, 2005)". Lawrence et al. (2015, p 298) define institutions as the "persistent and predictable systems of rules, decision-making procedures, programmes, and the values and norms that determine social practices, assign roles and guide interactions amongst those in those roles". Institutions can be global, such as in the case of water governance, the Integrated Water Resources Management, WASH principles and the SDGs, and they can be local, such as decisions made by an informal community on how they manage publicly provided water and sanitation systems in their settlement. They can therefore be formal or informal, and can be constructed at different scales. Figure 6-3 presents the relationships between governance arrangements in the uMngeni River catchment, institutions and water security interventions.

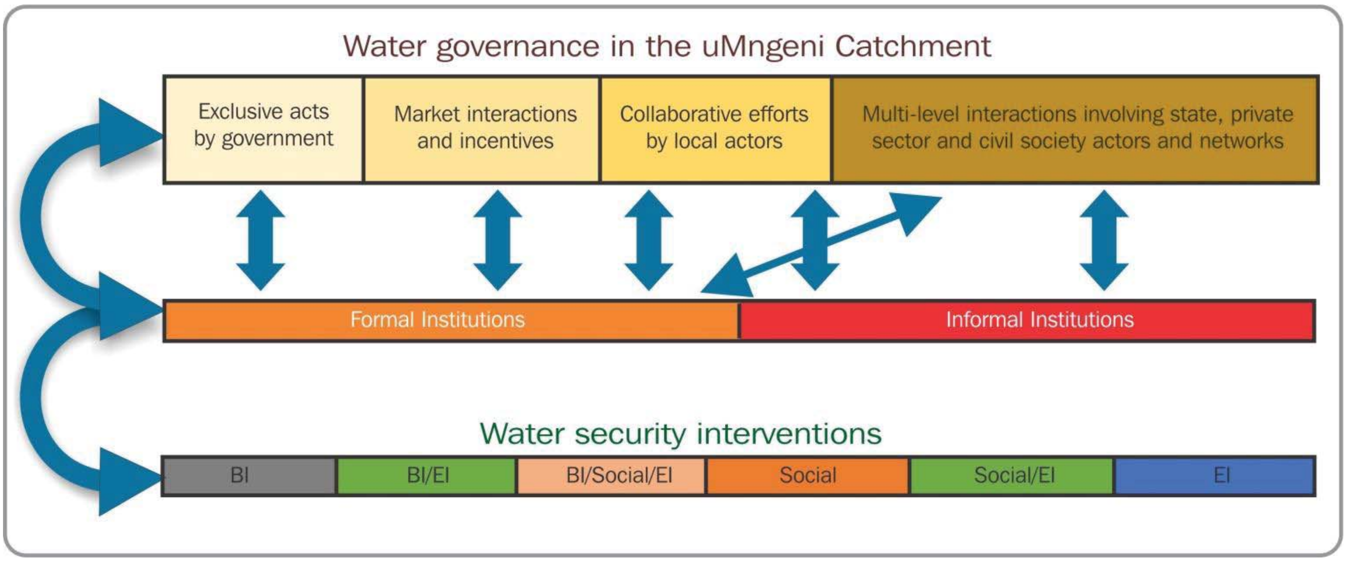

Figure 6-3 The relations between governance, institutions and water security interventions

It is also important to consider the barriers and enablers of the governance and institutional system and the biophysical system, which constrain and support the implementation of EI interventions in the catchment.

6.6 Barriers and Enablers of the Governance System

The concept of barriers and enablers to environmental transformation is well established in the climate adaptation literature. This chapter draws on this body of work, as well as literature on barriers to green infrastructure, to define the barriers and enablers to EI interventions in the uMngeni River catchment.

6.6.1 Barriers to EI Interventions in the uMngeni River catchment

According to Moser and Ekstrom (2010, p 22027) "barriers are defined as obstacles that can be overcome with concerted effort, creative management, change in thinking, prioritization, and related shifts in resources, land uses, institutions". The focus of climate change research has been on defining barriers (rather than enablers) and how to overcome them, so that they become enablers of positive environmental change. Enablers are therefore positive elements of any system that support change towards resilience, transformation and sustainability.

A summary of the main barriers to EI interventions in the uMngeni River catchment are presented in Table 6-5 below.

Table 6-5 Barriers to EI interventions in the uMngeni River catchment

(adapted from Pasquini et al., 2013; https://www.epa.gov/green-infrastructure/overcoming-barriers-green-infrastructure; Matthews et al., 2015; O'Donnell et al., 2015; Dhakal and Chevalier, 2017)

Barriers	Description
Regulatory and institutional barriers	Regulatory constraints which inhibit innovation and experimentation. Financial constraints: Municipalities are constrained by legislation and rely on revenue obtained from rates and taxes Cross-funding of disadvantaged areas – pressure on municipal finances (cross-subsidization) Silo effect of government – not their mandate or responsibility (e.g. a different departments responsibility) Responsibilities within the local government, as well as between the different tiers of government EI interventions cut across departments and hence require co-ordination Regulatory framework does not explicitly consider EI as a valuable asset, for example there is no legal mandate to implement EI interventions Lack of attention to value of EI at higher levels of government means lack of attention at lower tiers of government Party politics (political infighting and manoeuvring for political gain; undermines innovation and participatory governance which requires collaboration) Political change as a result of five-year political terms which leads to loss of institutional memory, lack of continuity and staff/turnover. This influences the planning horizon – short-term benefits favoured over long-

Barriers	Description
	term benefits. The benefits of EI often take longer to be seen/experienced, but then continue over long periods Corruption Lack of intergovernmental leadership and collaboration (between provincial and municipal authorities) Inter-departmental barriers (between water and environmental planning) Too few staff working on overcoming organisational barriers Difficult to enforce EI interventions on private land parcels
Social, cultural and political barriers	Impact of historical societal and hence planning decisions which produce inequality and create path dependencies Social and economic needs are prioritised by government over environmental concerns due to a lack of understanding about how critical a 'safe' environment is to the economically poor and marginalised Overcoming elitist and apartheid constructions of who benefits from investment in the environment Trade-off between BI and service provision with EI which is deemed to be 'inferior' to technological fixes Short termism of politicians who invest in interventions that ensure immediate gains, rather than in those that ensure sustainability in the longer term Broad lack of understanding of the value (role and contribution) of EI in addressing development deficits and ensuring social and economic transformation Municipal officials tend to favour BI and hence a dominance of BI discourses and practices in municipalities, business as usual approach Organisational culture in water department pro technical water management Broader societal culture related to water and the environment that favours short term, built or technical fixes as this is the mainstream approach
Cognitive and individual barriers	People's knowledge, understanding, beliefs and attitudes in relation to value of EI and ecosystem services Confusion over what exactly is EI (definitional ambiguity) Pro-BI mindset Perceived risk on cost and performance of EI Path dependency – reluctance to change existing practices Hesitation to take maintenance responsibility

Barriers	Description
Local government uncertainties and lack of capacity	Perceptions of unknown performance and limited track record of EI successes over the longer term Ongoing search for greater certainty (information/evidence/knowledge) 'paralysing' implementation of EI Perceptions of higher costs Unfamiliarity with maintenance costs Lack of government staff capacity and resources in relatively new field of EI investment
Urban form	Realities of current land use and state of the built environment Public and private land ownership Urbanisation and rapid densification of traditional authority areas Urban sprawl
Political barriers	Political will Political leadership, particularly municipal and provincial Vested political and economic interests in BI
Funding barriers	Public expenditure on BI vs ecological infrastructure – particularly in capital budgets Lack of use of funding tools (stormwater fees, procurement tools) Lack of shift in funding priorities and approaches
Knowledge, training and expertise	Lack of educational background and training of city staff related to EI Lack of interdisciplinary knowledge and expertise focused on integrated EI interventions (as per water security interventions continuum) Expertise primarily from grey infrastructure perspective
Engagement barriers	Lack of engagement of the private and non-government sectors Lack of engagement of developers and private land users
Governance barriers	Pro-grey infrastructure arrangements
Resource barriers	Lack of financial resources Lack of data on cost and performance Shortage of workforce trained on EI

WRC 2354 has revealed that the main barriers or obstacles to the implementation of EI interventions to support water security in the uMngeni River catchment are social, financial, political and institutional rather than technical or based on a lack of scientific knowledge of the value of EI. The legacy and path-dependency of hydro-modernism or BI, which is so strongly entrenched in the catchment is difficult to shift. However, pressure on the uMngeni River catchment to secure water so that six million people can live and prosper (Hay, 2017) has meant that innovative solutions, which include the use and value of EI need to be explored and implemented. The lack of a functioning Catchment Management Agency and hence the absence of Department of Water and Sanitation (DWS) in actively managing water security in the catchment is a major issue. The gap between local and national government does not support good water governance. DWS at the national level is governing from a far, but still wishes to retain control, even though many responsibilities for water security have been devolved to the local level. Local government hopes to have more control to be innovative and to transform systems, given that they are directly responsible for water and sanitation in the everyday lived worlds of their citizens and they are aware that the current systems of water management, services and provision are under pressure and not meeting societal needs nor ensuring environmental sustainability. The lack of authority of the Catchment Management Forums is also a critical issue.

High value EI is located predominantly in traditional authority areas, but it is these areas, that are rapidly densifying and urbanising, which is leading to the loss of valuable ecosystem services and placing increasing pressure on water and sanitation systems. This densification of under-developed areas that in many instances lack adequate services reinforces the need to protect EI and the ecosystem services it produces, as the environment is the buffer against inadequate BI provision. The need to find ways for administrative municipal governance systems to engage and resolve challenges with the traditional authorities now become critical (see Sim et al., 2019). Land use in the Upper catchment is also shifting towards more densified urban and peri-urban forms which is leading to the loss of valuable EI. Increasing informality in the catchment is both a barrier and an opportunity for investing in EI in the catchment.

Large rural industries and primary activities such as agriculture and forestry in the upper catchment are actively engaged in the governance of the water sector, as they are aware of the critical relationship between their activities, the catchment and water supply. They also act within regulations and policies which govern their activities as they operate within highly regulated industries and in the case of forestry, have to meet international certification standards for the sustainability of their activities. However, urban industries operate at a far greater distance to the water sector. They usually do not experience risk to their water supply in any significant way, and rather use the catchment and its rivers for the disposal of wastewater and pollution, often with very little consequence to their economic activities, other than relatively small fines that result from prosecutions due to lack of compliance. The recent Willowton ecological disaster, where 1.6 million litres of fatty oils and caustic soda flowed in to the Msunduzi River, and on to the uMngeni River and Inanda Dam in the Catchment (17 August 2019) reveals the high risk to the catchment. This disaster may well trigger a response to ensure greater compliance of urban industry to environmental and water regulations. Larger industries are also much easier to regulate than smaller industries, who often cannot meet the costs of ensuring environmental compliance. An effective pollution control measure in the past was when industries needed to pump their wastewater upstream, thereby ensuring that the costs of the pollution would land up on their 'doorstep' which led to greater care and concern.

The mandates and functions of different provincial and municipal departments determine what they can do where in the catchment. Departments that are actively engaged in supporting EI interventions do not always have the mandate, responsibility or finances to implement these interventions, and so have to convince other line functions to operationalise their vision on their behalf. Champions, with different personalities, will also act either as facilitators or implementers and so this shapes outcomes and possibilities for EI interventions.

6.6.2 Enablers for EI Interventions in the uMngeni River catchment

While the climate adaptation literature does not focus extensively on enablers to climate adaptation, WRC 2354 has identified a large number of levers of change, or enablers, which are currently supporting, and could support, EI interventions in the future. These are presented in Table 6-6.

Table 6-6 Levers of change/enablers for EI interventions in the uMngeni River catchment

Levers of change or enablers	Description
Proposed levers of change	
New legislation and policy with establishment of mandates to enable action/prioritisation	Greater interaction between national and local government in support of legislation and policy for EI interventions National creates the enabling framework for local government. Without this, there will be no incentive for action (EI is currently in National Planning Commission (water security document with EI); SIP19 EI should be included in Water Services Development Plans Reframing of the concept of the ecological reserve which refers to the amount of water required to maintain the natural environment, but does not recognise the value of the natural environment for water security Stronger forms of monitoring and compliance at the catchment scale, so that legislation and policy are not undermined
New ways of financing for EI	Partnerships/collaboration between downstream water users and upstream land-users Water Fund type approaches
Proactive versus reactive approach	Planning for EI as opposed to EI being the buffer when BI fails EI to complement BI EI investment can delay high capital investment in major water projects, for example investment in grassland restoration and wetland rehabilitation in the Upper catchment can delay the building of new dams
Existing levers of change evident in case studies	
Presence of champions	State and non-state actors involved in the case studies Committed, passionate about change Go beyond what is normally expected
High levels of enthusiasm towards EI investment	Communities are willing and want to engage in innovative EI projects (in areas of development deficits) Willingness to learn new skills Building of citizen-environment relations (changing of values)
Ecological infrastructure can do different things and have different benefits (broad appeal due to multiple benefits)	Social benefits (social cohesion) from establishing governance arena; elevating the status of the marginalised and voiceless (QRW) Definitional ambiguity, other than the narrow definition provided by SANBI, means that the way of doing things is not prescribed (enables innovation and a wide interpretation of EI) Water has always been attached to National agendas (e.g. focus on the job creation potential, green economy, links to the post-apartheid

Levers of change or enablers	Description
	transformation agenda; ecological infrastructure framed as a development issue)
Partnerships between state and non-state actors	Participatory governance is present within the case studies (aligned with IWRM; SDGs emphasis on participation) Building of relationships – state-citizen; citizen-environment relations; the role of boundary spanners / bridges Capacity building and social learning is valued
Partnerships at the catchment scale	The creation of the UEIP in the absence of the CMA Creation of a learning platform / potential to share resources and learn The will to improve by all partners in the UEIP
Innovation and some success in pilot projects and case studies	Experimental projects – can push the 'boundaries' Willing to be experimental and try new things (no fear of failure) Provide a space for learning in policy and practice
Disasters can be conceptualised as enablers for EI (disasters as opportunities)	Creates a platform for discussion Disasters open up spaces for change – e.g. of operating budget versus capital budget in the Municipal Finances Act EI/green infrastructure cannot be easily implemented if there is BI investment in operational budget Once there is damage or disaster, then municipalities can use their capital budget to repair or change things
Good relationships between researchers and local government	Leads to innovation Creates hubs of learning Researchers can engage in action research and experimentation outside of the constraints faced by municipal departments Can use this learning and action to support municipal departments

6.7 Investing in Ecological Infrastructure in the uMngeni River catchment: Best Practice in the Current Context

WRC 2354 has identified the main opportunities and risks across the catchment in relation to particular EI interventions. Its reveals how different EI interventions have greater potential and traction in different parts of the catchment, given the particular context, opportunities and risks in the upper, middle and lower catchment, and within each sub-catchment. These opportunities and risks are presented in Figure 6-4 to reflect how location, or the spatiality of the catchment, influences what to do where, how and by whom, in terms of EI interventions in the catchment.

6.8 Main Lessons and Outcomes

Water security in the uMngeni River catchment is a critical issue with both water quantity and water quality being at risk. The research has shown that using EI as an intervention to secure water in the uMngeni River catchment is a wise, cost efficient, valuable and necessary approach. The water security intervention continuum has revealed that EI and BI interventions, and combinations of them, along with social processes (governance, social learning, environmental advocacy and community actions) which are considered to be part of EI interventions, form part of a suite of interventions that together will ensure the sustainability of the catchment. The particular history and geography of the catchment and hence its biophysical, social, economic, environmental and political context must be understood if EI interventions are to be successfully inserted in to the water-society landscape of the uMngeni system.

These interventions need to be supported by the development of a vision and strategic plan for the uMngeni River catchment which is aligned with sustainability goals and principles, rather than being reactive and being driven by a neo-liberal pro-growth agenda. The governance of the catchment and water management by the state needs to be improved through the collaboration of multiple actors and participatory processes and by building state-citizen-business/industry relations. The path dependencies that exist need to be recognized and acknowledged, and levers of change which can begin to shift these, particularly through the use of EI interventions, need to be identified and supported by legislation and policy, collaborative partnerships and resources. The degradation of the environment needs to be halted through development and planning that is aligned with national environmental rights and legislation. Research and knowledge development which can be transferred and taken up in to policy and practice is essential. WRC 2354 has contributed to this endeavour by producing a new approach to understanding where, how and by whom, EI interventions should be undertaken.

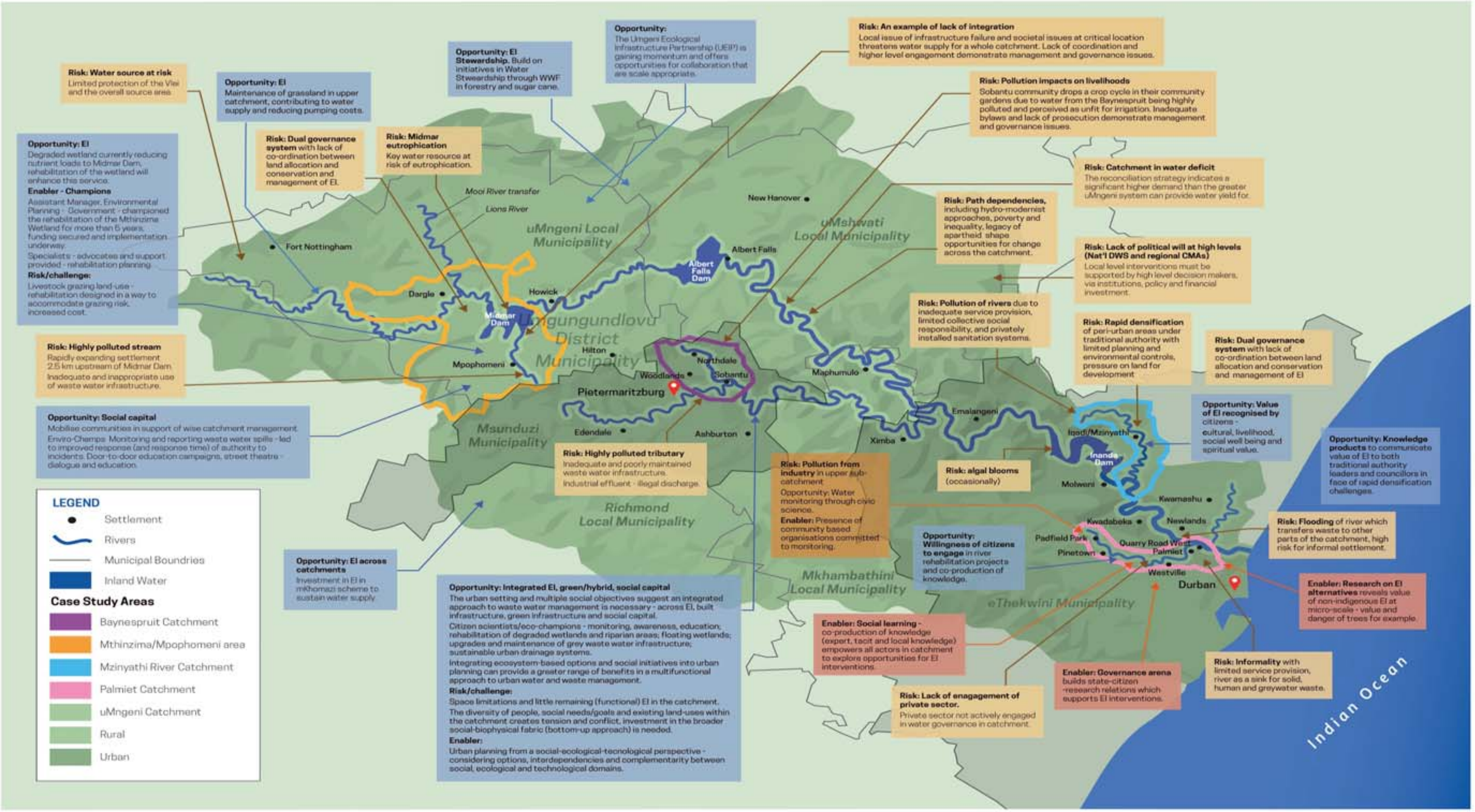

Figure 6-4 Main opportunities and risk in relation to EI interventions across the uMngeni River catchment

The traces of history continue to play a major role in shaping water outcomes in the catchment. The legacy of both colonialism and apartheid is a major challenge and barrier to improving water security, and this coupled with the dominance of hydro-modernism creates a water security context that can only be shifted by working within the current system, but using innovation through EI interventions, to slowly, patiently and wisely shift the catchment to a more sustainable, just and socio-ecological centred set of practices and way of being. The increasing pressure and demands on the catchment, and the resultant degradation of ecosystems, means that the environment, which has been the buffer for BI failures or the absence of services ever since hydro-modernism was introduced in to the catchment, can no longer absorb and manage the risk. This calls for a pro-active approach where EI and its resultant ecosystem services are rehabilitated and maintained so as to provide the support to BI interventions upfront, rather than being the reactive solution when they fail. This means planning for EI interventions along with BI growth and maintenance and integrating them in to water management and governance at the outset. This supports the argument that EI should form part of SIP 18, rather than being introduced as a separate SIP 19 in the future. EI needs to be seen as a fundamental part of water and sanitation infrastructure.

Weak governance and the lack of compliance, enforcement and monitoring is also a major challenge in the catchment at all scales. Where governance arenas have been built, this has presented opportunities for improvement in water security in the catchment, both for the water resource itself and for the people impacted by its poor quality and environmental risk, including floods. These governance arenas have supported social learning which is essential in building human capital for improved water security and enabling communities to draw on their own capabilities to shift their relationships with water. The absence of business and industry in these collaborative forums however is a critical challenge which needs to be urgently addressed.

Throughout the study the enormous value of social learning, including the willingness of communities to participate and commit resources such as time, voluntary work and effort for the improvement of the catchment and water security.

At a more practical level it is critical to identify which EI interventions work best in particular locations. The research has revealed that the early gains in EI interventions in the upper catchment relate to larger scale ecological restoration, while in the more settled or urbanized areas of the catchment, a range of EI interventions, often at a microscale, coupled with social processes are essential. We need to continue to invest in alien clearing and restoration in the Upper catchment. The value of the multi-pronged approach in Mpophomeni cannot be over-emphasized. The proposed WWTW must go ahead as soon as possible, as must the adjacent rehabilitated wetland. The social learning and environmental education processes through the EnviroChamps must also continue to be supported. By reflecting outcomes as stories of change a detailed and co-constructed evaluative mechanism is provided from which wider extrapolations can be made.

The multiple strategies in Baynespruit and the Palmiet, which have a stronger urban complexity, need more work including the support for water and climate governance. Building state-citizen relations through bridges or boundary spanners from research institutions is a further innovation that should be emphasized going forward. Of the multiple interventions, EI is cost competitive. It can be concluded that BI and EI not alternatives or substitutes for one another, but complementary, supporting each other, reducing risk and providing a range of benefits. To continue with social learning and engagement around water and climate issues at local level (such as environmental advocacy) as well as at a leadership level (such as through Leadership Seminars) is important. Society needs to bring EI to the forefront of planning and action-taking for more sustainable catchments.

A continuum of investing should be supported as the scales of investment can be across large areas but can also include small investments in multiple things (e.g. green roof tops, floating wetlands, improved rainwater harvesting, re-greening in areas of erosion, permeable surfaces). Investments can enable experimentation and testing of options to determine the most effective interventions for a particular location. In the Baynespruit, the floating wetland intervention experienced challenges and requires a different installation approach to ensure sustainability. Investment into this intervention would enable additional experimentation for installation techniques as well as to determine the most effective vegetation for application of this intervention in the South African context. The intervention has been implemented globally in the United States of America and India, but understanding its potential in the local context requires investment.

A transdisciplinary approach enabled an analysis that has produced contextual understanding. This is the case for the uMngeni River catchment as a whole and the various associated case studies. As a research team we have re-imagined and re-constructed the catchment through its political economies and political ecologies, which are reflected in Figure 6-5 below, which outlines future opportunities for investing in EI in the uMngeni River catchment.

6.9 Lessons and Future Opportunities for Investing in Ecological Infrastructure in the uMngeni River catchment

From this study, we have drawn out Ten Lessons to guide investments in EI. Although drawn from the uMngeni, they are broadly applicable to similar initiatives. These have been more fully developed as a standalone brochure.

1. People (human capital), the societies in which they live (societal capital), the constructed environment (built capital) and natural capital interact with, and shape each other
2. Investing in Ecological Infrastructure enhances water security
3. Investing in Ecological Infrastructure or Built/Grey infrastructure is not a binary choice
4. To be sustainable, investments in infrastructure need a concomitant investment in social and human capital
5. Investing in Ecological Infrastructure is financially beneficial
6. Understanding path dependencies is critical to shift thinking
7. Understanding the governance system is fundamental
8. Meaningful participatory processes are the key to transformation
9. Social learning, achieving transdisciplinarity and transformation takes time and effort
10. Students provide new insights, bring energy and are multipliers

Figure 6-5 Directions for future research

CHAPTER 7. STUDENT SHOWCASE

As a result of the significant financial investment from the Water Research Commission for this project as well as the period of five years across which it spanned, the opportunity was created to build extensive new capacity. The value of the project in developing capacity in the population of the catchment through various communities of practice has been highlighted in Chapter 5. This chapter focuses on education and capacity building through student training and occurred in different forms and at various levels.

Students registered for post graduate studies ranging from Honours (4th year) and Masters to PhDs. In total, 3 Postdocs, 9 PhDs, 15 MSc, and 7 Hons students have been affiliated with the project. Of these numbers, those that have graduated within the project scope include 2 PhDs, 9 MSc, and 7 Hons, while the remaining students are continue their studies with most in the final stages and on track to graduate this year (2019). In addition to the capacity building that occurred on an individual basis for each thesis or dissertation, students gained valuable insight regarding placement of their research within the broader framework of a research project and the various communities of practice. Below is a quote from one of the PhD students affiliated with the project that highlights the value of a project platform for researchers.

> *"My involvement in meetings and events related to the uMngeni Ecological Infrastructure Partnership (UEIP) has helped my understanding of the value of my research within the context of the UEIP Project. It also offered me the opportunity to present my research to an audience that included many accomplished and very experienced researchers, experts and students from a wide range of affiliated disciplines. This was mutually beneficial, as others were made aware of my research, and it provided invaluable feedback and suggestions for this project, as I interacted with other researchers and we exchanged ideas. Some of the documents generated during the UEIP process and data generated from this process has provided invaluable references for input information and data to train the ERA model. The UEIP project has brought together many disciplines and many different organisations and through my exposure to this WRC project, it has added immense value to my research, as the networks built will continue to expand the ERA project through ideas and further collaborative research opportunities."*
>
> *– Indrani "Hazel" Govender*

Students affiliated with the project were also encouraged to attend regular cohort meetings that facilitated interaction between not only supervisors and students, but amongst students for increased social learning. At each meeting, one or two students led the discussion by presenting aspects of their work and gained valuable presentation skills and received feedback from peers and supervisors on these aspects of their study. The building of such cohorts has benefits that extend beyond project meetings and fosters an academic community to support on-going research efforts.

The student research for this project on ecological infrastructure ranged across a spectrum of disciplines, as can be ascertained by the overview table presented below, with research spanning a variety of topics including hydrological modelling, stakeholder governance, biological life sciences, ecology and global change, economic evaluations of wetland rehabilitation, nutrient assessments, risks assessments, and overall monitoring of water quality and quantity. Some of the students utilized mixed methodologies of both qualitative and quantitative techniques in order to enhance the richness of the research and its application. Much of the research found direct application within the local context through a situated research approach enabling relevant impactful research. As the project spanned across a five-year period, its broad spanning influence helped to facilitate discussions that materialized the initial concept of ecological infrastructure towards a more tangible physical reality. This occurred in the broader surrounding framework as pointed out throughout this report, and as a result, provided an opportunity that allowed the project to follow a more programmatic approach. This programmatic approach has been able to ensure the future sustainability of the research beyond the actual life cycle of the project. A direct example of this programmatic approach includes the transition from research towards implementation through the involvement of the Institute of Natural Resources, the South African National Biodiversity Institute, and the uMngeni Ecological Infrastructure Partnership as elaborated in Chapter 4.

A programmatic approach provides opportunities for the continuation of the research project, providing greater momentum, e.g. project cycles do not always coincide with degree timelines. Therefore, many students' research concluded prior to the five-year project cycle and students progressed towards employment with other organisations. Fortunately, however, these students take the knowledge of the research and the concept of ecological infrastructure forward to these new endeavours and enable a multiplier effect for the concept to further integrate across sectors.

In this chapter, student research that was supported either directly or indirectly through this project is featured and provides, where possible, updates on how students progressed beyond the scope of project involvement and how they are applying or evolving the concept of ecological infrastructure.

Students are presented in Appendix I in order of degree hierarchy Postdoc, PhD, and Masters, then listed alphabetically by surname. Student research is presented again by degree hierarchy and then included based on timeline of project progression.

POST-DOCTORAL STUDENTS

Dr. Shaeden Gokool joined the project as a recent graduate to assist with **Identifying Hotspots for Investment in Ecological Infrastructure within the uMngeni River catchment, South Africa**. As Dr. Gokool pointed out, practice generally lags behind conjecture, therefore the research aimed to identify investment opportunities that were informed through robust ecosystem service modelling that would ensure greater returns on investment. The Resource Investment Optimization System (RIOS) and Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) models were applied to identify priority areas for investment and to evaluate the HES benefits that can potentially be achieved. Several global and local data sets were used to provide the requisite inputs to perform alternative land management scenario simulations. The results of these simulations demonstrated that potential investments in EI within the uMngeni River catchment can lead to substantial reductions in sediment export (≈ 47%). Although, this may be accompanied by marginal decreases in the surface water yield (≈ 1.40%), there is a net benefit associated with reducing sediment export. Despite, these investigations being limited in their representation of HES due to *inter alia* the lack of localized data sets and inherent model limitations, the study successfully demonstrated how the RIOS and InVEST models can be collectively applied to guide decision-making regarding investments in EI.

Where they are today…

Dr. Gokool continues as a Post-Doctoral researcher at the Centre for Water Resources Research and is currently working on various projects. Of particular interest is his current involvement in the Socio-Economic Benefits of Ecological Infrastructure (SEBEI) project, which aims to "develop an evidence-based integrated framework and prototype "investment case" for strengthening water-related Ecological Infrastructure (EI) while i) supporting well-functioning livelihood strategies/value chains; ii) creating new livelihood opportunities and value chains; and iii) reducing hydroclimatic risks". The project began in late 2018 and continues through to March 2020.

PHD STUDENTS

Dr. Jean N. Namugize's research determined the Effects of Land Use and Land Cover Changes on Water Quality of the Upper uMngeni River, KwaZulu-Natal Province, South Africa. A three-year study involving analysis of historical data, field work and desktop investigations was conducted in the upper reaches of the uMngeni River catchment (1653 km^2) to assess the spatial and temporal variation of land use and land cover and its influence on the flux of water, nutrients (nitrogen and phosphorus) and *Escherichia coli* (*E. coli*) in the catchment. This involved the analysis of historical land use/land cover information (1994, 2000, 2008 and 2011), and analysis and processing of historical datasets of *E. coli*, electrical conductivity, ammonium, nitrate, soluble reactive phosphorus (SRP), total phosphorus (TP), total suspended solids (TSS), temperature and turbidity. A water quality index based on a long-term database of water quality emanating from existing monitoring programmes was assessed. In addition, stations were established for river sampling (14) and collection of bulk atmospheric deposition (3) of ammonium, nitrates, SRP and TP, in the Midmar Dam catchment (927 km^2). These were consolidated with the application and testing of the Hydrological Predictions for the Environment (HYPE) model in the catchment, in simulating streamflow, transport and dynamic of inorganic nitrogen and total phosphorus, resulting from LULC changes. Results showed that the natural vegetation declined by 17% between 1994 and 2011, coinciding with an increase in cultivated, urban/built-up and degraded lands by 6%, 4.5% and 3%, respectively. This resulted in high variability in the concentrations of water quality parameters, but Midmar and Albert Falls Dams retain over 20% of nutrients and sediment and approximately 85% of *E. coli*. It was concluded that these dramatic changes in LULC directly affect the chemical composition of water in the catchment. However, these linkages are complex, site-specific and vary from one sub-catchment to another and decision-making regarding water resources management in the catchment must recognise this. Water quality in the catchment ranged between "marginal" and "fair", predominantly "marginal" in 90% of the sites and completely poor in the Mthinzima Stream, an important tributary of Midmar Dam. A declining monitoring frequency and resultant poor reporting of water quality in the catchment, led to a recommendation for the establishment of automatic or event-based samplers, which should provide the optimum information on nutrient loadings to the waterbodies. Bulk atmospheric deposition and river inflows into the Midmar Dam studies were conducted under severe drought conditions. Higher concentrations of NH4, NO3 and TP in precipitation samples than those of rivers were found because of the high retention of nutrients in the landscape. In terms of loading, the bulk atmospheric deposition provided significant quantities of NH4, while TP, SRP and nitrates were predominantly from river flows. Specific loads of DIN (nitrate + ammonium) and TP in the catchment were slightly higher that the previously reported values for the catchment and are comparable to the other human-disturbed catchments of the world. The information from this study highlighted the current state of LULC changes, the sub-catchments with the potentiality to export high levels of DIN and TP, the complexity of the relationship between LULC-water quality, the gaps in existing data collection programmes, the catchment responses to LULC changes and the usefulness of hydrological models which may apply beyond the upper reaches of the uMngeni River catchment.

Where they are today…

After departing UKZN in June of 2017 and graduating with a PhD in Hydrology in April 2018
Dr. Jean N. Namugize returned to the Department of Civil Engineering of the Rwanda Polytechnic-IPRC Kigali/Rwanda, who granted the PhD study leave. Currently, he works as a lecturer of water resources and environmental technology. In November 2018, Dr. Namugize was selected as a Representative of the Early Career Committee in the International Commission on Water Quality (ICWQ) of International Association of the Hydrologic Sciences (IAHS) and officially started these functions, co-convening some IAHS sessions, in July 2019 during the 27th General Assembly of the Union of Geodesy and Geophysics (IUGG) in Montreal, Canada. Dr. Namugize is also involved in other research and consultancy activities in Rwanda, including: (1) Project Coordinator "Assessment of the impacts of mining on sediment loads in the upper Nyabarongo catchment in Rwanda" (2019-2020).The project got funding from the Embassy of the Kingdom of Netherlands in Rwanda and is being implemented under the Rwanda Water and forestry Authority (RWFA) in collaboration with the International Union for the Conservation of the Nature (IUCN), (2) Rainwater Harvesting Consultant of the Netherlands Development Organization (SNV) in Kigali/Rwanda (2018-2019), and (3) The short-term consultant of the World Bank Group in Kigali Rwanda "Assessment of the impact of Nduba Landfill on the quality of surface and groundwater in its zone of influence (April to June 2019).

Dr. Catherine Hughes graduated in 2018 with her PhD in Hydrology on the **Degradation of Ecological Infrastructure and Its Rehabilitation for Improved Water Security**. This research aimed to illustrate that improvement in water-related ecosystem service delivery can be achieved through conservation and rehabilitation of ecological infrastructure. Defining what is meant by "water-related ecosystem services" and the different forms of human-induced degradation which impairs delivery of such services comprised a portion of the investigation. Followed by two modelling exercises. The first modelling study provided an understanding of the differing hydrological responses to alien plant invasion and livestock overgrazing across South Africa. The second modelling exercise focused on the uMngeni River catchment, in which high-resolution land cover data and a daily time-step hydrological model were used. We concentrated on three water-related ecosystem services, namely water supply, sustained baseflow and avoidance of excessive sediment loss. The final section of this thesis explored some of the wider issues associated with globalization and urbanization in the uMngeni River catchment, and their impacts on water-related ecosystem service delivery by ecological infrastructure. The thesis concludes with observations on the need for stakeholders to work together towards optimal investment decision-making with regard to ecological infrastructure projects, which may protect people from water-related risk, as well as ensure food security.

Where they are today…

Dr. Catherine Hughes graduated in September of 2018. Currently, she is working as a Senior Hydrologist at Piteau Associates (a global group of Geotechnical and Water Management Consultants) based at Illovo in Johannesburg since September 2018. Working with GoldSim software, Dr. Hughes undertakes water and chemical mass balance modelling for mining sector projects in Tanzania, Indonesia, Egypt and Chile, with a focus on water quality and volume management in storage facilities. Site visits to Tanzania, Mali and Egypt have been a core component, as well as training clients in GoldSim software. Part of the work includes geochemical, hydrological and meteorological data processing, as well as GIS mapping and analysis with a focus on water resources.

Simphiwe Ngcobo continues to investigate **A Climate Risk Index for Commercial Sugarcane in Southern Africa.** The future expansion and intensification of sugarcane production across Southern Africa is, for particular areas, highly likely, due in part to recognition of the economic and social importance of this activity for supporting livelihoods across this region. Significant knowledge gaps remain, however, regarding climate change impacts on water resources and sugarcane yields. By amplifying precipitation variability, climate change will increase the vulnerability of the cane crop to water stress and is likely to have a potentially devastating impact on cane yields. Using a combination of the Climate Risk Index (CRI) concept, as well as a well-established relationship between sugarcane yields and actual sugarcane water use, this study maps sugarcane water stress relative to actual cane water use and mean annual precipitation for six sugarcane mills located across four catchments, including the uMngeni in Southern Africa. Results show that understanding potential and actual crop water stress requires robust and accurate estimates of actual cane water use and MAP at mill area level. Further, while the CRI may not provide an entirely complete indication of actual and potential exposure of sugarcane to extreme water stress, it serves as a useful “first-look” at mill areas that are vulnerable to water stress. Finally, by amplifying inter-annual precipitation variability, it is not unreasonable to estimate that climate change will amplify the CRI within the individual mill areas included in this study. It is clear that more detailed CRI estimation studies are required, which will take into account critical aspects related to probable future sugarcane water stress, such as supplementary irrigation and improved cane varieties.

Where they are today…

Simphiwe pursues PhD studies in Hydrology part-time with the Centre for Water Resources Research and plans to submit by the end of 2019. He is currently in the process of writing up his research into three papers to complement thesis. As a lecturer within the Hydrology department at the University of KwaZulu-Natal, Simphiwe is engaged with teaching, supervising students, and conducting hydrological modelling research and field visits. Other projects include partial involvement with Uncertainty reduction in Models for Understanding development Applications (UMFULA), a project focused on climate impact modelling and consequences for society in the Shire River Basin in Malawi.

Michelle Browne has been conducting research into the **Economic evaluation of ecosystem restoration with a focus on wetland rehabilitation in South Africa.** Evaluating the outcomes of ecological restoration is critical to improve practice and justify further investment. While the benefits – particularly those related to water supply and water quality – of restoring wetland ecosystems in South Africa are frequently cited, their quantification and valuation is less common. The aim of the research is to develop a framework for the economic valuation of the outcomes of wetland rehabilitation in South Africa, thereby addressing a specific gap in the knowledge base identified in the literature. However, ‘value’ means different things to different people and encompasses a multitude of dimensions (i.e. not only the economic sense of value). The research, therefore, also explores the meaning of economic value and the limitations of conventional economic approaches in the evaluation of ecosystem restoration. A case study approach has been adopted in developing the framework and the research conducted as part of this Water Research Commission project.

Where they are today…

Michelle Browne is working towards a PhD in Commerce, Environmental and Natural Resource Economics at Rhodes University under the theme of Economic evaluation of ecosystem restoration: a focus on wetland rehabilitation in South Africa. The PhD is being undertaken by thesis currently in the ‘write-up’ stage with completion aimed for early 2020. Alongside doctoral research, Michelle has been employed since 2017 as a Senior Scientist at the Institute of Natural Resources, the Non-profit Organisation in partnership with this project, and works primarily within the Adaptation and Resilience theme. She has been involved in multiple projects exploring the society-economic-environment interface.

Patrick Martel is pursuing his PhD in Development Studies investigating **A temporal analysis of changing hydrosocial relationships in Durban, South Africa.** Working at the interface of natural and social sciences, Patrick is a PhD Candidate in Development Studies at the School of Built Environment and Development Studies, University of KwaZulu-Natal (UKZN), South Africa. Support for his scholarship was provided through this Water Research Commission Project and he intends to complete his PhD by late 2019 for graduation in 2020.

Patrick's research uses the hydrosocial cycle and governmentality as a theoretical lens to examine the main water moments in the city of Durban from the 1850s until the present day. He uses the concept of water moments, which relates the history of water and sanitation in Durban city to its geographical context. Over time, certain water moments have emerged and come to dominate Durban's waterscape, being characterised by distinct political rationalities, discourses and technologies of rule. His research reveals the core framings and practices of water management and water governance in Durban. With the passage of time the scalar focus of these framings and practices has changed, albeit that path dependencies in the water sector are established. Water moments have impacts at the local scale, but have been shaped over time by different paradigms, conceptualisations and approaches at a far greater scale. Patrick argues that the most recent water moment is situated around ecological infrastructure, and uses the Palmiet Catchment Rehabilitation Project as one of his case studies. His overall approach can be classified within the philosophy of political ecology, and is linked to socio-ecological relations theory, focusing on the ecological, social and economic dimensions of the catchment within a particular political context. Using this framing, Patrick's thesis aims to temporally analyse the range of hydrosocial relationships that have emerged in Durban.

Where they are today…

Patrick has had a number of opportunities to present aspects of his research at local and international workshops and conferences, including the University of West of England's Winter Conference (Bristol, United Kingdom, 2017); the African Centre for Cities Conference (Cape Town, 2018), the International Association of Impact Assessment Conference (Durban, 2018), and the BRICS Young Scientist Forum (Durban, 2018). In addition, he has presented his research at numerous Master's seminars at UKZN (Environment and Development Course; Comparative Development Problems and Policies Course). In June 2019, he received co-funding from WRC Project 2354 to travel to IHE Delft, where he presented aspects of his PhD to the Water Governance group. Patrick's research has contributed to various aspects of this WRC Project, particularly Deliverable 14, which looked at water resources connectivity, inter-dependency and social relations from a landscape perspective in the uMngeni River catchment. Furthermore, he is part of the team responsible for writing Chapter 2 in the Narrative Report, which focuses on levers of change and entry points for ecological infrastructure in the uMngeni River catchment.

Matthew Burnett is currently in the final stages of his PhD on **Managing the Ecological Consequences of Water Quality and Quantity in Real Time Using the FISHTRAC Monitoring System.** The study includes the development of the FISHTRAC system using radio telemetry techniques. This includes an outline of the FISHTRAC system highlighting its ability to monitor water quality, quantity and fish behaviour in real-time and remotely. The technique has been developed over several years with various Water Research Commission (WRC) projects. The uMngeni system was chosen as a case study with funding from Umgeni Water (UM) and the Brazil, Russia, India, China and South African (BRICS) joint multilateral study along with this current uMngeni River catchment project on Ecological Infrastructure with the WRC. The implementation of FISHTRAC on the uMngeni River contributed to understanding the water quality and quantity effects on the behaviour of the KwaZulu-Natal Yellowfish (Yellowfish). This is due for completion this year whereby a better understanding of the health of the river ecosystem can be determine by monitoring the fish behavioural responses using FISHTRAC, in real-time and remotely.

FISHTRAC's development showed the ability to monitor fish behaviour in real-time and remotely within South African Rivers. The FISHTRAC programme makes use of radio telemetry techniques to communicate data that is stored on smart tags attached to fish. This data is sent via a radio network established along the river to a data management system (DMS) whereby users are able to obtain the information. The data is transferred in real-time allowing managers to access the information from their desktop as it happens. Further the FISHTRAC programme allows for alerts to be set to inform managers when there is any abnormal behaviour from fish. The FISHTRAC programme also incorporates the water probes that measure water quality and quantity on the same radio network established to monitor the fish behaviour. This allows for water quality and quantity to be available in real-time to managers and alerts set to thresholds of potential concern.

The uMngeni River implementation

The FISHTRAC programme has been implemented along two sections in the uMngeni River catchment, both downstream of wastewater treatment plants, namely uMsunduzi (Darvil) and Howick wastewater treatment plant. The aims of this study were: (1) to monitor changes in water quality and flow in the uMsunduzi and uMngeni Rivers associated with Wastewater Treatment Works (WWTW) and Dam releases into the rivers, remotely in real time, (2) to monitor and evaluate the ecological response of the receiving rivers to these changes in environmental conditions using fish radio telemetry systems in real time remotely, and (3) to establish a real time ecosystem wellbeing and response digital early warning system to allow regulators to respond to ecosystem condition changes and associated ecological responses. The project is due to end in December 2019, whereby preliminary results show that FISHTRAC can be successfully implemented. Various flow experiments and water quality validations have demonstrated a response of Yellowfish to water quality and quantity variables.

Indrani (Hazel) Govender as a PhD student is performing an **Ecological Risk Assessment of the uMngeni River catchment.** Ecological Risk Assessment (ERA) focuses on the causal relationships between hazard, exposure and effects on an endpoint. Causal relationships which include multiple sources, multiple stressors and multiple endpoints, considers the complexity of socio-ecological systems, such as catchments, at the regional scale. As such, it is a suitable framework to apply to the uMngeni River catchment, which spans a large area, with diverse habitats, urban and rural communities, and a range of anthropogenic drivers influencing a system that is already under stress from many natural forces, such as drought, floods and climate change. The approach used in this project is based on a probabilistic, scenario-based model, incorporating Bayesian networks. This model considers different and unique characteristics of sub-catchments or risk regions within a catchment and predicts the likelihood of specific risks to selected endpoints. It is proposed that the final model will guide water resources management within the uMngeni River catchment as it highlights potential high-risk areas related to specific endpoints and will propose management interventions.

This project is framed by the legal requirements for sustainable utilisation of water resources in the uMngeni River catchment. The Water Resource Classes and Resource Quality Objectives (RQOs) for the uMngeni River catchment were published in the Government Gazette in December 2017. The RQOs are linked to specific endpoints (e.g. Basic Human Needs Reserve and the Ecological Reserve) in the model, under different scenarios, to determine which conditions will facilitate achievement of the RQOs. A number of RQOs within specific risk regions have already indicated that the system is stressed. The socio-ecological system may be further compromised in terms of providing much needed ecosystem services, especially under future development scenarios. The ERA project, on completion, will contribute to the overall management of ecological infrastructure to benefit the catchment. This will include (under different scenarios): 1) Highlighting those areas within the catchment that are at risk from specific drivers, such as development within the riparian zone; 2) Determining which activities show the highest probability of contributing to degradation of ecological infrastructure; 3) The habitats most likely to be impacted negatively by specific anthropogenic activities or natural disasters and; 4) The endpoints or management objectives likely to be most impacted by different drivers in the catchment system.

Where they are today…

At the current moment, Hazel is inputting data to the model and writing up the introduction and methodology for BN-RRM for the uMngeni River catchment. The literature review on ecological risk assessment in water resources management is also in progress. A paper is underway on the History of Water Resources utilisation and value in the uMngeni River catchment.

Hlengiwe Ndlovu is currently working on a PhD performing **An Assessment of the Importance of Ecological Infrastructure for Water Security in the Developing uMngeni River Catchment**. During her master's under this project she investigated **The Effect of the Lions River Floodplain on Downstream Water Quality.** Wetlands provide essential ecosystem services, including the purification of water. The uMngeni River catchment is an important basin providing water to the cities of Pietermaritzburg and Durban, South Africa's second largest economic hub. However, there are rising concerns over the deterioration of water quality in Midmar Dam, a large impoundment within this basin. The Lions River, one of the main tributaries to Midmar Dam, transports pollutants from its catchment, as well as the Mooi River catchment through the recently implemented Mooi-Mgeni transfer scheme (MMTS) into the impoundment. This study aims to establish a baseline ecological integrity and effect on downstream water quality of the Lions River floodplain, an important, but degraded, wetland in the uMngeni River catchment, to provide a guide for the planning and implementation of rehabilitation interventions. A comprehensive assessment of the wetland's structure was undertaken using vegetation and soil parameters, mapped and compared with an interpretation of landuse change within the wetland based on historical aerial photographs. The wetland's impact on downstream water quality was assessed by sampling water at various points in the Lions River channel through the floodplain over a period of one year. The study found that the wetland's ecological integrity has decreased due historical landuse in the floodplain. A comparison of soil wetness indicators, which reflect the historic extent of the floodplain, and vegetation wetness indicators, which reflect the current extent of the floodplain, suggest that although localised drying out of some areas has occurred, most of the historical floodplain area still supports wetland conditions. Wetness indicators of soil and vegetation indicate a transformation in the wetland's water regime. A moderate to high abundance of ruderal and alien invasive species in 61% of the floodplain, particularly the drier areas of the floodplain, further indicate a reduction in ecosystem health. Hydrological processes emerge as the key drivers of species composition and historical landuse in the floodplain. Water quality results indicate that total oxidised nitrogen decreased from upstream to downstream whilst ammonia concentrations remained stable at all the sampling points. Soluble reactive phosphorus concentrations increased, while total phosphorus concentrations decreased from upstream to downstream. This study highlighted the importance of detailed field studies and understanding for rehabilitation planning to return ecosystems to their natural function.

Where they are today…

Hlengiwe is a young mid-career environmental professional with 7 years' experience in the forestry sector. She was employed as an Environmental Officer by South African Pulp and Paper Industries (SAPPI) Limited Southern Africa – Forests and later progressed to the role of Environmental Manager within the organization. In these roles, she had in-depth exposure to biodiversity assessments and monitoring of conservation areas, including grasslands, riparian areas and indigenous forests, as well as environmental impact assessments and mitigation programmes for a wide range of developments. Hlengiwe also developed a deep understanding of the forestry industry and its impacts on water resources, which led her to pursue a master's degree. Since completing the MSc, she has moved to the non-profit sector for career development into a role at WWF South Africa of convening partnerships with plantation forestry role players in Strategic Water Source Areas to catalyse individual and collective action to improve water stewardship practices. To further her interests in forestry and water, Hlengiwe is exploring the impacts of forest certification as a mechanism for sustainable forest management and particularly its impact on water resource management in plantation forestry areas within South Africa's Strategic Water Source Areas through a part-time PhD.

Susan Risko continues research on **Water governance in the Msunduzi Catchment: The politics and construction of the socio-economic and environmental value of the Msunduzi River**. Governance extends beyond the normative definition of government to include economics and civil engagement, therefore in order to achieve good governance, all three aspects must be considered. This research study aims to understand the root causes of poor water quality of the Msunduzi River through the social constructivist paradigm and from various perspectives. The Msunduzi River runs through the heart of the Provincial capital, Pietermaritzburg, and is in close proximity to the third largest economic hub within South Africa, Durban. Previous research demonstrates the widely accepted knowledge that the water quality in the Msunduzi River is poor, identifying biophysical root causes, such as land use or commercial industrial pollutants, however, the overall governance surrounding the problem have not been addressed. Historical events in recent years have confirmed issues around economic instability of the provincial capital and government expenditure. Industry players, who are heavy water users, pose as missing actors for good water governance. Further compounding the issue, civil engagement is limited, believed to be a result of relaxed concern for democratic participation since the establishment of South Africa as a democratic republic. The study proposes to investigate three case studies: 1) an urban riverside community in the central business district, 2) a peri urban community surrounding Henley Dam and located on Traditional Authority land, and 3) a peri urban community located along a tributary and containing a wetland. The researcher's engagement with public Municipal meetings as well as discourse analysis of government documents from local to national are methods that will be utilized to answer the research question. Results from this study will enable a better understanding of the problem scale and highlight areas that can be addressed for increased good governance of the Msunduzi River.

MASTERS STUDENTS

Sessethu Matta studied **The Value of Community-Based Water Quality Monitoring Initiatives.** Water is an invaluable natural resource and plays an integral role in supporting human life and maintaining environmental health. Healthy environments are necessary for healthy ecosystems that ensure human wellbeing through the provision of ecosystem goods and services. The importance of water for economic and social development has and still is placing the resource under great threat. This is further exacerbated further by climate change and population growth, presenting a challenge for water resources management. To ensure coordinated development and management of water, land and related resources, Integrated Water Resources Management IWRM was adopted in the 1980s. Emerging from this management approach was the need to include stakeholders, particularly community members, in water resources management for water security. Deteriorating water quality due to salinisation, eutrophication, sedimentation, microbial and chemical water pollution results in negative impacts on people's livelihoods, which further reinforces the need to include stakeholders in water resources management. Community-based water quality monitoring has been suggested as means of encouraging participation and strengthening water governance, however the implications of such initiatives are not fully understood, especially in South Africa. International accounts however suggest that the benefits of community-based water quality monitoring initiatives can include environmental awareness, increased social capital, infilling of water quality monitoring gaps and the establishment of collaborative water governance. Community-based water quality monitoring initiatives are faced with three major challenges, namely, organisational, data collection and data use issues that threaten the sustainability of these initiatives. Stronger collaboration between institutions such as universities, NGOs and government authorities conducting conventional water quality monitoring is needed to enable community-based monitoring groups in South Africa to produce data that can be scientifically valued. This may make it possible for the two approaches to complement each other for sustainable water quality monitoring, as opposed to being run in parallel to each other.

Sanele Ngubane was **Assessing Spatial and Temporal Variations in Water Quality of the Upper uMngeni River catchment, KwaZulu-Natal, South Africa: 1989-2015.** Deteriorating water quality is a global concern. There is an increasing concern over the quality of water flowing into Midmar Dam, upper uMngeni River catchment, KwaZulu-Natal Province, given its status as a critical water supply impoundment for the cities of Pietermaritzburg and Durban. This study aims to assess the spatial and temporal variation in water quality of the upper uMngeni catchment by estimating nutrient loads and water quality trends for the upper uMngeni River catchment. The study was conducted in the Lions River, the uMngeni River and the Mthinzima Stream, which are the Midmar Dam's tributaries with a long-term water quality data (10-14 years). The main nutrients of concern were nitrogen and phosphorus in a form of ammonia (NH3), nitrate ($NO3^-$) and soluble reactive phosphorus (SRP) and total phosphorus (TP), respectively. Nutrient load estimation in the Lions River and uMngeni River catchments was computed using measured streamflow and nutrient concentrations were obtained from the local water service authority, i.e. Umgeni Water, where available. Given that no streamflow are available for Mthinzima, the daily time-step ACRU model was used to simulate streamflow. Statistical trend detection was done using the seasonal Kendall slope estimator (SKSE) to determine the magnitude of the trend and the seasonal Kendall trend test, which determines the significance of a trend. All data was analysed using Microsoft Excel 2010. Nutrient loads for all nutrients were found to be highest in 1995 for all tributaries. It was found that Mthinzima is the smallest of the three tributaries, but can contribute more loads entering the Dam. The results also showed that streamflow drives nutrient loads. Moreover, the study showed that Mthinzima has significant increasing trends ($p < 0.05$) for all water quality variables. The study also showed that data shortage limits our ability to make conclusive results. Some sites (i.e. in Lions River and uMngeni River) showed no trends ($p > 0.05$). However, the overall results showed that the quality of water in the upper uMngeni River catchment is deteriorating.

Jedine Govender performed **An Assessment of the Water Quality of the Baynespruit River and Its Linkages to the Health of the Sobantu Community.** In South Africa, the use of polluted river water for activities such as crop irrigation, washing clothes and recreation, is a common practice in many rural and urban communities. The Baynespruit River, in the province of KwaZulu-Natal, South Africa, is a typical example as it serves as a vital water source to the Sobantu community. There have been numerous reports of extremely poor water quality in this river and suggestions that this may pose health risks to the community. Thus, the aim of this study was to assess the water quality of the Baynespruit River and its linkages to the health of the Sobantu community. This was achieved through analyses of river water quality, river sediment, soil and crop samples, as well as an investigation of the pathways through which community members are exposed to the polluted river and finally, an analysis of urine from a sample of volunteers who are regularly exposed to the river water. The water quality assessment considered pH, electrical conductivity, As, Cd, Cu, Hg, Pb, Zn and E.coli, while the analysis of river sediment comprised of 23 elements including the aforementioned heavy metals. Using microwave acid digestion (EPA 3052) and Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES), soil and crop samples from farming sites in Sobantu were analysed for Cd, Cr, Cu, Pb and Zn, and compared against the South African Water Quality Guidelines for Crop Irrigation. These results showed that E.coli contamination was high, there were extremely low concentrations of the heavy metals apart from Cu and Pb, as well as occurrences of acidic water. While the heavy metal concentrations of surface water were low, the sediment analysis suggested elevated concentrations of As, Cd, Cr, Cu, Ni, Pb, Zn, Fe, Mn and Ag. Analyses of soils and irrigated crops showed concentrations of heavy metals in excess of national and international guidelines, respectively. It is suggested that these soil and crop results indicate historical flooding events, which mobilized heavy metals in the river sediments and transferred them onto the floodplain where the farming sites are located. Furthermore, long-term irrigation with low concentrations of heavy metals may have also resulted in the build-up of these contaminants in the soil and eventually the crops. A workshop was held in the Sobantu community which included a questionnaire and separate open-ended conversations conducted with various community members, in order to determine the exposure pathways to the river and the associated health issues of participants. The questionnaire and open-ended conversations indicated that the most common exposure pathways to the river included using river water for crop irrigation, consuming irrigated crops, washing clothes and children swimming in the river. The questionnaire and open-ended conversations also highlighted many cases of skin rashes, as a result of being in direct contact with river water, with one reported case of diarrhoea. The confirmation of the presence of heavy metals in the Baynespruit River and its surrounding environment gave rise to a urine analysis, which used microwave digestion and ICP-OES to determine whether community members who volunteered for the study incurred heavy metal toxicities. However, the analysis did not show any severe cases of heavy metal toxicities to exposed volunteers and the high levels of Pb noted could not be attributed to exposure to the Baynespruit River and/or its surrounding environments, since similar levels of Pb were found in the control volunteers. It was therefore unclear as to whether the health of the exposed people of Sobantu was compromised by heavy metal toxicities. However, the persistent mention of skin rashes in the questionnaire and open-ended conversations suggests that water related health issues in the community do exist. It was concluded overall that the water quality of the Baynespruit River is severely degraded, which may be linked to health issues, such as skin rashes, in the Sobantu community. A key recommendation from this study would be for further investigation, i.e. through a health monitoring programme, confirming the health issues that community members have associated with polluted river water.

Where they are today…

Jedine Govender graduated in 2017 and is currently a Hydrologist at JG Afrika in Pietermaritzburg working on Water Resource Assessments and Design Flood Estimation projects in the Thukela and uMngeni River catchments, respectively.

Ayanda Sithebe completed **A Comparative Microbiological Assessment of River Basin Sites to Elucidate Fecal Impact and the Corresponding Risks.** The study aims to assess and compare the concentration of microbial contaminants, their sources and distribution in surface water and sediment, and to determine the impact of seasonal variations and corresponding risks of faecal contamination using conventional and molecular methods. Historical data analysis was conducted using *E. coli* values from the eThekwini Water and Sanitation (EWS) department for 66 months (2009-2014). *E. coli* and *Enterococci* were analysed in surface water and sediment samples using the mFC/ spread plate and Colilert-18 (IDEXX) methods. Seasonal variations were assessed on rainfall and no rainfall events, using an auto-sampler and sediment trap in parallel. Conventional standard membrane filtration methods using mFC agar, Slanetz and Bartley/ Bile Esculin and Brilliance *E. coli* selective agar were compared to the enzymatic Colilert-18 and Enterolert (IDEXX) test methods along the Isipingo and Palmiet Rivers. In addition, comparison of the analytical performance of droplet digital PCR (ddPCR) and qPCR for the detection of *Salmonella* targeting *ttr* gene in river sediment samples collected from four sites of the Palmiet River. In order to assess the public health risk associated with exposure of men, women and children to microbial pathogens in polluted surface water during recreational activities, the QMRA tool was employed in relation to the risk exposure to pathogenic *E. coli, Campylobacter, Salmonella* and *Shigella.* Also, the risk associated with crop irrigation as well as the consumption of crops irrigated with surface water from the Isipingo river was determined. Sediment exhibited higher microbial concentrations than surface water, which was observed in both rivers. Also, rainfall had a significant impact on microbial variability. Higher microbial concentrations (indicator organisms) were observed in surface water after a heavy rainfall as appose to when there was no rainfall. This was due to contamination that is washed off into the river and sediment resuspension. Methodology comparison revealed that Colilert-18 and Brilliance *E. coli* were more selective compared to mFC agar. Brilliance *E. coli* /Coliform agar was comparable with Colilert-18 IDEXX, which was also observed with Slanetz and Bartley and Enterolert IDEXX. However, when mFC agar was compared with Colilert-18 IDEXX, significant difference was observed. In comparison of two Molecular methods, ddPCR were found to be fully amenable for the quantification of *Salmonella* and offer robust, accurate, high-throughput, affordable and more sensitive quantitation than qPCR in complex environmental samples like sediments. Quantitative Microbial Risk Assessment (QMRA) relating to recreational and occupational exposure showed that children were at the highest risk of getting infected. Also, it was observed that the probability of infection upon exposure to surface water from the Isipingo and Palmiet rivers was significantly high. Risk assessment on crops revealed that pathogenic bacteria may pose a risk to the consumer, however, a 9-log reduction may be achieved according to the WHO multi-barrier approach which involves proper washing and proper cooking of the crop before ingestion. Overall the sampling points that had the highest pollution level and constantly exceeded the WHO and DWAF guidelines at the Isipingo river were the points situated and named “Next to the WWTP”, and “Downstream of QRI” at the Palmiet River.

Silindile Mtshali performed **Estimating the Impact of Acacia Mearnsii in the uMngeni River catchment Using Remote Sensing and Hydrological Modelling.** The problem of invasive alien plants is a global challenge in KwaZulu-Natal, the second most invaded province in South Africa, impacting on biodiversity, water resources, and social wellbeing. Controlling invasive alien plants requires robust, accurate, and timely information to determine the spatial extent of these plants. This information is obtained by using technologies such as GIS (Geographic Information System) and RS (Remote Sensing), used in the study to identify, locate and map the spatial extent of *Acacia mearnsii* in the upper uMngeni River catchment. The study aimed to use two remotely sensed satellite data products, SPOT 7 and Landsat 8 OLI, to map the distribution of *Acacia mearnsii,* using an Artificial Neural Networks algorithm. The satellite images are both medium resolution images, with different spatial and spectral resolution properties. SPOT 7 has a spatial resolution of 6 m and a spectral resolution of 4 bands, while the Landsat 8 OLI has a spatial resolution of 30 m and a spectral resolution of 8 bands. The findings showed that GIS and RS can be used to determine the distribution of *Acacia mearnsii* in the upper uMngeni

River catchment. It was found more important to consider satellite data with a finer spatial resolution (like the SPOT 7), rather than a fine spectral resolution in order to achieve higher accuracy maps when using medium resolution images. The study further assessed the hydrological impact of the determined *Acacia mearnsii* distribution on the Karkloof catchment using the ACRU agro-hydrological model (Schulze, 1995). The results showed a significant increase in the streamflow when the *Acacia mearnsii* infestation in the riparian zone was removed, such results were more evident during periods of low flows in the 10th percentile, which are exceeded 90% of the time. The impact of *Acacia mearnsii* on low flows are of particular concern to water planners and rural communities, since there is an evident challenge in the allocation of water, as the streamflow is subsequently reduced by the invasion of *Acacia mearnsii* in riparian zones, threatening water security.

Where they are today…

Slindile Mtshali is currently working at AWARD, the Association for Water and Rural Development situated in Hoedspruit, South Africa.

Semeshan Naidoo investigated **The Relationship between the Infrastructure, within the Palmiet Catchment, and the Condition of the Palmiet River Water Quality and Riparian Zone.** The construction and daily operation of infrastructure systems has imposed significant negative consequences on the natural environment. The primary aim of this study was to explore the relationship between infrastructure within the Palmiet catchment and the condition of river water quality and riparian zone. It was hypothesized that the Palmiet catchment has been significantly impacted by the development of the surrounding land. Visual observations of the accessible areas of the Palmiet River and tributaries were assessed for key impacts of: indigenous vegetation removal, exotic vegetation, channel modification, inundation, water abstraction, flow modification, bed modification, water quality and rubbish dumping. The recorded impacts were then represented in Geographic Information Systems (GIS) forming baseline maps of the current ecological condition of the Palmiet River. Results indicated that the Palmiet and its riparian zone were in various degrees of degradation, extensive modification via hard infrastructure of the channel, reducing infiltration ability and stormwater outlets and obstructions in the river channel modified flow rate leading to scoured riverbed and riverbank. Numerous blockages and failures in the sewer system as well as illegal activities of industries, in the Pinetown and New Germany areas, has resulted in sewage, containing trade effluent, being discharged directly into the Palmiet River. The informal settlements, located near the mouth of the Palmiet River, are another major contributor to the degradation of the Palmiet catchment. Service delivery problems and trust issues in this area has resulted in the accumulation of waste items along the riverbank. The results obtained validate the hypothesis that urbanisation, and infrastructure development, in particular, has led to the degradation of the natural environment. By understanding the extent and severity of the impacts imposed on the Palmiet catchment, remedial interventions can be implemented. These interventions include: retention ponds, weirs and wetlands to regulate and slow down the flow of the Palmiet River; geotextile engineering solutions as opposed to hard infrastructure solutions to stabilise collapsing riverbanks; rainwater tanks and retention areas in industries and households to reduce the amount of runoff entering the Palmiet River, the rainwater tanks can potentially also serve as a supplement to the water needs, thereby, reducing the water bills; improved service delivery and the potential hiring of members from the informal settlement to reduce and remove the accumulation of waste and promote trust between different members of the community, and wider municipal area.

Nantale Nsibirwa completed **An Assessment of the Critical Source Areas and Transport Pathways of Diffuse Pollution in the uMngeni River catchment, South Africa.** The difficulty in locating and managing diffuse pollution sources and their transport pathways is one of the reasons for the continued degradation of surface water in South Africa. Dealing with this problem is complex, as the sources and transport pathways of the pollutants are often not known because of the diffuse nature of the pollution. This study demonstrates the constraints of conventional diffuse pollution assessment approaches in identifying Critical Source Areas (CSAs) and transport pathways of diffuse pollution. The use of various risk-based modelling approaches are reviewed for identifying the risk of diffuse pollution generation and transportation across a catchment landscape. The Sensitive Catchment Integrated Modelling and Analysis Platform (SCIMAP) Model is a risk-based tool that was developed to give a spatial representation of diffuse pollution sources. It is applied to identify and prioritise the protection and control of nutrient CSAs and transport pathways with results of the study displayed in a catchment scale web map. Hydrological connectivity risk in the catchment was higher in the high-lying western areas and lower in the middle-eastern areas. The upper and middle parts of the catchment that are dominated by commercial agriculture and built-up urban areas were identified as the most impactful CSAs for intervention. The results are immediately applicable to water managers in the catchment and are strongly linked to the investment efforts in ecological infrastructure. A walkover survey revealed that the SCIMAP Model was able to direct the CSA investigations to the nutrient sources at four out of five locations; and accuracy of the modelled transport pathways increased with increases in elevation difference. The sensitivity of the SCIMAP Model to input land cover weightings was assessed, using an objective function. A high sensitivity of the modelled high-risk areas was observed on the intermediate diffuse pollution risk map, and a slight sensitivity of the modelled high-risk areas on the final diffuse pollution risk map, when input landcover weightings were increased and decreased by 5%, 10% and 15%. Therefore, caution should be practised in the formulation of input land cover weightings, as they are a potential source of error in the model outputs. It is concluded that SCIMAP is a valuable tool for identifying the CSAs and transport pathways of diffuse pollution in a catchment. The results of the model can better inform the management of diffuse pollution and guide investments in protection of ecological infrastructure.

Where they are today…

Nantale Nsibirwa is currently working as a Hydrologist at Aurecon in Cape Town, South Africa, mainly involved in the Kenya Water Security and Climate Resilience Project, which aims to strengthen the water resources management and planning in Kenya. While completing an MSc, Nantale was awarded the KwaZulu-Natal Premier's Award 2017 at the Symposium of Contemporary Conservation Practice for the best student oral presentation at the conference. Furthermore, in 2018 Nantale was selected as a finalist for the International River Foundation's Emerging River Professional Award.

Nonthando Buthelezi evaluated **Investments in Ecological Infrastructure: An *Ex Ante* Assessment of the Costs and Benefits of Rehabilitation in the Mthinzima Wetland in KwaZulu-Natal.** The uMgeni River an important water resource in KwaZulu-Natal, is identified as a water resources that poses serious health risk to users of its (untreated) water. Increasing pollution in the upper catchment, supplying the Midmar Dam, has been attributed to sewage effluent due to inadequate sewage infrastructure, expanding agricultural lands and household waste from Mpophomeni Township. The Mthinzima River flows adjacent to the settlement and joins a tributary that flows through Mpophomeni settlement (a 6000-unit settlement arising in the 1960s), it then flows under district road R617, through a degraded wetland system (The Mthinzima wetland) and into Midmar Dam. Two interventions were proposed to reduce the pollution flowing from the Mpophomeni Township into Midmar Dam: a new Wastewater Treatment Works (WWTW) built in conjunction with rehabilitation of a wetland as ecological infrastructure (EI). The ability of wetlands to reduce nutrient loads, pathogens, sediments and other contaminants in water systems including those that result from human activities is well established. Though wetland services, especially water treatment, are important, assigning an economic value to wetlands to justify investments for maintenance or rehabilitation is often difficult due to the indirect market for wetland services. EI has value that is important for human well-being. Studies that aim to value investments in EI give total economic value of the EI instead of the change in total economic value attributable to the investment. The purpose of this study was to investigate the incremental change in supply of services from the wetland, post rehabilitation, considering the demand, supply and opportunities for those wetland services. The study considers the potential of EI to supply its services, the opportunity (activities or circumstances that make it possible for the wetland to be used) afforded to the EI to supply its services, and the demand for ecological services. It also examines the impacts of investments (or disinvestments) in EI and/ or engineering infrastructure on the value of EI. Cost-benefit analysis (CBA) was used as it is widely applied as an appraisal technique, particularly for public decision-making processes. CBA both helps inform decision-makers and hold them accountable for decisions. The cost benefit analysis technique was used to evaluate whether investments in ecological infrastructure bring about a worthwhile change in ecosystem services. The study was limited by data shortages and used the replacement cost technique (one mega litre wastewater treatment works) to value the incremental change in wetland services post rehabilitation. The cost benefit analysis net present value results were all positive, the estimated net present value for change in wetland services post rehabilitation over the period of 20 years was found to between R4 144 813 and R3 765 358 using different discount rates. The net present value of the wetland rehabilitation investment showed an increasing pattern as the wastewater treatment plant's maintenance costs were assumed to be a higher percentage of the wastewater treatment plant. Therefore, the study concluded that investments in EI in the form of the Mthinzima wetland rehabilitation was worthwhile as the investment yielded positive marginal results post rehabilitation.

Londiwe Dlamini is **Adapting the Social-Ecological Systems Framework to understand impacts of flooding in the Palmiet River Catchment.** African cities are facing increasing rates of urbanization contributing to some of the harshest impacts experienced in the wake of climate change. In light of this, associated increased frequency and intensity of urban risks such as flooding, thereby threaten human life and built infrastructure; and increase vulnerability of communities already strained by socio-economic challenges. Ecosystem services in urban catchments are poorly understood which further adds to the lack of understanding in the value of natural resource systems in urban catchments. Though research on flooding in African cities has gained momentum in recent years, it still remains crucial to understand, firstly, whether people are becoming more resilient to severe flooding as the realities of climate change become more evident; and secondly, the impacts of flooding on ecosystem services and the process for a system to recover and/or build resilience. The concept of resilience to natural disasters such as floods is challenging to quantify; however, can be done through various perspectives from different affected systems. The Palmiet catchment is located in the lower uMngeni River catchment, a highly urbanised and immensely degraded landscape in the Durban area. This study explores the dynamics of the resource system (Palmiet River) and the governance system by applying the SES framework, and aims to understand how flooding impacts the river functionality. The objectives of the study in the Palmiet catchment are to: 1) identify how ecosystem services enhance catchment management; 2) construct a social-ecological systems model (Ostrom, 2007) for the catchment, 3) identify how the social-ecological system in the Palmiet has evolved over time and the impact on the hydrological function of the Palmiet River, and 4) identify the value and potential of EI investments for the Palmiet catchment. The social-ecological systems framework is an interdisciplinary approach to understanding biophysical and social aspects in a landscape – both of which can no longer be studied in isolation in the context of the evolving understanding of the hydrological cycle. The process to achieving the outlined objectives involved building information on each system (natural system and governance system) of the SES framework in isolation through a qualitative approach in order to understand how each system influences the other. Land use change analysis compared changes in the catchment over time with the aid of drone maps to highlight flooding impacts. Study findings indicate ecosystem services once offered by the Palmiet River have been compromised by unprecedented rates of urbanisation, particularly impacts of growing informal settlements in the lower parts of the catchment As a result, the risks of flooding have been dominant in the catchment in recent years, affecting the most vulnerable. The role of EI in an urban catchment is most beneficial when integrating natural and manmade systems. This is found to be challenging in the Palmiet catchment – as per the reality of many South African catchments – where social issues in the landscape often take preference in municipal developmental plans.

Theolin Naidoo performed **An Assessment of Stakeholder Dynamics in Proposed Wetland Rehabilitation Projects: A Case Study of Wetlands in the Baynespruit Catchment, KwaZulu-Natal, South Africa.** Globally there has been a growing recognition of wetland function and importance as essential socio-ecological systems (SES), yet wetlands continue to be lost and degraded. While many wetlands are being purposely removed to accommodate development activities, others are left to degrade as a result of governance systems which fail to conserve them. A significant attempt at conserving these systems has transpired through the rehabilitation of degraded wetlands. However, in South Africa many of these have arguably failed as a result of not actively considering the perceptions of relevant stakeholders at all stages (i.e. initiation, planning, implementation, monitoring and evaluation (M&E), and aftercare) of such projects, community input in particular, is not adequately obtained before rehabilitation interventions are implemented. This study thus aimed to identify relevant stakeholders and investigate their perceptions, understandings and interactions in proposed wetland rehabilitation interventions, with a specific focus on the long-term sustainability of wetlands earmarked for rehabilitation (i.e. based on their internal site prioritisation process) within the Baynespruit catchment. This was achieved by investigating how three wetlands (namely, Old Greytown Road, Sobantu, and Confluence

Wetlands) in the catchment are perceived, understood and utilized by surrounding communities and other key stakeholders relevant for the overall governance process of a wetland rehabilitation. Further, the roles and responsibilities of other key stakeholders, their willingness to change behaviour, and the potential for co-management were explored. To understand these stakeholder dynamics, in-depth semi-structured interviews and structured questionnaires with surrounding community members and other key stakeholders were conducted across the three wetland sites. Five core themes; namely wetlands as assets, wetlands as liabilities, educational deficits, invisible authority, and zone of economic potential, emerged out of the responses from stakeholders across all three wetland sites. Thereafter a scenario-based framework was designed (i.e. using the responses from the research participants) to assist in the prioritisation of wetland sites suitable for rehabilitation based on the social, economic and environmental context of the catchment. An alternative to contemporary top-down and bottom-up governance approaches was formulated, referred to as 'W-drive', which suggests the incorporation of a community-based organisation (CBO) to help mediate and co-ordinate activities between the local community and municipal levels. Significant potential for co-management emerged from the Sobantu and Confluence Wetland sites as community members showed great interest in several strategic stages of the rehabilitation process. In terms of informing the local municipality's decision-making for their site prioritisation process, only the Sobantu and Confluence wetlands are suggested for potential rehabilitation interventions.

Where they are today…

Theo is currently working at the Institute of Natural Resources. There are three projects which he is involved with. The first is for the Department of Environmental Affairs (DEA) Natural Resources Management (NRM) Programme and involves coordinating all NRM projects/interventions currently being implemented throughout KZN. This requires all stakeholders and actors such as the Duzi Umgeni Conservation Trust (DUCT), Endangered Wildlife Trust (EWT), Agricultural Research Council's Plant Health and Protection (ARC-PHP), DEA, etc. to provide information (i.e. spatial layers, annual reports, etc. of their active interventions). This project aims to maximize investments into NRM by connecting all stakeholders (government, private, civil society – conservancies, etc.) in the sector and hopefully allow for their resources to be maximised. This involves creating various tools and resources to achieve the project's aim – such as creating an NRM portal (we developed a website which has information on stakeholders, maps which show where their active interventions are, a stakeholder database with contact details, etc.). KZN functions as the pilot site, if successful, the project aims to function in this manner on a national scale. The second project is a central uMngeni River Stewardship project which aims to connect all stakeholders along the central uMngeni River (i.e. between Albert Falls Dam and Nagle Dam) and encourage them to declare/sign off on a stewardship agreement. This aims to conserve the uMngeni River (clearing of AIS, etc.) and prevent illegal activities such as Sand Mining from occurring. It includes private landowners, government owned land, traditional land, etc. The INR is contracted by SANBI for this project – DUCT is also contracted. The third project is for Eskom's pump water storage scheme in the Drakensberg and involves collecting water samples to ensure that Eskom is compliant in terms of their water use license. Theo's internship at INR concludes next year February and thereafter he will start a PhD. The details, which are being discussed, will most likely be within the biological/ecological sciences.

Nosihle Mkhize was **Finding the significance of miniSASS as a citizen science tool and linking it to Resource Quality Objectives (RQOs).** Water is essential for human well-being and the quality of the water needs to meet acceptable standards for its different uses, such as industry, agriculture and domestic supply. South Africa's water quality issues are ongoing, increasing and need to be addressed. The Msunduzi River and its tributaries, the Baynespruit and Dorpspruit rivers, are of major interest in this project due to their current poor state. The aim of the project was to assess the river health and general water quality of the Msunduzi River using the miniSASS technique and to compare the collected data to water quality records (*E. coli*) collected by Umgeni Water. The standard miniSASS technique was conducted at the aforementioned rivers for six weeks. The distributions of miniSASS and *E. coli* results were statistically analysed using the box-and whisker method. All three rivers showed deterioration in water quality from upstream to further downstream sites. These results were due to industrial effluent, Darvill Wastewater Treatment Works, uncontrolled cattle grazing in close proximity to the river banks and raw sewage spills from settlements. In conclusion, it was found that the Baynespruit River was the most polluted, followed by the Msunduzi and the Dorpspruit with very poor, poor and fair ecological conditions respectively. The compatibility of miniSASS to *E. coli* was not clear due to limited water quality variables such as dissolved oxygen, electric conductivity, water temperature and pH. In terms of citizen science, it was concluded that citizen science is a powerful tool that has benefits, for citizens and for monitoring authorities. It can help with the availability and transparency of datasets and aid in the establishment of relationships between citizens and authorities to bridge the gap that exists, which can lead to greater conservation of water resources and water quality, especially in areas where water resources are threatened due to pollution.

Where they are today…

Nosihle Mkhize has chosen to undertake MSc studies on Investigating the changes in river health due to seasonal variation using MiniSASS with respect to resource quality objectives of the Umgeni system. She is studying under Dr. Sabine Stuart-Hill and is now sponsored by Umgeni Water.

Dylan Teasdale is **Comparing drought management from 1982/83 and 2015/16 in the uMngeni-Mooi system.** Water is a fundamental need for everyday human life, and without it, earth would no longer be habitable. The resource is not static and is constantly changing state and location, this makes it a complex task to implement good planning and management. A large portion of the earth is covered in water, however its availability, throughout time, has been constrained in terms of quantity and quality (Biswas, 2004). Since water is a vital resource for human development, it has become apparent, over the last decade, that there is a drastic need for sustainable water management. The need for integration, when dealing with the complex issues of water management, has become apparent, as environmental, human, and technological impacts need to be taken into consideration when undertaking good water management decisions (Pahl-Wostl, 2007). For these reasons, drought management implemented in the uMngeni-Mooi system in the 1980s is being compared to the drought management implemented during the drought in the 2015/2016 period. I am currently at the stage of data analysis, and I am still waiting on some data that is crucial to the project.

Where they are today…

I moved to Mpumalanga at the end of January this year to pursue a hydrology internship at IWR Water Resources. I have worked on many projects including floodline analyses and various modelling projects, as well as numerous water use license applications. I am now employed as a full-time hydrologist and have recently been helping finalise an updated report of the entire hydrology of the Crocodile catchment, and I will begin working on updating the hydrology of the Inkomati catchment soon, as well as modelling for the development of a new township. I am hoping, if all goes well, to complete my MSc by the end of this year.

Nolwazi Ntini investigated the **Dynamics of a Hydrosocial Relationship: a Case Study of the Pinetown/New Germany Industrial Complex and the Palmiet River**. This study sought to explore the relationship between industries located in the Pinetown/ New Germany Industrial complex and the Palmiet River. The objective of the study was to explore industry attitudes and perceptions towards water by studying the relationship between businesses located in the New Germany Industrial Complex and the Palmiet River, as well as external actors, processes and practices that regulate and govern this relationship. The hydrosocial cycle was used as the theoretical framework to guide this study as it better provided a space for a critical analysis of water and society; centring water to better understand the production of social power (Wittfogel 1957; Swyngedouw 1999; Linton 2010, Linton and Budds, 2013). Qualitative research methods such as in-depth interviews were utilized to gain insight from various stakeholders mainly; industry, the municipality and civil society. This study revealed the intricate and structural internal connections between water and society. Which challenged the notion of a one-dimensional didactic relationship, rather it highlights how these two entities shape and remake each other continuously. Through this internal connection, they embody influences from various external actors, processes and practices, which change the context as well as the nature of this relationship. In its location at an industrial complex, the Palmiet River has enhanced, altered and fostered new relationships amongst and between stakeholders, with ecological infrastructure and climate change playing a significant role in connecting and facilitating these relationships. Broadly, the findings of the study found that the river can be understood as an integrator; it blurs the line between the formal and informal. It enmeshes the formal public spaces with the informal invisible spaces. True to the cyclical nature of water it connects the dominant socio-economic challenges back to the municipality and the state.

Khayelihle Thethwayo is researching **The impacts of rapid peri-urban densification on drainage systems: Case study of uMzinyathi in Durban.** Densification in peri-urban areas at present is occurring rapidly without any proper planning to control it. The need for free basic services and proximity to the city is driving the rate of this process. As the economy is growing slowly people look for affordable ways to live hence the compromise of biodiversity rich areas. Rapid growth of households is being recognized on valuable parts of the environment like wetlands, biodiversity poor areas and floodplains. Environmental features such as biodiversity are essential for the sustainability of an area and for environmental services to be accessible. Peri-urban areas have a reputation of possessing enough vegetation and space, which allows for the attaining of sustainable development (Yankson and Gough 2013).

The unregulated peri-urban land development on them has however given rise to a complex mixed lifestyle that interferes with the former. The emerging land use pattern that indicates a mismatch with the proper sustainable development planning norms. Traditional ways of allocating land further play a role in the rapid densification as there is little collaboration amongst the municipality and traditional leaders. The rapid growth on the peri-urban creates excessive change on the landscape leading to hard environments. A hardened environment becomes a situation that leads to drainage issues. Drainage systems function to manage runoff, health and the safety of people where they are functioning effectively.

When there is poor drainage however health issues, flooding and land degradation occur as water is essential for human survival, and there must be enough biodiversity present for the drainage system effectiveness. In any built environment Sustainable urban Drainage systems (SuDs) are vital tool when development of human settlements is done. SuDs should also be included in the spatial development framework of any area being developed. Defra, 2011; Ashley et al. (2015) state that SuDs are a tool that can assist and boost biodiversity as they assure their conservation. The negative effects on drainage systems in the transitioning of peri-urban areas exposes them to environmental issues since their planning is not properly done. It is therefore significant that there must be enough biodiversity for ecosystem services that ensures effective sustainable drainage systems (SuDs).

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CHAPTER 6:

Sutherland, C. and Mazeka, B. (2019). Ecosystem services in South Africa. In Knight, J. and Rogerson, C. (eds) The Geography of South Africa, World Regional Geography Book Series, Nature New York: Springer.

Taylor, J., Ramburran, E., Janks, M. and Grewcock, M. (2019). The Baynespruit Floating Wetlands: A Modest experiment or a turning point in water management? *African Wildlife* Issue 70, WESSA, Bryanston, Johannesburg.

APPENDIX I: List of Students

CENTRE FOR WATER RESOURCES RESEARCH STUDENT RESEARCHERS ON THE WATER RESEARCH COMMISSION PROJECT K5/2354

Demonstration of how healthy ecological infrastructure can be utilized to secure water for the benefit of society and the green economy through a programmatic research approach based on selected landscapes.
2014-2019

NAME	YEAR START	YEAR END	TYPE	STATUS	INSTITUTION	DEPARTMENT	SUPERVISOR	RESEARCH TITLE
Gokool, Shaedon	05/2018	03/2019	Postdoc	Complete	UKZN	WRC 2354	Prof Graham Jewitt	Identifying hotspots for investment in ecological infrastructure within the uMngeni River catchment
Strydom, Sheldon	2018	02/2019	Postdoc	Complete	UKZN	WRC 2354	Prof Graham Jewitt	Microclimate trends and variability in the uMngeni River catchment and its influence on water resources
Varghese, Mathew	2018	05/2019	Postdoc	Complete	UKZN	WRC 2354	Dr Cathy Sutherland	Ecologies in the Anthropocene as Paradigms of Sovereignty
PhD								
Burnett, Matthew	2016	2019	PhD	In Progress	UKZN	Life Sciences	Dr Gordon O'Brien Prof Graham Jewitt	Managing the Ecological Consequences of Water Quality and

NAME	YEAR START	YEAR END	TYPE	STATUS	INSTITUTION	DEPARTMENT	SUPERVISOR	RESEARCH TITLE
							Prof Colleen Downes	Quantity in Real Time Using the FISHTRAC Monitoring System
Browne, Michelle	2015	2020	PhD	In Progress	Rhodes; INR	Economics	Prof Gavin Fraser Prof Jen Snowball	Economic evaluation of ecosystem restoration with a focus on wetland rehabilitation in South Africa
Govender, Indrani	2015	2020	PhD	In Progress	UKZN	Ecology/ Life Science	Dr Gordon O'Brien Prof Graham Jewitt Prof Thor Stenstrom	Ecological Risk Assessment of the uMngeni River catchment
Hughes, Catherine	2014	2018	PhD	Complete	UKZN	Hydrology	Prof Graham Jewitt Prof Roland Schulze	Degradation of Ecological Infrastructure and Its Rehabilitation for Improved Water Security
Martel, Patrick	2016	2020	PhD	In Progress	UKZN	Development Studies	Dr Cathy Sutherland	A temporal analysis of changing hydrosocial relationships in Durban, South Africa.
Namugize, Jean N	2014	2018	PhD	Complete	UKZN	Hydrology	Prof Graham Jewitt Dr Mark Graham	Effects of Land Use and Land Cover Changes on Water Quality of the Upper uMngeni River, KwaZulu-Natal Province, South Africa

NAME	YEAR START	YEAR END	TYPE	STATUS	INSTITUTION	DEPARTMENT	SUPERVISOR	RESEARCH TITLE
Ngcobo, Simphiwe	2015	2019	PhD	In Progress	UKZN	Hydrology	Prof Graham Jewitt	A Climate Risk Index for Commercial Sugarcane in Southern Africa
Ndlovu, Hlengiwe	2017	2020	PhD	In Progress	UKZN	Hydrology	Prof Graham Jewitt Dr D le Maitre	An Assessment of the Importance of Ecological Infrastructure for Water Security in the Developing uMngeni River catchment
Risko, Susan	2017	2021	PhD	In Progress	UKZN	Development Studies	Dr Cathy Sutherland Dr Sabine Stuart-Hill	Water governance in the Msunduzi catchment: The politics and construction of the socio-economic and environmental value of the Msunduzi River
MSc								
Buthelezi, Nonthando	2016	2019	MSc	Under Review	UKZN	Ag Econ	Dr Stuart Ferrer Ms Michelle Browne	Investments in Ecological Infrastructure: An Ex Ante Assessment of the Costs and Benefits of Rehabilitation in the Mthinzima Wetland in KwaZulu-Natal
Dlamini, Londiwe	2017	2019	MSc	In Progress	UKZN	Hydrology	Dr Sabine Stuart-Hill Dr Cathy Sutherland	Adapting the Social-Ecological Systems Framework to

NAME	YEAR START	YEAR END	TYPE	STATUS	INSTITUTION	DEPARTMENT	SUPERVISOR	RESEARCH TITLE
								understand impacts of flooding in the Palmiet River catchment
Govender, Jedine	2015	2016	MSc	Complete	UKZN; SAEON	Hydrology	Prof Graham Jewitt Dr Sabine Stuart-Hill	An Assessment of the Water Quality of the Baynespruit River and Its Linkages to the Health of the Sobantu Community
Mahloba, Siziphila †	2017	†	MSc	Incomplete	UKZN	ment	Prof Graham Jewitt	Investigating options for high frequency in situ water quality monitoring in the Msundusi river
Matta, Sesethu	2014	2014	MSc	Complete	UKZN	Hydrology	Prof Graham Jewitt Dr Jim Taylor	The value of community-based water quality monitoring initiatives
Mkhize, Nosihle	2019	2020	MSc	In Progress	UKZN	Hydrology	Dr Sabine Stuart-Hill	Finding the significance of miniSASS as a citizen science tool and linking it to Resource Quality Objectives (RQOs)
Mtshali, Silindile	2015	2017	MSc	Complete	UKZN	Hydrology	Prof Graham Jewitt Prof Oni Mutanga	Estimating the Impact of Acacia Mearnsii in the uMngeni River catchment Using Remote Sensing and Hydrological Modelling

NAME	YEAR START	YEAR END	TYPE	STATUS	INSTITUTION	DEPARTMENT	SUPERVISOR	RESEARCH TITLE
Naidoo, Semeshan	2016	2017	MSc	Complete	UKZN	Development Studies	Dr Elena Friedrich Prof Chris Buckley	The Relationship between the infrastructure, within the Palmiet catchment, and the Condition of the Palmiet River Water Quality and Riparian Zone
Naidoo, Theolin	2017	2019	MSc	In Progress	UKZN	Geography	Dayle Trotter-Boardman Dr Sabine Stuart-Hill	An Assessment of Stakeholder Dynamics in Proposed Wetland Rehabilitation Projects: A Case Study of Wetlands in the Baynespruit catchment, KwaZulu-Natal, South Africa
Ndlovu, Hlengiwe*	2014	2016	MSc	Complete	UKZN	Hydrology	Prof Graham Jewitt Dr Donovan Kotze	The Effect of the Lions River Floodplain on Downstream Water Quality
Ngubane, Sanele	2014	2016	MSc	Complete	UKZN	Hydrology	Prof Graham Jewitt	Assessing Spatial and Temporal Variations in Water Quality of the Upper uMngeni River catchment, KwaZulu-Natal, South Africa: 1989-2015
Nsibirwa, Nantale	2017	2018	MSc	Complete	UKZN	Hydrology	Prof Graham Jewitt Mr Mark Horan	An Assessment of the Critical Source Areas and Transport

NAME	YEAR START	YEAR END	TYPE	STATUS	INSTITUTION	DEPARTMENT	SUPERVISOR	RESEARCH TITLE
								Pathways of Diffuse Pollution in the uMngeni River catchment, South Africa
Ntini, Nolwazi		2018	MSc	Complete	UKZN	Development Studies	Dr Cathy Sutherland	The Dynamics of a Hydrosocial Relationship. A Case Study of the Pinetown/New Germany Industrial Complex and the Palmiet River.
Sithebe, Ayanda	2014	2017	MSc	Complete	DUT	Department of Food and Biotechnology, Faculty of Applied Sciences	Prof Thor Axel Stenstrom	A comparative microbiological assessment of river basin sites to elucidate faecal impact and the corresponding risks
Teasdale, Dylan	2018	2020	MSc	In Progress	UKZN	Hydrology	Prof Graham Jewitt Dr Sabine Stuart-Hill	Comparing drought management from 1982/83 and 2015/16 in the uMngeni-Mooi System
Thethwayo, Khayelihle	2017	2019	MSc	In Progress	UKZN	Development Studies	Dr Cathy Sutherland	The impacts of rapid peri-urban densification on drainage systems: Case study of uMzinyathi in Durban.

NAME	YEAR START	YEAR END	TYPE	STATUS	INSTITUTION	DEPARTMENT	SUPERVISOR	RESEARCH TITLE
Honours								
Dlamini, Londiwe*	2016	2016	Hons	Complete	UKZN	Hydrology	Dr Sabine Stuart-Hill	2015/2016 Drought: An Evaluation of the Management Responses on the Water Infrastructure in the uMngeni River catchment
Gouws, Sheldon	2015	2015	Hons	Complete	UKZN	Hydrology	Prof Graham Jewitt	Water Quality in the Karkloof catchment
Mahloba, Siziphila*	2016	2017	Hons	Complete	UKZN	Hydrology	Mr Jean Namugize Prof Graham Jewitt	Water quality monitoring of Nguklu and Gqishi streams upstream of Midmar Dam
Mkhize, Nosihle	2018	2018	Hons	Complete	UKZN	Hydrology	Prof Graham Jewitt	Using MiniSASS to Test the Water Quality of Rivers and Testing Its Compatibility with Formally Assessed Water Quality
Mtshali, Silindile*	2014	2014	Hons	Complete	UKZN	Hydrology	Prof Graham Jewitt Prof Oni Mutanga	Estimating Chlorophyll Content in Water Bodies, Using Multispectral and Hyperspectral Satellite Imagery
Nsibirwa, Nantale*	2014	2014	Hons	Complete	UKZN	Hydrology	Prof Graham Jewitt	Estimation of Pollution Load for the Mthinzima catchment,

NAME	YEAR START	YEAR END	TYPE	STATUS	INSTITUTION	DEPARTMENT	SUPERVISOR	RESEARCH TITLE
								KwaZulu-Natal, South Africa
Thabethe, Eddie	2016	2016	Hons	Complete	UKZN	Hydrology	Dr Sabine Stuart-Hill	Citizen Science Monitoring. The case of Howick Wastewater Treatment Works in the uMngeni River catchment.
ZweZwe, Nokulinga	2014	2014	Hons	Complete	UKZN	Hydrology	Prof Graham Jewitt	Monitoring of Water Quality of Inflow into Large Dams in the Upper UMngeni River catchment
† Deceased								
*Progressed onwards to higher degree levels								