BUILDING RESILIENT LANDSCAPES BY LINKING SOCIAL NETWORKS AND SOCIAL CAPITAL TO ECOLOGICAL INFRASTRUCTURE

Report to the
WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

BACKGROUND

Ecological infrastructure refers to the strategically planned and managed or otherwise preserved networks of natural and working landscapes that conserve ecosystem values and functions and provide associated benefits and services to society. Anthropocentric actions are driving substantial changes to ecological infrastructure and these changes are affecting the resilience of social-ecological systems and their ability to absorb, adapt and recover from disturbance. This in turn exposes society to a wide variety of increasing risks. Protecting or restoring ecological infrastructure is a shared responsibility between government, the private sector and society, and should include both formal and informal mechanisms of working towards a shared response at a landscape level. Scientific information on where to, how to and why to invest in ecological infrastructure must be linked to social networks to ensure implementation of suitable strategies for protection and rehabilitation of this infrastructure. The term social governance capacity refers to the ability of networks of stakeholders to cooperate to allow for the integration of diverse knowledge and interests, upkeep and responsible use of social capital, to achieve effective protection and rehabilitation of ecological infrastructure. This project has focused on integrated and systemic ways of approaching risk by linking the concepts of social capacity for governance and social and natural capital to ecological infrastructure in order to build resilient landscapes. The southern Cape region is known as an area vulnerable to frequent stochastic events, particularly floods and droughts, and is regarded as vulnerable to the impacts of climate change. Furthermore the Western Cape government has spent billions of Rand over the last decade on damages associated with environmental risks and impacts. As one of the most risk-prone areas of South Africa we focussed this study on the Eden district.

RATIONALE, AIMS AND OBJECTIVES

The overarching aim of the project is to promote social-ecological transformation towards a more sustainable future in the Eden district. This is done through influencing the way decision makers and land managers think, value and make decisions about ecological infrastructure and social governance capacity. The ultimate desire is to develop an inclusive system of governance and decision making, founded in learning, reflection and adaptation.

OBJECTIVES

- To create opportunities for knowledge exchange, reflection and learning, around the role of ecological infrastructure and social governance, with stakeholders in the Eden region.
- Develop an understanding of the key risk hotspots in Eden, and assess the capacity to manage and co-design alternative interventions which enhance landscape resilience by conserving ecological infrastructure, based on learning on related projects and interactions with stakeholders.
- At a finer scale within selected risk hotspots, *identify and quantify ecological infrastructure* most needed to enhance resilience and reduce the associated risks.
- Explore mechanisms and participatory activities for enhancing social governance capacity.
- Make recommendations and raise awareness around the utility of linking the concepts of social governance capacity and ecological infrastructure for more resilient landscapes.

METHODOLOGY

This project engaged in traditional ecological and hydrological assessment methods as well as social engagement. These included invitations and observations, sustainability dialogues, participatory mapping, writing popular articles for print media, interactive presentations, interviews, risk survey analysis, water quality assessments, land-cover change assessment, modeling sediment and nutrient flows, and modeling invasive alien plant impacts on water flows.

RESULTS AND DISCUSSION

The Wilderness catchment is made up of a diverse set of stakeholders with varying levels of social connectedness, information, knowledge, awareness and capacity to use and manage a common resource base. The lack of an overall shared meta-identity translated into the overall lack of a common vision for the catchment. Our finding highlighted the importance of using a variety of stakeholder engagement techniques and how vital it is to develop a detailed understanding to prior knowledge of stakeholder groups using this as a departure point for engagements. This allows for establishing a baseline collective understanding among stakeholder groups. Facilitation is vital in working towards a shared collective vision for a region amongst stakeholders.

Using a systems based approach, a number of key risks were identified in Eden (drought, fire, flood, storm waves - highlighted in detail in Nel et al. (2014) and Reyers et al. (2015)), and in the Wilderness catchment (water quality and quantify, invasive alien species, and sediment erosion). The concept of risk was found to play a facilitating role enabling the boundary work required to co-produce knowledge for enhancing ecosystem management activities in Eden. The incorporation of environmental information into decision making processes can be enhanced though engaging with issues related to ecosystem based risk reduction activities for disaster management. Through a post-hoc thematic analysis of work carried out in Eden (Sitas et al. in prep), the multidimensional nature of 'risk' provided a common starting point for all stakeholders to engage in dialogue around ecosystem management issues in Eden, thus acting as a boundary concept. Poor communication and inappropriate language has the potential to disrupt knowledge production and exchange and if not addressed in the early phases of engagement can lead to narrow entrenched disciplinary thinking (Sitas et al. in review). Using a knowledge co-production approach based on social-ecological systems research greatly assisted with the development of shared knowledge on the contribution of ecological infrastructure for reducing disaster risk (Reyers et al. 2015).

The identified risks with stakeholders were investigated at a finer scale in the Wilderness catchment. Here we developed creditable scientific information on issues directed by stakeholders, relating to water quality and quantity, sediment erosion, and invasive alien plants. The intensification of land-use in the last fifty years within Eden and more specifically the Wilderness catchment have impacting on the ecological infrastructure of the catchment. Studies highlighted where in the catchment key sources of pollutants, the location and quantification of key nutrient and sediment retention areas and their retention volumes, and the likely impact that the lack of a coherent invasive alien management plan will have on water supply in the catchment.

Developing the knowledge and action to respond to the impacts of risk and extreme events requires the determination of societal sensitivity to these issues and events, an understanding of ecological infrastructure and ecosystem services within social-ecological systems, and how we enhance governance capacity in matching this understanding. Our investigations highlight the importance of participatory approaches and the co-production of the required knowledge. We have synthesised our findings and understanding into the creation of two frameworks or approaches for assessing risk and social governance. The first is focussed on identifying environmental risks and developing responses to these. Here we outline a four-step resilience analysis approach, adapted from Walker et al. (2002) validated by the risk work of Nel et al. (2014), the co-development work of Reyers et al. (2015). The second framework is focussed on transdisciplinary learning as a means for enhancing social governance. This framework is focussed on understanding who we should learn with, what we should learn about and how we should learn together.

CONCLUSIONS AND RECOMMENDATIONS

Our learning on this project highlights the fact that building resilient landscapes requires understanding important social processes and histories, multi-stakeholder engagements and the well facilitated co-production and exchange of knowledge. The concepts of risk and ecological infrastructure were useful boundary objects around which we could building these social processes. We believed that we have taken clear steps towards reducing risk and vulnerability in this area by initiating processes for enhanced social governance. Below we distilled key recommendations based on this research which can guide other projects in doing the same.

- Employ a variety of techniques in engaging stakeholders in co-learning at all phases of projects.
- Ensure that the project team contains skill full facilitators or bridging agents who are able to generate interaction and promote social connectedness and knowledge sharing through enhanced communication and concept translation between stakeholder groups.
- Identify and use boundary objects (objects of mutual interest and relevance) in establishing shared understanding across different knowledge domains and stakeholder groups.
- Engage in network weaving. Focus on establishing, co-ordinating and enriching connections between groups and individuals so as to ensure healthy networks.
- Work towards creating or establishing a common vision or stakeholder identity as this will facilitate collective action and co-operation in place of self-interested action. Furthermore such a vision will promote strategic (forward looking) decision making and long-term considerations.
- Co-developing useful and credible purpose specific ecological understanding
- Use available social media in establishing communication forums.
- Support established initiatives that are focussed on sharing information.
- Explore mechanisms and participatory activities that can enhance social governance capacity that can effectively implement these shared responses.
- Ensure that building resilience in one catchment doesn't result in the creation of vulnerabilities in other areas.
- Develop a systematic understanding of risk. This will highlight cross-scale issues and will allow for ensuring that appropriate partnerships are made with those that can act across scales, thereby ensuring system appropriate planning.

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LIST OF ABREVIATIONS

- CAS - Complex adaptive systems
- CSIR - The council for Scientific and Industrial Research
- EDM – Eden District Municipality
- GRI – Garden Route Initiative
- NLC – National Land cover
- NMMU – Nelson Mandela Metropolitan University
- SANParks – South African National Parks
- TMS – Table mountain sandstone
- WRC – Water research commission
- WWF – World Wildlife Fund

LIST OF TERMS

The project is interdisciplinary in nature and furthermore it also deals with a multitude of concepts and definitions that are either new, or differently interpreted, depending on perspective and discipline. In an effort to provide more clarity, a list of commonly used definitions and their explanations is offered below:

- **Agency** is similar to social capital, and can be understood as the capacity of individuals to act independently to make their own free choices, including their choice to engage in – or drive collective action (McLaughlin and Dietz; Brown and Westaway, 2011).
- **Absorptive capacity** is 'the ability of an organisation to recognise value of new external information, acquire it, assimilate it, transform & exploit it'
- **Ecological infrastructure** is composed of critical landscape structures that are strategically identified and planned to safeguard the various natural, biological, cultural and recreational processes across the landscape, securing natural assets and ecosystems services, essential for sustaining human society. It functions as a framework for urban growth and indicates where should not be developed (Yu and Padua, 2006).
    - Typically, ecological infrastructure is not easy to quantify, not well-studied and therefore also not that prominent in the minds of decision-makers. Yet, its relation to other forms of infrastructure e.g. municipal infrastructure may make the concept of ecological infrastructure sufficiently compatible with existing knowledge systems at local levels of governance. It could aid adoption and implementation (in the same way that water resources planners related to systematic conservation planning and "absorbed" these new conservation plans relatively easily).
- **Ecosystem services** are the benefits people derive from their environment and their ecosystems (Millenium Ecosystem Assessment, 2005).
- **Governance** is a social function centred on steering human groups toward mutually beneficial outcomes and away from mutually harmful outcomes (Brondizio et al. 2009)
- **Resilience** (in a social context) is the ability of a social system to respond and recover from disasters and includes those inherent conditions that allow the system to absorb impacts and cope with an event, as well as post-event, adaptive processes that facilitate the ability of the social system to re-organize, change, and learn in response to a threat. OR resilience means the ability to survive and cope with a disaster with minimum impact and damage (National Research Council, 2006).

- **Landscape resilience** is the capacity of land to sustain ecological functioning and self-renewal in a dynamic environment; **conservation** is the effort to understand and preserve this capacity for self-renewal (Leopold 1949; Gunderson, 2000; Anderson et al. 2012).
- **Risk** can be defined in many contexts, but here it can be explained as the probability of loss, or as the proportion of elements that will be damaged or lost over time and as a result of influences, including examples of natural hazards and degradation (Coburn *et al.* 1994).
- **Risk hotspots:** Identified areas within a given landscape that are particularly prone to the impact of hazards.
- **Social capital**, similar to **agency**: refers to the value of trust generated by social networks to facilitate individual and group cooperation on shared interests and the organization of social institutions at different scales (Brondizio et al. 2009)
- **Social governance capacity**: Ability of network of actors/stakeholders to cooperate (in formal and informal ways) to allow for the integration of diverse knowledge and interests, upkeep and responsible use of social capital, to achieve effective protection and rehabilitation of ecological infrastructure (Pretty and Smith, 2004; Flitcroft, 2009)
- **Vulnerability** is the pre-event, inherent characteristics or qualities of social systems that create the potential for harm. Vulnerability is a function of the exposure (who or what is at risk) and sensitivity of system (the degree to which people and places can be harmed) (Adger, 2005).

LIST OF TEAM MEMBERS

Table 1. List of team members

Name	Institution	Involvement & role
Patrick O'Farrell	CSIR	Project leader
Jeanne Nel	CSIR	Researcher (Obj 1, 2, 5)
Dirk Roux	SanParks	Researcher (Obj 1 & 4)
Christo Fabricius	NMMU	Researcher (Obj 1 & 4)
David le Maitre	CSIR	Researcher (Obj 2 & 3)
Nadia Sitas	CSIR	Researcher (Obj 2 & 5)
Belinda Reyers	CSIR	Researcher (Obj 2 & 5)
Georgina Cundill	Rhodes/NMMU	Researcher (Obj 4)
Chantel Petersen	CSIR	Researcher & student (Obj 3)
Lindie Smith-Adao	CSIR	Researcher (Obj 3)
Abigail Crisp	NMMU	Student (Obj 3)
Thea Buckle	NMMU	Student (Obj 4)
Samantha McCulloch	NMMU	Student (Obj 4)
Ilse Kotze	CSIR	Student (Obj 2)
Klaudia Schactschneider	WWF	Researcher (and steering committee member)

1 INTRODUCTION AND OBJECTIVES

1.1 Introduction

We live in a time of unprecedented global complexity and change (MA, 2005). Whilst exemplified most clearly by the effects of global climate change, the nature of the changing world we live in is far broader. The concept of Global Change encompasses the interlinked effects of changes in climate, land use and human population demographics, social and economic development, governance regimes and changes to the buffering capacity of the earth's ecosystems. The substantial changes that are happening in the social-ecological landscape are severely affecting the resilience of these systems and their ability to absorb, adapt and recover from disturbance. This in turn exposes society to a wide variety of increasing risks, so much so that contemporary societies have been termed risk societies (MA,2005). Failure to understand and proactively respond to the risks and opportunities that are embedded in this dynamic social-ecological landscape can have grave consequences to society. Society's current trajectory is clearly not sustainable, and a series of social-ecological transformations (Olsson et al. 2006) are required to move social-ecological systems threatened by climate change towards an alternative, more desirable and more resilient state. This project has focused on integrated and systemic ways of approaching risk by linking the concepts of social capacity for governance and social capital to ecological infrastructure in order to build resilient landscapes.

Ecological infrastructure refers to the strategically planned and managed or otherwise preserved networks of natural and working landscapes that conserve ecosystem values and functions and provide associated benefits and services to society. Examples of ecological infrastructure include strips of riparian vegetation that filter pollutants from water (Kemper, 2001), wetlands that slow down flood waters (Kemper, 2001), or coastal and estuarine ecosystems such as salt marshes and fore dunes that can contribute to erosion control or absorb the impacts of sea storms (Barbier et al. 2011). Typically, ecological infrastructure is not easy to quantify, not well-studied and therefore also not that prominent in the minds of decision-makers. Yet, its relation to other forms of infrastructure e.g. municipal infrastructure may make the concept of ecological infrastructure sufficiently compatible with existing knowledge systems at local levels of governance. It could aid adoption and implementation (in the same way that water resource planners related to systematic conservation planning and absorbed these new conservation plans relatively easily). Ecological infrastructure, when neglected or eroded by human activity, declines slowly and unnoticeably until a surprise event such as a flood, coastal surge, fire or drought occurs, which makes the decline instantaneously relevant, due to the associated debilitating economic, social and political impacts (MA, 2005).

The effects of Hurricane Katrina in 2005, which cost the US economy in the region of $150 Billion, were greatly exacerbated by the degradation of ecological infrastructure such as wetlands, river systems and natural flood plains. On the other hand, local impacts of the Indian Ocean Tsunami of 2004, which killed more than 70,000 people and cost the area an estimated more than $10 Billion, were greatly reduced in areas where healthy mangrove ecosystems had been maintained (Costanza and Farley, 2007). Such findings provide a compelling argument for investing in maintaining and restoring ecological infrastructure. Ecological infrastructure can be considered the stock from which essential ecosystem services flow, which in turn supports human well-being (MA, 2005).

Building resilient landscapes by understanding the important social and ecological linkages that underpin vulnerability requires multi-stakeholder engagement processes that facilitate the co-production and exchange of knowledge. Protecting or restoring ecological infrastructure is a shared responsibility between government, the private sector and society, and formal and should include both informal mechanisms of working towards a shared response at a landscape level. This necessitates cooperation between many different government departments (local, provincial and national), between government and the private sector, and inhabitants (Brondizio, 2009). Ultimately, scientific information on where to, how to and why to invest in ecological infrastructure must be linked to social networks and translated into social capacity, understanding and ultimately buy-in of this issue, so as to ensure implementation of suitable strategies for protection and rehabilitation of such infrastructure. The term social governance capacity refers to the ability of networks of actors/stakeholders to cooperate (in formal and informal ways) to allow for the integration of diverse knowledge and interests, upkeep and responsible use of social capital, to achieve effective protection and rehabilitation of ecological infrastructure (Pretty and Smith, 2004; Flitcroft, 2009), and is the dominant feature of this project.

The southern Cape region is known as an area vulnerable to frequent stochastic events, particularly floods and droughts, and is regarded as vulnerable to the impacts of climate change. Between 2003 and 2008, the Western Cape government incurred direct damages exceeding R2.5 Billion in eight severe weather events associated with cut-off low events. The southern Cape incurred 70% of this damage, indicating its vulnerability to floods. The 2004/2005 Garden Route floods caused direct damage to infrastructure estimated at R 25 million at the time and the total cost of damage due to floods in the Western Cape from 2003-2008 was almost R 2.1 billion (Faling et al. 2012). Moreover, damage per capita in rural areas was 3.5 times the annual household income in some instances, indicating the social vulnerability of this region. Droughts are a more insidious risk than floods and more difficult to quantify. Agriculture is by far the largest water user in the area, and this sector is critically affected by the regular droughts in the region, particularly in the dry and/or high water-use seasons (Dec-Feb) which is also often the crucial growing season for many crops. Along with decreased water availability comes the aspect of water quality, as agriculture and urban areas produce nutrient-rich runoff from fertiliser and sewage treatment plants. Reduced flushing and dilution in dry times can result in significant reductions of water quality and specifically eutrophication and associated algal blooms (e.g. from toxic cyanobacteria). Prime fishing and recreational areas, such as estuaries would be particularly at risk, as all river runoff will flow through them en route to sea.

A recent study on risk and the insurance industry in the southern Cape showed that the impacts of human drivers of change were equivalent to the global climate change drivers (Nel et al. 2011). This means that it is possible to build or maintain landscapes that help people in this region to adapt better to pressures of climate change, using a range of feasible management options including: clearing of invasive alien plants; restoring river corridors to serve as buffers for water quality; ensuring water quality does not further impinge on water availability in the area; ensuring that groundwater is properly managed and monitored; managing the estuary mouths in a scientifically defensible manner; preventing excessive hardening of the coastline and improving connectivity of dune fields and sand budget management through coastal fore dune protection and rehabilitation.

We have focussed our attention on understanding of the role of social networks and capital, as well as ecological infrastructure in building resilient landscapes and reducing risks to society in the the Eden district of the Southern Cape. Here we have his has focussed on exploring the application of the concepts of ecological infrastructure and social governance for enhanced risk prevention and management in one of the most risk-prone areas of South Africa.

1.2 Aims and objectives

The overarching aim of the project is to promote social-ecological transformation towards a more sustainable future in the Eden district. Here we explored ways of influencing the way decision makers and landscape managers understand and the concepts of ecological infrastructure and social governance capacity. The ultimate desire is to develop an inclusive system of governance and decision making, founded in learning, reflection and adaptation towards more resilient landscapes. The five objectives listed below focused our investigations.

1. To provide opportunities for knowledge exchange, reflection and learning about the role of ecological infrastructure and social governance amongst the various relevant stakeholders in the region, including social and ecological projects, case studies and initiatives.
2. To use these learning interactions and engagement with role-players to identify and, in a participatory way, map key risk social and ecological hotpots where both the likelihood and consequence of risks are high – including an assessment of capacity to manage and co-design alternative interventions which enhance landscape resilience by conserving ecological infrastructure.
3. At a finer scale within selected risk hotspots, identify and quantify understanding around ecological infrastructure most needed to enhance resilience and reduce the associated risks.
4. Explore mechanisms and participatory activities for enhancing the social governance capacity needed to effectively implement these shared responses.
5. Based on the studies in Eden, make recommendations on how to enhance resilience, reducing risk through enhancing opportunities and approaches to social governance and raise awareness around the utility of linking the concepts of social governance capacity and ecological infrastructure for more resilient landscapes.

The objectives are designed to build on each other, as well as on outside related projects and past research within the study region. The following diagram (Figure 1) depicts its linkages:

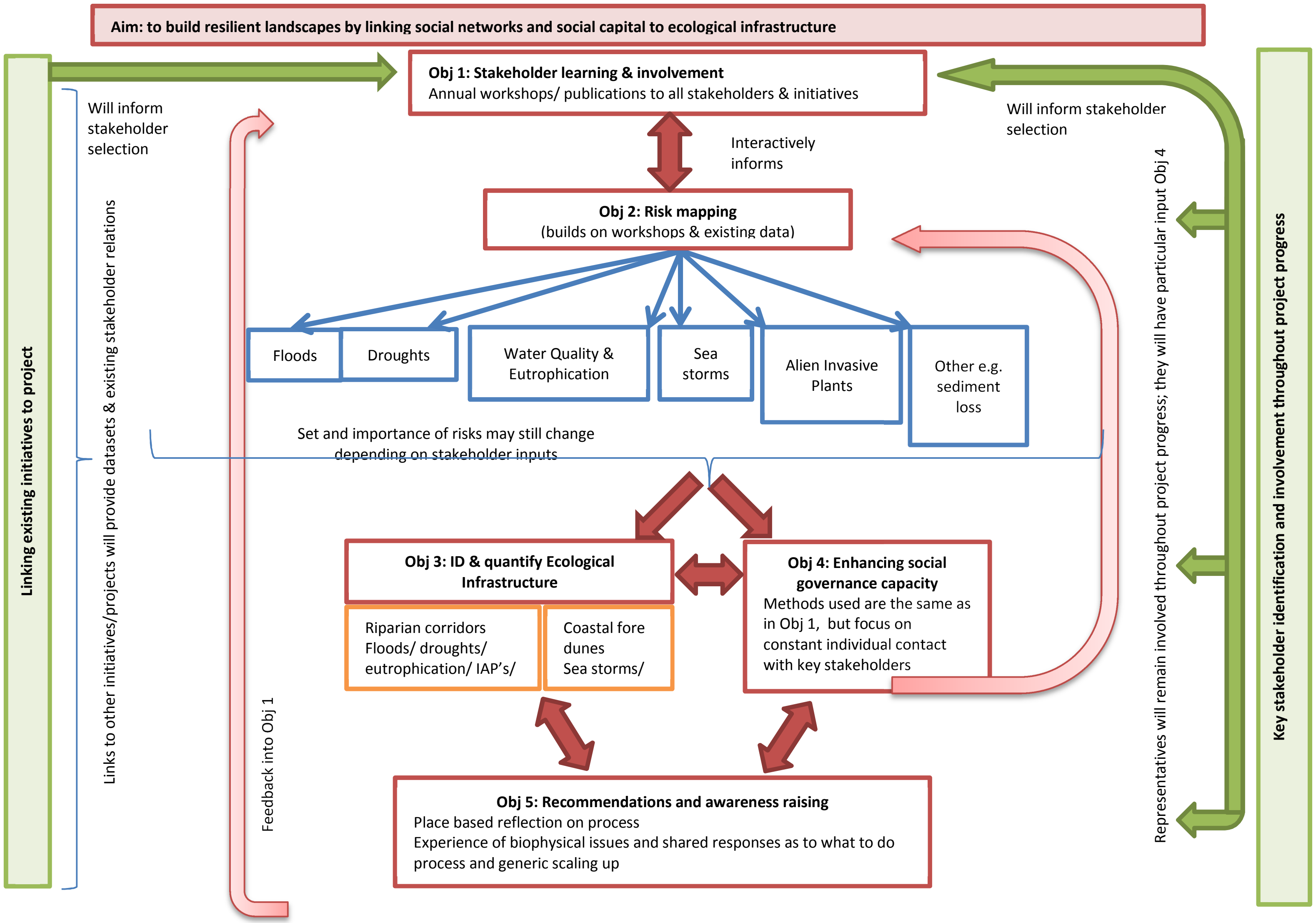

Figure 1. Diagram highlighting the project approach according to the key objectives and how these link together.

2 STUDY AREA

2.1 Location

The study area is situated in the southern cape region within the greater Breede-Gouritz Water Management Area (WMA) of South Africa between latitudes 33° and 35° south and longitudes 20° and 24° east (Figure 2b). This WMA falls predominantly within the Western Cape Province (53 139 km^2), with small portions in the Eastern Cape and the Northern Cape Provinces (DWA, 2013). It was chosen to focus the analysis at two scales: district level (Eden District) and catchment level (Wilderness river catchment) (Figure 2c) which were aligned with several initiatives (e.g. ProEcoServ and GouWater). The Eden District, hereafter "Eden", occupies an area of 23 321 km^2. It comprises seven Local Municipalities (Bitou, George, Hessequa, Kannaland, Knysna, Mossel Bay and Outshoorn) and a District Management Area nested within a district municipality (the scale of land use planning and management). Eden extends from the Breede River in the west to the Bloukrans River in the east and is flanked by the Indian Ocean with 340 km of coastline and the Swartberg Mountain Range inland. It is characterised by a rugged terrain with diverse topography (EDM, 2008).

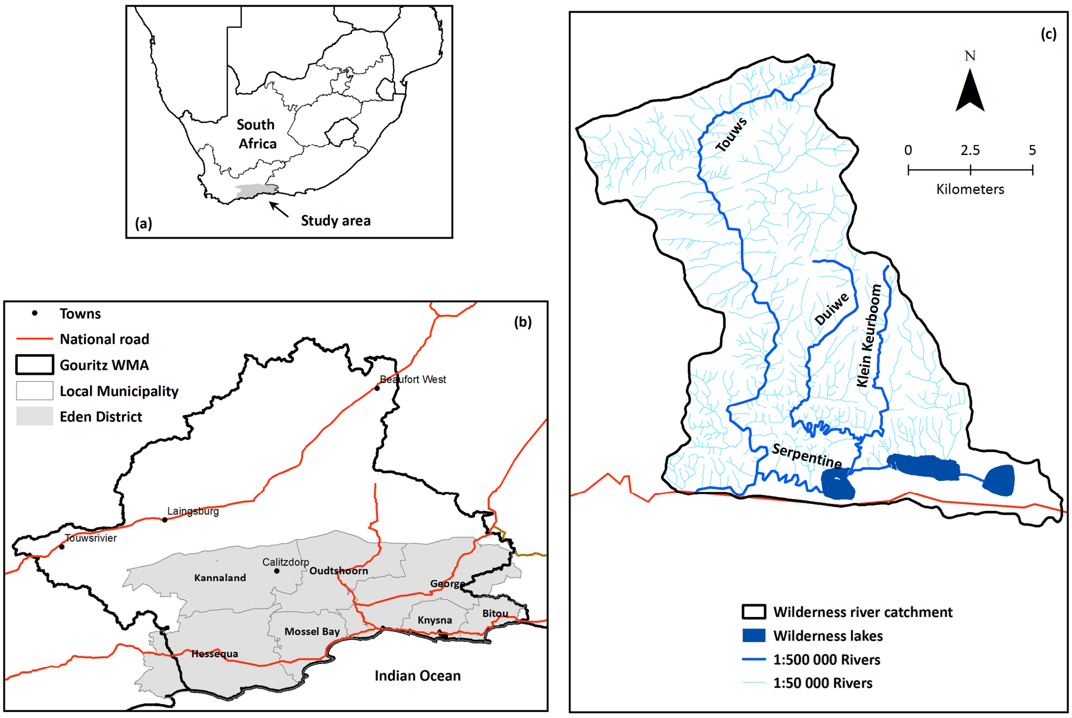

Figure 2. Location of the study area within the southern cape region of the Western Cape Province, South Africa. The position of some places or features mentioned in the text is also indicated.

The Wilderness catchment forms part of the Garden Route coastal catchments and comprises a quaternary catchment (K30B) in the national catchment naming system. The catchment area is ± 17 787 ha (Middleton and Bailey, 2009) and extends from the coastline in the south to the crest of the Outeniqua mountains in the north (maximum elevation ± 1 200 mamsl). This catchment can be divided into two main sub-catchments, the Touws River including the estuary (± 10 219 ha), and the lakes with their rivers (± 7 306 ha) (Figure 2c).

2.2 Geology, geomorphology and soils

The geology in Eden is dominated by the Cape Fold Belt which has resulted in the mountains typically comprising Table Mountain Group (TMG) quartzitic sandstones and shales. This is often accompanied by shales and sandstones of the Bokkeveld Group. The TMG rocks (highly fractured and faulted) are associated with poor soil development (shallow soils) and yield predominately nutrient-poor substrata (i.e. unsuitable for cultivation). In contrast, the Bokkeveld shales are usually deeply weathered and provide good soils suitable for agricultural purposes. The coastal plateau is characterised by extensive area of dune sand which are highly erodible (EDM, 2008).

The Wilderness river catchment consists of four physiographic zones: the middle and upper catchment of the Touws River; the coastal ridge (9500 mamsl); the raised coastal platform (± 200 mamsl) and the lakes, coastal dunes and coastline. Physiographic zones are regions of relatively uniform physical geography that are more or less unique (Partridge et al. 2010). The upper catchment is mainly underlain by coarse quartzitic sandstones of the TMG, with the Kaaimans Group (primarily phyllites, schists, quartzites) and the Cape granites forming the lower slopes of coastal ridge and platform, and Quaternary sands comprising the coastal section with the estuary and lakes. All the geological formations of this catchment date back more than 500 million years, except for the Quaternary sands and are, thus, heavily weathered. Also, the rocks of the various formations of the Kaaimans group weather to form deeper, loamy, more fertile soils. Most of area underlain by the Kaaimans formation is characterised by gently sloping ridge-tops and shallow river valleys which become steep-sided, incised river valleys and then deep gorges as they cut through the southern edge of the coastal platform.

Concerning river development, at around 45 000 yrs BP the Touws River and its tributaries drained directly into the southern ocean as the coastal plains and dunes had not been formed yet (Allanson and Whitfield, 1983; Holmes et al. 2007; Marker and Holmes, 2010). The coastline at that time was defined by what is now the steep slopes and cliffs that form the southern edge of the coastal platform though the sea level was much higher at the time. The sea level then dropped significantly exposing the continental shelf into which the rivers eroded. The sea level began rising again some 10 000 years BP and, combined with strong, south-westerly winds to transport the sand, built the coastal dunes, blocked the estuaries and in-filled the river valleys. By about 5 000 yrs BP the current estuary and the lakes had formed in the in-filled floodplain.

2.3 Climate

The climate in the study area is mild and temperate because it is strongly moderated by the cooling effects of the cold southern ocean. It varies significantly on either side of the Outeniqua Mountains which forms a natural barrier separating the coastal region from the semi-arid interior. The difference in climate is evident in the annual rainfall which averages between 700 mm and 1200 mm along the coast, and less than 400 mm in the interior (e.g. Little Karoo). The rainfall is fairly evenly distributed throughout the year with peaks in autumn and spring (EDM, 2008). The high rainfall on the coastal ridge also means that the rivers draining the lower Touws River and the lakes receive more rainfall than expected. For example, the mean for the Touws River has been estimated as 915 mm/yr while for the Langvleispruit River it was 900 mm/yr (Görgens and Hughes, 1981). Distinct orographic gradients in the area reflect the fact that most of the rainfall events are associated with frontal systems and south westerly winds.

Temperatures are generally moderate. The absolute minimum temperatures can reach 0°C and the absolute maximum temperatures can reach 40°C. The Karoo is hotter and shows greater variation in temperature. Here, mean annual temperature ranges from 15 to 17°C. Mean temperatures in the coastal areas are between 14.6 and 20.7°C (EDM, 2008). The humidity is high because of the proximity to the sea, but dry hot conditions occur during Berg winds which occur mainly in the winter months. Southwest and southeast are the predominant wind directions, with strong south easterly winds being relatively common. Cloudy and misty conditions occur frequently and generally reduce the potential annual evaporation rates. At George for example, this was about 916 mm (Penman method). This is much lower than the estimated A-pan evaporation of about 1 750 mm/yr (Schulze et al. 2008), possibly because of the cooler mistier conditions that are usually recorded in George.

2.4 Hydrology and limnology

Geology with regards to water storage and soil generation plays an important role in determining the hydrological characteristics of the study area. In Wilderness for instance, the shallow soils and limited groundwater storage of the TMG quartzitic sandstones make the river flows highly responsive to rainfall events. These upland areas yield most of water in the catchment. The water that is clear (i.e. very pure) but dark brown in colour, stained by humic and fulvic acids (Midgley and Schafer, 1992). Both the pH (4-5) and electrical conductivity (< 20 mS/m) are typically low. This contrast with the soils derived from the Kaaimans Formation and the granites which are associated with increased water storage capacity. Midley et al. (2001) noted that this should result in less flashy river flows and more sustained flows during the dry season, based on observations at Jonkershoek near Stellenbosch. These soils (particularly where they are red/yellow in colour), appear to absorb the dissolved organic carbon which, in turn, results in colourless water with higher pH values (6-7) and conductivities. They have been almost entirely converted to agriculture so unaltered streams are hard to find. There are no streams draining the dune systems but groundwater recharge is likely to be high. These systems generally also give rise to pale coloured water, but the dark colour of the lakes suggests that the groundwater feeding them is probably dark-stained (Midgley and Schafer, 1992).

The main river system is the Touws River (240.7 km) which drains the upper catchment, inland of the coastal ridge. The Outeniquas Mountains form the headwaters of the Touws River. It is supplied by some important tributaries and flows directly into the estuary on the western side of the catchment (Figure3). The Duiwe River (93.7 km) drains into Eilandvlei and has its headwaters on the coastal ridge and two perennial tributaries, Woodville (21.0 km) and Klein Keurbooms (27.86 km). A large number of farm dams have been built and the abstraction of irrigation water from them accounts for most of the reduction in river flows in the Duiwe and Langvleispruit. These agricultural abstractions resulted in the Duiwe changing from perennial to non-perennial. Moreover, the flow at the weir downstream on the Duiwe is generally low and irregular with frequent no-flow periods. Short-lived high flows after heavy rains alternate with periods of sustained flows (e.g. 1996-1997) and prolonged periods with virtually no flow (e.g. 2008-2010). The Langvleispruit River is of a similar size (21.2 km) but has lower runoff rates and is ephemeral due to intensive farming in the catchment. The lower reach of the Langvleispruit passes through a narrow valley which widens out at the base and is followed by about 600 m of alluvial wetland before it enters Langvlei. The Touws River has no dams or major abstraction points above the gauging weir therefore its flows are more or less natural. However, plantations influence the flows in the Touws River. This river system is highly responsive to heavy rainfall with very marked peaks in the months that are particularly wet and much lower flows in most other months. In 1995 the water availability and use in the catchment was estimated as input for a water management strategy (Kapp et al. 1995). An ecological reserve of about 25% of the runoff was estimated with the high value being largely due to the estimated groundwater seepage losses (± 2.6 million m^3/yr) and evaporation from the lakes (± 3.6 million m^3/yr).

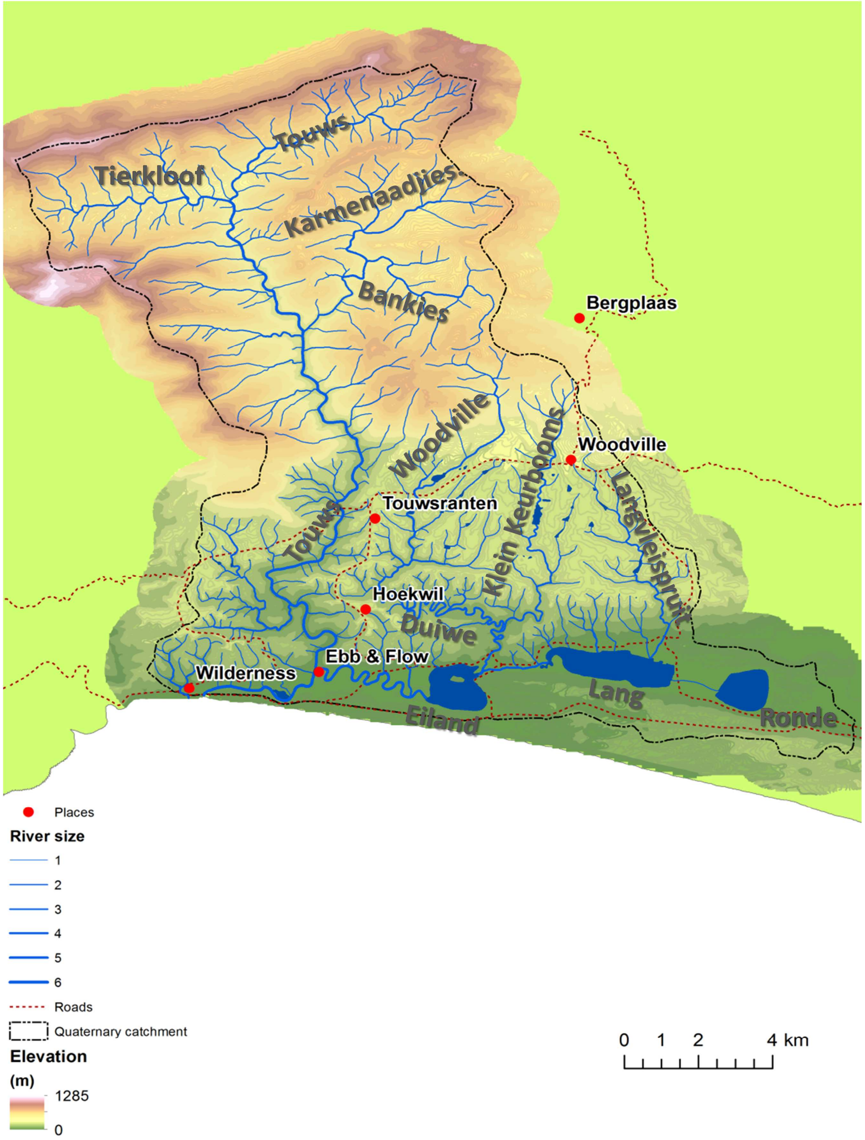

Figure 3. The lakes and river systems of the Wilderness river catchment.

The data is based on an edited version of the river arcs from the 1:50 00 topographic map series. River size is the widely used Strahler order which gives an indication of flow volumes (Strahler, 1957).

The rocky shoreline of Eden is highly varied and interspersed with for example bays, sandy beaches, estuaries and lakes. In total, 22 estuaries are found along the Eden coast (EDM, 2008). There are three lakes and an extensive estuarine system on the broad floodplain in the Wilderness river catchment. The bulk of the open water is in Rondevlei 108 ha, Langvlei 199 ha and Eilandvlei 128 ha and the remaining 77 ha is that of the Serpentine River and estuary (Allanson and Whitfield, 1983; Kapp et al. 1995).The streams flowing into the lakes (not including Rondevlei) are generally small, limited to 1st or 2nd orders (Figure 3), but have a total length of 27.3 km and those into the estuary total 11.1 km. Rondevlei is fed entirely by groundwater as there are no streams entering it and is connected to Langvlei by a narrow channel which restricts interchange. Langvlei is connected to Eilandvlei by a fairly well-developed channel while Eilandvlei is connected to the middle section of the estuary by the Serpentine. This section of the estuary is narrow and deep but becomes much shallower where the estuary widens below Fairy Knowe. It also has a limited floodplain surface linked to steep banks and development along the water's edge. Evaporation from the open water and the floodplain comprises a substantial portion of the water balance of the system (Allanson and Whitfield, 1983; Kapp et al. 1995). The drop in elevation from Rondevlei to the estuary is < 1 m so water level fluctuations affect large areas of the floodplain.

Reductions in flows have drastically changed the balance of the flows in the catchment and greatly reduced the flushing of the lakes. The inflows from Duiwe River system and Langvleispruit would have been channelled through the lakes, flushing them out regularly. The Wilderness estuary, which was naturally a temporary open/closed system, is now estimated to be closed 75% of the year, changing the biophysical and chemical properties of the lakes by retaining water and not allowing water levels to rise significantly. The management of the water levels at the mouth has had a major impact on the flows in the estuarine system and its flushing and on water exchange, particularly the salinity gradients. The estuary mouth breaching operates according to flood risk to property and is currently breached at 2.2-2.4 mamsl. The management technique is to skim the mouth of the estuary and maintain the estuary berm at 2.4 m so that it will breach automatically in floods.

Farming activities in the catchment are most likely also influencing the water quality in the Wilderness lakes (Allanson and Whitfield, 1983). Over the years concerns about impacts have been noted by various studies (e.g. Chunnett, 1964; Allanson and Whitfield, 1983; Kapp et al. 1995; Russell 2003). Inflows following the floods experienced in 1981 resulted in increases in the concentrations of total phosphorus and soluble reactive phosphorus and nitrogen rising in Langvlei and Eilandvlei but not in Rondevlei which is fed by groundwater. These rises were accompanied by rises in the chlorophyll concentrations in the water column, indicating algal growth spurts. However the levels soon dropped, presumably because the floodplain vegetation took the nutrients out of the system (Allanson and Whitfield, 1983). It is likely that a flood of this magnitude would also have flushed the farm dams of sediments and nutrients, increasing nutrient inflows into the lakes.

2.5 Vegetation

The study area supports a diverse plant life which has adapted to the physical conditions. The vegetation is situated in an area where four biomes (Fynbos, Succulent Karoo, Thicket, and Forest) converge. It forms a central part of the Cape Floral Kingdom. Fynbos vegetation types largely dominate (Mucina and Rutherford, 2006). The vegetation map (1:50 000) by Vlok et al. (2008) as modified by the South African National Parks (SANParks) depicts accurately the varied nature of the flora. In this area fine-scale mapping is particularly important for understanding the original distribution of the indigenous forest which was always very patchy. The main factor determining the distribution of forest is the spatial distribution of fires which is strongly influenced by the weather conditions prevailing during the main fire season. In Wilderness, fynbos and forest (Knysna Afromontane Forest) vegetation are confined largely to the hard-rock formations in the upper and middle catchment and the dune thicket to the Quaternary sands along the coast (Figure 4). The Outeniqua Mountain and Plateau Fynbos types are similar with both having an over storey of tall shrubs from the Proteaceae; with a middle layer of fine-leaved shrubs (e.g. Fabaceae, Ericaceae) and a ground layer of short shrubs, reeds (Restionaceae), sedges, geophytes and other herbaceous species (Vlok et al. 2008). Plateau Fynbos include for example fine-leaved shrubs such as *Erica sparsa* and *Phylica axillaris* which resulted mainly because of the finer textured and better developed soils derived from the Kaaimans formation and the granites.

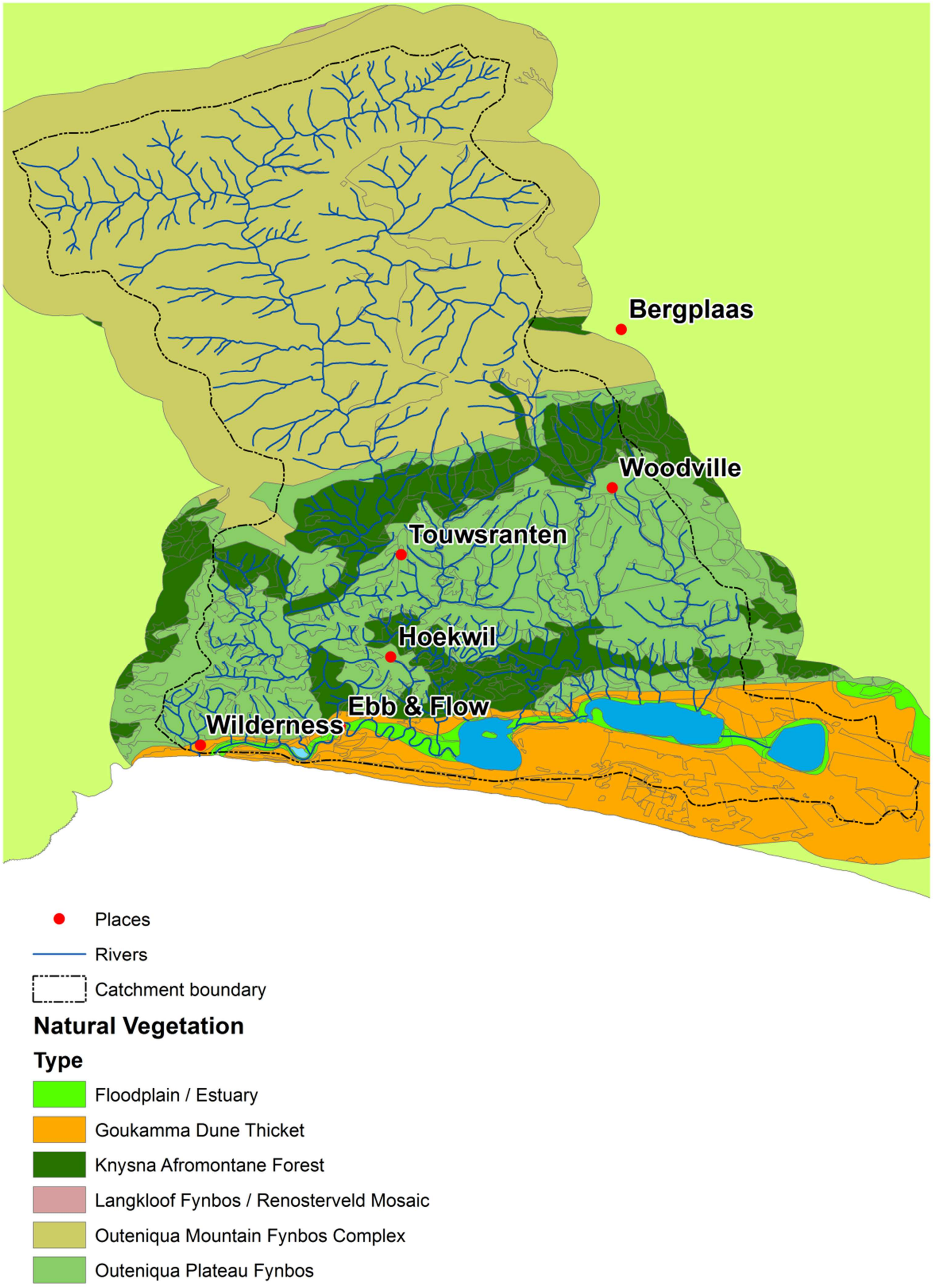

Figure 4. The natural vegetation types of the Wilderness catchment. After Vlok et al. (2008) as modified by SANParks.

The Knysna Afromontane Forest is similar to the Southern Afrotemperate Forest (Mucina et al. 2006) with a well-developed tree layer (i.e. canopy cover of > 75%); an understorey of shrubs, ferns and herbaceous species and a ground layer of herbs, sedges and grasses. Common tree species include *Afrocarpus* (*Podocarpus*) *falcatus* (Outeniqua yellow wood), *Canthium inerme* and *Olea capensis* spp. *macrocarpa*. The Goukamma Dune Thicket is really a mixture of sand-plain fynbos and thicket clumps which develop into a low forest in protected sites. The thicket clumps include species which can become very dense such as *Carissa bispinosa* and *Sideroxylon inerme.* The floodplain vegetation varies from a shrub or grass dominated community where the area is rarely inundated, to being dominated by reeds (*Phragmites australis*) and bulrushes (*Typha capensis*) where inundation is more permanent. Species typical of the saltmarshes occur along the shoreline of the estuary (e.g. *Chenolea diffusa* and *Suaeda fruticosa*) and some places on the lake shores, usually grading into terrestrial communities dominated by species such as *Cynodon dactylon*.

2.6 Land use

Eden is well known for its diverse natural areas (e.g. nature reserves, national parks and unspoilt coastline). Large parts of the area's vegetation is still unconverted with 63.46% consisting of indigenous shrubland and fynbos vegetation and a further 8.1% consisting of thicket and bushland (although natural vegetation is heavily grazed in places). Agricultural activities associated with crop cultivation and plantation forestry have transformed a further 18.58% of the landscape. The remaining areas have been transformed by alien plant invasions and seen an accelerated population growth rate, resulting in increased pressure for housing development and associated infrastructure (EDM, 2008).

The land uses (e.g. forest plantations, vegetable and dairy farming, low cost and high-income urban areas and conservation) in the Wilderness river catchment are representative of the district (Figure 5). About 75% of the catchment is still natural fynbos or forest vegetation, albeit with extensive invasions by pine and hakea species and riparian acacia invasions (e.g. *A. melanoxylon* and *A. mearnsii*). Other invading species are *Rubus* species (brambles), *Solanum mauritianum* (bugweed), *Sesbania punicea* and a variety of smaller shrub, herbs and grasses. About 6% is under commercial plantations, 11% under dryland and irrigated agriculture (8% of which is irrigated pasture), and about 6% is urban including small-holdings (1% formal urban mainly near the coast). Virtually all the pasture and cultivated land falls in the Duiwe River and Langvleispruit catchments, with most of the vegetable farming being located in the Klein Keurbooms and some in the Langvleispruit catchment.

The town of Wilderness was founded in 1877. It is a nationally important tourist attraction. Wilderness became a very popular area for holidays and the numbers of tourists rose steadily but it was only after the 2nd World War that tourism took off as the South African economy boomed from the late 1950s to the 1970s. This is when most of the older housing developments in Wilderness, Wilderness East, Hoekwil and other locations around the lakes were build. In the early 1960s a number of fishing communities were relocated from locations on the coast and around the lakes that had now been proclaimed whites-only under apartheid legislation. Much of the settlement that is now Touwsranten is one of the legacies of that period, as is Kleinkrantz on the coast just outside the catchment. Many of the smallholdings (e.g. Wilderness Heights, Hoekwil) were also established during this period, often through sub-division of the original farms.

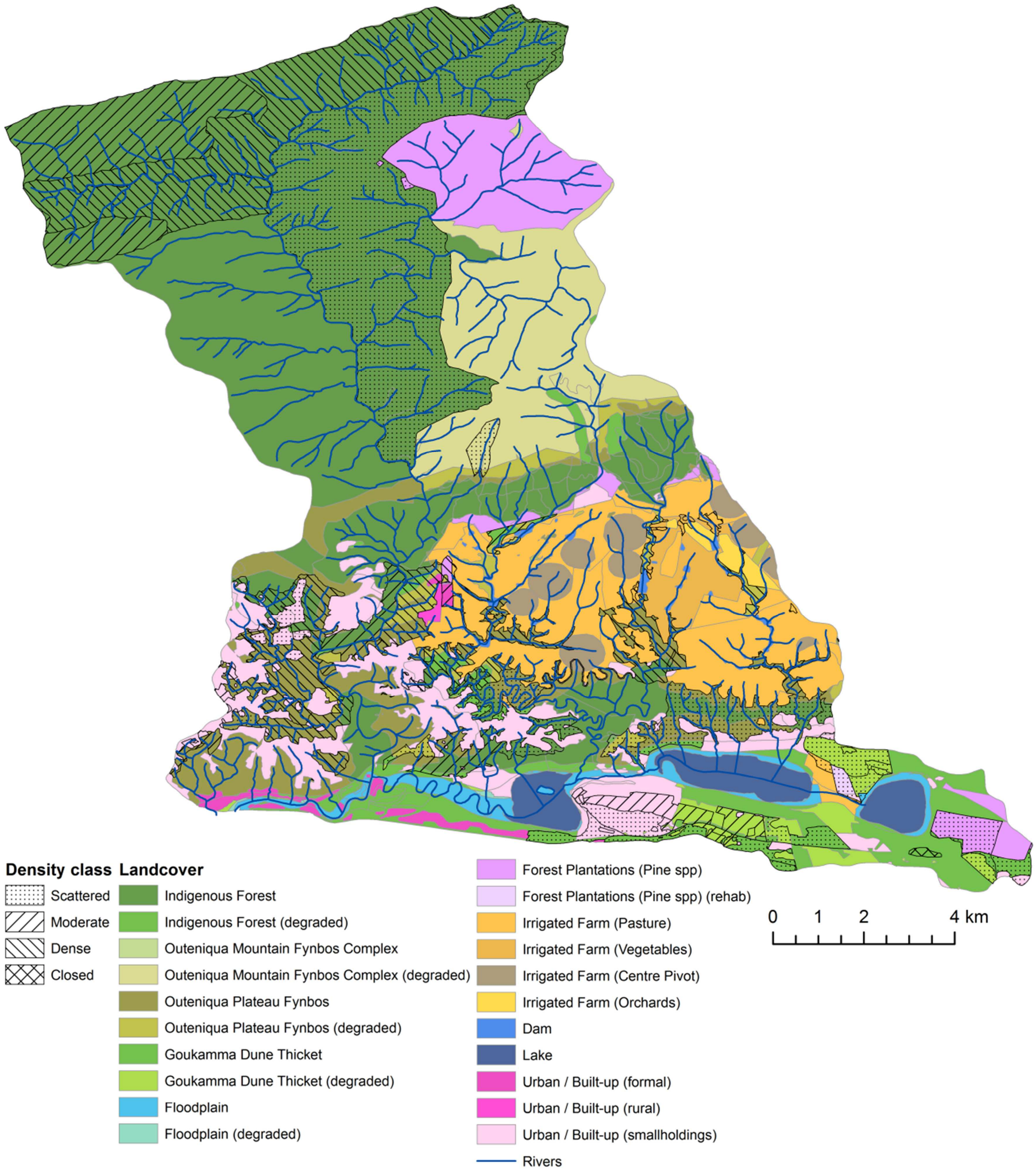

Figure 5. Catchment land use overlain with invasive alien plant densities. Data source: Garden Route Initiative then updated by the CSIR and edited by SANParks.

Conserved areas in Wilderness were managed either by Cape Nature or by the Department of Forestry who also were represented on the Lakes Area Development Board. In 1983 the board was dissolved and responsibility for management control was transferred to SANParks with the establishment of the National Lakes Area. More land was transferred to SANParks from the municipality, private owners and Cape Nature, and contractual land was added, resulting in the formation of the Garden Route National Park. This included the lakes and Ebb and Flow area. In 1991 areas around and including the lakes and much of the floodplain was designated and accepted as a Ramsar site, highlighting its importance for water birds in particular (Cowan and Marneweck, 1996).

3 LEARNING OPPORTUNITIES AND KNOWLEDGE EXCHANGE

3.1 Conceptualizing and engaging with catchments as social-ecological systems

Technical, command and control approaches that might work for engineering infrastructure are inappropriate in catchment management. They are often associated with “pathologies of natural resource management” (Holling and Meffe 1996) and their unintended consequences may result in disrupted ecosystem processes due to stabilization of river flows, loss of ecosystem processes linked to monoculture farming, suppression of fire and, importantly, ignoring human decision making and governance as key driving forces.

New conceptualizations, which recognize catchments as multi-faceted complex adaptive systems (CAS) that can only be managed using integrated, dynamic frameworks and conceptualizations have started emerging. Falkenmark and Folke (2002) called for “hydro-solidarity”, arguing that human activities are key drivers of catchment systems and that the human inhabitants of catchments should be acknowledged, respected and considered in the formation of catchment management and strategies. When viewed through the CAS lens, effective catchment management entails a) striving to adapt to and flow with change, instead of resisting it b) forming governance alliances between civil society, scientists, decision makers and land users c) developing informative models, supported by reliable data d) practicing meaningful active adaptive management and e) communicating effectively and accessibly (Rammel et al. 2007 Hopkins et al. 2011).

Initially, the CAS paradigm was more theoretical then practicable. Examples of its use in practical contexts are, however, now emerging. Stakeholders in the Goulburn-Broken catchment in Victoria, Australia, have made great progress in managing the catchment using a social-ecological systems approach, characterized by adaptive management, recognition of multiple thresholds and cross-sectoral collaboration (Walker et al. 2009). In the Crocodile River catchment and Kruger National Park in South Africa, and Macquarie Marshes Nature Reserve in Australia, systems perspectives coupled with strategic adaptive management are showing incremental and positive collaborative change for ecosystems and society (Kingsford et al. 2011). Over-extraction of South Africa’s Sabie River was prevented by the formation of a multi-institutional working group which, by adopting a complex adaptive systems perspective, agreed on a joint vision and made management compromises that avoided a potential crisis (Biggs et al. 2015).

The CAS paradigm in catchment management has at least five defining characteristics:

- catchments are multi-dimensional social-ecological systems
- feedbacks exist between the natural, socio-economic, institutional and technological dimensions of the system
- new interactions and configurations emerge
- they can self-organize and
- when thresholds are crossed, change can be rapid and sometimes irreversible (Cilliers 1998).

Conceptual frameworks that correspond with these characteristics focus on the linkages and interactions between the social and ecological components of the system (e.g. Anderies et al. 2004 Ostrom 2009). The consider feedbacks in space, and over time, between different system elements (e.g. Schlüter and Herrfahrdt-Pähle 2011), and consider the emergence of new, often wicked challenges when history, politics, governance and natural resources intersect (Patterson et al. 2013), leading to self-organization (Olsson et al. 2004). Importantly, conceptual frameworks that view catchments as complex adaptive systems incorporate multiple states and numerous possible trajectories, determined by different configurations of system drivers (e.g. Enfors and Gordon 2007).

The conceptual frameworks used in this study combined appropriate elements of complex adaptive systems. Firstly, the study was embedded in a social-ecological systems perspective , incorporating interactions and interdependence between humans and nature (Fischer et al. 2015). Secondly, they incorporate the feedbacks between ecosystem services, nature’s intrinsic values, people’s good quality of life, governance and multiple knowledge systems. The conceptual framework put forward by the

Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) (Díaz et al. 2015) is a good example. This framework emphasizes the importance of governance, and multiple knowledges, as drivers of the dynamics of social-ecological systems. It also incorporates interactions across scales, and highlights the dynamics of social-ecological systems over time and adds global relevance to our work.

Thirdly, we incorporated the notion of multiple trajectories or 'adaptation pathways' (*sensu* Wise et al. 2014). These pathways are influenced by natural, social, ecological and institutional drivers and by perceptions of uncertainty. Capacity is an important determinant of the trajectories of adaptations, which could end up in either an adaptive, or maladaptive space, characterized by adaptations made in societal interest or own interest, respectively (Figure 6). This conceptualization is useful in the construction of scenarios and creating awareness amongst stakeholders of the imperative to, in addition to their own interests, also incorporate societal interests (Brown and Westaway 2011).

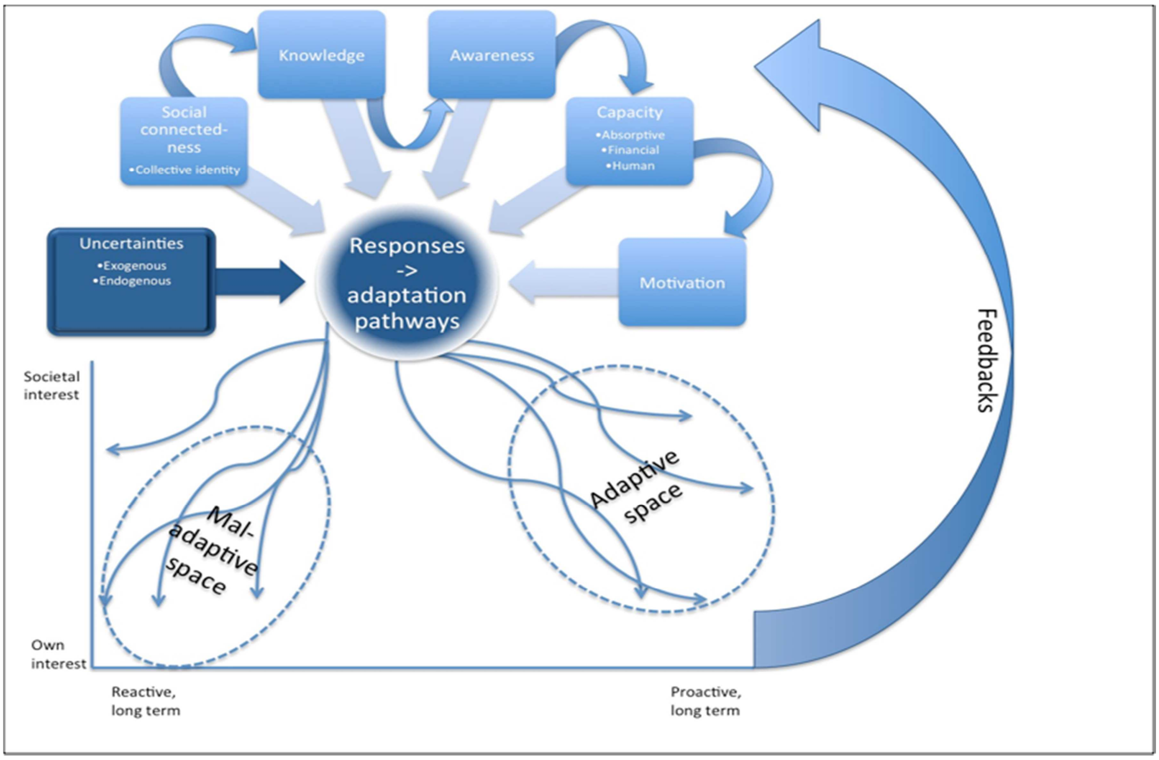

Figure 6. Uncertainties, social connectedness, knowledge, awareness, capacity and motivation all come together in a suite of adaptive responses. These responses pave the way for several possible adaptation pathways (bottom part of Figur6). Responses in own interest, especially those that are reactive, end up in maladaptive spaces, while proactive responses in societal interest often lead to adaptive spaces. Curved arrows represent opportunities for knowledge brokering and facilitation by bridging agents. The 'Feedback' arrow (righ-hand side of Figure 6) represents opportunities for learning and reflection.

Fourthly, we had to envisage interactions between resources, resource users, public infrastructure providers and public infrastructure, respectively. The 'robustness-vulnerability framework' described by Anderies et al. (2004), which inspired the social-ecological systems assessment framework proposed by Oström (2009), is useful in understanding the interactions shaping common property management (Ostrom 1990). The robustness-vulnerability framework has four cornerstones (Figure 7):

- **resources** (for example ecological infrastructure or EI, and water)
- **resource users** (e.g. farmers foresters subsistence users urban residents)
- **public infrastructure provider**s (e.g. local authorities national and provincial government departments) and
- **public infrastructure** (e.g. impoundments services roads and legislation and policies).

The links between these four cornerstones are as important is the cornerstones themselves. Communication, for example, moderates the interaction between resource users and public infrastructure providers. Monitoring creates a link between public infrastructure and resource users as well as between resources and resource users. The framework was useful in understanding and communicating the importance and value of functional interaction and feedback between the different components of the system and the risks when these feedbacks become dysfunctional (Figure 7).

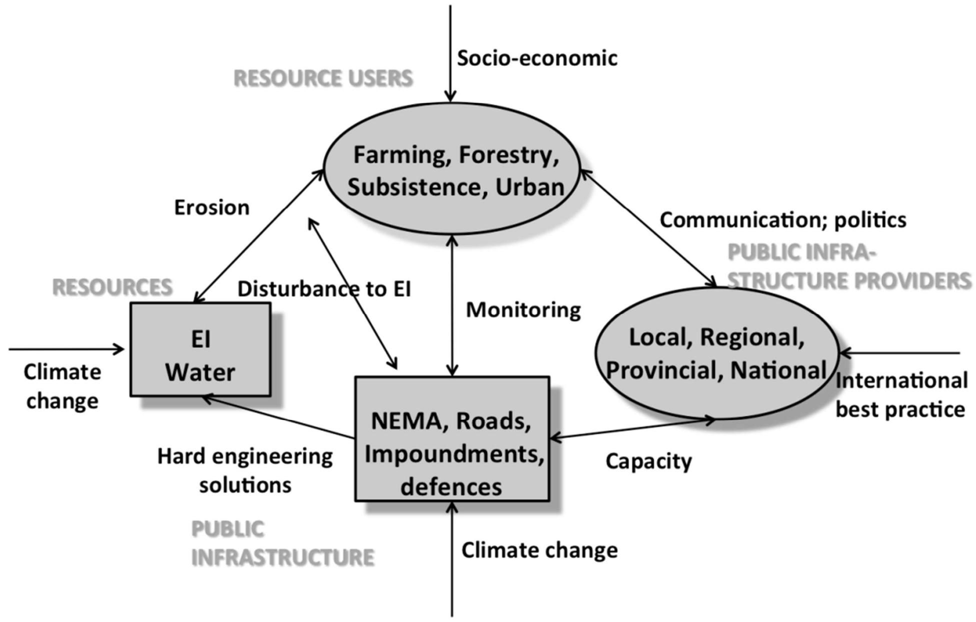

Figure 7. The robustness-vulnerability framework of Anderies et al. (2004), modified to depict the Wilderness Rivers social-ecological system. Resource users are the primary stakeholders and include farmers, foresters, subsistence users and urban residents, as well as associations. Public infrastructure providers are mandated organizations tasked with constructing and maintaining public infrastructure, and with policy making. Public infrastructure includes physical constructions as well as plans, policies and laws. Resources include all the natural assets that are used or which maintain ecological processes, with ecological infrastructure as the primary resources. These interactions are affected by external changes, shocks and surprise, for example the global economy, political processes, climate change or public sentiment

Kolb and Kolb (2005) have typified experiential learning styles into nine categories, dependent on the level of abstraction vs. concrete experience, in one dimension, and the level of active experimentation vs. passive observation in another dimension. Our goal in this project was to facilitate learning in the "feeling-acting" and "reflecting" domains by stimulating experimentation and reflecting on actual experiences. Inspired by Lambin (2005), the interactive research process is diagrammatically presented in Figure 8. It demonstrates that the process was incremental with cycles of data collection, interaction with stakeholders, awareness raising, learning and reflection, identifying options and opportunities and only then choosing actions.

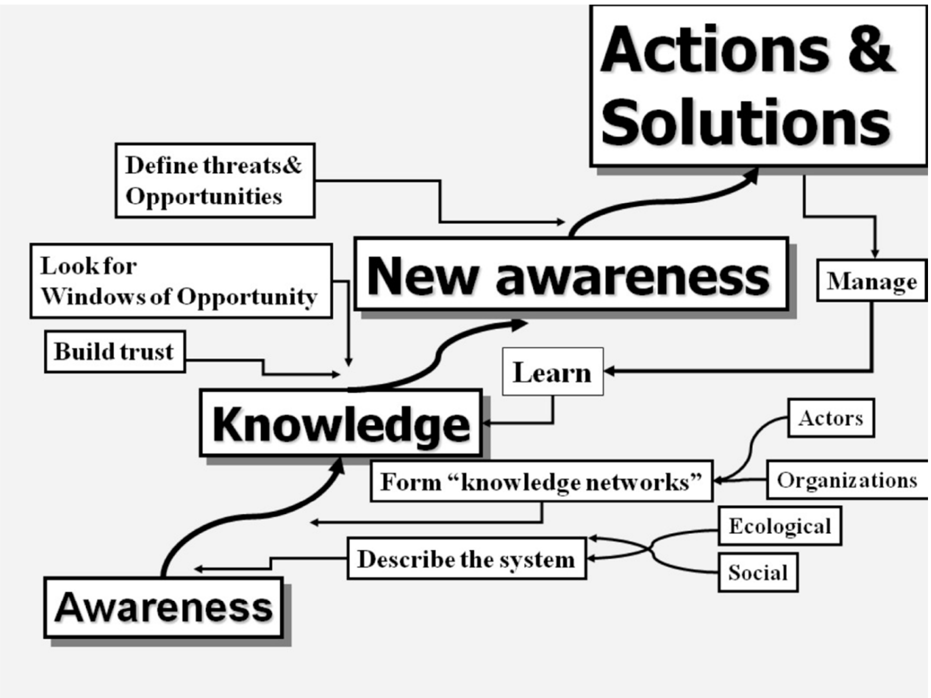

Figure 8. The process of sharing knowledge to create new awareness, motivation and reflection through trust building and reliable data in the Wilderness Rivers. A good description of the system, using a social-ecological framework, the formation of knowledge networks, and collective identification of threats and opportunities are crucial factors in making progress towards collective action.

The implementation part of the research was designed around five work packages (Figure 1): stakeholder engagement; risk mapping; quantifying the status of and trends in ecological infrastructure; enhancing governance capacity; and creating awareness. The packages ran in parallel, and the team communicated and reflected often.

We experimented with seven innovative strategies to put substance and meaning to our conceptual frameworks.

1. Getting to know our stakeholders. An advantage of living and working in the study area was that many of us already had good links and connections with key role players. We nevertheless conducted a thorough inventory of stakeholders and their links with ecological infrastructure, using desk-top analysis supplemented by interviews and snowball sampling. We created a stakeholder database which is regularly updated.
2. Building trust and credibility through a light-handed approach. We chose to, initially, focus on developing trust and credibility with stakeholders by interacting with them at every possible occasion. This meant being flexible and willing to attend stakeholder meetings at short notice, and waiting for invitations to present our insights instead of imposing presentations on stakeholders. We deliberately avoided organizing workshops in the early stages, unless stakeholders asked us to facilitate some of their processes, which happened on two occasions. Our strategy was to listen, make presentations when requested to, avoid raising expectations and pretending to know everything, and yet provide stakeholders with quiet assurances that we had knowledge to share with them, and that we are 'here to stay'.
3. Communicating frequently and effectively. Strategies to achieve this included articles in the local newspapers (WildNews and George Herald) frequent communication with journalists to keep them informed creating a blog and setting up a bulk SMS distribution list. We also reported back about progress at every stakeholder meeting we attended, and appointed a dedicated part-time community liaison officer whose job description includes maintaining contact with stakeholders, and expanding the stakeholder information base,

4. Producing reliable scientific information. Through good science and making use of multiple sources of information, we ensured that stakeholders were given access to the best possible information about ecological infrastructure in the catchment.
5. Linking with broader regional networks and planning processes. Our team one of the founding members of a community-based organization, the Southern Cape Landowners Initiative, and formed a sub-group called the Kaaimans-toTouw Ecological Restoration Forum or KTT, with representation by most mandated organizations and landowners between the Wilderness Rivers and Kaaimans catchments. We also made presentations at the Garden Route Initiative and Garden Route Biosphere forum, attended coastal planning committee meetings and workshops organized by the District Municipality on disaster risk management, where we shared some of our findings with participants.
6. Bringing stakeholders together, to expose them to each other's views, insights and aspirations. Founded in the 'Time to Think' methodology, this workshop provided an impetus for a catchment management plan and catchment management organization, which is envisaged for the next phase of the research.
7. Taking a long term perspective. The project described here stretches far beyond the initial three-year period we are looking at change over a period of 10-15 years. This is possible due to our proximity to the study site – our team is indeed part of the social-ecological system, our growing credibility and connections with role players, and the constant stream of students working on various aspects of the study.

The incremental implementation of these activities is depicted in Figure 9.

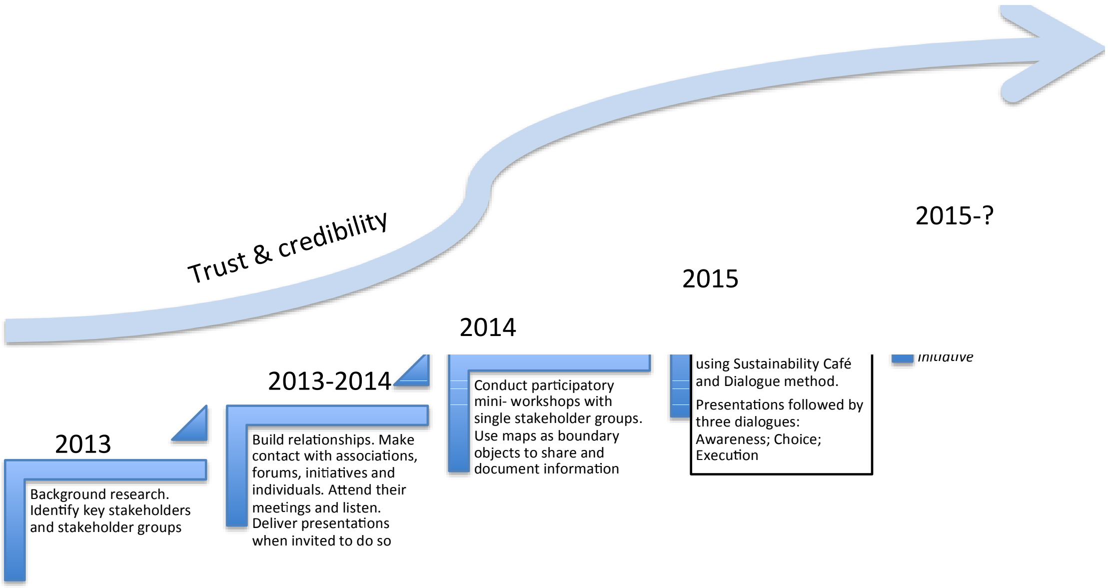

Figure 9. Step-wise implementation of the project

By combining the conceptual frameworks described above with dedicated personal contact, local knowledge and absorption of different types of information, we made significant contribution to the social-ecological systems approach to catchment management. We believe the Wilderness Rivers is an emerging example of the "hydro-ecological solidarity" and stewardship envisaged by Falkenmark and Folke (2002), and trust that it could eventually become a beacon of hope in sustainable catchment management.

3.2 Place-based adaptations

'Place-based' strategies integrate many functionally distinct activities within a delimited area to achieve a specific objective. Our approach was to understand the processes and pathways that lead to adaptive and maladaptive strategies, and share these with stakeholders. Our departure point is that responses are a product of complex interactions and feedbacks between external uncertainties.

When diverse stakeholders use the same river system, decisions taken by upstream land users and regulators inevitably have cumulative effects on downstream users. In the case of a catchment, the inherently connected nature of the social-ecological system enables both positive and negative feedbacks. Water, knowledge and ecological infrastructure are the glue the keeps the system functioning and connected. When some of the critical connections are 'broken', for example when landscapes become fragmented through alien plant infestations, land transformation or erosion, or when governance systems fall apart due to lack of communication and coordination, the probability of unintended negative consequences increases exponentially.

Our departure point is that responses do not just happen out of the blue. They are the result of adaptation pathways, defined as "alternative possible trajectories for knowledge, intervention and change, which prioritise different goals, values and functions" (Wise et al. 2014) that are:

- the product of a dynamic process, starting with existing experiential knowledge, identity and entrenched world views
- evolve and develop through absorbing new knowledge, learning from others, experiencing the impacts of uncertainties and adapting to them
- are tempered or enhanced by capacity actors who lack capacity may know what is needed to respond appropriately, but may be constrained by lack of resources, lack of skills, knowledge people may know what needs to happen but lack the ability, know-how and courage to control their own destinies.

We thus conceptualize adaptive responses as a complex set of interactions between uncertainties, that come from outside the system actors' cognitive perceptions, paradigms or mental models that can be influenced by their collective identity, history, culture, peer groups, norms and codes of conduct, and contemporary events their knowledge and awareness, influenced by access to information, formal education, learning and experience their identity, strongly influenced by their sense and meaning of place, group identity or 'tribal' affiliations their social and economic roles or 'place' in society their capacity and agency to respond and their motivation, influenced by incentives and disincentives but also by values and ethics and societal norms. All this translates into suites of responses which can be either reactive, short term, or long term or in their own interest, or in the interest of society as a whole. The outcomes of these responses can either be adaptive or maladaptive, i.e. either building new connections, healing broken connections or, conversely, fragmenting the system even further (cf. Figure 6 above).

3.3 The role of collective identity in place-based strategies

Collective identities are critical determinants of cooperation. They are key in determining who we trust and identify with as well as what is important and what not (Hardy et al. 2005). Cooperation is nurtured when a higher-level identity emerges as a product of collective identities across knowledge domains. It is now understood that research into collective identities can suggest solutions for the social dilemmas that we face regarding natural resource management (Klandermans et al. 2002). Multiple sources of information were assessed and triangulated. These includes informal meetings and conversations, document analysis, participatory mapping sessions with small groups, focus group meetings with four to five individuals, and a multi-stakeholder workshop where all groups in the catchment were represented.

3.4 Uncertainties

The most prevalent adaptation strategies amongst land users were to reduce uncertainty and 'variance' to deal with shocks and surprise.

Exogenous uncertainties included:

- Climatic fluctuations, especially periodic droughts and floods.
- Economic uncertainties such as currency fluctuations, increases in input costs in the form of fuel, electricity, agro-chemicals and labour costs, and demand for e.g. tourism services.

- Fluctuations in the labour market which affect unemployment and capacity of authorities to do their work.
- Budget fluctuations in government departments, parastatals and municipalities which affect their capacity to execute their mandates.
- Policy uncertainties linked to land reform, labour legislation and natural resource policies, especially those affecting access to water.

Endogenous uncertainties are within the control of local stakeholders. They include:

- Poorly planned development which disrupted the flow of the river and weakened ecological infrastructure, especially down-stream, and created pollution risks.
- Pollution which peaks during holiday months and creates health risks. The ageing municipal sewerage infrastructure, with pump stations and abandoned conservancy tanks all along the lower reaches of the Touw River, poses a major threat to human health. The risk is increased by staff shortages and lack of transparency about the threat. Agro-chemicals are a significant, albeit reducing, source of pollution.
- Governance shortcomings, e.g. the lack of coordination between different tiers and sectors of government has created uncertainties about the way policies are being implemented, different government departments interpretation of policies, and lack of coordinated planning. This has resulted in mistrust in government at all levels with negative implications for collaborative catchment management.
- Varying absorptive capacity in mandated organizations. Conservation officials who were interviewed were aware of the importance of understanding and adapting to environmental change. However, they lack the time and motivation to experiment with new approaches or develop their own capacity by absorbing scientific information. Officials believed that information was frequently shared across their organizations and that their scientific services play an important information-sharing role, but that this seldom included insights about environmental change. Information about innovations in climate change adaptation is communicated within and across departments, despite communication bottle-necks.
- Officials at middle management level are eager to work together but there appear to be obstacles to meaningful collaboration, related to high turnovers of senior officials, political interference and changing priorities.
- Short term decision making is both a source of and response to uncertainty. Role players focus on immediate priorities and proximate causes, with negative unintended consequences. The reason for this is a combination of ignorance, lack of cash flow and immediate financial priorities. High turnovers of officials and politicians also play a role. The dairy-farming community (as a commercial user) has become more proactive than other stakeholders, actively researching their options and make strategic decision. The local dairy industry has evolved from being a collection of small-scale dairy farmers to be shareholders in a corporatized dairy business.
- Ecological uncertainties include the spreading of invasive alien plants and animals. Plantations are viewed as a threat due to historical seed dispersal, particularly in the Fynbos areas. This has led to the invasion of catchments by Pine species with negative impacts on the hydrology of the rivers. Alien vegetation also represents a fire risk in the catchment and around the urban fringes.

3.5 Access to information

Access to information is relevant to stakeholders' awareness of environmental change and ecological infrastructure. Information is shared through local knowledge exchange and the printed media, and may lead to innovation while also influencing environmental attitudes amongst stakeholders. Imbalanced access to and dispersion of information, and thus awareness, contribute to worsening inequality in the area. This extends to job opportunities, small business and governance.

- *Awareness* - Most of the stakeholders agreed on the importance of information in shaping their decision making. Participants from Touwsranten, for example, cited knowledge and education as the most important factors in reducing environmental misconceptions. Many of the farmers actively seek information from overseas sources through e.g. study tours, having access to this knowledge because of their privileged economic position. Farmers are also part of study groups and have access to printed and electronic media. Farmers' awareness of climate change varied but was surprisingly high. Steyn (2013), for example, found that more than 70% of the farmers she interviewed were aware of the impacts and causes of climate change. All stakeholders were very aware of the threats posed by invasive alien plants, in particular fire risks and water uptake. There was also a high awareness of the governance shortcomings and the need for cooperative governance. People's capacity, whether real or self-perceived, to respond, prevents them from being proactive in addressing these challenges. Development practitioners (developers, engineers and environmental practitioners) have an understanding of how dune systems work and that human influence can disrupt and change the functioning of dune systems. Developers and engineers also had a good understanding of the proximate drivers of the change to coastal dunes.

- *Local knowledge* - Local knowledge about the catchment and estuary varies, with some evidence of misinformation or misunderstanding. Various stakeholders have demonstrated an incomplete understanding of the importance of run-off, believing that fresh water that runs away into the ocean is 'wasted'. This mis-perception was most common amongst the farmers, with claims that this misinformation might have been perpetuated by some agricultural researchers and advisors. Another belief is that dams established in tributaries and ground-water extraction have no impact on the river's flow. These beliefs play a role in the illegal extraction of water and will be difficult to change since they seem to be deeply entrenched.
- *Influence of the media* - The role of the media in shaping information and knowledge should not be underestimated. Journalists tend to focus on the economic implications of the environment and rarely concentrate on environmental issues in isolation. The coverage of issues such as climate change is erratic and dwindles when the immediate threat (floods, droughts) dissipates. Even though the media was not identified as an important source of information, the agricultural media and the local mass media surveyed echoed the same eco-economic underpinnings of regional agricultural practices, in terms of seeing water as a commodity for production. The coverage also reiterated increased storage capacity as a solution to the environmental changes in the area, as found in the interviews. The climate change discourses were centred around the dire situation the area finds itself in, framing the possible consequences economically, environmentally and socially.
- *Innovation* - The way innovative water conservation practices may have diffused through the community was also investigated. Firstly, it was evident that reliance on formal knowledge from the experimental farm and national and international experts was prevalent. Secondly, interpersonal communication was an important source of information, with farmers indicating their preferred opinion leaders in various aspects. They had experience dealing with fellow farmers and knew which peers to trust for different expertise. The farmers indicated that the media doesn't affect their farming practices, although some of them indicated interest in environmental topics and conceded that the sensationalist coverage of labour-related issues discouraged them.
- *Attitudes* - Pro-environmental attitudes were found along with a mixture of economic principles, since farming has become predominantly business driven. For example, water as a subject emitted emotive language from the participants, but they also indicate that using it conservatively is mostly due to rising input costs of irrigation (apart from water). Increasing storage capacity, commonly assumed to be environmentally-unfriendly, was raised as a way of storing storm water runoff. This is not only to reserve adequate water for individual use, but also to ensure the downstream agricultural and residential users have adequate water supply during drought periods, by releasing water out of newly built dams in lower rainfall periods. The farmers also found it pertinent to consider these adaptations with the increasingly sporadic rainfall patterns in the area.

3.6 Motivations

We found that most stakeholders were motivated by concerns over threats rather than by a common vision or hope of a better future. This has important implications for our intervention. Fear results in reactive and short term responses and selfish behaviours which can easily result in maladaptations. The factors that motivated stakeholder groups were strongly related to their capacity, identity and values.

- Commercial stakeholders such as farmers and the forestry sector were primarily motivated by short term commercial considerations: continued access to water impacts of policies on profitability crime and land reform.
- Tourism role players were motivated by concerns about impacts of environmental degradation, particularly pollution, on visitor numbers.
- Subsistence users were mostly motivated by livelihood considerations, i.e. jobs, service delivery, access to resources such as fish, and education.
- Civil society stakeholders were motivated by concerns about human well-being, particularly health, crime and hazards to property.
- Regulators (public infrastructure providers) were motivated by their mandate to enforce policies and by long term concerns about environmental degradation and biodiversity loss. Public service providers (the municipality) were motivated by concerns about their image and public perceptions.

When these role players were brought together in a multi-stakeholder workshop and engaged in dialogue, they identified the need for a common vision and articulated it as: *"A healthy river system and healthy community through collective effort, beyond our own back yards".*

3.7 Adaptation strategies

Adaptation strategies can be either short term and reactive and long term or proactive, and may be intended to be in societal interest or personal interest (Figure 10).

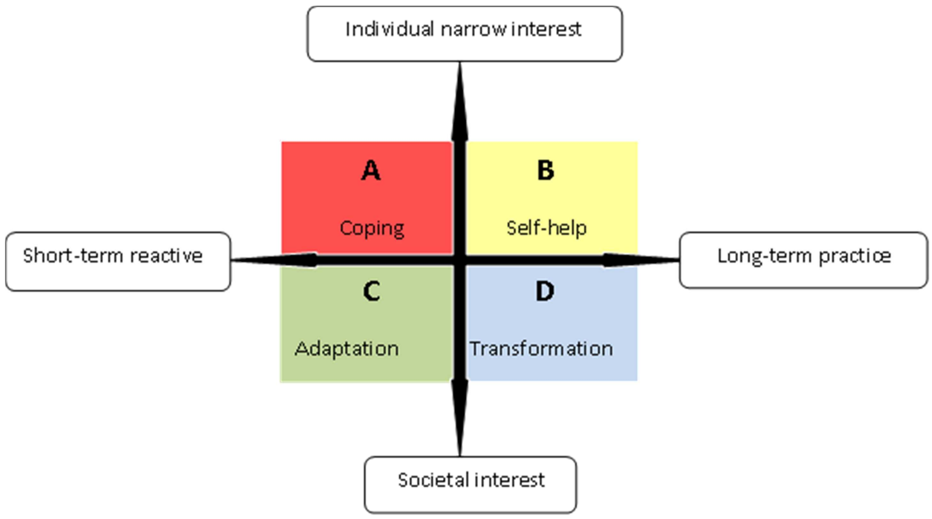

Figure 10. A typology of adaptation strategies. Strategies can be short term or long term aims, and be in individual self-interest or societal interest (adapted from Brown & Westaway 2011)

Short-term adaptations in own interest (quadrant C in Figure 10) included win-neutral and win-lose solutions. Win-lose adaptations included:

- construction of illegal dams
- illegal abstraction of water from the catchments
- illegal fishing
- clearing indigenous vegetation in riparian zones to plant larger pastures
- developments on coastal foredunes.

Win-neutral short term adaptations included:

- purchasing emergency feed during drought
- establishing fire-breaks around properties
- removing obstacles from rivers
- cleaning up litter around homesteads (Touwsranten)
- removing evidence of sewerage spills (municipality).

Some short-term responses in societal interest (Quadrant B in Figure10) included:

- artificial opening of the river mouth to reduce the risk of property damage upstream in case of a heavy rainfall event
- patching of dilapidated sewerage infrastructure by the municipality
- establishment of Fire Protection Associations to protect people and property against runaway fires
- disaster management preparedness
- repairing of public infrastructure such as roads and bridges previously constructed in the wrong places
- dredging of the river to reduce sand-banks
- artificial opening of reed beds and
- short term job creation through alien plant clearing; anti-poaching activities.

Long term responses in own interest (Quadrant B in Figure 10) hold promise for adaptation studies and may benefit society as a whole, even though this was not their intention. Commercial farmers have developed a number of innovative long-term adaptations.

- Purchasing farms in irrigation schemes to grow their own fodder; 45% of farmers interviewed by Steyn (2013) said they are purchasing animal feed from other regions;
- Insurance - a minority of farmers have insurance policies against extreme climatic events, and those who don't have disaster insurance cite the high cost.
- Applying for permits to build dams for water storage during droughts.
- Using technology such as moisture probes to save electricity.
- Eradicating alien plants to make space for larger pastures.
- Changing their farming practices, e.g. replacing forage crops with more drought-resistant crops, changing the planting dates of crops, farming with more heat-tolerant animals, practicing conservation farming, using low or no tillage, low chemical inputs and planting diverse pastures.
- Diversifying by becoming involved in nature and agri-tourism, which could motivate farmers to manage ecological infrastructure.

The forestry sector has embarked on an exist strategy (Figure 7), with more than 11 000 Ha being exited in the Wilderness catchments. These areas are being handed over to SANParks and Cape Nature, but a large proportion of it is not of high conservation value and the conservation organizations are concerned about the 'unfunded mandate'. Working for Water has embarked on an alien eradication strategy in collaboration with SANParks, who receives a large budget from them for alien plant clearing. Many of the local stakeholders are dissatisfied with the inefficiencies of Working for Water and the ineffectiveness of their alien plant management. Ratepayers are putting pressure on the municipality to maintain infrastructure, have regular meetings with them and are working on good relations. Coastal property owners are investing in 'hard' defenses against sea level rise and coastal surges, a cause of great concern to authorities due to the transfer of the problem of sand erosion to other areas or properties. Property owners along the Touw River have lobbied for rules to open the mouth when the water level in the Touw River exceeds 2,1 metres to protect their properties against flooding but creating new ecological and conservation problems.

Long term adaptations in societal interest (Quadrant D in Figure 10) hold the greatest promise for sustainable catchment management, especially if these are coupled with short term responses to prevent immediate deterioration. Examples include:

- Establishment of the Seven Passes initiative as a means to reduce inequality and crime, coupled with short term law enforcement.
- Planning and follow-up clearing with rehabilitation of areas invaded by alien plants, coupled with reactive clearing of new invasions.
- The establishment of the Garden Route Biosphere Reserve, coupled with the day to day management of existing protected areas.
- Determination of the Ecological Reserve, coupled with short term enforcement of water quotas.

- Development of the Eden Coastal Management Strategy, coupled with the enforcement of existing coastal management regulations and EIA processes.
- Formation of conservancies, coupled with enforcement of NEMBA.
- Establishment of new businesses and SMMEs to deal with ecosystem management and alien plant clearing, coupled with short term employment through public works programmes.
- Biological control of invasive aliens, coupled with manual removals and chemicals.
- Progress towards effective and vertically aligned catchment governance, e.g. stronger links with the Breede-Gouritz Catchment Management Agency; implementation of the recommendation of the river classification system and ecological reserve determination; formation of a Catchment Management Forum; development of a Catchment Management Strategy; while maintaining existing informal governance structures.

3.8 Adaptation pathways

By assessing the interplay between uncertainties, social connectedness or alternatively fragmentation, knowledge, awareness, capacity, motivation and responses, we are able to identify levers for action or intervention. In this way the research team would ultimately be in a position to raise participants' awareness of the consequences of their decisions (or, more often, indecision), the maladaptive traps ahead, and the opportunities associated with adaptive spaces (Figure 6).
Actions or levers co-identified by participants in a multi-stakeholder dialogue included:

- collective action through co-management and co-operative governance
- repair of riparian buffer zones
- managing invasive alien plants
- making use of good science to find solutions.

The priorities highlighted by participants were:

- Initiate an integrated strategic approach backed up by a management plan around collective action and common vision.
- Conduct ongoing research, communication and monitoring.
- Provide access to information and education to all stakeholders.
- Elect a credible champion to coordinate everything.
- Establish a forum or forums to address current catchment problems.
- Facilitate more dialogues.
- Restore riparian buffer zones and in this manner create jobs.

Participants were willing to experiment with innovative solutions, communicate and participate. This bodes well for the Kaaimans to Touw Forum, established in response to an identified need amongst stakeholders.

3.9 Conclusion

Our research has emphasised the importance of two mechanisms in facilitating the above transformation. First, in any stakeholder engagement process, it is important to engage with the prior knowledge of each stakeholder group and use that as a departure point for developing mutual respect and collective understanding among groups. Second, skilful facilitation seems to be crucial in mending social fragmentation and promoting collective action, especially where divides are deep and have long histories. Academics are important bridging agents and have to play this role. Our experience shows that action borne out of such a facilitated social process is likely to navigate out of the maladaptive space towards the adaptive space shown in Figure 6. Our team is committed to playing a long term knowledge bridging role in the Wilderness rivers and to transfer these experiences and insights elsewhere.

4 IDENTIFYING RISK HOTPOTS AND ASSESSING RISK

4.1 Co-identifying the key risks in the Eden district

This project has built on existing and ongoing stakeholder engagement and research in Eden over the last five years. As stated in the introduction, Eden was selected for local level engagement in order to better understand and address the impacts of increasing environmental risk associated with land use change and extreme weather events linked to climate change, and explore the role of ecological and infrastructure in mitigating some of the risks.

The focus on analysing and understanding the key risks in Eden at a district level was intentional as it aligns with various planning and decision making processes related to disaster management (e.g. Integrated Development Plans and Spatial Development Frameworks) and builds on good capacity to understand and manage risk within the district municipality. Further, in order to understand how risk emerges within a region, it is important to take a broader view of the system in order to identify areas or features that contribute towards risk (risk generating areas) together with areas where the impacts of the risk occur (risk receiving areas). Understanding the relationships between these areas and features (which often span municipal boundaries) enables the co-development of response strategies that can address underlying vulnerabilities.

In early February 2012, a brief survey initiated by the Project for Ecosystem Services (ProEcoServ) was implemented with a variety of stakeholders present at the Garden Route Initiative Plus Indaba. A key focus of the Indaba was bring diverse stakeholders in Eden together in order to facilitate knowledge exchange opportunities and build a community of practice for enhanced social-ecological resilience in Eden. A total of 47 participants from a variety of institutions (e.g. NGOs, local and national government departments, businesses and research institutions) engaged in issues related to the governance of natural resources participated in the survey (Sitas 2012). The survey found that the top three challenges of most concern in Eden related to invasive species, followed by freshwater security and human population growth (Figure11). Further, participants agreed on average that it is the responsibility of all institutions and individuals to work together in reducing environmental risk, boosting ecological infrastructure within Eden will help reduce risks, and that environmental risks in Eden are increasing (Figure 11) (Sitas 2012).

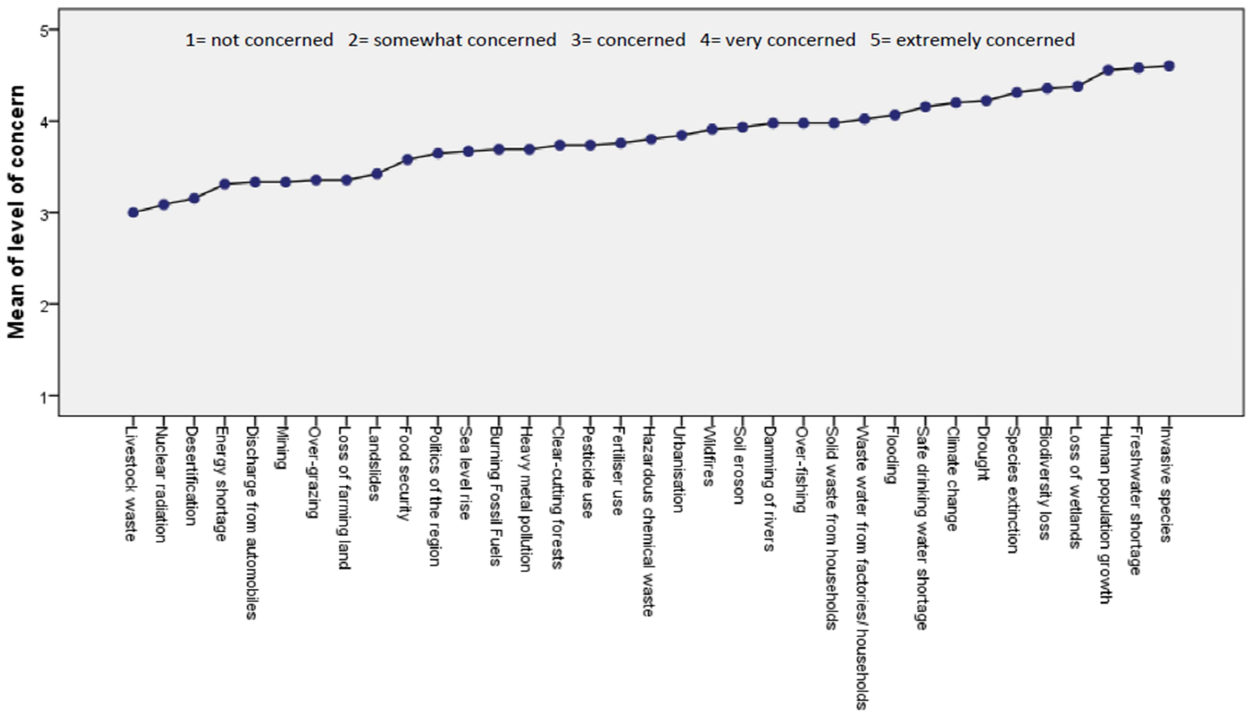

Figure 11. Key stakeholder concerns of emerging challenges in Eden.

The results of the survey, along with findings from studies that found key opportunities for enhancing the integration of environmental information in decision making though engaging with decision makers around issues related to ecosystem based risk reduction activities and disaster management (Sitas et al. 2014a & b), facilitated the progression of future work in the region.

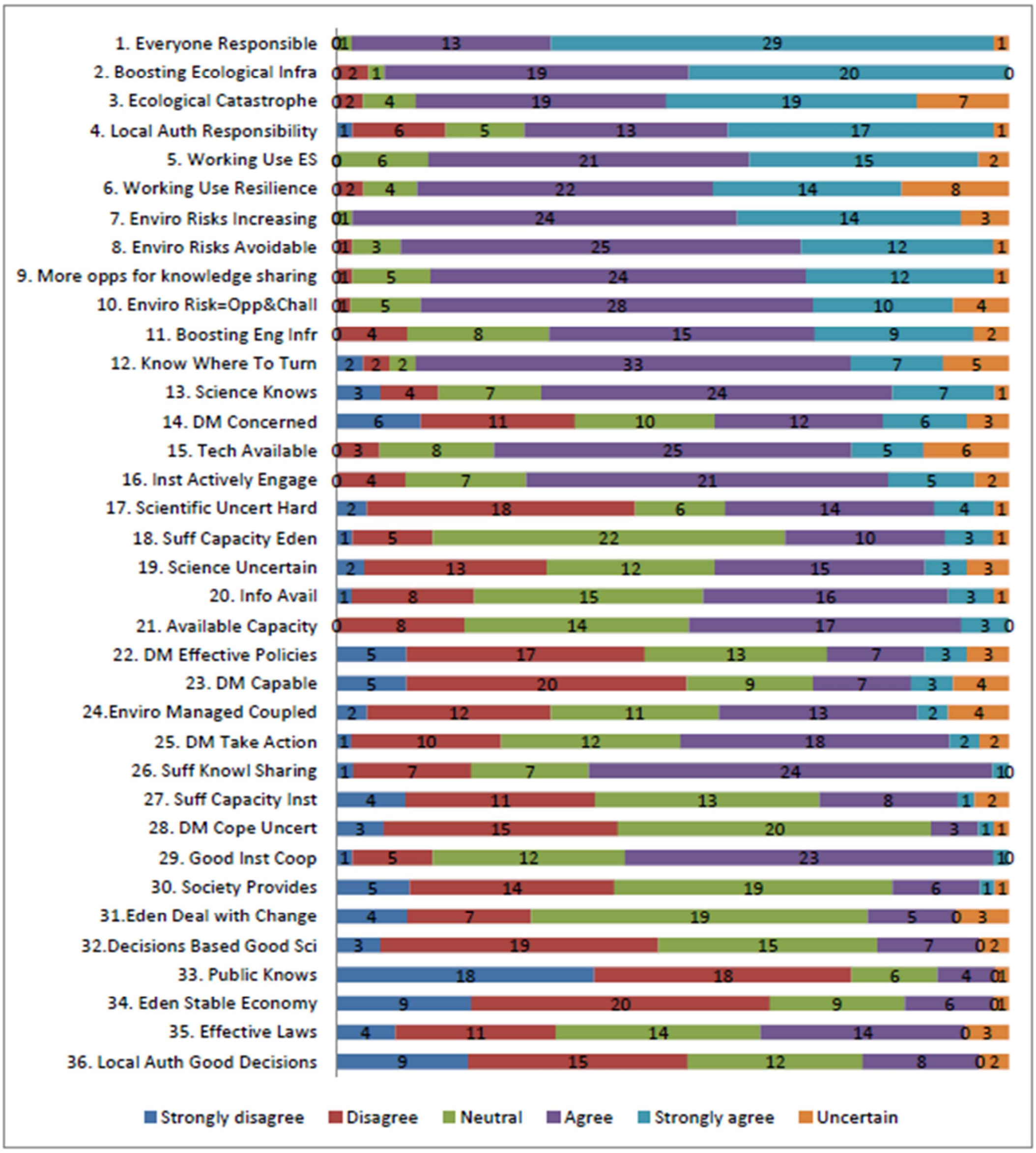

Figure 12. Chart highlighting levels of respondent agreement on a range of issues in Eden

Using a systems based approach, a number of key risk were identified which are highlighted in more detail in Nel et al. (2014) and Reyers et al. (2015). While presented in isolation below, the risks are interconnected in reality and require collaborative efforts in order to mitigate them.

4.2 Understanding the key risks

The varied topography and climatic conditions in Eden (see study area), the onset of climate change along with dense infestations of invasive alien plants have resulted in an increase in risk in Eden. Collaborative research in Eden focused on four main natural hazards and their associated risks, namely: floods, drought, fire and storm waves (Figure 13).

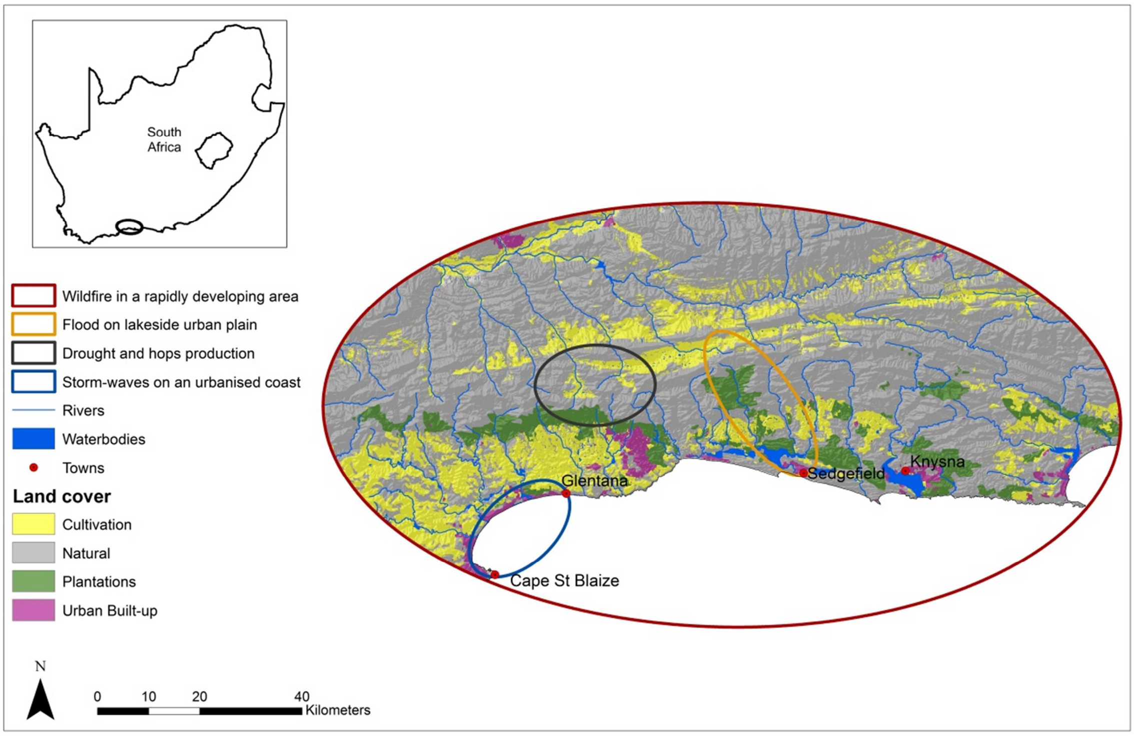

Figure 13. Key risks in Eden District related to flood, drought, fire and storm waves and the specificgeographic areas of engagement on these issues.

Flood risk

Eden is located in a transition zone between a winter and summer rainfall regime, with rainfall occurring throughout the year, but with peaks in March and October (Reyers et al. 2015). These peaks in rainfall often coincide with cut-off low pressure systems over southern Africa which are often associated with extreme weather events. Around one in five cut-off low events results in flooding and associated damages to the coastal areas of Eden (Holloway et al. 2012), which is often exacerbated by the steep catchments in the coastal areas resulting in high runoff and flash flooding (Nel et al. 2014). Early studies have shown that landscape drivers of run-off can halve the return period of a flood event, and that managing ecological landscapes (such as riparian buffer zones) is a key risk management and climate change adaptation mechanism (Le Maitre et al. 2011). Through a case study in a lakeside urban plain it was found that changes to plantation forestry management altered the 1:100 year flood events to a 1:80 year return period (Nel et al. 2014).

A new approach to mapping flooding hotspots for Eden has been trialled by PhD student Ilse Kotzee - see section 11.3 of this report which discusses this issue.

Storm wave risk

The southern Cape is particularly vulnerable to sea storms. It is already subject to large sea storms that cause flood damage and coastal subsidence, but this is predicted to become six times more frequent in the future (Theron et al. 2011). The most severe incidences of flooding overlap with the occurrence of large storm waves associated with cut-off low events which results in coastal flooding, especially if estuary mouths are closed (Reyers et al. 2015). The proactive management of estuary mouths (e.g. breeching estuary berms in extreme weather conditions) has been highlighted as important in managing flood risk in coastal regions. The degradation of shoreline ecosystems (e.g. beaches and dunes) increase the risk of large storm-waves by disrupting natural sediment transport processes which regulate landward migration of the shoreline, facilitate the recovery of beaches following storms and maintain shallow beach profiles that minimise wave run-up (Reyers et al. 2014). Restoration of the coastal fore-dune has been identified as a major management intervention to reduce present-day risk and to allow for adaptation to climate change.

An analysis of ecological infrastructure as it is perceived by development role players has been undertaken by MSc student Abigail Crisp – see section 11.3 of this report for further details.

Drought risk
Maintaining assurance of water supply is a critical aspect to the agricultural and urban sectors in the southern Cape, especially in dry season months. The degradation of certain riparian areas around sub-catchments in Eden can result in a reduced ability of landscapes to capture and store rainfall in soil, rock and organic material resulting in increased run-off and altered flow patterns (Reyers et al. 2015). Further, disruptions to riverine ecosystems ability to discharge and recharge groundwater can increase drought risk yielding lower base-flows in rivers and reducing surface water availability for irrigation in dry seasons (Reyers et al. 2015). Clearing invasive alien plants from riparian buffer zones is a key mechanism for managing this risk as it helps to restore base-flows that are otherwise used by invasive alien plants.

Fire risk
Large areas of Eden lie in the fynbos biome, a fire dependant and fire prone system where wildfires are common. Degraded ecosystems, for example landscapes heavily invaded with invasive alien plants disrupt the ability of healthy ecosystems to regulate the intensity, extent and occurrence of fires through altering interactions between fuel loads, connectivity, microclimate regulation, vegetation flammability and ignition sources (Reyers et al. 2015). Changes in climate are predicted to intensify the frequency and occurrence of wildfires, especially in dry, hot weather conditions and drought (Nel et al. 2014). Altered fire regimes and increased intensity of wildfires pose significant risks to areas in Eden with high population densities, especially those associated near large tracts of invasive alien plant stands (Nel et al. 2014).

Invasive alien plants
Intensifying many of the risks mentioned above are the threats posed by invasive alien plants, especially those located in riparian buffer zones. In Eden, the spread of alien invasive plants in riparian buffer zones poses a significant risk to water-based ecosystem services. Alien vegetation growth tends to denser and more vigorously than indigenous species due to increased evapotranspiration. This in turn reduces overall water yield for other uses and ecosystem services. Riparian invasions also suppress and replace native plant species but they are typically less stable during floods and the debris that is washed down can block infrastructure. Key invaders in this are Acacia species which fix nitrogen and some of this nitrogen leaches into the rivers, potentially aggravating eutrophication problems. Invasive alien plants also increase fuel loads, and are associated with the spreading of larger, more intense wildfires.

Additional risk issues of increasing concern
Not included in the main risks mentioned above, but of increasing concern in the southern Cape, are those risks associated with the eutrophication, the gradual accumulation of nutrients in waterbodies. As droughts and water overutilization reduce overall available water, there is increasing risk of nutrients to accumulate in river systems with reduced dilution capacity from adjacent intensive agriculture, as well as urban sewage runoff and degraded riparian buffer zones. Particular water quality issues have surfaced in the Groot Brak and Wilderness catchments. Reports of poor river water quality and planktonic algal blooms in lake systems indicate that lakes may be reaching certain tipping points and could become eutrophic.

While the focus of this section is to identify and map key risk hotspots in Eden, we also identified some factors within the broader enabling environment which if left unchecked could hamper future risk reduction activities, notably those related to the production and dissemination of knowledge related to risks in Eden, and integration of that information into decision making processes.

4.3 Synthesised learning - Risk as a boundary object

Building resilient landscapes by understanding the important social and ecological linkages that underpin vulnerability requires multi-stakeholder engagement processes that facilitate the co-production and exchange of knowledge. In order for research to be geared for action, careful attention needs to be paid to issues related to credibility, legitimacy and saliency and understanding the trade-offs associated with these issues (Cash et al. 2002). Here, boundary work (i.e. working at the "boundaries" between different knowledge types (e.g. practitioner and scientific)) is important, yet remains challenging given the different value systems, norms and mental models of different individuals (Mollinga 2008). Therefore, generating understanding of how knowledge is coproduced amongst diverse stakeholders with a particular focus on what factors might facilitate or impede knowledge production and exchange can assist in bridging the gap between research and action (Cowling et al. 2008).

Through the work in Eden, it was found that issues related to a lack of communication, including preconceived assumptions, entrenched disciplinary thinking and inappropriate language have the potential to disrupt knowledge production and exchange if not addressed in the early phases of engagement (Sitas et al. in review). Using a knowledge co-production approach based on social-ecological systems research greatly assisted with the development of shared knowledge on the contribution of ecological infrastructure for reducing disaster risk (Reyers et al. 2015), as did ensuring that the research was co-created by participants. The importance of effective knowledge brokering amongst communities of practice was also highlighted especially in relation to the promotion of systems thinking that is grounded in practice (Sitas et al. in review).

A significant finding of this study was the role that the concept of risk played in facilitating the boundary work that was required to coproduce knowledge for enhancing ecosystem management activities in Eden. Through a post-hoc thematic analysis of work carried out in Eden (Sitas et al. in prep), the multidimensional nature of 'risk' provided a common starting point for all stakeholders to engage in dialogue around ecosystem management issues in Eden, thus acting as a boundary concept (Mollinga 2008). The concept of risk was also very useful for configuring boundary objects (which are approaches or methods which enable action in the context of complex systems where information of the system is incomplete) through the use of 3 different integration strategies:

1. Analytical integration using risk-models as mediators (Process-based and statistical models used to develop risk analysis framework (Nel et al. 2012; 2014));
2. Integration using assessments which were risk based frameworks as learning and decision tools (social-ecological systems based approach for knowledge co-production (Reyers et al. 2015));
3. Participatory integration using processes and people to negotiate boundaries using a frame of risk (participatory engagement techniques e.g. participatory mapping)

The problem-driven nature of the research assisted with developing enabling boundary settings where institutions pooled resources in order to undertake joint problem solving activities (Sitas et al. in prep).

5 FINE SCALE IDENTIFICATION AND QUANTIFICATION OF ECOLOGICAL INFRASTRUCTURE MOST NEEDED TO ENHANCE RESILIENCE AND REDUCE THE ASSOCIATED RISKS

Whilst multiple levels of understanding of risk and stakeholder engagement with this issue, as well as identifying key area associated with managing this risk, were developed within Eden, this project provided further opportunity for developing a fine scale understanding of specific risk associated issues. This section focus on key risks associated with water supply: pollution and nutrient contamination, soil erosion and sedimentation, alien plant invasions and flood risk. We demonstrate the approaches we have taken in developing a fine scale understanding of the role of ecological infrastructure in reducing risks to the stakeholder with whom we have engaged. These risks are among the key natural hazards identified both for Eden (Nel et al. 2010) and within the Wilderness catchment (see section three of this report).

5.1 Developing a conceptual model of the wilderness catchment: Water quality issues and hotspots

Catchment level studies of water quality have found that it is very important to understand the spatial distribution of the biophysical features of the catchment and how they regulate and direct the flows of water and water quality (Basnyat et al. 2000; 2004; Maillard and Santos, 2008; Dabrowski, 2014). This involves developing a systems understanding of the natural characteristics of the water quality in the catchment, the location and kinds of change in land-cover and land-use practices and the consequences of this for water quality. This analysis describes and applies a simple, qualitative Water Quality Index to identify where the impacts of land-use practices in Wilderness river catchment are likely to be having their greatest impacts on water quality. Hence, the model highlights areas where water quality impacts are relatively high. These areas can then be assessed in more detail to test the models predictions and identify potential solutions. In our assessment we have used general information about the potential impacts of different land-use and land management practices to infer their impacts on water flows and quality. This study does not focus on water flows but does deal with the effects of changes in flows on water quality. We recognise that this general information may not accurately depict the farming practices in this catchment but they provide a starting point for discussions.

Methods used to identify water quality hotspots

The input data are basic modeling and comprise:

- An ordinal classification of a land-cover dataset based on the expected impacts on water quality likely to be associated with different land-cover types; in this case we used the updated GRI mapping
- An assessment of the relative impacts on the river sub-systems using the cumulative scores calculated for buffers of different widths around the river reaches

This method is still under development and testing with the aim of developing a simple but robust model that will allow the most affected river sub-systems to be identified and prioritised.

The water quality index approach was originally developed using the National Land Cover (NLC) Classification (Van den Berg et al. 2008) and was adapted for this study which was based on the mapping done for the Garden Route Initiative (GRI). The land-cover mapping for the GRI study did not use the 49 land cover classes defined for the NLC 2000 (Van den Berg et al. 2008) because it was focused more on the vegetation types and states. We have used three measures of the impacts: (a) the amounts of fertilisers likely to be applied to the land to maintain high yields, (b) the amounts of herbicides, pesticides and other chemicals applied or used; and (c) the degree of disturbance of the soil (e.g. cultivation, plantation clear felling). Each of the three factors affecting water quality was rated as low (no change from reference conditions), medium or high (scale 1-3) for each land cover class (see Figure 14). The three impact type scores were then multiplied to arrive at an overall water quality index (Table 2). The scoring and the classification are provisional and are based on some ordinal weights developed by the CSIR for assessing land-cover change impacts on water quality.

Table 2. Rating of the different land cover classes based on the potential impacts on the quality of the water in rivers based on surface water runoff or subsurface (groundwater). The ratings go from low (1) to high (3) and are based on information from water quality literature and not on measurements in this system.

Land cover class	Fertiliser (nutrients)	Chemicals	Sediment loss	Water Quality Index
Outeniqua Mountain Fynbos Complex (natural)	1	1	1	1
Outeniqua Mountain Fynbos Complex (degraded)	1	1	2	2

Outeniqua Plateau Fynbos (natural)	1	1	1	1
Outeniqua Plateau Fynbos (degraded)	1	1	2	2
Knysna Afromontane Forest (natural)	1	1	1	1
Knysna Afromontane Forest (degraded)	1	1	2	2
Goukamma Dune Thicket (natural)	1	1	1	1
Goukamma Dune Thicket (degraded)	1	1	2	2
Floodplain (natural)	1	1	1	1
Floodplain (degraded)	1	1	2	2
Lake	1	1	1	1
Dam	1	1	1	1
Forest Plantations (pines)	1	1	2	2
Forest Plantations (pines, rehabilitation)	1	1	2	2
Irrigated Farm (Pasture)	3	2	1	6
Irrigated Farm (Vegetables)	3	3	3	27
Irrigated Farm (Centre Pivot)	3	2	1	6
Irrigated Farm (Orchards)	3	3	2	18
Urban / Built-up (smallholdings)	1	1	2	2
Urban / Built-up (residential, formal suburbs)	1	2	3	6
Urban / Built-up (rural cluster)	2	2	2	8

The natural vegetation types, floodplain and lakes all get the lowest rating of one not because there are never any soils losses but because they are as low as they can be, a state generally termed the reference condition. Degraded natural vegetation was given a rating of two for sediment lass because there is generally a lack of ground cover under dense stands and the invasions have occurred in areas that were disturbed already. Forest plantations generally have limited soil loss except when clear felled, but there can also be soil loss from the roads, especially if the roads are not properly maintained. Irrigated pastures do have fertilisers applied to them and the cow manure adds additional nutrients but the use of chemicals is limited and the good grass cover limits sediment loss. Most of the centre pivots are for pasture but there are some that are partially or fully used for vegetable production as well (for this assessment we have assumed they are all on pasture). Long lived crops like orchards require fertiliser and pesticide applications but sediment loss is not high except when tilled for weed control and when replanted. Vegetable production is typically highly intensive, requiring the most fertilisers, chemical inputs and soil tillage so it gets the highest water quality index.

There was little indication that people living on small holdings in this area are practicing intensive cultivation but there are usually activities and other disturbances that can increase sediment losses. Many households living in formal urban areas have intensively cultivated gardens and there are many disturbed areas where soil loss is increased, especially in unpaved pavements and paths, ditches and other storm water channels. Petrochemical such as engine oils from the road surfaces and other sources are often a characteristic of urban runoff. The urban rural cluster class was developed for dense, settlements that have not developed to any formal plan and often include a mixture of standard houses and shacks. They often have unpaved roads and sparsely vegetated areas, informal workshops and other sources of nutrients, chemicals and sediment loss. Parts of the Touwsranten settlement fall in this class. Dams are more complicated, there is little impacts on water quality if the banks and earth walls are well vegetated. But dams retain sediments nutrients and chemicals and become polluted, and they function like sinks. We have not included this sink function in the water quality index at this stage but do discuss its implication later.

We then used a Geographic Information System (GIS) to create buffer strips at increasing distances (based on literature sources) from, the water courses (1: 50 000 rivers and streams) and calculated the mean index in the successive strips. The buffering technique is similar to that applied in the National Freshwater Ecosystems Priority Areas study (Nel et al. 2011). Four widths were used: 10, 20, 50 and 100 m on each side. A large body of research shows that, if the buffer strips are intact, there is a rapid decline in the potential impacts as the distance from the edge the successive strips to the river increases. We did this for each the water course subsections or reaches independently. This means that each reach is treated as though it was not connected to others. We know that this is not true but working out cumulative values is not a simple matter of addition so we have left this for future assessments. Most of the benefits are realised within a width of about 30 m so that land use changes at greater distances have relatively little impact. The end result is a map showing the reaches of the river systems in the catchment shaded according to their water quality indexes (Figure 2).

The river reach scores were then compared with data for the same reaches on chemical and microbial water quality sourced from studies conducted for the Gouwater project. A set of water quality sites was chosen for the this project (Petersen et al. 2015). The aim was to obtain information on how the river water quality changed from the headwaters, typically in reasonably intact natural ecosystems, to the lower reaches which were affected primarily by agricultural activities (Table 2). Two sites in the Wilderness catchment also have historical data. This data are available online from the Resource Quality Services website: www.dwaf.gov.za/iwqs/wms/data/WMS_pri_txt.asp and are updated regularly.

The river water quality index (WQI) ranges from about 1.6 which represents the natural state to 37.3 for the potentially most adversely affected river reaches which drain or pass between the irrigated vegetable fields on Mandalay (Figure 14). Most of the river reaches of the Touws itself and the Tierkloof are in an essentially natural condition except for the alien plant invasions in the lower reaches and tributaries of the Touws. The Bankies and Karmenaadjies have a WQI of 3.2 due to the presence of plantations and the small increase in sediment losses that plantations typically cause (Table 3). Much of the Duiwe River is situated in river valleys and gorges where the alien plant invasions, classified as having minimal impacts on water quality, do not affect the score. However, the upper reaches and tributaries are situated in pasture lands which raise the WQI to 9.5. The catchment of the Woodville is mainly natural vegetation, albeit invaded, and only its lowest reaches are influenced by being adjacent to irrigated pastures which raise the WQI to 8.4.

The highest mean WQI is found at the Langvleispruit where almost the entire catchment has been converted to dryland and irrigated pastures, followed by the Klein Keurbooms which also has been largely transformed. The maximum WQI for a reach is 37.3, which is the Klein Keurbooms tributary that drains the vegetable farm, while the vegetable farm reaches of the Langvleispruit have a WQI of 28.6. The low water quality indexes of the lower reaches of the Duiwe, Klein Keurbooms and Langvleispruit are due to their passing through natural vegetation areas in the river gorges characteristic of the coastal escarpment. The effects of the urban areas on the estuary are not known but are likely to be limited as shown by the moderate score. Many of the reaches pass through the floodplain wetlands that surround the lakes (e.g. Langvliespruit) which also may improve the quality of the water entering the lakes. One exception is the Duiwe River which has a deep channel though this wetland which limits the potential for enhancing the water quality. Based on their overall scores, the Klein Keurbooms and the Langvleispruit are likely to be the most affected by impacts on their water quality.

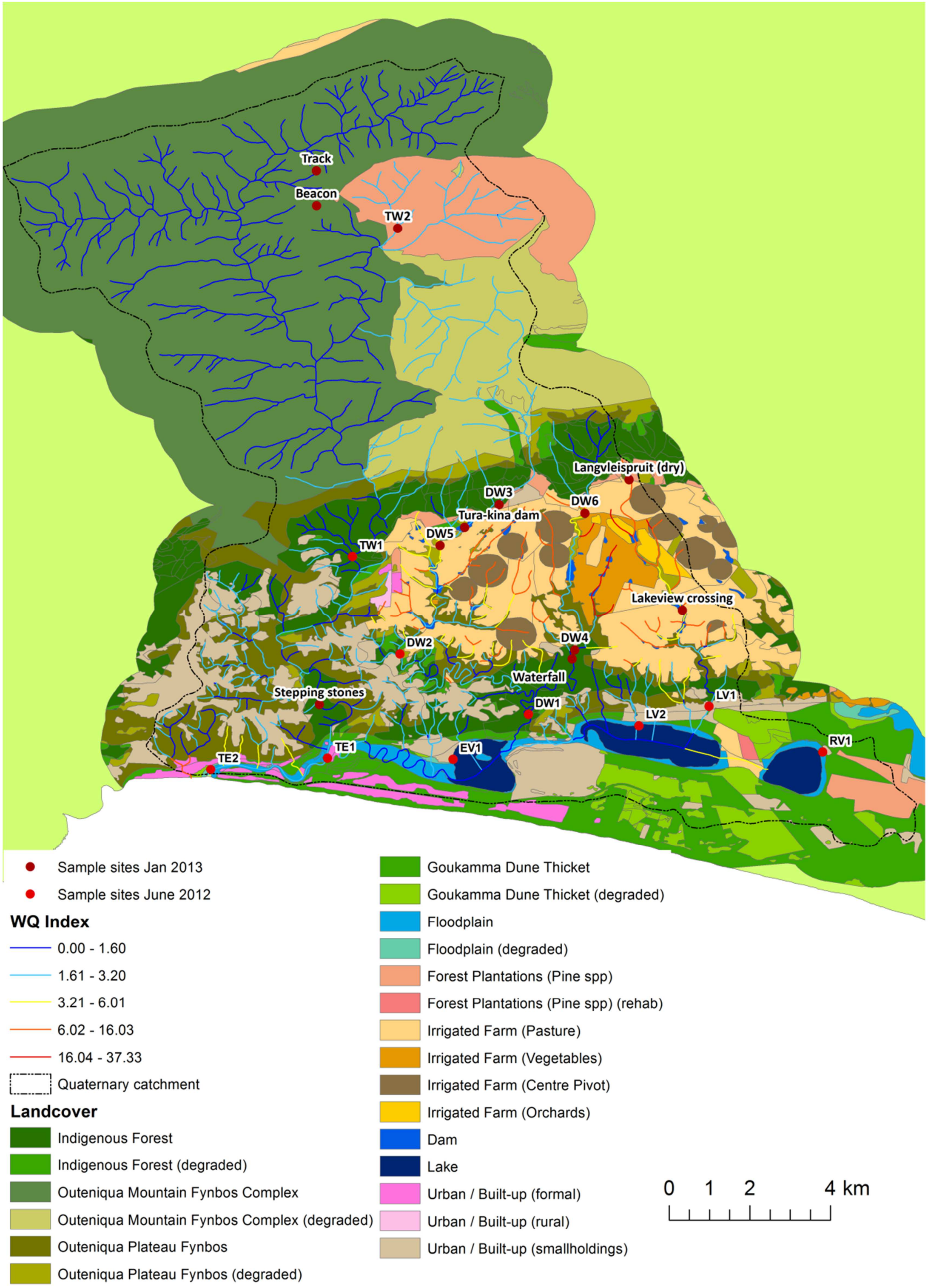

Figure 14. The river water quality index calculated from land cover impacts. Impact type scores as per Table 2. The water quality impact index is based on the potential for pollution of surface runoff or groundwater by toxic substances (e.g. pesticides), nutrients and increased sediment loss associated with the land use practices. The higher the score the greater the potential impact on river water quality.

The WQI values for the river reaches at the measurement sites (Table 3) do not compare well with the water quality measurements taken at those sites. The WQI at DW3 is lower than that at DW5 but DW6 is much higher than DW4 and DW2 and DW1 are at near natural values (1.6) although LV1 is a little higher. However, when the values for the river systems are examined, then the relationships between the WQI and the measured water quality are much clearer. The apparent discrepancies at the reach level are to be expected though when the WQI values for the different buffer widths of each reach are examined (Table 3). The WQI values show that the buffers on all these reaches are near natural, except for those for DW5 and DW6. So, most of these reaches themselves are in a reasonable condition, at least up to the maximum buffer width of 100 m. The differences from the measured values are primarily due to the WQI being reach-based and not cumulative, so that it does not reflect impacts on the reaches upstream of the one where the measurement site is located. What it does show though, is the reaches where the non-point sources of the measured impacts on those systems are likely to be located.

Table 3. Values of the Water Quality index (WQI) for the river reaches where the sampling sites are located.

Site	River name	Buffer strip (mean WQI)				WQ Index
		0-10 m	10-20 m	20-50 m	50-100 m	
TW2	Karmenaadjieskraal	1.71	1.88	1.76	1.77	2.81
TW1	Touws lower	1.00	1.00	1.00	1.00	1.48
DW3	Woodville	1.42	1.53	1.40	1.38	2.30
DW5	Woodville	2.33	3.61	3.67	4.24	4.47
DW2	Duiwe	1.00	1.00	1.00	1.00	1.59
DW6	Klein Keurbooms	2.80	4.50	4.94	12.85	5.58
DW4	Klein Keurbooms	1.00	1.00	1.00	1.07	1.59
DW1	Duiwe	1.00	1.60	1.40	1.80	1.93
LV1	Langvlei River	1.31	1.29	1.34	1.56	2.08

The river water quality index clearly highlights the location of the impacts on the Duiwe River system, and the substantial impacts on the Klein Keurbooms (e.g. DW4) and Langvleispruit where most of the catchments are under irrigation or vegetable cropping (Figure 14). However, the water quality index does not really explain the levels of pollution, in particular microbial pollution, observed at DW3 and DW6 which should be relatively unaffected as there is little evidence of concentrated human activity upstream. The water quality issues found at site DW6 appear to be due to leaking sewage, probably a leaking or overflowing septic tank at Beyond the Moon, but nothing has yet been found to explain the observations of microbial contamination at DW3. Site DW2 is interesting because, although it would be expected to be among the worst affected, the nutrient levels are not particularly high. On the other had the algal indicators clearly show that it is eutrophic. The dams, particularly the new dam just upstream, and the fact that it is not affected by vegetable growing may help explain the observed water quality at this site.

The index in its current form does not take the impacts of riparian invasions on the river's assimilation capacity or water quality, and this is something that could be improved. How much impact the invasions actually have on the ecosystems assimilation capacity is not clear because the natural riparian communities provide similar amounts of shade (Oberholster et al. 2013). However, there is evidence that Australian *Acacia* invasions change soil microbial communities (Jacobs et al. 2007; Slabbert et al. 2014) and they may also alter the benthic and streambed alluvial communities and nutrient assimilation processes. There are numerous farm dams on all these rivers which could play an important role by accumulating pollutants depending on how often they get flushed (for example by flood events). Initially we believed that the Langvleispruit rarely flowed because of the large number of dams but we now know that it does so episodically in winter, particularly flowing mid- to late-winter storms when previous rains have already filled-up the dams.

So far we have not taken the effects on the river flows into account. There are river flow gauges on the Touws and Duiwe rivers. The extensive irrigation in these sub-catchments has also significantly reduced the total runoff from this catchment, decreasing the dilution of the any pollutants entering the system from the cultivated areas. Preliminary calculations using rainfall:runoff ratios suggest that the pre-development runoff of the Duiwe was about 6.7 million m^3/yr compared with 0.96 million m^3/yr based on the flow gauge record (Le Maitre et al. 2015). The Touws River itself and its tributaries are relatively unaffected by the land-cover changes, mainly because the river valley is incised so that arable land is largely limited to the ridge tops between the stream valleys. The relatively good quality water, and the large proportion of the total quaternary catchment runoff it contributes (measured flow 13.1 million m^3/yr or 94% of the total) should help to maintain good water quality in the estuary itself.

The flows remaining in the Duiwe (including the Klein Keurbooms) and Langvleispruit river systems now are largely short-lived responses to high rainfall events and some return flows from the irrigated lands. These very drastic flow reductions have two main effects. The extraction of the water means that it is no longer available to dilute the polluted water from the irrigated lands. It also means that there is virtually no water flowing through these systems and then through the lakes so that there is very little flushing and dilution of the water in the lakes. On the contrary, the inflows are likely to be simply adding to the accumulation of pollutants in the lakes. Our data show that the inflows to the lakes are relatively unpolluted which suggests that either the water quality from the irrigated lands is much less polluted than we expect, or the pollutants are being retained in the dams. The algal blooms evident in the dams and a report of livestock deaths after drinking dam water suggest that pollutants, particularly nutrients, are accumulating in the numerous dams in these river systems.

The Langvleispruit should be given the top priority for restoration of adequate river buffers as it is probably having the greatest impact on the water quality in this part of the Wilderness lake system. The fact that it drains into the upper part of Langvlei is important, because its effects can be circulated throughout the lake system down to the estuary. However, it is important to note that the water from this river passes through about 600 m of reed beds before reaching the vlei so much of the nutrient load could be assimilated by this natural wetland system. This is not the case with the Duiwe which has a clear channel all the way into Eilandvlei. Provided the main nutrient transport mechanism from fields to rivers is overland flow, the creation and restoration of adequate river buffers should help to reduce the impacts on water quality. If the main transport mechanism is sub-surface flows than reductions at source are needed.

The Wilderness rivers have extensive invasions which should be given priority for clearing, particularly along the heavily affected Duiwe and Langvleispruit, so that the rivers limited natural assimilative capacity can be restored. Clearing of these invasions should be given priority as they also result in substantial flow reductions and reduce the dilution capacity of the system (Le Maitre et al. 2015). In addition, studies have shown that (riparian) invasions by black wattle increase soil nitrogen levels (Ehrenfeld, 2010; Le Maitre et al. 2011; Slabbert et al. 2014; Fourie, 2015) and may increase influxes of nitrogen into the system via the groundwater (Jovanovic et al. 2009).

This assessment does not take point discharges or discharges from overloaded and overflowing septic tank systems, which are concentrated in the urbanised areas in the lower catchments but also occur from time to time at Touwsranten (De Lange and Mahumani, 2013), into account. They would undoubtedly alter the picture somewhat, especially in the river sub-systems which drain directly into the estuaries.

5.2 Assessing land cover change effect on water yield and nutrient and sediment retention

Soil erosion and nutrient enrichment of water bodies have major implications for water quality, the economy and human welfare (MEA, 2005; Hulme, 2006), as described and demonstrated in the conceptual model for the Wilderness catchment. Soil erosion is the detachment and transportation, by wind or water (Morgan, 1995), of soil material such as organic matter, minerals and nutrients, at a rate that exceeds soil formation (Visser et al. 2004). While this is a natural process, it is often enhanced by human activities such as overgrazing, cultivation and the removal natural vegetation (Snyman, 1999). It is a major form of land degradation (Le Roux et al. 2008) and has been described as one of the world's greatest environmental and agricultural problems (Skidmore, 1994), with numerous significant ecosystem service repercussions. The loss of topsoil has both immediate effects on soil fertility, soil moisture and productivity as well as additional distant impacts down valleys or down wind. Deposited sediments can cover areas with silt and sand, clog reservoirs and canals, increase pollution with suspended sediments affecting water use and health (Morgan, 1986; Flügel et al. 2003). The processes and conditions of natural ecosystems responsible for soil retention, enhancing infiltration, reducing wind speeds, and thereby preventing erosion, are critical ecosystem services in agricultural areas (O'Farrell et al. 2009b). The benefits of these services extend beyond the area where the service is provided, with food and water security for the broader population directly linked to this service. Soil erosion has been estimated to cost the country around R 2 bn annually (Hoffman and Ashwell, 2001).

Eutrophication, or the gradual accumulation of nutrients in waterbodies, is also becoming an increasing concern in the southern Cape. As droughts and water overutilization reduce overall available water, there is increasing risk of nutrients to accumulate in river systems with reduced dilution capacity from adjacent intensive agriculture, as well as urban sewage runoff and degraded riparian buffer zones. The risk of eutrophication in the Wilderness catchment is being investigated in detail in an associated CSIR three-year project (C. Petersen, CSIR, Stellenbosch, pers. comm., 2012). Sediment retention and nutrient retention in the landscape are vital services within this catchment. Understanding and identifying sites which are playing a key role in providing these services (ie. they have important ecological infrastructure) is important for developing future management and land-use plans within the catchment. Furthermore it is important to understand the actual trade-offs that are being made when decisions regarding change in land-use are made. In addition, modeling these key services allows us to assess the potential benefits of restoring areas or introducing alternative land managemnt pratcices so as to enhance service delivery. We used the InVest modeling approach and software provided by the Natural Capital Project to undertake this fine scale analysis (Talls et al. 2008). Below we describe the data collation processes followed in developing models that enable us to identify critical ecological infrastructure and test future land use scenarios.

Methods used to identify key areas of nutrient retention

The nutrient retention service model is focused on estimation the quantity and value of nutrients (in this case nitrogen) retained by ecosystems – therefore their water purification function. The InVest modeling approach (Talls et al. 2008) consists of three separate steps or stages: (1) calculating the annual average runoff from each land parcel, (2) determining the quantity of pollutant retained by each parcel on the landscape, (3) and valuation. We describe each of these stages in turn below.

Runoff and water yield

The runoff water yield component of the model determines how much water is available for human use once evaporation, infiltration and plant water use have been taken into consideration. Annual water yield for each pixel, in the landscape of interest, is derived using the Budyko curve and annual average precipitation. The following equation (1) is used to determine this annual water yield:

$$Y_{xj} = \left(1 - \frac{AET_{xj}}{P_x}\right) \cdot P_x \qquad 1$$

Where:
Y_{xj} = Annual water yield
AET_{xj} = the annual actual evapo-transpiration on pixel *x* with LULC *j*
*P: sub:'x'** = the annual precipitation on pixel **x*.

For the evapotranspiration portion of the water balance, an approximation of the Budyko curve (see Zhang et al. 2001) has been derived. The equation (2) below is used to derive the evapotranspiration.

$$\frac{AET_{xj}}{P_x} = \frac{1+\omega_x R_{xj}}{1+\omega_x R_{xj}+\frac{1}{R_{xj}}} \qquad 2$$

Where:

R_{xj} = the Budyko Dryness index on pixel *x* with LULC *j*, defined as the potential evapo-transpiration to precipitation (Budyko 1974) (see the equation below).

W_x = a modified dimensionless ration of plant accessible water storage to expected precipitation during the year, and is determined by the equation (3) below.

$$\omega_x = Z\frac{AWC_x}{P_x} \qquad 3$$

And where:

AWC_x = the volumetric (mm) plant available water content (the soil texture and effective soil depth define AWC_x which established the amount of water that can be held and released in the soil for use by a plant. This is estimated as the product of the difference between field capacity and wilting point and the minimum of soil depth and root depth).

Z is a seasonality factor that presents the seasonal rainfall distribution and rainfall depths.

The Budyko drynesss index, where Rxj values that are greater than one denote pixels that are potentially arid is defined as follows in the equation (4) below.

$$R_{xj} = \frac{k_{xj} \cdot ETo_x}{P_x} \qquad 4$$

Where:

ETo_x = the reference evapo-transpiration from pixel x

kxj = the plant (vegetation) evapo-transpiration coefficient associated with the LULC *j* on pixel *x*.

ETo_x represents an index of climatic demand while k_{xj} is largely determine by *x*'s vegetative characteristics.

Quantity of pollutant retained
The objective of this step is to determining the quantity of pollutant retained by individual parcels of land or pixels, and in so doing calculate the broader landscape level effects. The model does this by calculating the amount of pollutant that is exported from each pixel based on export coefficients. Export coefficients are input variables into the model derived from literature and expert knowledge. (See equation 5 below). As these coefficients are average fluxes a hydrological sensitivity score is included allowing for variation between areas to be incorporated.

$$ALV_x = HSS_x \cdot pol_x \qquad 5$$

Where:

ALV_x is the adjusted loading value at pixel x

polx is the export coefficient at pixel x

HSSx is the Hydrological Sensitivity Score at pixel x (see equation 6).

The Hydrological Sensitivity Score *(HSS)* is calculated as:

$$HSS_x = \frac{\lambda_x}{\overline{\lambda_W}} \qquad 6$$

Where λ_x is the runoff index at pixel x calculated using the following equation below, and $\overline{\lambda w}$ is the mean runoff index in the watershed of interest.

$$\lambda_a = \log\left(\sum_U Y_u\right) \qquad 7$$

Where:

$\sum_u Yu$ = the sum of the water yield of pixels along the flow path above pixel x

This series of equations enables us to determine the amount of nutrient retained by each downstream pixel, as surface runoff moves the pollutant towards a stream. Each pixel along a routed downstream path retains a calculated amount of pollutant dependant on its cover type and its ability to retain the pollutant. The model then accumulates the load retained from the pixel values to both the sub-catchment and the catchment level.

Methods used to identify key areas of soil retention

The key objective of the sediment modeling approach used here is to calculate the average annual soil loss from a gridded land surface and determine how much of that soil may end up in a specified dam. In doing so, we estimate the ability of each parcel of land to retain sediment and assess the costs of removing sediment on an annual basis. Here, land use or land cover is a key determinant of this soil loss.

The model estimates potential soil loss based on geomorphological and climate conditions (Talls et al. 2008). It uses the universal soil loss equation (Wischmeier and Smith 1978; Renard et al. 1994) to estimate soil average soil loss in tons per hectare on an annual basis.

USLE = R.K.L.S.C.P

Where:
USLE = the spatial average soil loss in t/ha·yr
R = the rainfall runoff erosivity factor in MJ.mm/ha·h·yr
K = the soil erodibility factor in t/ha per unit R
L = the slope length factor
S = the steepness factor
C = the cover management factor
P = the support practice factor

To estimate the ability of vegetation to retain soil in place for a given pixel (or single area in our gridded surface), the model assesses each pixel according to its erosion rate with its current vegetation cover compared to its erosion rate if no vegetation was present (bare soil). Bare soil is simulated by removing the C and the P factors from the equation. Vegetation also traps sediment that has eroded upstream. This is not considered within the USLE equation and the model includes this factor by routing all the estimated erosion downstream via a flow path. This enables estimation of how much sediment eroded on all pixels will be trapped by downstream vegetation based on the ability of vegetation in each pixel to capture and retain sediment. The model also determines the total sediment load exported that reaches the stream from each pixel in the landscape. Finally, the total retained sediment is calculated as the sum of the sediment retained by the pixel itself and the sediment retained through routed water flow

We have also collated the water quality site and index data and integrated these into the model to enhance the nutrient and soil retention outputs. Table 3 captures this synthesis highlighting the nutrient loads and filtering values for all the land classes within the Wilderness catchment. These adjustments have enabled us to more accurately pinpoint key sites of ecological infrastructure. We present four examples of this below (Figure 15a-d) highlight key sites nutrient (N and P) and soil retention, and water yield. The Ecosystem services maps generated in this processes and have been summaries here according to their maximum values for each of the land use classes within each of the 1112 sub-catchments. The results were then classified into five categories (Kourgialas and Karatzas 2011) using the standard deviation classifications and Jenks natural breaks (ESRI, 2010). Here the green shaded values indicate where ecological infrastructure is playing a key role in providing these services.

Table 4. Land cover classes in Wilderness linked to nutrient loads and retention weighting. The data are based on the mapping done for the Garden Route Initiative and updated in 2013, N and P load values for each of these land classes (Ha-1 yr -1) and the filtering or retention weighting (expressed as a weighting between 0-1) for both nutrients and soil.

Description of land cover	**N load**	**P load**	**P retention**	**N retention**	**Sediment retention**
Dam	10	1	0.9	0.5	0.9
Degraded Floodplain	440	150	0.2	0.25	0.8
Degraded Goukamma Dune Thicket	1000	150	0.2	0.25	0.8
Degraded Knysna Afromontane Forest	1000	150	0.2	0.25	0.8
Degraded Outeniqua Mountain Fynbos Complex	440	150	0.2	0.25	0.6
Degraded Outeniqua Plateau Fynbos	1000	150	0.2	0.25	0.6
Forest Plantations (*Pine* spp)	1000	100	0.75	0.4	0.6
Forest Plantations (*Pine* spp) (rehab)	440	50	0.2	0.25	0.6
Irrigated Farm (Centre Pivot)	8650	1500	0.75	0.2	0.8
Irrigated Farm (Orchards)	5190	1200	0.5	0.3	0.6
Irrigated Farm (Pasture)	5190	1200	0.5	0.3	0.8
Irrigated Farm (Vegetables)	16090	1200	0.2	0.2	0.4
Lake	10	1	0.7	0.1	0.9
Natural Floodplain	10	1	0.9	0.5	0.8
Natural Goukamma Dune Thicket	440	20	0.75	0.35	0.8
Natural Knysna Afromontane Forest	440	20	0.75	0.35	0.9
Natural Outeniqua Mountain Fynbos Complex	440	20	0.75	0.35	0.9
Natural Outeniqua Plateau Fynbos	440	20	0.75	0.35	0.9
Urban / Built-up (residential, formal suburbs)	1520	190	0.25	0.15	0.85
Urban / Built-up (rural cluster)	1000	100	0.25	0.15	0.85
Urban / Built-up (smallholdings)	1000	100	0.25	0.15	0.85

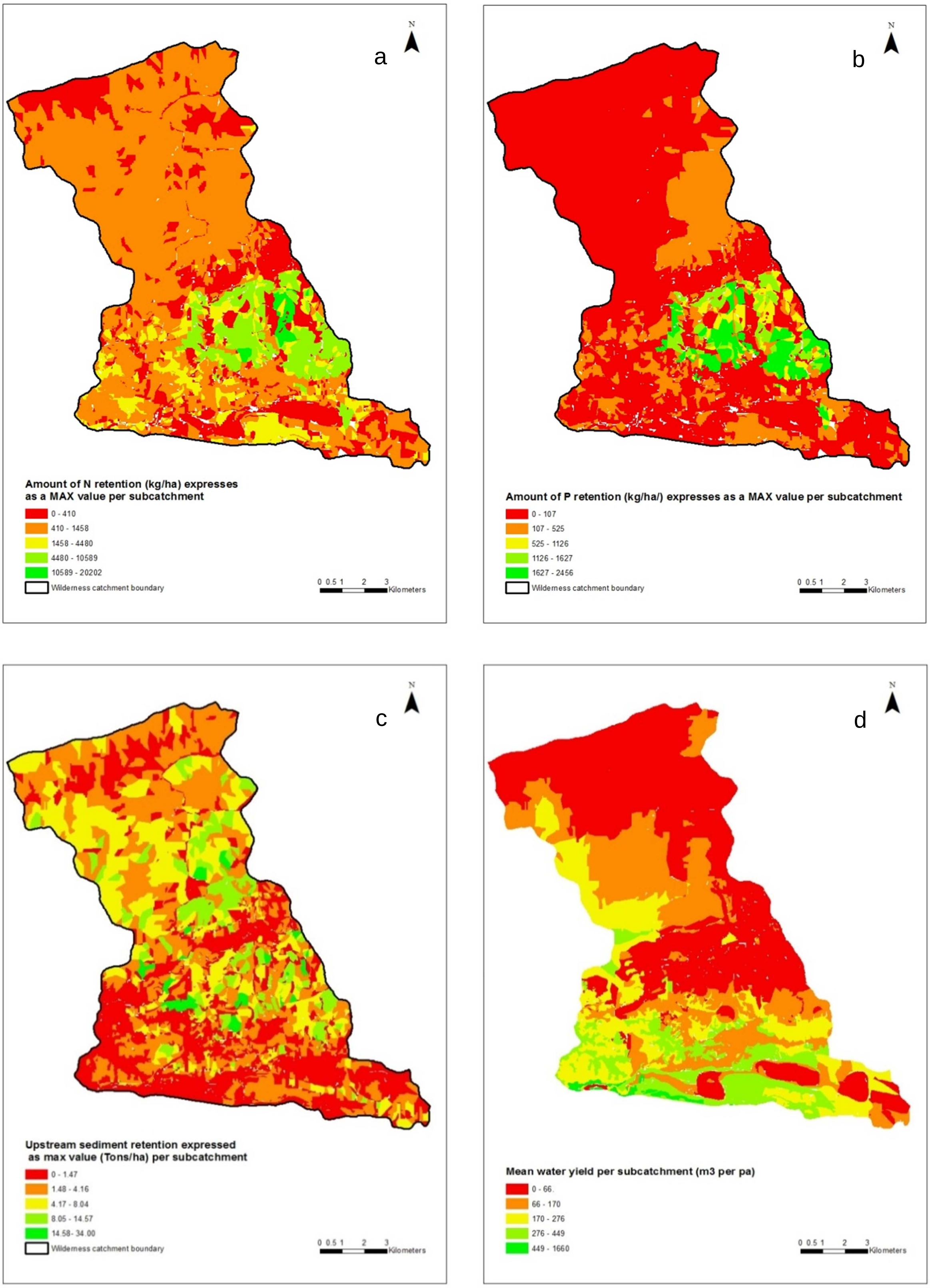

Figure 15. Fine scale examples of ecological infrastructure mapped for the Wilderness catchment. (a) The maximum amount of N (kg/ha) received from upstream sub-catchments and retained within the catchment. (b) The maximum amount of P (kg/ha) received from upstream sub-catchments and retained within the catchment. (c) The maximum amount of sediment tons/ha) received from upstream sub-catchments and retained within the catchment. (d) The mean water yield per sub-catchment (m^3).

5.3 Assessing invasive alien species and water flow reduction effects

Invasive alien plants (IAPs) have a major impact on biodiversity, ecosystem services, agriculture, forestry, the economy and human welfare (MEA, 2005; Hulme, 2006). Alien plant invasions are known to change community structure and processes; increase fuel loads and change fire regimes and modify stream flows (Richardson et al. 2007). Invasions can further affect flood patterns, water table levels and soil moisture conditions (Tickner et al. 2001). One of the greatest threats to ecological integrity and water resources in this area is the spread of IAP species, which reduce water availability by virtue of the fact that they utilise more water than the naturally occurring vegetation (Le Maitre et al. 1996; Dye and Jarmain, 2004). Within the Wilderness catchment we are understanding how best to manage this key driver, so as to lessen its negative impacts, particularly on water resources. Below we describe the approach taken in modeling invasive aliens (both species and density) within the sub-catchments in the Wilderness catchment. This model allows us to determine within a stakeholder workshop, where the maximum gains can be achieve in clearing opperations within this catchment. This will enable stakeholders to plan and determine both approaches to clearing as well as where benefits can be generated.

Methods used to identify high water use areas

The main input layers for this analysis consisted of: (1) sub-catchments, (2) updated land cover (Van Den Berg et al. 2008; Vlok et al. 2008), (3) updated GRI invasive alien plant species and (4) Mean Annual Runoff (Midgley et al. 1994; Middleton and Bailey 2009). The land cover map was used to assign a natural or transformed category to each land cover class based on literature and expert inputs. The natural and transformed area in each of the study area sub-catchments was then calculated. The natural category includes essentially pristine natural areas and areas in which the majority of natural functions and processes were perceived to still be operating. Natural water bodies (e.g. lakes) and areas with scattered alien vegetation but not in densities that were estimated to prevent natural ecosystem functioning were also classified as natural. The transformed category includes areas where alien vegetation had become quite dense such as along rivers, artificial water bodies (i.e. dams) as well as cultivated and built-up areas. The condensed areas for all the alien species present in each of the sub-catchments in the study area were calculated. We then rescaled the 1 x 1 minute MAR grid cell resolution at a 60 x 60 m resolution to determine the mean MAR (mm/yr) for each of the sub-catchments. This was followed by coding the sub-catchments either as dryland or riparian using improved 1:50 000 river arcs as a selection criteria. In addition, groundwater availability in each of the sub-catchments was assessed. Groundwater containing sub-catchments were coded as such utilizing the floodplain area from the 1: 250 000 local geology data layer. We then refined the species list, made the necessary unit conversions and assigned flow reduction factors (FRFs) (Table 5) to all the remaining invasive alien plant species. A set of reduction flow factors was developed for the 28 taxa mapped by Kotzé et al. (2010) based on the species attributes and data on the measured water-use of some of the invading species. This set has since then been extended to all the 300+ species on the NEM: BA list (Le Maitre et al. 2013).

Table 5. Invasive alien plant species and their flow reduction factors, Wilderness (after Le Maitre et al. 2013).

Species	Flow reduction factors
Acacia cyclops	0.86
Acacia melanoxylon	0.90
Acacia saligna	0.86
Cestrum laevigatum	0.86
Eucalyptus spp.	0.72
Hakea spp.	0.78
Lantana camara	0.90
Leptospermum laevigatum	0.86
Paraserianthes lophanta	0.86

Pinus spp.	0.57
Rubus spp.	0.72
Sesbania punicea	0.86
Solanum mauritianum	0.90
Wattle spp.	0.90

Finally, the flow reduction (FR) for all the species present in each sub-catchment was calculated to acquire the total flow reduction per sub-catchment per year (i.e. also expressed as a percentage). This was done using the following formula:

FR = FRF x MAR (m3/ha) x multiplication factor x species condensed area (ha) (Le Maitre et al. 2013)

A multiplication factor was introduced because the water use of riparian plants can exceed the MAR from the adjacent dryland areas. If the planning unit was riparian, the multiplication factor was 1.5. If not, it was adjusted to 2.0 for dryland planning units and 1.2 for groundwater planning units. All the above mentioned computations were done using ARCGIS 10.1 (ESRI, 2010) software as well as MS Excel 2010.

Table 6 clearly shows that *Pinus* spp., *Hakea* spp., *Wattle* spp. and *Acacia melanoxylon* predominate in the Wilderness (Touws) river catchment. Hence, these IAP species use most of the available surface water in the study area. Overall, the analysis indicated that invasive alien vegetation use 13% of the annual runoff each year. However, this amounts to 4.2 million cubic metres per annum which is 9% of the yearly water demand for the Gouritz Coastal sub-area of which this quaternary catchment forms part off (DWAF, 2003). Figure 16 further demonstrates that high to very high water use by IAPs are common to the upper and bottom left hand side of the Wilderness catchment. This trend is also mirrored in the updated GRI invasive alien plant species data (Table 6).

Table 6. Invasive alien plant summary statistics, Wilderness river catchment.

Species	**Condensed area (ha)**	**Flow reduction (m^3)**	**% Mean Annual Runoff (m^3)**
Acacia Cyclops	42.88	69161.71	0.22
Acacia melanoxylon	134.07	424068.56	1.32
Acacia saligna	7.84	11909.64	0.04
Cestrum laevigatum	0.01	18.79	0.00
Eucalyptus spp.	87.70	154657.41	0.48
Hakea spp.	601.40	930614.37	2.89
Lantana camara	1.68	4510.54	0.01
Leptospermum laevigatum	0.99	1420.18	0.00
Paraserianthes lophanta	0.04	68.20	0.00
Pinus spp.	961.60	1294745.45	4.03
Rubus spp.	4.26	8174.53	0.03
Sesbania punicea	0.23	526.73	0.00
Solanum mauritianum	2.31	6348.90	0.02
Wattle spp.	499.90	1389720.20	4.32
Total	2344.92	4295945.21	13.36

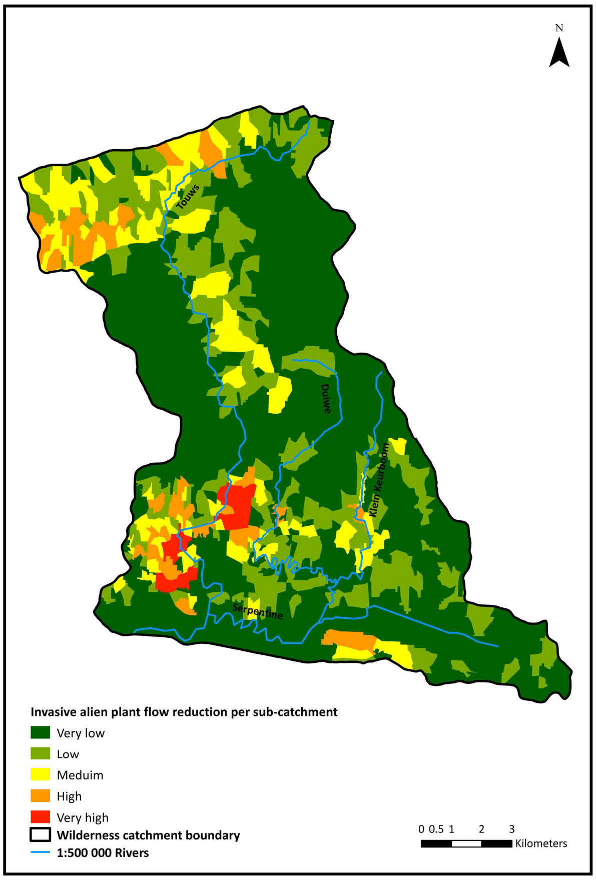

Figure 16. Invasive alien species water use per sub-catchment, Wilderness river catchment.

5.4 Future scenarios associated the restoration of ecological infrastructure

A useful way of helping stakeholders understand and appreciate model outputs is to demonstrate how changes in modeled systems as a result of key drivers are doing to impact of the ecosystem service they are ding to receive. Scenario development is a useful way of creating this broader awareness, allowing stakeholders and managers to determine the future desired conditions and states which they would like to work towards once this systemic understanding have been achieved.

Scenarios for enhanced sediment and nutrient retention

In initiating this processes and demonstrating the potential of scenario development we developed four example scenarios as a starting point for discussions with stakeholders, relating to management and restoration for soil retention and nutrient retention services. These were 1) Business as usual – current condition maintained, 2) Restoring all degraded areas within the catchment – large scale intervention, 3) Allowing all catchments of degrade – no intervention nor maintenance, 4) Restoring all those areas adjacent to or abutting river catchments – returning riparian areas to natural conditions (Figure 17).

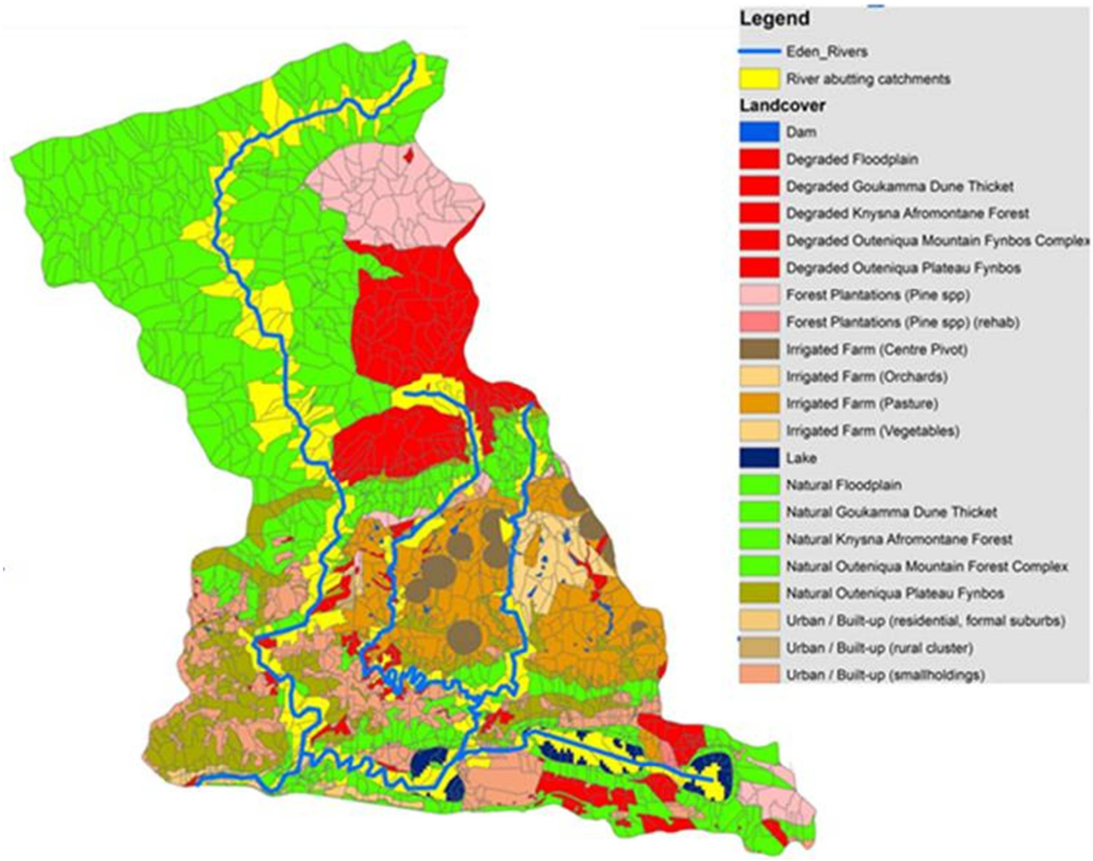

Figure 17. Land cover condition (natural, degraded, plantations, cultivated and urban), river systems and catchment areas.

Running models according to these scenarios parameters demonstrate both the gains that could be made through restoration of ecological infrastructure and the losses which could be experienced as a result of rampant unchecked degradation (Figures 18, 19, 20). The models indicate that volumes, in the order of 160 000 kg of nitrogen, 200 000kh of phosphorous and 300 tons of sediment can be retained in the landscape simply by restoring riparian buffer strips (Figures 18, 19, 20).

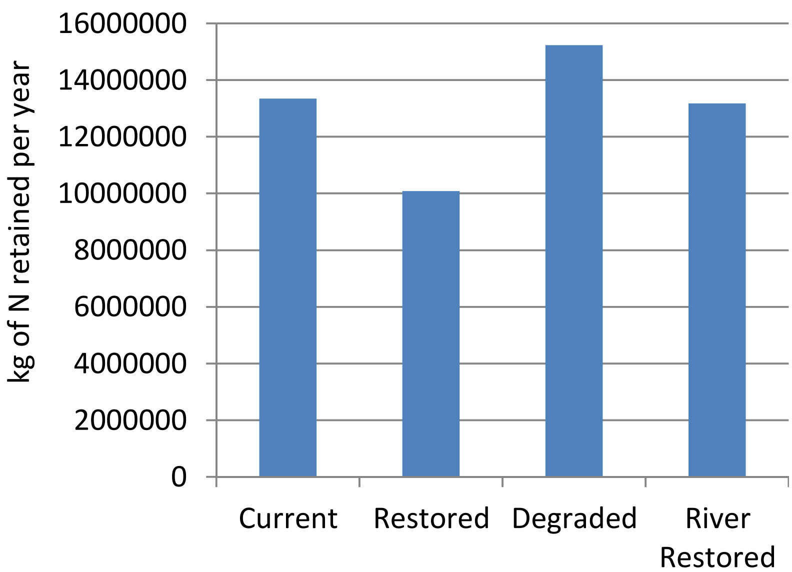

Figure 18. The mass of nitrogen retained per year (kg) for each of the scenario land use type interventions, current conditions, restored degraded areas, allowing all areas to degrade and restoring riparian strips.

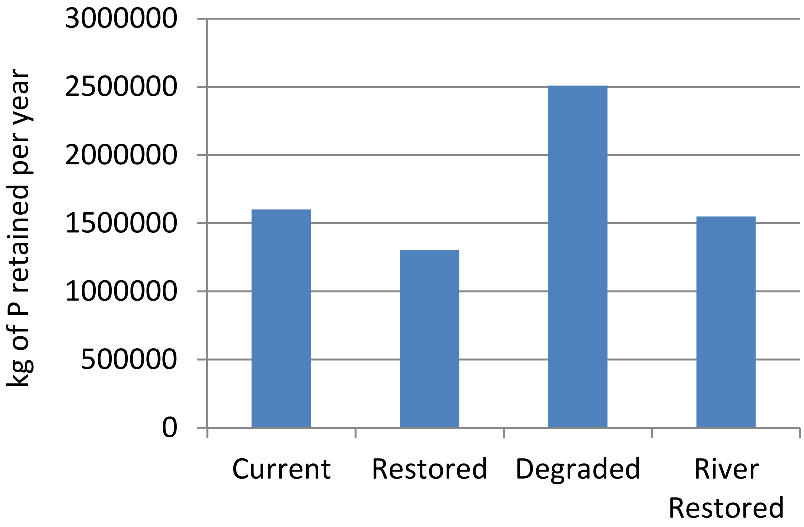

Figure 19. The mass of phosphorous retained per year (kg) for each of the scenario land use type interventions, current conditions, and restored degraded areas, allowing all areas to degrade and restoring riparian strips.

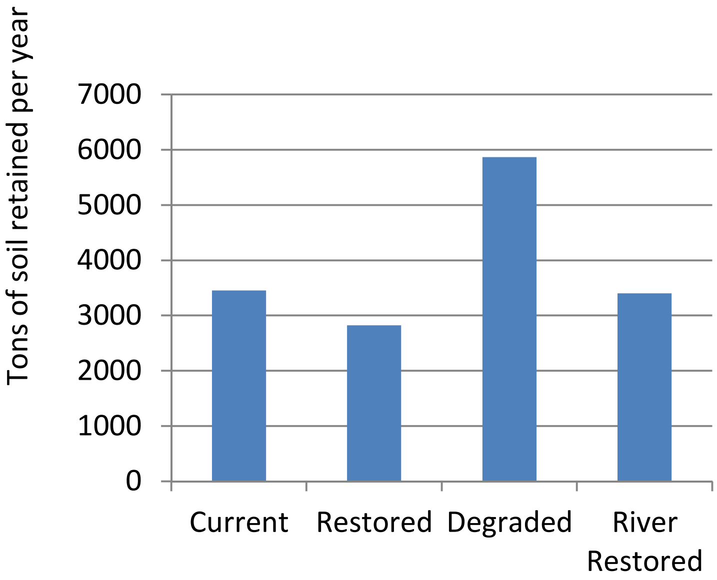

Figure 20. The mass of soil retained per year (tons) for each of the scenario land use type interventions, current conditions, restored degraded areas, allowing all areas to degrade and restoring riparian strips.

Scenarios for enhanced water provision

We also developed three example scenarios relating to alien plant invasion levels and how these translated into % water flow reductions. The scenarios were: 1) Buisness as usual – current condition are maintained, 2) Allowing wattle species to invade all areas of natural vegetation, 3) Reducing wattle invaded areas to only 5% of their current level of invasion – a maintenance level.

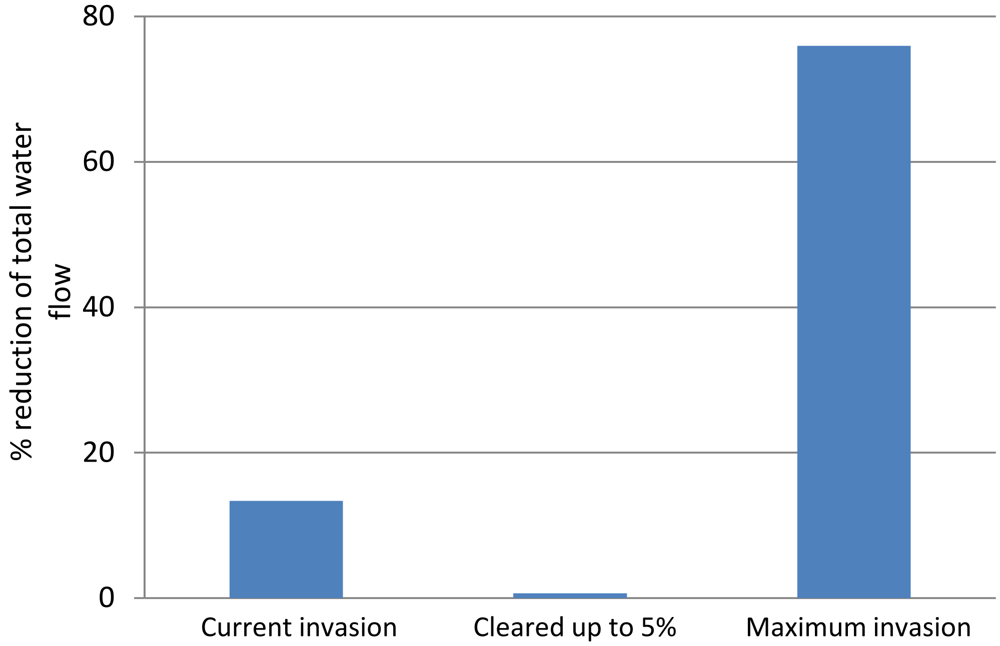

Figure 21. The percentage reduction of water flow as a result of invasion by wattle species, expressed according to three scenarios: current levels of invasion, clearing invasion so that only 5% of current invasion remains, and maximum invasion were all natural area are invaded.

This scenario driven analysis indicated the potential volumes of water that will be foregone if invasion is not kept in check, with a 78% reduction in flow anticipated in these areas (Figure 21). Furthermore it demonstrates than reducing wattle invasions to a 5% level will result in approximately 15% more water being released from catchments. This is significant in this area which is under severe water stress.

6 A RESILIENCE APPROACH FOR IDENTIFYING ENVIRONMENTAL RISKS AND RESPONDING TO THESE THROUGH THE RESTORATION AND MANAGEMENT OF ECOLOGICAL INFRASTRUCTURE AND REGULATING SERVICES

6.1 Introduction

The concept of resilience has proved a popular lens through which to analyse complex social-ecological systems. Through adopting a resilience perspective, research processes focus on producing knowledge on the capacity of a social-ecological system to cope with future change and surprises, without changing in undesirable ways (Folke 2006; Anderies et al. 2004). Ecological infrastructure and ecosystem services are fundamental to this capacity (or resilience) of social-ecological systems through their role in supporting and regulating life support systems, as well as in providing the adaptive basis for coping with gradual and sudden change (Folke et al. 2004; Adger et al. 2005; Díaz et al. 2006; Mace et al. 2012; Mace et al. 2014;

Elmqvist et al. 2003). A resilience perspective therefore not only helps clarify the social-ecological system and its components in the knowledge co-production process, but also the central role of ecosystem services in these systems.

Moreover, a resilience perspective shifts the focus of system analysis and decision-making from prediction, forecasting, and stability to knowledge, policies and decisions that acknowledge both gradual and sudden unpredictable change, and that manage the capacity of systems to cope, adapt and shape change (Folke 2006). Adopting a resilience perspective in social-ecological systems analysis and management is therefore more likely to identify development choices that are designed for changing and unpredictable environments (Chapin et al. 2010; Walker et al. 2002; Adger et al. 2005)

The concept of resilience has seen particular traction in vulnerability assessment and adaptation planning in the area of climate change and extreme events (Turner, Kasperson, et al. 2003; Adger 2006; Brown & Westaway 2011; Nelson et al. 2007; Schwarz et al. 2011; Vogel et al. 2007; Chapin et al. 2010). While often mistaken for opposite sides of the same coin, vulnerability and resilience are different, but complementary and related concepts, with distinct disciplinary origins, methodologies, scales of analysis and traction in practioner communities (see Turner 2010; Miller et al. 2010; Cutter et al. 2008). Turner et al. (2003) make clear that vulnerability is a property of a social-ecological system dependent on several elements including exposure (nature and degree to which the system experiences stress) and sensitivity (degree to which a system is affected by stress) which ultimately determine the degree to which a system is susceptible to, and unable to cope with, adverse effects (Adger 2006). Resilience and vulnerability thus share their focus on coupled social-ecological systems, shocks and stresses to the system, and capacity of the system to adapt.

In the conceptual frameworks developed by Turner et al. (2003) and Chapin et al. (2010) for the assessment and management of vulnerability, the links between stresses, social-ecological components (including ecosystem services), sensitivity, vulnerability, and the system's resilience or ability to cope, respond and adapt to impacts are made clear. Further, these frameworks prove useful in constraining a potentially broad analysis of general resilience (capacity to cope generally with unknown shocks), to a narrower focus on specified resilience (resilience considered to be of value in the region to the identified shocks and changes (Walker et al. 2009; Carpenter et al. 2001; Miller et al. 2010).

As Chapin et al. (2010) make clear, adopting a resilience approach to vulnerability assessment aims to minimize the system's exposure to stresses, as well as to reduce social-ecological sensitivities through sustaining ecosystem services and human wellbeing in vulnerable areas. Through adopting this approach, vulnerability assessment and management shift from reactive responses to observed impacts, to proactive strategies able to adapt to and shape change (Chapin et al. 2010). The resilience perspective helps clarify the importance of ecosystem services in determining and reducing system sensitivity and vulnerability to stresses, as well as their importance in design and implementation of responses to cope with and adapt to change (Turner, Matson, et al. 2003). It therefore offers a potential route to integrate knowledge on ecosystem services into decision making and action in the management of vulnerability, extreme events and climate change.

The resilience analysis participatory approach developed by Walker (2002) outlines a process to co-produce knowledge on the resilience of a system and how it might be increased in the light of known and unforeseeable future change. Its strong focus on ecosystem services, as well as its ability to integrate existing quantitative models and datasets on ecosystem services, makes it relevant in efforts to co-produce ecosystem service knowledge for decision making. The approach builds on a long history of theoretical development in the area of complex social-ecological systems and resilience, as well as a diverse set of methods for the participatory assessment of complex systems, people and nature. The approach has since been applied in a number of research and decision-making contexts in various settings from water management, marine conservation, agriculture and disaster management (O'Farrell et al. 2008; Maynard et al. 2010; Wang et al. 2012; Hughes et al. 2005), has been further developed into new frameworks, approaches and guidelines (e.g. (Cumming et al. 2005; Resilience Alliance 2010), and has subsequently seen wide use in various decision-making contexts (http://www.resalliance.org/cdirs/raprojects/index.php /0/browse). However, as with many participatory approaches, evaluations of the impacts and outcomes of the use of the approach remain largely undocumented in the peer-review literature (Blackstock et al. 2007; Ruckelshaus et al. 2013).

6.2 An approach for identifying and responding to risk

We adapted the four-step participatory process outlined by Walker et al. (2002) for analysing and managing the resilience of social-ecological systems. We narrowed the broad approach of analysing "general" resilience set out in Walker et al. (2002), to a more specific focus on social-ecological vulnerability, sensitivity and exposure to extreme events drawn from the vulnerability assessment frameworks of Chapin et al. (2010) and Turner et al. (2003).

This narrowing to a focus on "specified" resilience to known extreme events was done in all the stages of the approach limited and limited the process, data, models and responses mostly to ecological infrastructure and regulating ecosystem services, and their social and ecological features and drivers, relevant to extreme events. We tailored this approach based on our experience and learning in the Eden district and to a lesser degree our work in the Wilderness catchment. In doing so we drew extensively from the experience and learning emerging from four key publications here, Nel et al. (2014), Reyers et al. (2015), Sitas et al. (in review), and Sitas et al. (in prep). These Eden focused studies focused on risk related issues studies (drought, flood, storm-waves, and fire) and documented stakeholder engagement approaches and outcomes. These stakeholders, from the private and public sectors, were motivated to form collaborative research projects to discover the causes of these risk events and ways of reducing their impacts.

The four step framework and approach presented below (Figure 22) is a synthesis of their approaches and findings integrated with Walker et al. (2002), Chapin et al. (2010) and Turner et al. (2003), into a repeatable method for identifying environmental risks and responding to them. This participatory approach works with stakeholders to identify important system attributes (Step 1), and possible future trajectories of the system (Step 2), as a basis for analysis of system resilience (Step 3), and ends with an evaluation of implications for policy and management (Step 4).

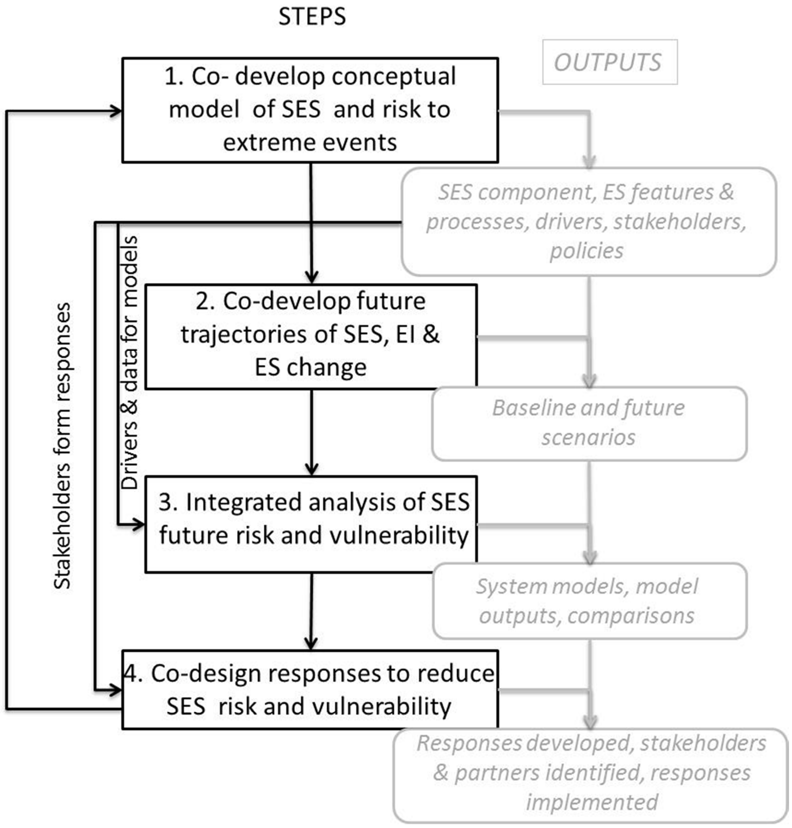

Figure 22. Outline of the four-step resilience analysis approach, derived from the work risk work of Nel et al. (2014), the co-development work of Reyers et al. (2015), in the Eden district, highlighting the aim and outputs of each step, as well as the interactions between steps. The approach is adapted from Walker et al. (2002) and tailored to a narrower focus on vulnerability, sensitivity and exposure to extreme events as outlined by Turner et al. (2003), and Chapin et al. (2010).

Step 1 Co-develop a conceptual model of risk and vulnerability

In Step 1 of the approach the co-development a conceptual model of the social-ecological system is undertaken with stakeholders (Figure 22). In this step the focus in on the development of a conceptual model of social-ecological vulnerability - spatially, temporally and systemically - through a description of exposed social and ecological elements, and conditions that determine sensitivity to a specific stress or extreme event (Turner, Kasperson, et al. 2003). Because of the importance of ecosystem services in determining system sensitivity to stresses, it is vital that in this step effort is dedicated to integrating the ecosystem features, processes and their drivers of change relevant to ecosystem services into the conceptual model. This can be done using a combination of participatory approaches, including interviews, workshops, reviews of literature and data from research and practice, policy analysis, aerial photographs and maps, and collaborative field trips (see Nel et al. 2014; Reyers et al. 2015).

Through this process, new stakeholders should be identified for future engagement, as well as necessary knowledge and datasets for subsequent steps. This step needs to have a broad inclusive focus with regards to co-developing knowledge of the social and ecological components and interactions within each system relevant to identified stresses and impacts. Co-produced knowledge of the main drivers of change in the system, and separating those that are controllable or can be managed (e.g. land use) from those that are not / cannot (e.g. climate change) is a necessary key outcome of this step.

Step 2 – Co-develop scenarios of vulnerability

Step 2 of the approach aims to co-develop and compare scenarios of vulnerability with in the social ecological system in question. Focus here must be on making clear the role and the relative importance of ecological and social components, and the impacts of changes in these, on the future vulnerability of the social-ecological system (Figure 22). The drivers of change identified in the Step 1 should be used in developing a set of scenarios. This set of scenarios can be broad and linked to a variety of social and biophysical drivers of change identified in Step 1, but should remain manageable. Walker et al. (2002) recommends a set of between three to five scenarios). In the Eden study area Nel et al. (2014) developed a baseline scenario of current or natural ecosystem condition, and has two scenarios which examined moderate and severe changes to ecosystem features of relevance for ecosystem services. For comparative purposes they also developed two scenarios relating to future climate change based on the A2 SRES scenario of enhanced anthropogenic forcing.

Step 3 – Analyse system resilience for scenario's

Step 3 is focussed on analysing the resilience of the system by developing and using a range of models and input data useful for exploring, quantifying and demonstrating differences between future scenarios and their impacts on the system's vulnerability to extreme events. . In the Eden studies highlighted in this report, quantitative process-based and statistical modeling approaches were used to quantify changes in vulnerability measured as a change in intensity of an extreme event impact across the developed scenarios (see Nel et al. (2014), Reyers et al. 2015). Walker et al. (2002), however, make clear that there are a wide diversity of qualitative and quantitative approaches for use in this step. Whist this is a fairly technical step, it should also be participatory, involving stakeholders in the choice, testing and use of the models and scenarios.

Step 4 – Co-develop response strategies

Step 4 involves taking the co-developed knowledge of the system and using this in co-designing of responses needed to mitigate the impacts of extreme events in the system. This step requires the use of priority controllable drivers of change identified by the models to decide on necessary actions and outcomes, and the relevant stakeholders responsible for managing the drivers and implementing the actions. The types of actions and responses such as the restoration of ecological infrastructure at key sites, such as coastal fore-dunes and riparian buffer strips need to be identified here. As is often the case (especially in developing countries), the lack of capacity and resources within responsible institutions, as well as their fragmented nature across sectors, may undermine the success of some responses. Engagement with higher level projects, such and the Natural Resource Management programmes of DEA, may be away around this issue. In this final step efforts must be focussed on going beyond just identifying who is mandated (but often unable) to manage the drivers to design interventions needed to building the additional capacity, support and connections for the responsible institutions, and identify possible partners with resources and knowledge to implement these interventions. The conceptual system model identified in the first step is useful in highlighting some of these other groups involved and potential interested partners for the co-design and implementation of responses and on the ground actions.

6.3 Conclusion

Developing the knowledge and action to respond to the impacts of extreme events is not a simple task. This broader resilience approach make clear the systems nature of vulnerability, and the importance of focus on ecological infrastructure and ecosystem services within these systems in determining societal sensitivity to extreme events. The participatory resilience approach that we present here is however built upon the successes in co-developing new capacity, knowledge and learning, as well as catalysing new investments and initiatives within studies that have taken place in the Eden area (see Nel et al. 2014, Reyers et al. 2015, Sitas et al. in prep). The methods and approaches suggested within each of these steps have proved effective within the study area at integrating knowledge about ecosystem services both into the way stakeholders frame extreme event causes and responses, and the options considered by stakeholder for managing these events. Knowledge integration was made evident in the list of social and ecological features co-developed by the stakeholders in Eden, and increased awareness of the importance of ecosystem services in the area revealed in in a survey of decision-makers in the case studies (Sitas et al. 2014a), as well as by new actions to invest in and manage ecosystem services which flowed out of these projects such as fore-dune restoration actions (see Nel et al. 2014, Reyers et al. 2015).

Nel et al. 2014 and Reyers et al. 2015 that an integrated understanding of the social-ecological system and its vulnerability can be developed among a broad range of stakeholders using a resilience approach to co-production. This approach supports strongly integrated learning between researchers and practioners, where communication, translation and mediation were fundamental processes of the interaction, supported by intermediary (boundary) organizations (usually non-governmental organizations in the case studies) able to create and sustain mutually beneficial problem-solving activities (Fazey et al. 2013; Fazey et al. 2014; Cash et al. 2003; Buizer et al. 2010). This “boundary work”, in turn, provided the necessary credibility and legitimacy needed to support proactive strategies to manage and reduce system vulnerability (Berkes et al. 2003; Turner 2010). By moving to a broader reframing of the social and ecological determinants of sensitivity, vulnerability and resilience, the role of ecological infrastructure and ecosystems and their services were made visible (Simonit & Perrings 2011).

7 SOCIAL GOVERNANCE CAPACITY FOR SHARED RESPONSES

7.1 Background

The current era is being referred to as the Anthropocene, bearing testimony to the dominance that the human species has gained on Earth and our widespread modification of ecosystems at local to global scales (Crutzen, 2006). Typical of complex and unpredictable systems (see Cilliers et al. 2013), feedbacks from this human influence is revealing a number of unintended consequences. Foremost, unprecedented loss of biodiversity and associated ecosystem services now threatens the ability of Earth to sustain the ideals and options of modern-day societies. Moreover, threshold effects aided by synergistic interaction and positive feedbacks between system components can abruptly and irreversibly transform ecosystems into states that may be both undesirable and unknown to human experience (Barnosky et al. 2012, Rockström et al. 2009). It has become acutely important to address the root causes of human-driven ecosystem change and to improve general stewardship of biodiversity and ecosystem services.

Inappropriate knowledge systems are regarded as one such root cause for impeding the ability of societies to respond to problems of unsustainability (Cash et al. 2003). The ways in which scientific research produces, validates and disseminates information are central to the discourse on the appropriateness of knowledge systems for addressing the complex challenges of sustainability. Evidence suggests that when people are closely involved in knowledge production, they are more likely to view the resulting knowledge as credible, salient, and legitimate and to adopt such knowledge for implementation (Cash et al. 2003). Credibility refers to the scientific robustness of the arguments and outputs, salience deals with relevance to user needs, and legitimacy represents the extent to which the information is perceived as fair, unbiased, and respectful of all stakeholders.

Achieving relevance and particularly legitimacy poses a challenge to traditional scientific practice because it implies that scientists are not only masters of relatively closed knowledge systems but also active participants in open knowledge systems. Knowledge systems are made up of agents, practices and institutions that organize the production, transfer and use of knowledge (Cornell et al. 2013). In open knowledge systems, many agents from across different institutions (including science and policy communities, resource users, funders of research, wider society, and business) are connected through formal or informal relationships to dynamically produce, transfer and use knowledge to bring about specific actions for sustainable development (Van Kerkhoff and Lebel, 2006, van Kerkhoff and Szlezák, 2010).

At the very core of all of these features of transdisciplinary research, therefore, is the expectation that people from a variety of backgrounds and interests will learn together through collaborative problem solving and innovation. This has led to an interest in social theories of learning…

In an open learning system, the perceptions, understandings and values of participating stakeholders evolve, and coevolve, as they engage in a process of mutual learning that is grounded in some practical application (Cornell et al. 2013). From a sustainability perspective, such learning can be deemed effective if it results in new and shared understanding as well as collective action among stakeholders towards improved governance/management of human-environment interrelations. In this context, sustainability can be viewed as an emergent property of knowledge and understanding produced through social learning. It follows that systems transformations may depend on how well we can design and maintain inclusive learning processes.

In this section we look at the role that researchers can play in designing and maintaining open and inclusive learning processes to promote a sustainable future. We first introduce a few concepts that provide a philosophical foundation for understanding mutual learning across diverse stakeholders within a social-ecological system. We then present a framework for use by researchers to guide them in designing and facilitating system-wide learning interventions. We use this framework to reflect on the learning that has taken place during the course of this project and to retrospectively suggest aspects of this project might have been done better from a learning perspective. We conclude with generic insights that could be considered in the design of similar projects.

7.2 Key concepts

Knowledge co-production and boundary work

Knowledge co-production is defined as "*the collaborative process of bringing a plurality of knowledge sources and types together to address a defined problem and build an integrated or systems-oriented understanding of that problem*" (Armitage et al. 2011). The process of knowledge co-production encompasses working iteratively and interactively toward collaborative learning, shared understanding of key concepts, and coevolution of common purpose and action. The work is transdisciplinary in nature and facilitates the exchange and co-production of knowledge not only between scientific disciplines (multi- and interdisciplinary research) but also between science and stakeholders from a variety of non-scientific knowledge domains (transdisciplinary research) (Young et al. 2014). Such an engaged approach helps uncover complementarities and create synergies across diverse knowledge systems. This generates an enriched picture of an issue of concern, which serves as a legitimate starting point for multiple stakeholders to participate in producing further knowledge (Jasanoff, 2004, Tengö et al. 2014).

Exchange of knowledge between diverse knowledge systems is challenging and often characterized by lack of mutual understanding and tensions that arise from differing views of what constitutes credible, salient, and legitimate knowledge (Cook et al. 2013). **Boundary work** has been suggested as a means of managing these tensions. Originally conceived to explain how scientists intentionally defended the boundaries between science and non-science (Gieryn, 1983), boundary work is now also applied as a means of creating permeable knowledge boundaries that satisfy the needs of multiple social groups (Jasanoff, 2009, Clark et al. 2011). The right permeability should allow meaningful communication across boundaries while guarding the functional integrity of contributing knowledge systems (Bijker et al. 2009). The growing scholarship on boundary work (Guston, 2001, Van Kerkhoff and Lebel, 2006, Mollinga, 2010) suggests that such work will promote uptake of research through facilitating meaningful participation of relevant stakeholders in issues framing and knowledge co-production.

Boundary work is commonly mediated by boundary spanners (Cash et al. 2003), boundary organizations (Parker and Crona, 2012), or bridging organizations (Hahn et al. 2006). These individuals, teams, or organizations are perceived as neutral and are trusted by the relevant parties (Berkes, 2009). They are skilled at mobilizing resources required for collaboration on issues of common interest, creating arenas for inter-organizational learning, trust building, and conflict resolution (Hahn et al. 2006).

Transdisciplinary research and social learning

Transdisciplinary research is increasingly being proposed as a mechanism for facilitating new and shared understanding as well as collective action among diverse but interdependent parties. In sustainability science, transdisciplinary research aims to overcome knowledge fragmentation with respect to complex social-ecological problems. Although the term "transdisciplinarity" can mean many different things (Jahn et al. 2012), its central features in a sustainability context include mutual learning and collaboration among diverse stakeholders, i.e., scientists, citizens, policy makers and resource managers, who are committed to solving complex social-ecological problems (Funtowicz and Ravetz 1993, Gibbons et al. 2004, Russell et al. 2008, Hirsch Hadorn et al. 2010, Mobjörk 2010, Roux et al. 2010). Transdisciplinary research makes science and decision making interactive through the co-production of knowledge with society (Max-Neef 2005), and success is often deemed to be a function of the degree to which science, management, planning, policy, and practice are interactively involved in issue framing, knowledge production, and knowledge application (Reyers et al. 2010, Roux et al. 2010). The resulting coevolution of understanding and alignment of purpose makes transformational change through transdisciplinary research a real possibility (Pennington et al. 2013).

The mutual learning orientation of transdisciplinary research overlaps with the academic field of social learning. **Social learning** has indeed become a central theme in natural resource management (Cundill and Rodela, 2012). As a philosophy it has enjoyed broad application, and perhaps as result the concept is characterised by somewhat vague definition. As an example, social learning that forms part of adaptive management can be highly structured, based on scientifically designed experiments, and primarily taking place amongst scientists and managers. In the co-management literature, social learning tends to be more inclusive of all parties that interact with the same resource. These parties deliberate over problems in a long-term self-organising process, and may generate the collective ability to direct their social-ecological system onto a more sustainable trajectory (Cundill and Rodela, 2012).

7.3 Framework for transdisciplinary learning

The above concepts provide a theoretical lens for framing some of the dynamics that relate to learning across knowledge systems. From here onwards, we will refer to this type of learning as transdisciplinary learning, to mean a form of social learning where actors from the domains of science, management, planning, policy and practice learn together about a complex socio-ecological issue. The project team acted as boundary spanning agents to mediate social learning and associated co-production of knowledge among relevant actors. The anticipated outcome of transdisciplinary learning is coevolution of understanding, alignment of purpose and harmonized action (Roux et al. 2010), i.e. capacity for a shared or collective response.

While facilitating transdisciplinary learning to improve our capacity to collectively respond to a changing world may sound like a most desirable purpose, it may not be intuitive for prospective researchers to prepare themselves to participate in, or facilitate, such transdisciplinary learning. Furthermore, acknowledging that "transdisciplinary learning" is a complex and context-specific process in itself, it would be futile to compile or attempt to follow an "implementation manual" for enabling such learning. As alternative, we provide a heuristic framework that could be used by researchers as guidance when navigating through emerging and interacting patterns of change across the transdisciplinary knowledge landscape. The framework is structured around three questions, namely who to learn with, what to learn about and how to learn.

Who to learn with?

Scientific researchers are generally rewarded for learning with other scientists in their field, because such learning may lead to papers and impact in the discipline that they represent. Such intra-disciplinary learning is usually relatively efficient because of a uniform vocabulary (jargon) that exists within each discipline. In contrast, transdisciplinary research necessarily involves learning with researchers from other disciplines as well as with actors from outside science. Such learning is not necessarily proficient because researchers may have to slow down their own learning in order to learn with and from actors who represent knowledge and use professional vocabulary that are not immediately compatible with those that the researcher is familiar with. The perceived benefit of such inclusive learning is that it would enhance broad ownership and legitimacy of the resulting knowledge which is likely to promote uptake and use. Here we consider the desirable makeup of a transdisciplinary learning team.

Actors from across the transdisciplinary pyramid of influence

Transdisciplinary learning aims to create knowledge solutions for societally relevant issues (Lang et al. 2012). To produce such socially contextualised knowledge and promote the readiness and ownership of potential users, issue framing and knowledge co-production should involve those parties that are likely to use or be influenced by the research. For identifying the spectrum of relevant parties, we draw on Max-Neef's transdisciplinary hierarchy, whereby the higher level coordinates and gives a purpose to, while being informed by, the lower level (Max-Neef, 2005). The higher level consists of normative and purposive disciplines and the lower level of empirical and pragmatic disciplines (see Figure 23). Transdisciplinary learning would strive to connect individuals vertically and horizontally across these levels and disciplines into a learning network (Reyers et al. 2010).

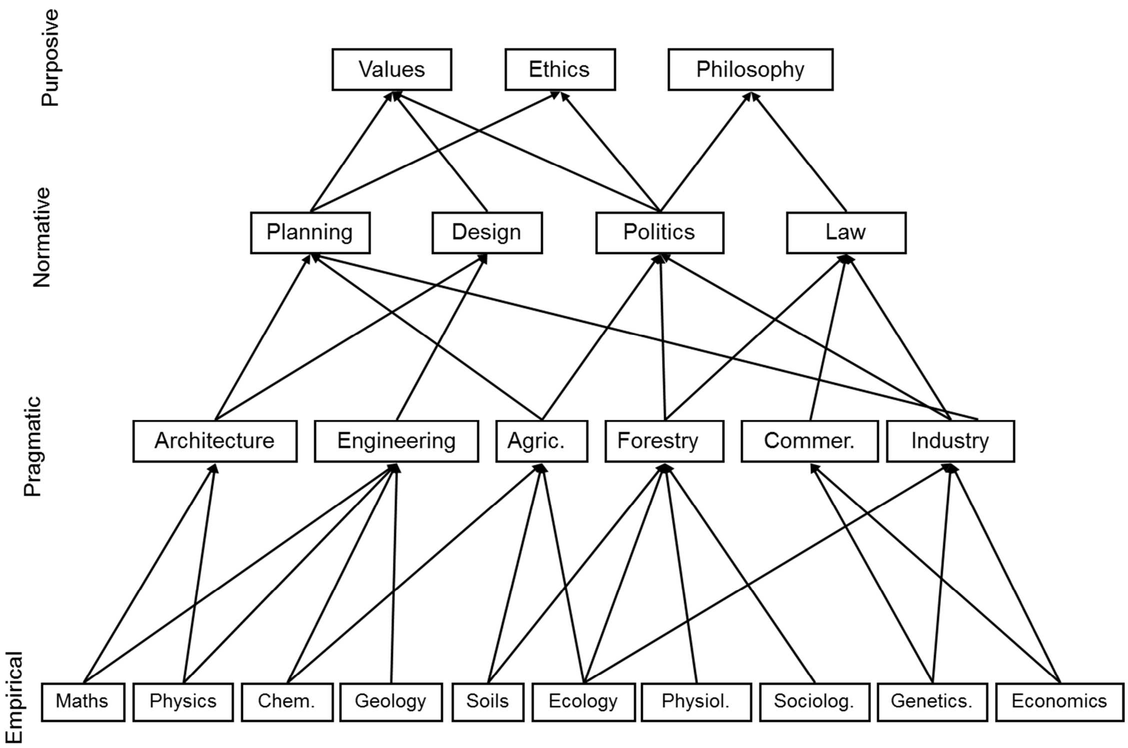

Figure 23. Hierarchy of knowledge for use in designing an inclusive and transdisciplinary learning process. Empirical disciplines at the base of the pyramid describe what exists, those at the pragmatic level describe what can be done, those at the normative level describe what is desired, and the top purposive level deals with disciplines that describe what should be done (after Max-Neef, 2005).

In the Wilderness project, the empirical level in Figure 23 was essentially constituted by members of the project team. These members represented various disciplines from across the natural and social science realms, including conservation biology, systems ecology, aquatic ecology, communication and social-ecological resilience. At the pragmatic level, the team engaged agriculture (mainly dairy farmers) and civil society (e.g. Seven Passes Initiative, Touw River Conservancy, Wilderness Ratepayers and Residents Association). At the Normative level co-learning occurred with CapeNature, SANParks and Eden District Municipality. The purposive level was informed by national policy and literature related to a sustainable future.

Experts, novices and networkers

Experts, novices and networkers can each make different but valuable contributions to a transdisciplinary learning process. Experts or seasoned professionals have acquired extensive knowledge that affects their ability to interpret information, reason and solve problems (Bransford et al. 2003). Importantly, these individuals often extend their competence credibility to the projects that they support and, because of their substantial prior knowledge, can absorb new and related information quickly. Novices on the other hand are eager to learn new things and do not have the restrictions of overly conditioned mental models. They might be in a position to 'see' new opportunities or solutions. Teams should be populated with a balance of seasoned professionals and novices to facilitate mentoring, succession and a constructive and complementary tension between more established and more open mental models. Networkers, on the other hand, are skilled in connecting key individuals from different knowledge domains across the transdisciplinary knowledge hierarchy in Figure 23.

In the Wilderness project the research team consisted of a number of established scientists (experts) as well as master and doctoral-level students (novices). Some experts and novices were also natural networkers and in fact drew extensively on existing relationships with actors from across the transdisciplinary knowledge hierarchy (Figure 23). These established relationships proved to be a significant asset for achieving learning outcomes during the course of the project. However, the same distribution of experts and novices were not achieved within all stakeholder groups. As examples, the farmers and officials from Eden District Municipality appeared to be mostly from one generation, namely established/late career (experts).

Funders of research

A further party that is co-responsible for research attaining its social intentions is the funders of research. Whereas conventional research projects are characterised by contractual or transactional relationship between funders and researchers, transdisciplinary research requires an inter-dependant and complementary knowledge partnership where funders, providers and users accept joint accountability for the outcomes of their research and dedicate time to mutual learning (Roux et al. 2010).

During the Wilderness project, the Project Manager from the Water Research Commission (WRC) did exceptionally well to absorb, and comment on, progress made by the project team. However, the team did not manage to facilitate face-to-face (other than during annual Reference Group meetings) and experiential (action in the field) co-learning with the WRC. While this is understandable considering the large number of projects that WRC Research Managers are responsible for, it remains a missed opportunity for adaptive learning at a systemic institutional level.

What to learn about

Individual learning proficiency is highest when learning about things that the individual already knows a lot about (Bransford et al. 2003). However, in transdisciplinary learning there are other subject that also require some learning attention.

Each other's prior knowledge

The rationale for learning about each other's prior knowledge is twofold. First, the more similar individuals of a social system are in attributes such as language, belief, education and socioeconomic status (homophily – 'love of the same", often expressed as "birds of a feather flock together"), the more likely effective communication is to occur, with associated effects in terms of knowledge gain, attitude formation and change, and behaviour change (Rogers, 1995). Learning about each other can help to reduce the perceived differentness. Secondly, learning theory suggests that people construct new understanding based on what they already know and believe (Bransford et al. 2003). In this sense, learning is cumulative in a context-specific way. It is thus conceivable that the understandings developed by a number of individuals during a learning intervention can be quite different from each other and also different from what the 'instructor' intended. It is therefore important for the facilitators of transdisciplinary learning to understand and engage existing knowledge of learning partners and to pay attention to potential gaps in understanding and false or naïve interpretations of concepts.

Actors across our transdisciplinary pyramid displayed substantial dissimilarity in at least education and work culture, and would not naturally be 'members of the same flock'. During the Wilderness project an effort was made to design engagements in a way that would also facilitate learning about each other's realities. A successful innovation in this regard was to attend meetings at the offices or homes of the various learning partners, and get to know more about their worlds.

History and imagined futures

In complex settings, learning from the past while anticipating the future contribute to meaningful assessment and experience of the present (Cilliers, 2006). The histories of individuals and groups are important contributors to their identities and how they make sense of new information. By co-imagining a new and desirable future, all these groups share a meta-identity, which allows them to co-learn about aspects related to this imagined common purpose.

During the Wilderness project, one master-level study focussed on unpacking the historical events that played a significant role in shaping the social-ecological system to its current state. The project concluded with a stakeholder workshop during which a collective and aspiration statement of society's relationship with nature was articulated.

Relevant scientific concepts

In transdisciplinary learning, researchers are expected to share conceptual understanding that is relevant to the social-ecological issue at hand with relevant stakeholders. In this context, the Wilderness project team has used various engagements (e.g. sustainability dialogues) as opportunities to introduce such concepts to various stakeholders. Key concepts that were discussed include eutrophication, ecological infrastructure, social learning, cooperation, complexity, stewardship and ecosystem services.

How to learn [together]

The way in which we inquire into diverse perspectives is a cultural phenomenon and will strongly influence the 'flavour' of the learning process, as well as determine the kind and nature of knowledge that is generated. Here we suggest ways of learning that are not necessarily part of everyday scientific practice.

With humility, empathy and patience

An aim of transdisciplinary learning is for science, society and government to co-evolve their understanding of a social-ecological issue, reconcile their diverse perspectives, and co-produce appropriate knowledge to serve a common purpose. An important part of this process is to make the multiple perspectives of stakeholders explicit. This can be achieved through appreciative inquiry, which involves a cooperative and evolutionary search for the best in people, their organisations and the world around them (Senge et al. 1999). Appreciative inquiry also requires bringing empathy into day-to-day practice. Empathy means developing an understanding of another so intimate that the feelings, thoughts and motives of a person are readily comprehended. To be empathetic means to "try on" different perspectives and assumptions, temporarily suspending your own in the process, so that you can inquire into the reasons why people hold them.

This philosophy challenges the notion of a scientist as the 'expert' (Rogers, 2006). Rather, an appreciative approach promotes humility and respect in the inquiry process, regardless of the level or domain of knowledge. Rather, multiple perspectives are respected and sourced with appreciation and humility to produce a robust and dynamic joint perspective over time.

In the Wilderness project the research team made a dedicated effort to listen first and then offer their perspectives only when asked.

Through using boundary objects

A key aspect of boundary work is the creation and use of boundary objects, which establish a shared understanding of knowledge for action across multiple knowledge domains. Boundary objects are defined as co-produced outputs that are adaptable to different viewpoints yet robust enough to maintain identity across them. Although boundary objects may be interpreted differently from the different sides of a boundary, they are also objects of mutual interest and relevance that facilitate communication and knowledge translation. As such "*the creation and management of boundary objects is key in developing and maintaining coherence across intersecting social worlds*" (Star and Griesemer, 1989). Examples of boundary objects include definitions and standards (Clark et al. 2011), models that integrate scientific and political viewpoints (White et al. 2010), and indicators that improve communication between different knowledge domains (Turnhout et al. 2007). Boundary objects allow local understanding of participating groups to be reframed in the context of some wider collective activity, which can promote cooperation among stakeholders.

During our project, stakeholders were asked to participate in focus group meetings, typically with 4-5 individuals from a single stakeholder group at one time. These meetings took place in informal settings, for example people's homes or at the NMMU George Campus. The meetings commenced with introductions and where appropriate a ritual such as an opening prayer. During these meetings an A0-sized outline map was laid out on a table around which participants aggregated. Maps were printed using ArcGIS, focusing on the area that the participants were from and showed the various ecological as well as built infrastructures. Placing these maps between the participants, a list of prompts (Appendix) was used to guide the conversation. Participants indicated their answers on the printed map using various colour pens to e.g. differentiate between the various sections of the interview guide.

By creating a 'third place'

Transdisciplinarity, by design, should create a 'third place' and produce a 'third position': The third place refers to a social environment other than home or the workplace that provides neutral ground for engagement, conversation and community building, and for establishing feelings of a sense of place (Oldenburg, 1989). Transdisciplinarity should also create a third place, a safe space characterized by a culture of mutual tolerance and respect. A place where academics and non-academics have an equal voice when they engage to find common ground regarding a particular social-ecological issue. During this process it is likely, and perhaps desirable, that not an academic position, nor a traditional or management or policy position, but a third position will emerge – a position that acknowledges and reflects the values and believes of all the relevant parties. It might not be possible for any one party to imagine this third position without the rich interaction of all the positions during the interactive process of iterative issue framing, knowledge production and knowledge application. Importantly, transdisciplinary work does not start once the third position emerges. Rather, the third position is a product of transdisciplinary engagement.

The most notable third places that were 'created' during the Wilderness project are the sustainability dialogues, which were held at the George Campus of NMMU and Hoekwil Primary School Hall respectively. Substantial care was taken to create a friendly and open ambiance and to facilitate inclusive participation. From the feedback of participants, these events were learning highlights.

7.4 Generic lessons

Science and society are at risk of drifting further apart. Science is more connected and learning faster than ever before. Society is overwhelmed with increasing crises/surprises and increasingly operates in reactive mode. A logical solution to mending this science-society disconnect is to nurture knowledge flows between the two domains. Transdisciplinary learning is an approach tailored to do that. Our study frames transdisciplinarity as a form of social learning, directed by a desired social-ecological outcome, and semi-bounded by a scale-dependent and transdisciplinary pyramid of influence. We suggest that enacting transdisciplinarity with attention to who to learn with, what to learn about and how to learn, promotes systemic learning and institutional change.

A transdisciplinary approach to research is not easy and not for every scientist. For those with such inclination it can be rewarding, and they would do well to be cognisant of the following insights emanating from our study:

- Transdisciplinary learning is mediated through social facilitation. This is the role of bridging agents (played by members of the project team in the Wilderness project), who have to migrate horizontally and vertically across the transdisciplinary pyramid to connect different knowledge functions and domains, act as conduits for knowledge flows, and mend knowledge fragmentation. This knowledge connectivity / fragmentation can be likened to ecological connectivity / fragmentation.
- When embarking on a process of transdisciplinary learning, it is important to have realistic expectations of the rates at which societal norms evolve. A three-year projects is not long enough to ensure social-ecological transformation but it can serve as a foundational phase for establishing conditions suitable to foster transdisciplinary learning.
- Researchers pursuing transdisciplinary involvement might have to follow an 'oscillating career path' whereby periods of deeper embeddedness in science (to get up to speed with literature) is altered with periods of higher social connectedness during which trust and relationship are build. The periods of science engagement serve to build competence credibility as well as to satisfy the basic reward system of science, namely to publish papers in peer-reviewed literature. Periods of social engagement serve to embed scientific information within a broader societal understanding.

8 CONCLUSIONS

This project has investigated the approaches and methods trialled in promoting resilience focussed social-ecological transformation within the Eden district in the Western Cape. Our ultimate desire was to work towards more inclusive systems of governance and decision making relating to landscapes and common pool resources, founded in transdisciplinary learning, reflection and adaptation with the study area. We foregrounded the role that ecological infrastructure plays in building more resilient landscapes with both district and catchment level managers, decision makers and stakeholders. We did this by creating opportunities for knowledge exchange and learning with different stakeholders. We used these interactions and engagements in conjunction with other related projects at the district level, to identify and map places were both the likelihood and consequences of risk where high. We selected specific social ecological issues which had been identified in these engagements, these being water security, erosion, invasive alien plants, drought, storm waves and flooding, and co-developed a detailed understanding of the importance of ecological infrastructure associated with these issues.

Our analysis showed that in the Wilderness catchment land cover change had reached its maximum extent by the late 1960's, being dominated by irrigated pasture and irrigated vegetables. Expansion and intensification intensified water demand matched by the increase in dams in the catchment for water storage. The flows in the Touws River were reduced by extensive pine plantations while flows in the Duiwe were drastically reduced by abstractions for agriculture. With intensive diary and vegetable farming practiced in the area, the use of fertilizers has increasing impacted on surface and groundwater quality. The water quality in the Duiwe river has been most affected, and most noticeably impacted by nutrients associated with farming activities. Farm dams were found to be playing a significant role in water quality regulation in the catchment by retaining nutrients, agrochemicals and microbes harmful to human health. Invasive aliens were found to be causing river bank instability and exacerbating erosion within the catchment. Scenarios developed within this context demonstrated the benefits of retaining and restoring riparian vegetating buffers for the retention of sediments and nutrients. We also show how inaction with regards to the control and clearing of invasive alien plants will lead 75% reduction in stream flow in contract to the current 13% reduction that is being experienced. Conversely the water benefit in controlling wattle species to 5% of their current extent was also demonstrated. Technical information was presented at a variety of stakeholder engagement session, thereby contributing to learning and knowledge exchange.

Our investigations into social issue here revealed that the Wilderness catchment was comprised of a diverse set of stakeholders with varying levels of social connectedness (high degree of social fragmentation), information, knowledge, awareness and capacity to use and manage a common resource base. The lack of an overall shared meta-identity translated into the overall lack of a common vision for the catchment. Furthermore, different organisations involved in managing these resources were found to have different levels of information assimilation. This raises challenges for collaborative management of common pool resources, starting with the need for a common identity or common set of values. However there are places where stakeholders with completely different asset bundles are indeed working together, and in the future we need to learn for their successes.

Our learning on this project revealed that building resilient landscapes by understanding the important social processes and ecological infrastructure and ecosystem services, thereby reducing risk and vulnerability, requires multi-stakeholder engagement processes that facilitate the co-production and exchange of knowledge. In order for research to be geared for action, careful attention needs to be paid to issues related to credibility, legitimacy and saliency of the information generated. Our stakeholder engagement processes demonstrated the importance of engaging with the prior knowledge of stakeholder groups and to use this understanding as a departure point for developing mutual respect and collective understanding. It also demonstrated the importance of facilitation in bringing different groups together and generating social cohesion and promoting collective action. Bridging agents, in this project, academics were able to facilitate social processes, enabling others towards an adaptive path. Using a knowledge co-production approach based on social-ecological systems research greatly assisted with the development of shared knowledge on the contribution of ecological infrastructure for reducing disaster risk (Reyers et al. 2015). The importance of effective knowledge brokering amongst communities of practice was also highlighted especially in relation to the promotion of systems thinking that is grounded in practice (Sitas et al. in review). Boundary work seems to be critical in providing an area of focus where collective understanding can be generated and potential outcomes co-generated. The concepts of risk and ecolocial infrastructure are useful boundary objects around which we could building social processes for co-producing knowledge and enhancing ecosystem management activities.

This learning has culminated in the development of the tools we have presented. The first focussed on building resilience through the identifying environmental risks and responding to these. Here the steps in the processes are the co-developing conceptual models of risk and vulnerability, developing a systemic understanding, co-development of future scenarios, analysing system resilience using models and analytical approaches, and co-generating response strategies for moving the system or catchment onto a sustainable trajectory. The second tool we present deals with enhancing social governance capacity through transdisciplinary learning. The framework is structured around three questions, namely who to learn with, what to learn about, and how to learn. It is through these co-production processes and procedures that we can bring about transformational learning, building more inclusive systems of governance that allow for reflection and adaption, and thereby move towards more resilient social ecological systems. We believed we have taken clear steps towards reducing risk and vulnerability in this area through these activities and have created opportunities for enhanced social governance.

9 RECOMMENDATIONS FOR BUILDING RESILIENT LANDSCAPES

Our studies within Eden and the wilderness catchment have generated much learning on the issues of social governance capacity and ecological infrastructure for more resilient landscapes. From this learning we have distilled a number of recommendations on how to enhance social governance as it relates to the management of ecological infrastructure and the reduction of environmental risk. These recommendations are highlighted here.

9.1 Learning together

- Engage stakeholders in co-learning at all phases of the project. Action orientated research requires stakeholders to be actively engaged in co-learning and co-producing knowledge from the project.
- Employ a diversity of engagement methods in ensuring participation and engagement.
- Ensure that the project team contains skill full facilitators or bridging agents who are able to generate interaction and promote social connectedness and knowledge sharing through enhanced communication and concept translation between stakeholder groups.
- Identify and use boundary objects (objects of mutual interest and relevance) in establishing shared understanding across different knowledge domains and stakeholder groups.
- Pay attention to the creation of third spaces, places where knowledge domains have equal weighting and where stakeholders are secure in expressing themselves .
- Acknowledge absorptive capacity differences among stakeholder groups and engage with the prior knowledge of each stakeholder group. Use this process a departure point for developing mutual respect and collective understanding among groups.
- Ensure that teams are carefully assembled so that they contain experts, novices, networkers, and funders of the research.
- Identify champions within stakeholder groups who are likely maintain project momentum after the project has been completed.
- Persistence and perseverance are required and speak to the fact that co-production and co-learning will and will need to extend way beyond three year project time frames.

9.2 Understanding and connecting people

- Engage in network weaving. Focus on establishing, co-ordinating and enriching connections between groups and individuals so as to ensure healthy networks.
- Work towards creating or establishing a common vision or shared stakeholder identity as this will facilitate collective action and co-operation in place of self-interested action. Furthermore such a vision will promote strategic (forward looking) decision making and long-term considerations.

9.3 Developing useful and credible purpose specific ecological understanding

- A valuable first step in co-learning is the co-generation of a conceptual systems model that adequately captures social and ecological issues and drivers of risk.
- Ensure that the team is able to develop the required technical understanding. Technical information is foundational in working towards the co-creation of a stakeholder-driven management plans for building landscape resilience.
- Utilise the latest available ecosystem service modeling tools in creating an understanding of ecosystem service for given areas. This can be done in conjunction with stakeholders. Scenario's should be co-developed. Models constructed in workshop environments should be able to quickly produce outputs that are understandable and are expressed in units of relevance.

9.4 Communications – staying in touch

- Use available social media in establishing communication forums. For example setting up WhatsApp groups for neighbourhood watch have proved effective.
- Create blog sites for the effective sharing of more technical information.
- Support established initiatives that are focussed on sharing information such as local forums.
- Attend other initiatives meetings, demonstrating broader interest and commitment within a region.

9.5 Collective action and monitoring

- Explore mechanisms and participatory activities that can enhance social governance capacity which can then facilitate the effectively implementation of shared responses.
- To consolidate the adaptive learning of stakeholders, feedbacks between social action and environmental responses need to be monitored, articulated and fed into the facilitated dialogues.
- Develop possibilities for citizen science initiatives. Citizens can play a useful monitoring role, for example taking water samples and monitoring water quality.
- Facilitate sharing and networking between conservancy groups.
- Pooling of resources between actions groups can facilitate tackling issues at more appropriate scales – such as invasive alien clearing programmes.
- Develop a joint management plan with priority water ways and buffer zones to repair.

9.6 Avoiding vulnerability transfers

- Ensure that building resilience in one catchment does not result in the creation of vulnerabilities in other areas.

9.7 Working across scales

- Develop a systematic understanding of risk. This will highlight cross-scale issues and will allow for ensuring that appropriate partnerships are made with those that can act across scales, thereby ensuring system appropriate planning.

10 LIST OF REFERENCES

ADGER W.N., HUGHES, T.P., FOLKE, C., CARPENTER, S.R. & ROCKSTRÖM, J. 2005. Social-ecological resilience to coastal disasters. *Science*, 309 (5737: 1036–1039.

ADGER, W.N. 2006. Vulnerability. *Global Environmental Change.* 16 : 268–281.

ALLANSON, B.R. & WHITFIELD, A.K. 1983. *The limnology of the Touw River floodplain*. Report No. 79, South African National Scientific Programmes, Cooperative for Scientific Programmes, CSIR, Pretoria.

ANDERIES, J.M., JANSSEN, M.A. & OSTROM, E., 2004. A framework to analyze the robustness of social-ecological systems from an institutional perspective. *Ecology and Society*, 9: 1-18.

ARMITAGE, D., BERKES, F., DALE, A., KOCHO-SCHELLENBERG, E. & PATTON, E. 2011. Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. *Global Environmental Change*, 21, 995-1004.

BARNOSKY, A. D., HADLY, E. A., BASCOMPTE, J., BERLOW, E. L., BROWN, J. H., FORTELIUS, M., GETZ, W. M., HARTE, J., HASTINGS, A. & MARQUET, P. A. 2012. Approaching a state shift in Earth's biosphere. *Nature*, 486: 52-58.

Basnyat, P., Teeter, L.D., Lockaby, B.G. & Flynn, K.M. 2000. The use of remote sensing and GIS in watershed level analyses of non-point source pollution problems. *For. Ecol. Manage,* 128: 65–73.

BERKES, F. 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management,* 90: 1692-1702.
BERKES, F., COLDING, J. & FOLKE, C. 2003. *Navigating social-ecological systems: Building resilience for complexity and change*. Cambridge University Press, Cambridge, UK.
BIGGS, R., RHODE, C., ARCHIBALD, S., KUNENE, L. M., MUTANGA, S. S., NKUNA, N., OCHOLLA, P. O. & PHADIMA, L. J. 2015. Strategies for managing complex social-ecological systems in the face of uncertainty: examples from South Africa and beyond. *Ecology and Society*, 20 (1): 52.
BIJKER, W. E., BAL, R. & HENDRIKS, R. 2009. *The paradox of scientific authority: The role of scientific advice in democracies*. MIT press, Mass, Cambridge.
BLACKSTOCK, K.L., KELLY, G.J. & HORSEY, B.L. 2007. Developing and applying a framework to evaluate participatory research for sustainability. *Ecological Economics*, 60(4): 726–742.
BRANSFORD, J. D., BROWN, A. L. & COCKING, R. R. 2003. *How people learn: Brain, mind, experience, and school: Expanded Edition*. The National Academies Press, Washington, DC.
BRAUMAN, K.A., DAILY, G.C., DUARTE, T.K. & MOONEY, H.A. 2007. The nature and value of ecosystem services: An overview highlighting hydrologic services. *Annual Review of Environment and Resources*, 32: 67-98
BROCCA, L., MELONE, F. & MORAMARCO, T. 2008. *Soil moisture monitoring at different scales for rainfall-runoff modelling*. *In*: *International Congress on Environmental Modelling and Software*. pp. 407–414.
BROWN, K., & WESTAWAY, E. 2011. Agency, capacity, and resilience to environmental change: Lessons from human development, well-being, and disasters. *Annual Review of Environment and Resources,*36: 321–342.
BUIZER, J., JACOBS, K. & CASH, D. 2010. *Knowledge systems for sustainable development special feature sackler colloquium: Making short-term climate forecasts useful: Linking science and action.* Proceedings of the National Academy of Sciences.
CARPENTER, S. WALKER, B., ANDERIES, J. M. & ABE, N. 2001. From metaphor to measurement: Resilience of what to what? *Ecosystems*, 4(8): 765–781.
CASH, D. W., CLARK, W. C., ALCOCK, F., DICKSON, N. M., ECKLEY, N., GUSTON, D. H., JÄGER, J. & MITCHELL, R. B. 2003. Knowledge systems for sustainable development. Proceedings of the National Academy of Sciences, 100 (14): 8086-8091.
CHAPIN, F. S., CARPENTER, S.R. KOFINAS, G.P., ET AL. 2010. Ecosystem stewardship: Sustainability strategies for a rapidly changing planet. *Trends in Ecology and Evolution*, 25(4): 241–249.
CHUNNETT, E.P. 1964. *The deterioration of the Wilderness lakes system*. Special Report MEG 306. Hydromechanics Research Department, National Mechanical Engineering Research Institute, CSIR, Pretoria.
CILLIERS, P. 1998. *Complexity and postmodernism: Understanding complex systems*. Routledge, London.
CILLIERS, P. 2006. On the importance of a certain slowness. *Emergence: Complexity & Organization*, 8 (3): 106-113.
CILLIERS, P., BIGGS, H. C., BLIGNAUT, S., CHOLES, A. G., HOFMEYR, J.H. S., JEWITT, G. P. W. & ROUX, D. J. 2013. Complexity, modeling, and natural resource management. *Ecology and Society*, 18 (3): 1.
CLARK, W. C., TOMICH, T. P., VAN NOORDWIJK, M., GUSTON, D., CATACUTAN, D., DICKSON, N. M. & MCNIE, E. 2011. *Boundary work for sustainable development: Natural resource management at the Consultative Group on International Agricultural Research (CGIAR)*. Proceedings of the National Academy of Sciences, 200900231.
COOK, C. N., MASCIA, M. B., SCHWARTZ, M. W., POSSINGHAM, H. P. & FULLER, R. A. 2013. Achieving conservation science that bridges the knowledge–action boundary. *Conservation Biology*, 27: 669-678.
CORNELL, S., BERKHOUT, F., TUINSTRA, W., TÀBARA, J. D., JÄGER, J., CHABAY, I., DE WIT, B., LANGLAIS, R., MILLS, D. & MOLL, P. 2013. Opening up knowledge systems for better responses to global environmental change. *Environmental Science and Policy*, 28: 60-70.
COWAN, G.I., MARNEWECK, G.C., 1996. *South African national report to the Ramsar Convention 1996*. South African Wetlands Conservation Programme, Department of Environment Affairs and Tourism, Pretoria.
CRUTZEN, P. J. 2006. *The "anthropocene"*. Earth System Science in the Anthropocene. Springer, Berlin.
CUMMING, G.S., BARNES, G., PERZ, S. ET AL. 2005. An exploratory framework for the empirical measurement of resilience. *Ecosystems*, 8(8): 975–987.

CUTTER, S.L. ET AL. 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change*, 18(4): 598–606.

DABROWSKI, J.M. 2014. Applying SWAT to predict ortho-phosphate loads and trophic status in four reservoirs in the upper Olifants catchment, South Africa. *Hydrol. Earth Syst. Sci.,* 18: 2629–2643.

DEPARTMENT OF WATER AFFAIRS (DWA). 2013. *National Water Resource Strategy*. Government Printers, Pretoria.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF). 2003. Gouritz WaterManagement Area. Overview of water resources availability and utilisation. Report P WMA 16/000/00/0203. Department of Water Affairs and Forestry, Pretoria. Available online: http://www.dwa.-gov.za/Documents/Default.aspx.

DÍAZ, S. ET AL. 2006. Biodiversity loss threatens human well-being. *PLoS biology*, 4(8): p.e277. Available at: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1543691&tool=pmcentrez&rendertype=abstract [Accessed July 16, 2011].

DÍAZ, S., S. DEMISSEW, J. ET AL. 2015. The IPBES Conceptual Framework: Connecting nature and people. *Current Opinion in Environmental Sustainability,* 14:1–16.

DYE, P. & JARMAIN, C. 2004. Water use by black wattle (*Acacia mearnsii*): Implications for the link between removal of invading trees and catchment streamflow response. *South African Journal of Science*, 100: 40–44.

EDEN DISTRICT MUNICIPALITY (EDM). 2008. *State of the Environment Report*. Eden.

EHRENFELD, J.G. 2010. Ecosystem Consequences of Biological Invasions. *Annu. Rev. Ecol. Evol. Syst.,* 41: 59–80.

ELMQVIST, T. ET AL. 2003. Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and the Environment*, 1: 488-494.

ENFORS, E. I., & L. J. GORDON. 2007. Analysing resilience in dryland agro-ecosystems: A case study of the Makanya catchment in Tanzania over the past 50 years. *Land Degradation & Development*, 18: 680–696.

ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE (ESRI). 2010. ArcGIS Desktop, Environmental Systems Research Institute, Redlands, USA.

FALKENMARK, M. & C. FOLKE. 2002. The ethics of socio-ecohydrological catchment management: towards hydrosolidarity. *Hydrology and Earth System Sciences*, 6:1–9.

FAZEY, I. ET AL. 2013. Knowledge exchange: A review and research agenda for environmental management. *Environmental Conservation*, 40: 19–36.

FAZEY, I. ET AL. 2014. Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. *Global Environmental Change*.

FISCHER, J., T. A. GARDNER, E. M. BENNETT, P. BALVANERA, R. BIGGS, S. CARPENTER, T. DAW, C. FOLKE, R. HILL, T. P. HUGHES, T. LUTHE, M. MAASS, M. MEACHAM, A. V NORSTRÖM, G. PETERSON, C. QUEIROZ, R. SEPPELT, M. SPIERENBURG, & J. TENHUNEN. 2015. Advancing sustainability through mainstreaming a social–ecological systems perspective. *Current Opinion in Environmental Sustainability* 14: 144–149.

FLÜGEL W., MÄRKER M., MORETTI S., RODOLFI G. & SIDROCHUK A. 2003. Integrating geographical information systems, remote sensing, ground truthing and modelling approaches for regional erosion classification of semi-arid catchments in South Africa. *Hydrological Processes,* 17: 929-942.

FOLKE, C. ET AL. 2004. Regime Shifts, Resilience, and Biodiversity in Ecosystem Management. Annual Review of Ecology. *Evolution and Systematics*, 35(1): 557–581.

FOLKE, C. 2006. Resilience: The emergence of a perspective for social–ecological systems analyses. *Global Environmental Change*, 16(3): 253–267.

FOURIE, M. 2015. *Measuring the impact of invasive N-fixing Acacias on nitrogen dynamics in fynbos riparian zones of the Western Cape* [WWW Document]. SAEON eNewsletter. URL http://www.saeon.ac.za/enewsletter/archives/2015/february2015/doc08.

GIERYN, T. F. 1983. Boundary-work and the demarcation of science from non-science: Strains and interests in professional ideologies of scientists. *American Sociological Review*, 781-795.

GÖRGENS, A.H.M. & HUGHES, D.A. 1981. Hydrological investigations on the Wilderness catchments, In: Jacot Guilllarmod, A., Allanson, B.R. (Eds.), *Touw River Floodplain Report*. Part II. Hydrology and Hydraulics. Prepared for the Cooperative research Programmes, CSIR, by the Institute for Freshwater Studies, Rhodes University.

GUO, Z., XIAO, X., GAN, Y., ZHENG, Y. 2001. Ecosystem functions, services and their values – A case study in Xingshan county of China. *Ecol. Econ.*, 38: 141–154.

GUSTON, D. H. 2001. Boundary organizations in environmental policy and science: an introduction. *Science, technology, and human values*, 26: 399-408.

HAHN, T., OLSSON, P., FOLKE, C. & JOHANSSON, K. 2006. Trust-building, knowledge generation and organizational innovations: the role of a bridging organization for adaptive comanagement of a wetland landscape around Kristianstad, Sweden. *Human Ecology*, 34: 573-592.

HARDY, C., LAWRENCE, T. B. & GRANT, D. 2005. Discourse and collaboration: The role of conversations and collective identity. *Academy of Management Review* [Online], 30: Available: http://www.jstor.org/stable/20159095. [Accessed 26 September 2011].

HOFFMAN T. & ASHWELL A. 2001. *Nature Divided*. Land Degradation in South Africa. University of Cape Town Press, Cape Town.

HOLLING, C. S. & G. K. MEFFE. 1996. Command and control and the pathology of natural resource management. *Conservation Biology,* 10: 328–337.

HOLLOWAY, A., FORTUNE, G., ZWEIG, P., BARRETT, L., BENJAMIN, A. ET AL. 2012. *Eden and Central Karoo drought disaster 2009-2011.* The scramble for water Report Number LG 10/2011/2012, Disaster Migration for Sustainable Livelihoods Programme, Stellenbosch University.

HOLMES, P.J., BATEMAN, M.D., CARR, A.S. & MARKER, M.E. 2007. The place of aeolian coversands in the geomorphic evolution of the southern Cape coast, South Africa. *South African J. Geol*. 110: 125–136.

HOPKINS, T. S., BAILLY, D. & STOTTRUP, J. G. 2011. A Systems Approach Framework for Coastal Zones. *Ecology and Society*, 16.

HUGHES, T.P. ET AL. 2005. New paradigms for supporting the resilience of marine ecosystems. *Trends in Ecology and Evolution*, 20: 380–386.

HULME, P.E. 2006. Beyond control: wider implications for the management of biological invasions. *Journal of Applied Ecology,* 43: 835–847.

JACOBS, S.M., BECHTOLD, J.S., BIGGS, H.C., GRIMM, N.B., LORENTZ, S., MCCLAIN, M.E., NAIMAN, R.J., PERAKIS, S.S., PINAY, G. & SCHOLES, M.C. 2007. Nutrient Vectors and Riparian Processing: A Review with Special Reference to African Semiarid Savanna Ecosystems. *Ecosystems,* 10: 1231–1249.

JASANOFF, S. 2004. *States of knowledge: The co-production of science and the social order.* Routledge.

JASANOFF, S. 2009. *The fifth branch: Science advisers as policymakers.* Harvard University Press.

JOVANOVIC, N.Z., ISRAEL, S., TREDOUX, G., SOLTAU, L., LE MAITRE, D., RUSINGA, F., ROZANOV, A. & VAN DER MERWE, N., 2009. Nitrogen dynamics in land cleared of alien vegetation (*Acacia Saligna*) and impacts on groundwater at Riverlands nature reserve (Western Cape, South Africa). *Water SA,* 35: 37–44.

KAPP, J., FIJEN, A.P.M. & VAN ZYL, F. 1995. Towards a Water Management Strategy for an environmentally sensitive and popular tourist region. *Water Sci. Technol*., 32: 245–254.

KINGSFORD, R. T., BIGGS, H. C. & POLLARD, S. R. 2011. Strategic Adaptive Management in freshwater protected areas and their rivers. *Biological Conservation*, 144: 1194–1203.

KLANDERMANS, B., SABUCEDO, J. M., RODRIGUEZ, M. & DE WEERD, M. 2002. *Identity processes in collective action participation: Farmers' identity and farmers' protest in the Netherlands and Spain*. Political Psychology [Online], 23. Available: http://www.jstor.org/stable/3792289 [Accessed 27 August 2011].

Kolb, A. Y. & D. A. Kolb. 2005. Learning Styles and Learning Spaces: Enhancing experiential learning in higher education. *Academy of Management Learning & Education,* 4: 193–212.

KOTZÉ, I., BEUKES, H., VAN DEN BERG, E. & NEWBY, T. 2010. *National Invasive Alien Plant Survey. Report No. GW/A/2010/21.* Agricultural Research Council – Institute for Soil, Climate and Water, Pretoria.

KOURGIALAS, N.N., & KARATZAS, G.P. 2011. Flood management and a GIS modelling method to assess flood-hazard areas—a case study. *Hydrological Sciences Journal,* 56(2): 212–225.

LAMBIN, E. F. 2005. Conditions for sustainability of human-environment systems: Information, motivation, and capacity. *Global Environmental Change-Human and Policy Dimensions,* 15: 177–180.

LANE, S.N., BROOKES, C.J., HARDY, R.J., HOLDEN, J., JAMES, T.D., KIRKBY, M.J., MCDONALD, A.T., TAYEFI, V. & YU, D. 2003. *Land management, flooding and environmental risk: New approaches to a very old question.* In: CIWEM National Conference.

LANG, D. J., WIEK, A., BERGMANN, M., STAUFFACHER, M., MARTENS, P., MOLL, P., SWILLING, M. & THOMAS, C. J. 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science*, 7: 25-43.

LE MAITRE, D., NEL, J., TALJAARD, S., VAN NIEKERK, L., GENTHE, B., OBERHOLSTER, P., SOMERSET, V., PETERSEN, C., SMITH-ADAO, L., MAHERRY, A., DE LANGE, W., AND MAHUMANI, B. 2015. *Living document technical report: Understanding the system dynamics of the Touws River Catchment and how they influence water quality of the rivers and lakes.* Parliamentary Grant Report in preparation, Natural Resources and the Environment, CSIR, Stellenbosch.

LE MAITRE, D., VAN NIEKERK, L., ARCHIBALD, S., NEL, J. & KOTZEE, I. 2011. Chapter 4: Flood risks and their interactions with land cover changes, fires and human activities: Sedgefield case study, pp 40-1 ? 4-40 In: Nel, J, Archibald, S, Le Maitre, D, Forsyth, G, Theron, A 2011. *Understanding the implications of global change for the insurance industry: The Eden Case Study.* Final report for component 1: understanding the risk landscape. Report No. CSIR/NRE/ECOS/IR/2011/0063/B, Natural Resources and the Environment, CSIR, Stellenbosch.

LE MAITRE, D.C., FORSYTH, G.G., DZIKITI, S. & GUSH, M.B. 2013. *Estimates of the Impacts of Invasive Alien Plants on Water Flows in South Africa.* Report No. CSIR/NRE/ECO/ER/2013/0067/B, Natural Resources and the Environment, CSIR, Stellenbosch.

LE MAITRE, D.C., GAERTNER, M., MARCHANTE, E., ENS, E.-J., HOLMES, P.M., PAUCHARD, A., O'FARRELL, P.J., ROGERS, A.M., BLANCHARD, R., BLIGNAUT, J., RICHARDSON, D.M., 2011. Impacts of invasive Australian acacias: implications for management and restoration. *Divers. Distrib.,* 17: 1015–1029.

LE MAITRE, D.C., VAN WILGEN, B.W., CHAPMAN, R.A. & MCKELLY, D.H., 1996. Invasive plants in the Western Cape, South Africa: modelling the consequences of a lack of management. *Journal of Applied Ecology*, 33: 161–172.

MACE, G.M. ET AL. 2014. Approaches to defining a planetary boundary for biodiversity. *Global Environmental Change*, 28:289–297.

MACE, G.M., NORRIS, K. & FITTER, A.H. 2012. Biodiversity and ecosystem services : A multi layered relationship, *Trends in ecology & evolution*, 27(1): 19–26.

MAILLARD, P. & SANTOS, N.A.P. 2008. A spatial-statistical approach for modeling the effect of non-point source pollution on different water quality parameters in the Velhas river watershed-Brazil. *J. Environ. Manage*., 86: 158–70.

MARKER, M.E. & HOLMES, P.J. 2010. The geomorphology of the Coastal Platform in the southern Cape. *South African Geogr. J.*, 9:, 105–116.

MAX-NEEF, M. A. 2005. Foundations of transdisciplinarity. *Ecological Economics*, 53: 5-16.

MAYNARD, J.A. ET AL. 2010. Building resilience into practical conservation: Identifying local management responses to global climate change in the southern Great Barrier Reef. *Coral Reefs*, 29: 381–391.

MIDDLETON B.J. & BAILEY A.K. 2009. *Water Resources of South Africa, 2005 study.* Water Research Commission Report Number TT 380/08, Water Research Commission, Pretoria, South Africa.

MIDGLEY, D.C., PITMAN, W.V. & MIDDLETON, B.J. 1994. *Surface Water Resources of South Africa 1990: User's Manual.* Report no. 298/1/94, Water Resource Commission, Pretoria.

MIDGLEY, J. & SCHAFER, G. 1992. Correlates of water colour in streams rising in Southern Cape catchments vegetated by fynbos and/or forest. *Water SA,* 18: 93–100.

MIDGLEY, J.J., SCOTT, D.F. & HARRIS, C. 2001. How do we know how much groundwater is stored in southwestern Cape mountains? *S. Afr. J. Sci.,* 97: 285–286.

MILLENNIUM ECOSYSTEM ASSESSMENT (MEA). 2003. *Ecosystems and Human Well-being: A Framework for Assessment.* Island Press, Wash.

MILLENNIUM ECOSYSTEM ASSESSMENT (MEA). 2005. *Ecosystems and Human Well-Being: Synthesis*. Island Press, Washington, DC.

MILLER, F. ET AL. 2010. Resilience and Vulnerability : Complementary or Conflicting Concepts ? *Ecology and Society*, 15(3), 1-25.

MOLLINGA, P. 2010. Boundary work and complexity of natural resource management. *Crop Science*, 50: 1-9.

MORGAN R.C.P. 1995. *Soil erosion and Conservation (2nd edition).* Longman Group Limited, London, UK.

Morgan R.P.C. 1986. *Soil Erosion and Conservation*. Longman, Essex.

NEL, D.C., COLVIN, C., NEL, J.L., DE LANGE, W., MWENGE KAHINDA, J., ET AL. 2010. *SAB hop farms water risk assessment: Project report.* CSIR Report CSIR/NRE/ECOS/2011/066/B, CSIR, Pretoria.

NEL, J. L., LE MAITRE, D. C., NEL, D. C., REYERS, B., ARCHIBALD, S., VAN WILGEN, B. W., & BARWELL, L. 2014. Natural hazards in a changing world: a case for ecosystem-based management. *Plos One,* e95942.

NEL, J.L., MURRAY, K.M., MAHERRY, A.M., PETERSEN, C.P., ROUX, D.J., DRIVER, A., HILL, L., VAN DEVENTER, H., FUNKE, N., SWARTZ, E.R., SMITH-ADAO, L.B., MBONA, M., DOWNSBOROUGH, L. & NIENABER, S., 2011. *Technical report for the National Freshwater Ecosystem Priority Areas project*. WRC Report No. 1801/2/11, Water Research Commission, Pretoria.

NELSON, D.R., ADGER, W.N. & BROWN, K. 2007. *Adaptation to environmental change* : Contributions of a resilience framework. *Annual Review of Environment and Resources*, 32: 395-419

O'FARRELL P.J., DONALDSON J.S. & HOFFMAN M.T. 2009. Local benefits of retaining natural vegetation for soil retention and hydrological services. *South African Journal of Botany*, 75: 573-583.

O'FARRELL, P.J. ET AL. 2008. Applying a resilience framework in the pursuit of sustainable land-use development in the Little Karoo, South Africa. In: M. Burns & A. Weaver, eds. *Exploring Sustainability Science: A southern African perspective*. Stellenbosch: SUN Press, pp. 383–432.

OBERHOLSTER, P.J., DABROWSKI, J. & BOTHA, A.-M. 2013. Using modified multiple phosphorus sensitivity indices for mitigation and management of phosphorus loads on a catchment level. *Fundam. Appl. Limnol. / Arch. für Hydrobiol*. 182: 1–16.

OLDENBURG, R. 1989. The great good place: Cafés, coffee shops, community centers, beauty parlors, general stores, bars, hangouts, and how they get you through the day. Paragon House, New York.

OLSSON, P., FOLKE, C. & BERKES. F. 2004. Adaptive Co-management for building resilience in social–ecological systems. *Environmental Management,* 34:75–90.

OSTROM, E. 1990. Governing the Commons: The Evolution of Institutions for Collective Action. University Press, Cambridge.

OSTROM, E. 2009. A General Framework for Analysing Sustainability of Social-Ecological Systems. Science 325:419–422.

PARKER, J. & CRONA, B. 2012. On being all things to all people: Boundary organizations and the contemporary research university. Social Studies of Science, 42, 262-289.

PARTRIDGE, T.C., DOLLAR, E.S., MOOLMAN J. & DOLLAR, L.H. 2010 *The geomorphic provinces of South Africa, Lesotho and Swaziland: A physiographic subdivision for earth and environmental scientists.* Trans R Soc South Africa 65:1–47. doi: 10.1080/00359191003652033.

PATTERSON, J. J., C. SMITH & J. BELLAMY. 2013. Understanding enabling capacities for managing the "wicked problem" of nonpoint source water pollution in catchments: A conceptual framework. *Journal of Environmental Management,* 128: 441–452.

PETERSEN, C.R., DE LANGE, W., LE MAITRE, D., MAHERRY, A., MAHUMANI, B., MWENGE KAHINDA, J.-M., NEL, J., GENTHE, B., OBERHOLSTER, P., SOMERSET, V., TALJAARD, S. & VAN NIEKERK, L., 2015. *Living document technical report: Gouritz coastal sub-WMA catchments.* Parliamentary Grant Report in preparation, Natural Resources and the Environment, CSIR, Stellenbosch.

RAMMEL, C., MCINTOSH, B. S. & JEFFREY, P. 2007. (Co)evolutionary approaches to sustainable development. *International Journal of Sustainable Development and World Ecology,* 14: 1–3.

RENARD, K.G., FOSTER, G.R. YODER, D.C. & MCCOOL, D.K. 1994. RUSLE revisited: Status, questions, answers, and the future. *J. Soil Water Conserv.* 49(3): 213-220.

RESILIENCE ALLIANCE. 2010. Assessing resilience in social-ecological systems: Workbook for practitioners., Resilience.

REYERS, B., NEL, J. L., O'FARRELL, P. J., SITAS, N., & NEL, D. C. 2015. Navigating complexity through knowledge coproduction: Mainstreaming ecosystem services into disaster risk reduction. *Proceedings of the National Academy of Sciences*, 112(24): 7362-7368.

REYERS, B., ROUX, D. J., COWLING, R. M., GINSBURG, A. E., NEL, J. L. & O'FARRELL, P. 2010. Conservation Planning as a Transdisciplinary Process. Conservation Biology, 24, 957-965.

RICHARDSON, D. M., HOLMES, P. M., ESLER, K. J., GALATOWITSCH, S. M., STROMBERG, J. C., KIRKMAN, S. P., PYSEK, P. & HOBBS, R. J. 2007. Riparian vegetation: degradation, alien plant invasions, and restoration prospects. *Diversity and Distributions*, 13: 126-139.

ROCKSTRÖM, J., STEFFEN, W., NOONE, K., PERSSON, Å., CHAPIN, F. S., LAMBIN, E. F., LENTON, T. M., SCHEFFER, M., FOLKE, C. & SCHELLNHUBER, H. J. 2009. A safe operating space for humanity. *Nature*, 461: 472-475.

ROGERS, E. M. 1995. Diffusion of innovations, New York, The Free Press.

ROGERS, K. H. 2006. The real river management challenge: integrating scientists, stakeholders and service agencies. River Research and Applications, 22, 269-280.

ROUX, D. J., STIRZAKER, R. J., BREEN, C. M., LEFROY, E. C. & CRESSWELL, H. P. 2010. Framework for participative reflection on the accomplishment of transdisciplinary research programs. Environmental Science & Policy, 13, 733-741.

RUCKELSHAUS, M. ET AL. 2013. Notes from the field : Lessons learned from using ecosystem service approaches to inform real-world decisions. *Ecological Economics,* 115: 11-21

RUSSELL, I.A. 2003. Changes in the distribution of emergent aquatic plants in a brackish South African estuarine-lake system. *African J. Aquat. Sci.,* 103–122.

SCHLÜTER, M. & HERRFAHRDT-PÄHLE, E. 2011. Exploring resilience and transformability of a river basin in the face of socioeconomic and ecological crisis: An example from the Amudarya river basin, Central Asia. *Ecology and Society,* 16.

SCHWARZ, A.-M. ET AL. 2011. Vulnerability and resilience of remote rural communities to shocks and global changes: Empirical analysis from Solomon Islands. *Global Environmental Change*, 21(3): 1128–1140.

SENGE, P., KLEINER, A., ROBERTS, C., ROSS, R. & SMITH, B. 1999. A fifth discipline resource: the dance of change. New York, Currency Doubleday.

SIMONIT, S. & PERRINGS, C., 2011. Sustainability and the value of the "regulating" services: Wetlands and water quality in Lake Victoria. *Ecological Economics*, 70: 1189–1199.

SITAS, N. 2012. *Baseline understanding of stakeholder perceptions regarding risk, resilience and uncertainty in ecosystem management in Eden*. ProEcoServ report, deliverable 1.1.9.1. UNEP and GEF.

SITAS, N., PROZESKY, H. E., ESLER, K. J. &. REYERS, B. 2014. Exploring the gap between ecosystem service research and management in development planning. *Sustainability* 6(6): 3802-3824.

SITAS, N., PROZESKY, H. E., ESLER, K. J. &. REYERS, B. 2014. Opportunities and challenges for mainstreaming ecosystem services in development planning: perspectives from a landscape level. *Landscape Ecology* 19(8): 1315-1331.

SITAS, N., REYERS, B. , PROZESKY, H. E., ESLER, K. J. CUNDILL, G. & NEL, J. (IN PREP). Facilitating boundary work in ecosystem based disaster risk reduction

SITAS, N., REYERS, B., CUNDILL, G. PROZESKY, H. E., ESLER, K. J. & NEL, J. (IN REVIEW). Fostering collaboration for knowledge and action in disaster management in South Africa. *Current Opinion In Environmental Sustainability*.

SKIDMORE E.L. 1994. Wind Erosion. In Lal, R. (Ed), Soil erosion research and methods. St Lucie Press, Floridia, pp. 256-294.

SLABBERT, E., JACOBS, S.M. & JACOBS, K., 2014. The soil bacterial communities of South African fynbos riparian ecosystems invaded by Australian Acacia species. *PLoS One,* 9: e86560.

SNYMAN H.A. 1999. Soil Erosion and conservation. *In:* Tainton NM (ed) *Veld management in South Africa*. University of Natal Press, Scottsville, South Africa, pp. 355-380.

STAR, S. L. & GRIESEMER, J. R. 1989. Institutional ecology,translations' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social Studies of Science*, 19: 387-420.

STEYN, C. J. 2013. *Exploring ethical challenges, climate change and implications on land and water use within the agricultural sector of the Garden Route, Western Cape, South Africa*. MPhil Thesis, Stellenbosch University.

STRAHLER, A.N. 1957. Quantitative analysis of watershed geomorphology. *Trans. Am. Geophys. Union,* 38: 913–920.

TALLIS, H.T., RICKETTS, T., GUERRY, A.D.,WOOD, S.A., SHARP, R., NELSON, E., ENNAANAY, D.,WOLNY, S., OLWERO, N., VIGERSTOL, K., PENNINGTON, D., MENDOZA, G., AUKEMA, J., FOSTER, J., FORREST, J., CAMERON, D., ARKEMA, K., LONSDORF, E., KENNEDY, C., VERUTES, G., KIM, C.K., GUANNEL, G., PAPENFUS, M., TOFT, J., MARSIK, M., BERNHARDT, J., & GRIFFIN, R. 2013. *InVEST 2.5.3 User's Guide.* The Natural Capital Project, Stanford, USA.

TENGÖ, M., BRONDIZIO, E. S., ELMQVIST, T., MALMER, P. & SPIERENBURG, M. 2014. Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. *Ambio*, 43: 579-591.

THERON, A., BARWELL, L. & MAHERRY, A. 2011. Chapter 6: Quantifying risk and vulnerability of sea-storm damage in coastal areas: Eden District, Mossel Bay to Glentana. In: Nel, J, Archibald, S, Le Maitre, D, Forsyth, G, Theron, A 2011. *Understanding the implications of global change for the insurance industry: The Eden Case Study*. Final report for component 1: understanding the risk landscape. Report No. CSIR/NRE/ECOS/IR/2011/0063/B, Natural Resources and the Environment, CSIR, Stellenbosch.

TICKNER, D.P., ANGOLD, P.G., GURNELL, A.M. & MOUNTFORD, J.O., 2001. Riparian plant invasions: hydrogeomorphological control and ecological impacts. *Progress in Physical Geography* 25: 22–52.

TURNER, B.L. 2010. Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science? *Global Environmental Change*, 20: 570–576.

TURNER, B.L., KASPERSON, R.E., ET AL. 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences of the United States of America*, 100: 8074–8079.

TURNER, B.L., MATSON, P.A., ET AL. 2003. Illustrating the coupled human-environment system for vulnerability analysis: three case studies. *Proceedings of the National Academy of Sciences of the United States of America*, 100: 8080–8085.

TURNHOUT, E., HISSCHEMÖLLER, M. & EIJSACKERS, H. 2007. Ecological indicators: between the two fires of science and policy. *Ecological Indicators*, 7: 215-228.

VAN DEN BERG, E.C., PLARRE, C., VAN DEN BERG, H.M. & THOMPSON, M.W. 2008. *The South African National Land Cover 2000*. Agricultural Research Council (ARC) and Council for Scientific and Industrial Research (CSIR), Pretoria. Report No. GW/A/2008/86.

VAN KERKHOFF, L. & LEBEL, L. 2006. Linking knowledge and action for sustainable development. *Annu. Rev. Environ. Resour.,* 31: 445-477.

VAN KERKHOFF, L. & SZLEZÁK, N. A. 2010. *The role of innovative global institutions in linking knowledge and action*. Proceedings of the National Academy of Sciences.

VISSER S.M., STERK G. & RIBOLZI O. 2004. Techniques for simultaneous quantification of wind and water erosion in semi-arid regions. *Journal of Arid Environments,* 59: 699-717.

VLOK, J., EUSTON-BROWN, D. & WOLF, T. 2008. *A vegetation map for the Garden Route Initiative.* Unpublished 1:50 000 maps and report supported by CAPE FSP task team. Prepared by Regalis Environmental Services for the Garden Route Initiative.

VOGEL, C. ET AL. 2007. Linking vulnerability, adaptation, and resilience science to practice: Pathways, players, and partnerships. GLOBAL ENVIRONMENTAL CHANGE, 17(3-4): 349–364.

WALKER, B. ET AL. 2002. Resilience Management in Social-ecological Systems : A working hypothesis for a participatory approach. *Conservation Ecology*, 6: 14.

WALKER, B. H., N. ABEL, J. M. ANDERIES, & P. RYAN. 2009. Resilience, adaptability, and transformability in the Goulburn-Broken Catchment, Australia*. Ecology and Society,* 14 (1).

WANG, S.-H., HUANG, S.-L. & BUDD, W.W. 2012. Resilience analysis of the interaction of between typhoons and land use change. *Landscape and Urban Planning,* 106(4): 303–315.

WHITE, D. D., WUTICH, A., LARSON, K. L., GOBER, P., LANT, T. & SENNEVILLE, C. 2010. Credibility, salience, and legitimacy of boundary objects: water managers' assessment of a simulation model in an immersive decision theater. *Science and public policy*, 37: 219-232.

WISCHMEIER, W. H. & SMITH, D. D. 1978. *Predicting rainfall erosion losses: A guide to conservation planning*. USDA, Agriculture Handbook 537. U.S. Government Printing Office, Washington, DC.

WISE, R. M., FAZEY, I., SMITH, M.F. PARK, S. E., EAKIN, H. C., ARCHER VAN GARDEREN, E. R. M. & CAMPBELL, B. 2014. Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change,* 28: 325–336.

YOUNG, J. C., WAYLEN, K. A., SARKKI, S., ALBON, S., BAINBRIDGE, I., BALIAN, E., DAVIDSON, J., EDWARDS, D., FAIRLEY, R. & MARGERISON, C. 2014. Improving the science-policy dialogue to meet the challenges of biodiversity conservation: having conversations rather than talking at one-another. *Biodiversity and Conservation*, 23: 387-404.

APPENDIX:

11 SCIENTIFIC PAPERS, THESIS AND CHAPTERS

11.1 Publications co-funded by this project

Identifying flood generating hotspots: A hydrological landscape perspective

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Abstract

Increases in extreme weather events are expected to lead to increases in the occurrence of floods, threatening communities and infrastructure in flood prone areas. Assessment of how elements combine and interact with one another at a landscape scale to generate floods can provide important information for improved landscape management and development of mitigation measures, especially in understudied and data-poor parts of the world. This research aims to develop and pilot a decision support tool using globally available data to identify flood generating hotspots at a landscape scale. We use the Eden District catchments in South Africa, an area with a history of regularly occurring flood events, to pilot our approach. Results show that although landscape attributes of rugged terrain and high hydrological connectivity makes the area inherently flood prone, the way in which these attributes link and interact with land use can exacerbate or attenuate flood impacts. The use of the model as a cost-effective decision support tool for land managers is exemplified and discussed along with some recommendations for mitigation actions.

Submission Journal: Natural Hazards

Facilitating boundary work in ecosystem based disaster risk reduction

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Abstract

Engaging diverse stakeholders from natural and social sciences, as well as society, in collaborative processes integrating environmental information into decision-making is important, but challenging. Part of the challenge centres on how to design effective collaborations that co-produce legitimate, credible and salient knowledge that is geared for impact. Such work requires working at the boundaries between academic disciplines and between knowledge types, which is inherently complex given the different value systems, norms, and mental models of diverse stakeholders. Drawing on a long-term collaborative program for ecosystem-based disaster management in South Africa, this paper reflects on the concepts, outputs, approaches, and relationships useful in bridging the gaps between different disciplines, and between science, society, policy and practice. The collaboration has proven effective at not only generating new knowledge and awareness about the role of ecosystems in disaster management, but also new actions to manage and restore ecosystems including policy and institutional shifts, investments, and partnerships. The review highlights the importance of multidimensional concepts e.g. 'risk' which enable different disciplinary and knowledge communities to participate in joint activities during which information is co-produced and exchanged. Risk assessment approaches and outputs including assessment frameworks, analytical and conceptual models, and risk maps were found to be useful collaborative outputs. Further, relationships that

facilitated both learning and action with regards to the importance of ecosystem based management for mitigating disaster risk.
Submission Journal: Global Environmental Change

11.2 Publications funded by related projects

Le Maitre, D.C., Kotzee, I.M., O'Farrell, P.J. (2014). Impacts of land-cover change on the water flow regulation ecosystem service: Invasive alien plants, fire and their policy implications. Land Use Policy 36 (2014) 171– 181.

Abstract: Land and water resource issues typically fall under separate governance systems. For example, agri-cultural policy regulates land-cover change while water departments regulate water quality. However, land-use changes can directly affect water resources. Water flow regulation is a key service which is affected by changes in land-cover but its dynamics are poorly understood by most policy makers and land management organisations. We simulated and quantified the effects of plant invasions on land-cover, hydrological soil characteristics and catchment responsiveness on flow regulation using a hydrological model. The case study was located in the indigenous fynbos shrublands in South Africa. Fynbos requires fire to regenerate, has moderate biomass, occurs mostly in areas with a potential to erode and is prone to invasion by woody plant species, particularly trees. Invasions can affect flow regulation by changing community structure and function and increasing fuel loads. The greater fuel load increases fire intensity and severity which, in turn, changes the hydrological responses of catchments. Few studies have assessed the effects of invasion on hydrological responses but studies on plantations have recorded significant increases in soil water repellence following fire, resulting in increased overland flow similar to impacts of fires in invaded areas. Simulation of clear-felling of pines and different degrees of water repellency increased both the responsiveness of the catchment to rainfall and extreme rainfall events. The simulated fire effects were consistent with other studies of hydrological responses to fire. Our study indicates that invasions of pines and acacias in the study area could substantially increase the risk of flood damage even from moderate rainfall events, and highlights the importance of maintaining flow regulation capacity. New policy approaches are required which take account of the linkages and interactions between land-use choices, water resources and ecosystem services, and address them when considering governance arrangements.

Nel, J.L., Le Maitre, D.C. Nel, D.C., Reyers, B., Archibald, S., van, Wilgen, B.W., Forsyth, G.G., Theron, A.K., O'Farrell, P.J., Mwenge Kahinda, J-M, Engelbrecht, F.A., Kapangaziwiri,E., van Niekerk, L., Barwell, L. (2014). Natural Hazards in a Changing World: A Case for Ecosystem-Based Management. PLOS ONE 9(5): e95942. doi:10.1371/journal.pone.0095942.

Abstract: Communities worldwide are increasingly affected by natural hazards such as floods, droughts, wildfires and storm-waves. However, the causes of these increases remain underexplored, often attributed to climate changes or changes in the patterns of human exposure. This paper aims to quantify the effect of climate change, as well as land cover change, on a suite of natural hazards. Changes to four natural hazards (floods, droughts, wildfires and storm-waves) were investigated
through scenario-based models using land cover and climate change drivers as inputs. Findings showed that human induced land cover changes are likely to increase natural hazards, in some cases quite substantially. Of the drivers explored, the uncontrolled spread of invasive alien trees was estimated to halve the monthly flows experienced during extremely dry periods, and also to double fire intensities. Changes to plantation forestry management shifted the 1:100 year flood event to a 1:80 year return period in the most extreme scenario. Severe 1:100 year storm-waves were estimated to occur on an annual basis with only modest human-induced coastal hardening, predominantly from removal of coastal foredunes and infrastructure development. This study suggests that through appropriate land use management (e.g. clearing invasive alien trees, re-vegetating clear-felled forests, and restoring coastal foredunes), it would be possible to reduce the impacts of natural hazards to a large degree. It also highlights the value of intact and

well-managed landscapes and their role in reducing the probabilities and impacts of extreme climate events.

Reyers, B., Nel, J.L., O'Farrell, P.J., Sitas, N, and Nel, D.C. Navigating complexity through knowledge co-production: Mainstreaming ecosystem services into disaster risk reduction. PNAS 112(24) 7362–7368 doi/10.1073/pnas.1414374112.

Abstract: Achieving the policy and practice shifts needed to secure ecosystem services is hampered by the inherent complexities of ecosystem services and their management. Methods for the participatory production and exchange of knowledge offer an avenue to navigate this complexity together with the beneficiaries and managers of ecosystem services. We develop and apply a knowledge co-production approach based on social–ecological systems research and assess its utility in generating shared knowledge and action for ecosystem services. The approach was piloted in South Africa across four case studies aimed at reducing the risk of disasters associated with floods, wildfires, storm waves, and droughts. Different configurations of stakeholders (knowledge brokers, assessment teams, implementers, and bridging agents) were involved in collaboratively designing each study, generating and exchanging knowledge, and planning for implementation. The approach proved useful in the development of shared knowledge on the sizable contribution of ecosystem services to disaster risk reduction. This knowledge was used by stakeholders to design and implement several actions to enhance ecosystem services, including new investments in ecosystem restoration, institutional changes in the private and public sector, and innovative partnerships of science, practice, and policy. By bringing together multiple disciplines, sectors, and stakeholders to jointly produce the knowledge needed to understand and manage a complex system, knowledge co-production approaches offer an effective avenue for the improved integration of ecosystem services into decision making.

Sitas, N., Prozesky, H.E., Esler, K.J., Reyers, B. (2014a). Opportunities and challenges for mainstreaming ecosystem services in development planning: perspectives from a landscape level. Landscape Ecology 29:1333.

Abstract: Despite much progress in ecosystem services research, a gap still appears to exist between this research and the implementation of landscape management and development activities on the ground, especially within a developing country context. If ecosystem service science is to be operationalised and used by decision-makers directing local development, an in-depth understanding of the implementation context for landscape planning and management, and of the opportunities and challenges for ecosystem services in this context are needed. Very little is known about these opportunities and constraints, largely because of the absence of methods to explore the complexity of the landscape planning, management and implementation context and the possibilities of integrating scientific information into these processes within a real-world setting. This study aims to address this need for information and methods, by focusing on a region in South Africa with a long history of ecosystem service research and stakeholder engagement, and testing a social science approach to explore opportunities and challenges for integrating ecosystem services in landscape planning processes and policies. Our methodological approach recognises the importance of social processes and legitimacy in decision-making, emphasizing the need to engage with the potential end-users of ecosystem service research in order to ensure the relevance of the research. While we discovered challenges for mainstreaming ecosystem service at a local level, we also found strong opportunities in the multi-sectoral planning processes driving development and in how the concept of ecosystem services is framed and aligned with development priorities, especially those relating to disaster risk reduction.

Sitas, N., Prozesky, H.E., Esler, K.J., Reyers, B. (2014b). Exploring the Gap between Ecosystem Service Research and Management in Development Planning. Sustainability 2014, 6 1-x manuscripts; doi:10.3390/su60x000x

Abstract: The gap between science and practice has been highlighted in a number of scientific disciplines, including the newly developing domain of ecosystem service science, posing a challenge for the sustainable management of ecosystem services for human wellbeing. While methods to explore science-practice gaps are developing, testing and revisions of these methods are still needed so as to identify opportunities for mainstreaming ecosystem service science into development policies and practice. We designed and tested an approach to explore the presence and nature of a research-management gap in order to identify ways to close the gap, using a South African case study. Our combining of traditional review processes with stakeholder interviews highlighted that ecosystem services are not explicitly referred to by the majority of ecosystem management-related documents, processes or individuals. Nevertheless, at the local level, our approach unearthed strategic opportunities for bridging the gap in the tourism, disaster management and conservation sectors. We also highlighted the current trend towards transdisciplinary learning networks seen in the region. While we found a gap between the research and management of ecosystem services, a rigorous study thereof, which transcends its mere identification, proved useful in identifying key opportunities and challenges for bridging the gap.

11.3 Contributions by students to this project

Student: Chantel Petersen Phd Student CSIR / UWC

This WRC project co-funded a number of Chantel's theses chapters. The focus of her thesis and major findings to date are documented.

Thesis title: Impacts of land use management on geomorphic processes: Linking riparian and river-morphodynamics in an ecological infrastructural framework
Introduction

Knowledge gaps exist on how catchment activities and especially land use changes impact the generation, transport, delivery and storage of sediments and associated pollutants, as well as river morphology. Investigations in the field of contaminants to river systems and its effects on water quality are dominated by chemical and more recently biological research. Very few studies take into account the impact of the physical river template. Geomorphic processes have become important in river management as they can be used to understand the physical transport and storage of sediment-bound pollutants in water resources. Channel type can determine water quality on different spatial and temporal scales as it is associated with a particular flow regime, potential stream energy and substrate type, so longitudinal changes in water quality is possible (Young *et al.* 2005). For example, Marti and Sabater (1996) showed that differences in local catchment conditions (lithology, soil type, and vegetation) and channel form (bedrock and sand-cobble) influenced nutrient retention in streams. Human activity can change channel morphology and thereby also alter water quality. Schlosser and Karr (1981) found that rivers in agricultural landscapes were impacted by increased suspended solids with higher runoff and discharges, where unstable beds and banks provided increased sediment to the channel, where riparian vegetation were removed and where channel morphologies were modified. Potential stream energy becomes important in transporting sediment and differing channel morphologies will result in varying transportation rates of suspended or bedload material, which may be temporally influenced. By understanding the geomorphology and how it influences river dynamics, a more holistic approach is provided, which enables improved management practices, decision making and implementation of mitigation measures.

Riparian vegetation forms an integral part of fluvial systems and exerts control on channel morphology by increasing bank stability (root binding), flow resistance and deposition of organic material and fine sediment. Flow resistance reduces velocities and bed shear stress and with this erosion and sediment transport. Deflection of flows towards channel centres results in reduced bank erosion and increased bank accretion, thereby creating smaller width-to-depth ratios at the cross-section scale. Similar results were

found by Huang and Nanson (1997) where non vegetated banks were two to three times wider than channels with banks that were well vegetated. Studies have shown that different riparian vegetation densities or its presence/absence can prevent or result in channel changes from straight to braided channels (Saleh and Crosato, 2008). Others showed that obstruction of flow by in-channel woody debris during high discharge may lead to local avulsion and overbank sedimentation in restricted areas of the floodplain low-gradient, higher order streams, or to the development of chutes and meander cut-offs. Hydrology occurring within the floodplain and riparian zone due to regular disturbances by flooding, erosion, accumulation and then reworking of sediments also creates habitat diversity. Hydrology, geomorphology and vegetation dynamics therefore have complex inter-relationships, from which physical templates are created for riparian habitat according to physiographic context, river styles and valley forms (Steiger *et al.* 2005).
The riparian zones are known to provide numerous benefits to the society, directly and indirectly such as flood attenuation, aquifer recharge, maintenance of surface and groundwater as well as recreation. The importance of riparian zones as buffer areas in retaining sediment and nutrients/pollutants was also realised (Steiger *et al*. 2005). It is expected that functioning riparian buffer areas will have an influence on sediment and contaminant loads transported with sediments, between the up and down stream river reaches. Nitrogen and phosphorous from fertilizers and animal waste, as well as other pollutants originating from pesticides and herbicides, are often bound to soil particles and are mostly associated with finer sediment grains carried in suspension or sometimes with wash load (Thodsen *et al.* 2004; Hawes and Smith, 2005). Contaminants or chemicals, especially from agricultural non-point source areas, can therefore be removed from the site of origin or application by erosion and transported to receiving water bodies. Liu *et al.* (2008) found that sediment in runoff can carry particulate forms of phosphorus with a high proportion of total phosphorus found to occur during high flow periods. When the phosphorus is deposited in-stream it can often lead to accelerated eutrophication in rivers and other receiving water bodies (Hawes and Smith, 2005).

Fewer studies have focussed on riparian buffers as mitigation measures to sediment/nutrient attenuation when compared to vegetated filter strips or grassed waterways (Reichenberger *et al.* 2007). The effectiveness of riparian buffers in attenuating sediment and associated contaminants/nutrients to improving water quality are dependent on factors such as soil, buffer width, and flow rate, rainfall intensity, slope and area ratio of buffer to source field, vegetation type and relative height of water to plants (Liu *et al*. 2008). In studies where the riparian zone consisted of a combination of grass and woody vegetation higher trapping efficiencies for total nitrogen, sediment and total phosphorus loads occurred (Newham *et al*. 2005). The combination of plant species of trees, shrubs and grasses maximises the adsorption and retention of pesticides and other non-point source agricultural pollutants (Schultze, 1995) and nitrogen and other pollutants are often transformed by soil and biological activity resulting in substances that are less harmful (Hawes and Smith, 2005). From the various studies it can be concluded that the importance of the factors affecting riparian buffer effectiveness will vary depending on the specific experimental settings of the studies conducted. Most studies focussed on pollutant removal efficacy with very specific environmental conditions and the relationships identified between buffer efficacy and the associated factors can be inconsistent (Zhang, 2010). So, although numerous studies worldwide focussed on vegetated buffers and the effectiveness, it is still important to define the factors and variables conducive to local (South African) conditions and to include the linkages between riparian vegetation and river-morphodynamics, which are found to be lacking in river management and restoration (Camporeale *et al.* 2013).

This project allows the opportunity to assess the link between geomorphology and riparian vegetation and its effectiveness in mitigating nutrients, while trying to quantify the goods and services it provides.

Main aim
To evaluate linkages between catchment management, riparian zone morphodynamics, and ecosystem services.

Hypothesis: Improved understanding and knowledge of geomorphological river functioning will enable improved land management and implementation of mitigation measures thereby maintaining ecosystem goods and services.

Research objectives

The objectives of this study are as follows: -

- To investigate controls on the morphodynamics of riparian zones (this incorporates vegetation effects)
- To evaluate linkages between riparian morphodynamics and physical and biological water quality indicators
- To assess linkages between morphodynamics and water quality that determine the effectiveness of riparian zones in providing ecosystem services

Approach and data

Study sites were selected in the Western Cape Province, Gouritz Water Management Area of South Africa, focussing specifically on sites that were both alien free and alien infested (i.e. vegetated banks, bare river banks and degraded banks). Much of the focus in this area has been on estimating the quantity of water available to use in the area (e.g. groundwater, water use by alien plants that could be released if cleared), with very few (if any) studies focussing on water quality. The larger Gouritz WMA is already a host to several conservation programmes and initiatives as well as an integrative project focussing on water quality issues in the water management area to address this gap. Due to the in-depth studies in the area, a vast amount of literature and existing data (spatial, geological and hydrogeological description of the area, water quality parameters, flow data, etc.) was available for the study site, as support to this particular project. The study made extensive use of this spatial and non-spatial data compiled from both existing desktop data and detailed field surveys. The final sites were selected on the Kleinkeurbooms River (a tributary of the Duiwe) and Duiwe River. Three different river reaches along the Kleinkeurbooms were selected and one on the Duiwe River. A reference site occurred in an area free of impacts with indigenous forest vegetation, a semi-degraded reach impacted by some alien plant invasion, a degraded reach, almost completely invaded and a cumulative impact site on the lower Duiwe River before it flows into Eilandvlei Lake. The reaches selected had to be representative of the geomorphology/geology, have similar land use for water quality impacts comparisons and be accessible for sampling.

Outline

<u>Chapter 1</u> will provide an introduction to the research topic.

<u>Chapter 2</u> will examine historical influences of land use and land use changes on water quality

<u>Chapter 3</u> the objectives are two-fold 1) examine how the physical river template, macroinvertebrates and algae are associated with the template and their link to water quality

ii) examine riparian vegetation patterns and the ability to provide a mitigation measure to water quality

<u>Chapter 4</u> will provide a synthesis on ecological infrastructure: Framework for ecosystem service provision of riparian zones

<u>Chapter 5</u> concludes the research with a brief discussion on all the major findings in the study and its implications for river management and conservation in South Africa.

Chapters 2-5 will each address specific research objectives, while Chapters 1 and 5 will serve as introductory and conclusion chapters.

CHAPTER 1: INTRODUCTION

Research approach: A two-step approach will be adopted in this chapter. Firstly, an extensive literature review on relevant literature will be undertaken on some of the pertinent issues regarding the research topic highlighting only the main issues that are important to this study to be examined in detail. The review would highlight the current state of knowledge on the topic and emerging challenges. The second step will involve the completion of a catchment assessment for the selected study sites from spatial and non-spatial data to obtain a general overview of catchment or site characteristics (e.g. topography, land use and vegetation, climate, geology and soils, hydrology and geomorphology, etc.). Much of the catchment assessment is complete. The literature review is on-going.

CHAPTER 2: HISTORICAL LAND USE CHANGE AND ITS INFLUENCE ON WATER QUALITY

Hypothesis: By understanding the past we can place recent and ongoing river channel changes and water quality changes into perspective, which will give us an understanding of the factors, which influence the nature of our rivers today.

Key questions

How has land cover and land use changed over time?

How has the land influenced development and the type of uses currently present?

How the land use influenced water quality in the past and present and has land use had an impact on the river channel (physical template).

Research approach and methods

This chapter aims to explain past land cover and land use changes at a catchment scale in the Touws and Duiwe River catchment in order to explain changes to water quality in these two mainstem rivers. The methodology related to the historical mapping included two main procedures: data acquisition and data handling. Data acquisition consisted of interpretation of multi-temporal aerial photographs for the study area. This process included using available GIS data layers. These sequential sets of aerial photographs or photo comparisons provide a time-series from which land cover and land use changes could be mapped. Historical/present water quality collections in the study catchment were also sourced and used to relate to changes seen in land cover and use over time.

Main findings

Farming activities on the coastal plateau in the catchment began as early as the 1800's, although on a small scale.

Mapping analysis of aerial photographs started with 1936 and followed through until 2013.

The Touws River catchment remained largely natural with agricultural impacts in the lower reaches whereas the Duiwe River was more impacted by agriculture.

Small scale farming occurred in 1936 with substantial changes to land use occurring by the 1950's.

Farming shifted to irrigated pastures becoming the dominant land use as a result of increasing dairy farming as well as irrigated vegetables.

By the 1960's the farming (pasture and vegetables) reached their maximum extent in land use.

Urban expansion makes up a small percentage of the total land use but the extent increased 6- fold from 1966 to 1980 and thereafter doubled in 2006.

As farming intensified the need for water increased shown by the extensive increase in dams in the catchment for water storage.

The flows in the Touws River were reduced by extensive pine plantations while flows in the Duiwe were drastically reduced by abstractions for agriculture.

With intensive diary and vegetable farming practiced in the area, the use of fertilizers also increased impacting on the surface and groundwater quality.

The water quality in the Touws River was more natural than the Duiwe.

The Duiwe was impacted by especially nutrients associated with farming activities and dams in the catchment. Farm dams are playing a significant role in water quality regulation in the catchment by retaining nutrients, agrochemicals and microbes harmful to human health.

CHAPTER 3: THE PHYSICAL RIVER TEMPLATE, BIOLOGICAL INDICATORS OF WATER QUALITY AND THE LINK TO RIPARIAN MORPHODYNAMICS

Hypothesis: Geomorphology plays a role in the presence of certain species of macroinvertebrates and algae, which are also linked to water quality

Hypothesis: There is a link between riparian vegetation patterns, stream bank stability and fluvial landforms and riparian zones provide and sustain ecosystem goods and services

Key questions

1. How zonal geomorphological change relate to fluvial land forms and riparian vegetation distribution patterns.
2. To examine linkages among riparian vegetation patterns and stream bank stability.
3. What are the downstream changes of biological assemblages of riparian vegetation?

4. How do the geomorphological zones determine habitat availability for macroinvertebrates and algae and how does it relate to water quality?

Research approach and methods

To achieve the objectives of this chapter primary data on longitudinal zones based on techniques derived from Rowntree and Wadeson (1999) will be employed. Fieldwork occurred during summer low flows and winter high flows collecting data on physical conditions at the sites identified. Activities completed included; cross-section data that was required to obtain information on bed level changes e.g. where degradation or aggradations of the river bed is occurring or changes in the river form and banks. Repeat cross-sections were required to ascertain river channel changes over the study period. Three cross-sections occurred at each of the river reaches selected in the design of the monitoring programme. Sediment data (e.g. particle size analyses) was collected from beds and banks for size distribution and will be related to hydrology (by discharge data) collected during surveying events and by water level loggers. The data, together with discharge data, will be used to assess the bank stability relative to sediment and vegetation. Water quality data will also be collected for nutrients and suspended sediment. Macroinvertebrates and algae is sampled seasonally to link to habitat and water quality.

Vegetation was assessed according to belt transects using the surveyed cross-sections. Sediment was collected from each grid to analyse for e.g. grain sizes, moisture content. The vegetation was identified to species level. Natural rainfall together with run-off plots will be used to assess and quantify the level of ecosystem services in terms of sediment and nutrient retention, provided by riparian buffer zones. A comparison will be made between degraded riparian, semi-degraded and natural riparian areas. Runoff will be analysed for sediment and water quality in terms of nutrients, especially phosphates, nitrites and nitrates, considering the land use is mainly agricultural. This field work is still on-going. Run-off plots (1m X 1m) were installed at the reference site, semi-degraded and degraded site. Three replicate plots were installed at each site in the riparian zone and six were installed in the adjacent pasture area together with collecting tanks. Rain gauges were installed in the riparian zones, in the forest and in the pasture area to get an idea of the type of rainfall occurring beneath the tree cover. The plots were in place for about 1 year at this stage so collections are still on-going for at least another 6-7 months.

Main findings:

Little to no run-off occurs in the natural forest area even with sandy soils. The forest floor is well covered with dense network of roots and leaf litter protecting from rain drop impact.

No run-off was collected from the plot under dense black wattle stands in the semi-degraded site but run-off is always collected from the section with indigenous vegetation, which occurs in an open canopy area.

Banks appear to be stable with very little changes occurring between cross-section surveys. No large flooding event occurred during the study period as yet but photographic evidence showed that large floods can have a substantial impact on channel morphology.

Banks were largely eroded at the degraded site (where black wattles were the dominant vegetation) in past high flow events.

Macroinvertebrate scores and habitat scores were relatively high at all three sites on the Kleinkeurbooms River but become heavily impacted at the Duiwe River site. This site represents the cumulative impacts from upstream land use and occurs below the farming activities.

The rivers in the catchment have a quick response time in terms of flows to large rainfall events, with improved water quality occurring due to flushing.

CHAPTER 4: SYNTHESIS: ECOLOGICAL INFRASTRUCTURE: FRAMEWORK FOR ECOSYSTEM SERVICE PROVISION FROM RIPARIAN ZONES

Study context

Riparian vegetation along a river, which serves as a buffer to water quality from runoff pollutants from the land is an example of ecological infrastructure (Meier *et al.* 2005). It is well known that healthy buffers of natural vegetation mitigate the impact of land-based activities, which helps maintain healthy freshwater ecosystems able to support resilience and adaptation to climate change (Camporeale *et al*. 2013). Many buffer zones in South Africa have been either invaded by alien vegetation, or they have been damaged or destroyed by inappropriate human land use practices (Le Maitre *et al.* 2004). These practices impact on riparian zones in catchments and in so doing reduce their ability to perform certain ecosystem services.

Research approach and methods

A synthesis will be provided from the previous chapters to provide a framework for ecosystem goods and services for riparian zones. All processes documented from river and riparian morphodynamics and water quality will be integrated to provide this framework.

CHAPTER 5: CONCLUSION

This chapter will bring together all the investigations, make conclusions on major findings in the study and will provide recommendations for further research. Implications of the research for river management in South Africa will be discussed.

References

Camporeale, C., Perucca, E., Ridolfi, L. & Gurnell, A. M. 2013. Modeling the interactions between river morphodynamics and riparian vegetation. *Reviews of Geophysics,* 51**,** 379-414.

Hawes, E. & Smith, M. 2005. Riparian buffer zones: Functions and recommended widths. . Yale: Yale School of Forestry and Environmental Studies.

Huang, H. Q. & Nanson, G. C. 1997. Vegetation and channel variation; a case study of four small streams in southeastern australia. *Geomorphology,* 18**,** 237-249.

Le Maitre, D. C., Versfeld, D. B. & Chapman, R. A. 2004. The impact of invading alien plants on surface water resources in south africa: A preliminary assessment. *Water SA,* 26**,** 397-408.

Liu, X., Zhang, X. & Zhang, M. 2008. Major factors influencing the efficacy of vegetated buffers on sediment trapping: A review and analysis. . *Journal of Environmental Quality,* 37**,** 1667-1674.

Marti, E. & Sabater, F. 1996. High variability in temporal and spatial nutrient retention in mediterranean streams. *Ecology,* 77**,** 854-869.

Meier, K., Kuusemets, V., Luig, J. & Mander, Ü. 2005. Riparian buffer zones as elements of ecological networks: Case study on parnassius mnemosyne distribution in estonia *Ecological Engineering,* 24**,** 531-537.

Reichenberger, S., Bach, M., Skitschaket, A. & Frede, H.-G. 2007. Mitigation strategies to reduce pesticide inputs into ground- and surface water and their effectiveness; a review. . *Science of the Total Environment,* 384 1-35.

Rowntree, K. M. & Wadeson, R. A. 1999. A hierarchical geomorphological model for the classification of selected south african rivers. Pretoria, South Africa: Water Research Commission Report No. 497/1/99, Pretoria, South Africa.

Saleh, M. & Crosato, A. Effects of riparian and floodplain vegetation on river patterns and flow dynamics. 4th ECRR Conference on River Restoration, 16-21 June 2008. 2008 Italy, Venice S. Servolo Island.

Schlosser, I. J. & Karr, J. R. 1981. Riparian vegetation and channel morphology impact on spatial patterns of water quality in agricultural watersheds. *Environmental Management,* 5**,** 233-243.

Schultze, R. E. 1995. Hydrology and agrohydrology: A text to accompany the arc 3.00 agrohydrological modeling system. . Pretoria, South Africa: Water Research Commission.

Steiger, J., Tabacchi, E., Dufour, S., Corenblit, D. & Peiry, J. L. 2005. Hydrogeomorphic processes affecting riparian habitat within alluvial channel–floodplain river systems: A review for the temperate zone. *River Research and Applications,* 21**,** 719-737.

Thodsen, H., Hasholt, B. & Pejrup, M. Transport of phosphorus, wash load and suspended sediment in the river varde â in southwest jutland, denmark. Sediment transfer through the fluvial system Proceedings of the Moscow Symposium, 2004.

Young, R., Quarterman, A., Eyles, R., Smith, R. & Bowden, W. 2005. Water quality and thermal regime of the motueka river: Influences of land cover, geology and position in the catchment. *New Zealand Journal of Marine and Freshwater Research,* 39**,** 803-825.

Zhang, W. 2010. Pool effects on longitudinal dispersion in streams and rivers. *Journal of Water Resource and Protection,* 02**,** 960-971.

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This WRC project co-funded a single chapter of Ilse's thesis. The aims methods nd key findings of this chapter are documented.

Chapter Title : Identifying flood generating hotspots from a hydrological landscape perspective

Introduction

Increases in extreme weather events are expected to generate an increase in the occurrence of floods, threatening communities and infrastructure in flood prone areas. Assessment of how elements combine and interact with one another at a landscape scale to generate floods can provide important information for improved landscape management and development of mitigation measures, especially in understudied and data-poor parts of the world. Intact landscapes are able to capture and store water from rain storms and slowly release it in a process known as flood regulation, which forms part of the benefits humans receive from nature (MA 2003). These ecosystem features and processes can, depending on rainfall intensity, lessen flood impact or in some cases even prevent flooding (Brauman et al. 2007; Brocca et al. 2008; Guo et al. 2001). Most landscapes have largely been fragmented by human land-use activities e.g. agriculture and urban development which have disrupted the ecosystem's natural flood regulatory capacity. The interaction of land use, landscape position and distance from a hydrological flow pathway can make certain areas more flood prone than others (Lane et al. 2003). This can create spatially concentrated areas of high flooding potential. The identification of these areas offers the potential for flood mitigation through restoration of natural vegetation and soil infiltration rates.

Method

For the purposes of this study, the software package of SCIMAP (Sensitive Catchment Integrated Modeling and Analysis Platform) developed by the Durham and Lancaster Universities along with the Environment Agency was used. Model inputs consisted of a Digital Elevation Model (DEM), national land cover map, design rainfall data and soils data. The final outputs of the model consist of two thematic maps: a map of flood generating areas where regulation of run-off is paramount and a map of flood receiving areas where mitigation is the main focus. The map of flood generating areas identifies areas within the landscape where runoff is likely to be produced during a storm event. The flood receiving map identifies areas which contribute to the flood hazard either by causing the flooding or by exacerbating flooding from another source.

Findings

- Flood generating areas were identified predominantly within the upper parts of the catchment.
- In mountainous catchments such as this, the relief energy is very high, and run-off is formed mainly on the shallow soils of the steep mountain areas of the catchment.
- Areas within the catchment which were identified as being most flood-prone are urban and built up areas within the downstream part of the catchment.
- In these areas spatial interaction between, hydrological features, slope and land use combine to increase the local flood hazard.
- The combination of this method with an effective forecasting-warning system can be used to avoid extensive flood damage and ensure public safety.

References

Brauman, K.A., Daily, G.C., Duarte, T.K., Mooney, H.A., 2007. The Nature and Value of Ecosystem Services: An Overview Highlighting Hydrologic Services. Annu. Rev. Environ. Resour. 32, 6.1–6.32.

Brocca, L., Melone, F., Moramarco, T., 2008. Soil Moisture Monitoring at Different Scales for Rainfall-Runoff Modeling, in: International Congress on Environmental Modeling and Software. pp. 407–414.

Guo, Z., Xiao, X., Gan, Y., Zheng, Y., 2001. Ecosystem functions , services and their values – a case study in Xingshan County of China. Ecol. Econ. 38, 141–154.

Lane, S.N., Brookes, C.J., Hardy, R.J., Holden, J., James, T.D., Kirkby, M.J., Mcdonald, A.T., Tayefi, V., Yu, D., 2003. Land management, flooding and environmental risk: New approaches to a very old question, in: CIWEM National Conference.

Millennium Ecosystem Assessment, 2003. Ecosystems and Human Well-being: A Framework for Assessment. Island Press, Wash.

Student: Samantha McCulloch Masters, Nelson Mandela Metropolitan University

This WRC project co-funded a number of Samantha's heses chapters. The focus of her thesis and major findings to date are documented.

Thesis Title: Absorptive capacity in the public-sector: A comparative assessment of adaptive capacity for environmental change. (In progress – to be completed by 29 November 2015)

Introduction

We are living in a time when the speed of global environmental change within in the biosphere is unprecedented at all scales. A major driver of this change is human advancement, so much so that scientist are now referring to this era (1800 +) as the Anthropocene (Folke *et al.* 2011; Rockström *et al.* 2009; Steffen *et al.* 2007). The associated natural resources and services that are provided by the earth's ecosystems are key to human well-being (Biggs *et al.* 2004). It is therefore imperative that the public sector organisations that are charged with the care and distribution of these resources and services, do so with the best and most up to date knowledge to ensure sustainability.

There are vast amounts of scientific literature refining conservation techniques, however there are repeated examples of unsuccessful application and non-implementation (Knight *et al.* 2008; Reyers *et al.* 2010). This phenomena has been recorded in many branches of applied science and is not unique to conservation alone (Pfeffer & Sutton, 1999). It has been suggested that the uptake and implementation of conservation action strategies are highly dependent on the ability of mandated organisations and the individuals in their employ to absorb and use externally produced information (Murray *et al.* 2011; Roux & Nel, 2013).

Knowledge is an accumulative process, the more you know about a topic the easier it is to absorb new information pertaining to that topic (Cohen & Levinthal, 1990; Flatten, *et al.* 2011; Schmidt, 2005; Vega-jurado *et al.* 2008; Zahara & George, 2002). This capability has been referred to as absorptive capacity in organisational research (Cohen & Levinthal, 1990; Zahara & George, 2002) and is defined as *'the ability of an organisation to recognise the value of new external information, acquire it, assimilate it, transform and exploit it'* (Zahra and George, 2002; Pg 186). By absorbing and transforming external information, organisations are able to innovate and adapt with the new knowledge faster than if they had to create the knowledge from scratch.

Absorptive capacity is essentially a capacity developed within organisations by a set of routines and processes that are promoted to give them the ability to rapidly recognise changing environments and address them by renewing and building on their knowledge and capabilities to deal with the change (this is referred to as a dynamic capability within organisational research literature) (Lane *et al.* 2006; Van den Bosch, *et al.* 1999; Zahra, S. & George, 2002). Studies have shown that absorptive capacity influences organisations' capacity for innovation, intra-organisational knowledge transfer, inter-organisational learning and overall economic and business management performance (Flatten et al. 2011; Lane & Lubatkin, 1998). It is therefore no wonder absorptive capacity has been labelled as one of the most important constructs to emerge in organisational research over recent decades (Murray *et al.* 2011; Lane *et al.* 2002; Murovec *et al.* 2008).

The internal factors that determine the absorptive capacity include organisational knowledge (including the knowledge and skills of individuals), combinative capabilities and the organisational form (Cohen & Levinthal, 1990; Murray *et al.* 2011; Schmidt, 2010; Van den Bosch *et al.* 1999; Vega-jurado *et al.* 2008; Zahra, S. & George, 2002). The distinction between the determinants and the multiple dimensions (acquisition, assimilation, transformation and exploitation) of absorptive capacity highlight the complexity of this construct which partly accounts for the absence of a recognised global measurement (Flatten *et al.* 2011; Jiménez-Barrionuevo *et al.* 2011; Vega *et al.* 2007). In the development of a multidimensional measure of absorptive capacity, Flatten *et al.* (2011) reviewed 269 peer reviewed articles in ten different management journals and found that most studies on absorptive capacity were theoretical or descriptive and only 33 had categorical measurements, mainly focusing on a single precursor that makes up a determinant (e.g. Research and development proxies). It is this multidimensional measure constructed by Flatten *et al*. (2011), that this study adopted and adapted to explore the perceptions of employees of absorptive capacity within three environmentally mandated public-sector organisations.

Research Statement
The purpose of this research is to gain an understanding about the current state of absorptive capacity in three public-sector organizations with environmental mandates.

Research Aims
This study aims to explore the perceptions of employees on the absorptive capacity of three public-sector organisations with environmental mandates in the Southern Cape, to better understand their capacity to adopt new external information in order to be more adaptive to environmental change.

Research Objectives
To categorically and descriptively explore the absorptive capacity of three public-sector organisation that are mandated as environmental custodians in the Southern Cape
To assess the reliability of the survey instrument that was adopted and adapted from Flatten *et al*. (2011)

Approach and data
The study focused on three public-sector organisations with environmental mandates that operate in the Southern Cape region, within the Western Cape Province of South Africa. A measurement tool (questionnaire) was adopted from Flatten *et al*.(2011) and adapted to assess the attitudes and perceptions of the employees with regard to the four dimensions that build absorptive capacity namely; knowledge acquisition, assimilation, transformation and exploitation.

A concurrent mixed method approach was used to collect and analyse the data in order to explore the construct of absorptive capacity. The questionnaire allowed the participants to rank subjectively their attitudes and perceptions of the state of absorptive capacity and then comment qualitatively to shed more light on what informs their subjective experience. The quantitative data from the questionnaire allowed the author to be objective when analysing the results with statistics, whereas the analysis of content from the qualitative data can be considered subjective to the author's world view, i.e. subjected to the author's depth of knowledge on absorptive capacity and therefore her interpretations.

The study tested the survey tool adopted and adapted from Flatten *et al*. (2011) with the aid of validity statistics to assess its applicability within environmental organisations and measures were put in place to assure greater reliability.

It is difficult to compare these findings with those of prior research due to 1) this being a novel application of the concept and 2) the lack of a common global measurement. This is therefore an explorative study with the aim to gain greater understanding of the current absorptive capacity within the selected public-sector organisations, outlining the obstacles and enablers of absorptive capacity for these organisation. This study does not explain the causal relationships of the capabilities that build absorptive capacity within the organisations.

Outline

- **Chapter 1:** Introduction into the research topic
- **Chapter 2:** A contextual background on the selected organisations and absorptive capacity
- **Chapter 3:** Research design, research parameters, methods and ethical considerations explained
- **Chapter 4:** Results and discussion
- **Chapter5:** Conclusion and recommendations for future research

Chapter 1: Introduction

This chapter will be used to set the scene for the research study. It will outline some of the major environmental challenges faced in today's social-ecological systems, as well as some of the challenges faced by organisations mandated to manage these systems. This chapter will then argue the need for these organisations to have the capacity to be aware and up to date on newly produced information in order to be innovative and navigate through these complex challenges.

Chapter 2: A contextual background on the selected organisations and absorptive capacity

In this chapter a contextual background of the selected organisations will be given. In this section a review of the organisations vision, mission and management plans will be written. A brief outline of the legislation that mandates them will also be written. The next section will go into a review of the absorptive capacity literature. Here the author will review work that has been done on absorptive capacity in organisational research. The author will finish this section by linking the concept of absorptive capacity to the current paradigms in environmental literature and therefore the need for it to be considered in environmental management.

Chapter 3: Research design, research parameters, methods and ethical considerations explained

This chapter will be presented in four main sections. Section one will explain the research design that the author undertook to do the study. In this section the author will explain the methodology that was followed, this includes the paradigm that the author subscribes too and the knowledge philosophy that was followed in the concurrent mixed method approach that was used.

The second section will describe the research parameters and assumptions that constrained this study.

The third section will describe the methods used for data collection and analysis. Data was collected in the form of a survey tool that was designed to measure absorptive capacity. This data was quantitatively analysed in R 3.2.1 statistical software. Under each question in the survey a comment box was added for any examples or comments which the participant wished to add. This data was analysed qualitatively using Atlas.ti 7.5.7 with the method of content analysis. This data was used to support the quantitative results.

The fourth section will describe the ethical considerations and processes followed to insure the study upheld to the ethical standard of the South African Health Act (Act 61 of 2003) and Nelson Mandela Metropolitan University with regard to using human research participants.

Chapter 4: Results and discussion

This chapter will display and discuss the results that were obtained according to the objectives of the study. Objective 1) to categorically and descriptively explore the absorptive capacity of three public-sector organisation that are mandated as environmental custodians in the Southern Cape.

Some findings so far:

- The mean level of years' experience for employees with in the organisations was 12 years.
- The mean percentage score for all organisations for acquisition, assimilation, transformation and exploitation respectively were; 70 %, 69 %, 69% and 63%. An overall average score for absorptive capacity was 68%.
- There is a significant difference in the score for assimilation of information between organisations
- There is a significant difference between the score for transformation of information between job categories
- Education level came out as a significant variable for whether or not a respondent made comments under each survey question
- No significant difference was found in the scores for acquisition and exploitation of information

Objective 2) to assess the reliability of the survey instrument that was adopted and adapted from Flatten *et al*. (2011)

Findings:

- The Cronbach's alpha test was used to test the internal consistency of the survey tool used for the study. This gives an estimate of reliability of the tool. The overall alpha score was 0.89 and therefore can be considered internally consistent and reliable.

Chapter 5: Conclusion and recommendations for future research

This chapter will bring together all the explorative results of the study and make propositions based on the findings. The author will then make recommendations based on these finding for future research and outline any relevance that these results have for the management of the selected organisations.

References

Biggs, R., Bohensky, E., Desanker, P., Fabricius, C., Lynam, T., Misselhorn, A., … van Jaarsveld, A. (2004). *Nature supporting people: The Southern African Millennium Ecosystem Assessment.* Pretoria: CSIR.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly*, *35*, 128 – 152. http://doi.org/10.2307/2393553

Flatten, T. C., Engelen, A., Zahra, S. A., & Brettel, M. (2011). A measure of absorptive capacity: Scale development and validation. *European Management Journal*, *29*(2), 98–116. http://doi.org/10.1016/j.emj.2010.11.002

Folke, C., Jansson, Å., Rockström, J., Olsson, P., Carpenter, S. R., Stuart Chapin, F., … Westley, F. (2011). Reconnecting to the biosphere. *Ambio*, *40*, 719–738. http://doi.org/10.1007/s13280-011-0184-y

Jiménez-Barrionuevo, M. M., García-Morales, V. J., & Molina, L. M. (2011). Validation of an instrument to measure absorptive capacity. *Technovation*, *31*(5-6), 190–202. http://doi.org/10.1016/j.technovation.2010.12.002

Klein, K. J., & Knight, A. P. (2005). Innovation Implementation : Overcoming the Challenge. *Current Directions in Psychological Science*, *14*(5), 243–246.

Knight, A. T., Cowling, R. M., Rouget, M., Balmford, A., Lombard, A. T., & Campbell, B. M. (2008). Knowing But Not Doing: Selecting Priority Conservation Areas and the Research–Implementation Gap. *Conservation Biology*, *22*(3), 610–617. http://doi.org/10.1111/j.1523-1739.2008.00914.x

Lane, P. J., Koka, B. R., & Pathak, S. (2002). A thematic analysis and critical assessment of absorptive capacity research. *Academy of Management Proceedings*, *2002*(1), M1–M6.

Lane, P. J., Koka, B. R., & Pathak, S. (2006). The reification of absorptive capacity: a critical review and rejuvenation of the construct. *Academy of Management Review*, *31*(4), 833–863.

Lane, P. J., & Lubatkin, M. (1998). RELATIVE ABSORPTIVE CAPACITY AND INTERORGANIZATIONAL LEARNING. *Strategic Management Journal*, *19*, 461–477. http://doi.org/10.1002/(SICI)1097-0266(199805)19:5<461::AID-SMJ953>3.0.CO;2-L

Murovec, N., & Prodan, I. (2008). The Influence of Organizational Absorptive Capacity on Product and Process Innovation. *Organizacija*. http://doi.org/10.2478/v10051-008-0005-7

Murray, K., Roux, D. J., Nel, J. L., Driver, A., & Freimund, W. (2011). Absorptive capacity as a guiding concept for effective public sector management and conservation of freshwater ecosystems. *Environmental Management*, *47*(5), 917–925. http://doi.org/10.1007/s00267-011-9659-7

Pfeffer, J., & Sutton, R. (1999). *The knowing-doing gap: How smart companies turn knowledge into action*. USA: Harvard Business School Press.

Reyers, B., Roux, D., Cowling, R., Ginsburg, A., Nel, J., & Farrell, P. O. (2010). Conservation planning as a transdisciplinary process. *Conservation Biology*, *24*(4), 957–965.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F., Lambin, E., … Schellnhuber, H. (2009). Planetary boundaries: exploring the safe operating space for humanity. *Ecology and Society*. Retrieved from http://www.ecologyandsociety.org/vol14/iss2/art32/

Roux, D. J., & Nel, J. L. (2013). Freshwater conservation planning in South Africa: Milestones to date and catalysts for implementation. *Water SA*, *39*(1), 151–164. http://doi.org/10.4314/wsa.v39i1.15

Schmidt, T. (2005). What determines absorptive capacity. *DRUID Tenth Anniversary Summer Conference on the Dynamics of Industry and Innovation Organization, Networks and Systems* . Copenhagen, Denmark: Department of Industrial Economics and International Management.

Schmidt, T. (2010). Absorptive capacity—one size fits all? A firm-level analysis of absorptive capacity for different kinds of knowledge. *Managerial and Decision Economics*, *31*(1), 1–18. http://doi.org/10.1002/mde.1423

Steffen, W., Crutzen, P. J., & McNeill, J. R. (2007). The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature. *AMBIO: A Journal of the Human Environment*, *36*(8), 614–621. http://doi.org/10.1579/0044-7447(2007)36[614:TAAHNO]2.0.CO;2

Van den Bosch, F. A. J., Volberda, H. W., & De Boer, M. (1999). Coevolution of Firm Absorptive Capacity and Knowledge Environment: Organizational Forms and Combinative Capabilities. *Organization Science*, *10*(5), 551–568. http://doi.org/10.1287/orsc.10.5.551

Vega, J., Gutierrez-Gracia, A., & Fernandez-de Lucio, I. (2007). APPROPRIABILITY , PROXIMITY , ROUTINES AND INNOVATION. In *DRUID Summer Conference 2007*.

Vega-jurado, J., Gutiérrez-Gracia, A., & Fernández-de-Lucio, I. (2008). Analyzing the determinants of firm ' s absorptive capacity: beyond. *R&D Management*, *38*(2005), 392–405. http://doi.org/10.1111/j.1467-9310.2008.00525.x

Zahara, S. A., & George, G. (2002). Absorptive Capacity : A Review, Resonceptulization , and Extension. *The Academy of Management Review*, *27*(2), 185–203. Retrieved from http://www.jstor.org/stable/4134351

Student : Thea Buckle Masters, Nelson Mandela Metropolitan University
This WRC project co-funded a number of Thea's theses chapters. The focus of her thesis and major findings to date are documented.

Thesis Title : An assessment of communication and farmer's perception of water conservation and management in the Garden Route, South Africa (title subject to change) - Thea Buckle

Introduction

Water, as a limited resource, will become even more scarce and the management thereof more problematic in the future. Understanding water issues in the Garden Route can be done through the lens of Social-Ecological-System theory, because it conceptualizes the system as socially and ecologically integrated and considers the feedbacks and interactions between individual elements of the system. Recent literature has focused on analysing systems as social-ecological systems (SES), or human-environment system, in order to understand the human dynamics behind ecological issues (Binder et al. 2013). Agriculture, along with industry, forestry and households, are the areas main water users (Pauw 2009:7), but the droughts in the area are particularly insidious when it comes to the agricultural sector (Schachtschneider 2013:7).

The relationships and influences between stakeholder groups within the selected Catchment Areas are important because of additional strain put on the natural resources through diverging views and competition (Pollard and Toit 2008). A fundamental shift is required in the stakeholder engagement processes in South Africa, specifically in government instances. Values, attitudes and worldviews of the stakeholders should be taken into consideration to create an understanding of the various economic and socio-cultural values of the land to the community (Wilhelm-Rechmann et al. 2014). This project aims to comply with this restructuring and investigate the reasoning behind perceptions and consequent behaviours.

Agriculture is a demanding water use industry in South Africa which has led to negative perceptions of agriculture by various publics (Lotter 2009). Government entities are predominantly in charge of policies on land use and development processes and subsequent decision making. This often leads to short-sightedness of potential consequences which is felt by the water-intensive economic sector and the public and is succeeded by activist backlash from local communities (Wilhelm-Rechmann et al. 2014).

Environmental communicators and scientists assume they have an impact on the water conservation awareness of farmers. Agriculture, specifically with regard to environmental change, faces many challenges and risks (Trautmann 2014:42) . It is also assumed that in the tension between environmental and economic considerations public awareness will lead to the stewardship of aquatic ecosystems in catchments. Other influences should be taken into account when researching the effects of mass media messages, especially because channels of influence could be diverse.

Previous experiences and perceptions influence the way we interpret messages. Communication doesn't exist inside a vacuum, but is informed by the cognitive perceptions behind certain actions and behaviours. This is attempted in order to determine how the various communication processes informs, or possibly does not inform, the farmers who are also the key focus of this study (Kilbourne 2006). This understanding of the influence of environmental communication on behaviour is crucial for environmental communicators and scientists who are interested in promoting ecosystem stewardship of catchments, which would form the 'building blocks' for ecological transformation. One first has to understand what these perceptions are, and how they are shaped, to be able to analyse the different influences and their respective impact on the farmers' relationship to water as a resource.

Environmental communication then serves to fulfil a double duty. It has theoretical implications as an academic field of inquiry, as well as practical implications in what it aims to achieve. Theoretically, even though environmental communication research has been increasing drastically, there is no 'gold standard' journal available for practitioners and scholars to turn to. A more "centralized point of publication" has been identified as an issue by the literature (Pleasant et al. 2002:197). The focus of environmental communication is pragmatic, in that its goals are not merely academic but are intended to trigger behaviour changes among the public or specific targeted recipients. (Ralston 2011). The academic engagement with this field thus explores the communication process and practical engagement, to base both content and medium upon scientific inquiry as a prerequisite to effecting academic endeavours.

This research will therefore assess which type of messages could possibly have an effect on which types of audiences, alongside the overall environmental inclination and view of water to see how these perceptions influence uptake of information. The measurement of the success of environmental communication has been focused on its immediate effect on the behaviour of the public towards the physical environment, whilst ignoring that it could also have an effect on academic observation (Stephens 2014), as well as on public perceptions, and subsequently, behavioural change in the long run.

Modern farmers are more likely to adopt conservation practices than their traditional counterparts, if it helps achieve their economic, social and environmental goals (Greiner et al. 2008). However, the largest water user, worldwide, remains irrigated agriculture and it is also one of the main water users in the study area (Ward and Pulido-Velazquez 2008). The industry has also been identified as a possible source of pollution through excess nutrients and pesticides, which would have negative impacts on the entire system (De Lange and Mahumani 2013, Schachtschneider 2013:7). It is therefore clear that agriculture, as land users, have an impact on the catchment as a whole. Their water usage has, however, changed quite significantly over the years depending on the available technology and costs associated with these.

The study area predominantly focuses on dairy farming, with vegetable and beef cattle farming to a lesser extent. A case study measuring climate change implications on agriculture for water and land use in the area determined that irrigation demand requires half of the available water. This exerts reasonable pressure on the water availability (Lotter 2009). Many farmers in the area employ water saving practices, including minimum till, technologically advanced irrigation systems with moisture probes, and scheduled irrigation at night (De Lange and Mahumani 2013). Other than these practices, alien plant invasions pose another huge risk in the area, specifically related to water availability and security. Clearing of these invasive plants is starting to take off amongst the farmers in the area (Schachtschneider 2013:7, van Wilgen et al. 2007).

Main aims and Objectives

- Develop an understanding of the relationship between perceptions and water conservation practices by agricultural water users.
- Link different forms of communication and knowledge to perceptions surrounding water conservation and ecosystem functioning.
- Contribute to the understanding of the link between environmental views and water-related practices.
- Contribute to the understanding of current mass media representations of water-related issues in the Garden Route.
- Discover new avenues and research opportunities for environmental communicators and conservationists who wish to engage with the farmers in the area.

Thesis outline

- <u>Chapter 1: Introduction and Background</u> will provide an introduction to the research topic, creating a backdrop of social and ecological issues faced in the area and highlighting the importance of investigating these.

- <u>Chapter 2: Research Methodology</u> gives a basis on which methods were employed for data gathering, and why these were chosen. It also outlines the various steps in the research process, including data gathering and the adapting of methods with the setbacks of the research.

- <u>Chapter 3: Results and Findings</u> will be organised according to the Research questions, with each sub-question as a different sub-chapter. The media content analysis, questionnaires and interview results will be merged to find overlaps and answer the questions from multiple angles and perspectives.

- <u>Chapter 4: Discussion</u> will attempt to find relationships between the factors explored, to determine the possible influences on the perceptions of water conservation.

- <u>Chapter 5: Conclusion and Recommendations</u> concludes the research with a brief discussion on all the major findings in the study and its implications for environmental communicators and future researchers. Implications for research and practice will also be discussed, specifically with regards to the limitations of the scale used in the research.

Chapter 1: **Introduction and Background**

The chapter outlines the background to the Garden Route's social and ecological issues. Firstly, water management and conservation as a contentious issue because of increasing demand and competition between industries. Secondly, erratic seasons and sporadic rainfall combined with a steep catchment that doesn't allow for adequate extraction of water has been identified as a challenge to the farmers. Thirdly, there appears to be disconnect between stakeholders in the area. Understanding of the adaptive practices employed by the farmers to optimize water usage is low, and assumptions of water wastage run high. It is this disconnect and finger-pointing that gets in the way of meaningful communication between farmers and other stakeholders.

In order for meaningful changes to be inspired by conservationists, they first need to understand a) the current state of water conservation, b) how farmers decide to employ various adaptations, c) what influences the thinking behind these adaptations, and d) how to communicate effectively to encourage positive adaptations.

Chapter 2: **Research Methodology**

This chapter outlines the following methods and the reasons behind their usage:

- Semi-structured interviews: Farmers were interviewed about their views on water regulation, quality and conservation. They were also asked about their information acquisition practices, and where they would find information for a crisis. Questions about media usage was included
- Questionnaires: Used for obtaining demographic information and employing the New Ecological Paradigm (NEP) scale. However, the questionnaire was filled out during the interviews which proved useful for collecting qualitative data for the NEP scale.
- A content analysis was also performed on the most read local newspaper, and the niche magazine read by the majority of the participants.

Chapter 3: **Results and Findings**

The farmers in the area have survived extreme economic downfalls with flooding and droughts, and have had to adapt to changing markets and more stringent regulations. A lot of the farmers have moved from the area, and even the industry. This means that the ones who are still farming are already adaptable in their practices.

In what follows, the research questions are used to structure the findings, to illustrate how the questions are answered.

Current main findings:

1. <u>How do farmers of selected Catchment Areas view water and ecosystem functioning regarding quality and regulations?</u>

Data from interviews presented here. Main findings are:

Even though some farmers lack the ecological systems thinking regarding water running off into the sea, most of the participants understood the interconnectedness of the upper and lower catchments of a river. They do, however, tend to weigh the social requirements, specifically food security, against the ecological needs of the system.

Furthermore, water regulations in the area pose some problems. The farmers claim that they do not manage to obtain permits for dams efficiently, and that this is hindering farming practices and expansion severely. They disagree with the regulations put in place as they are unnecessarily stringent.

- <u>How did their past and present experiences of various media texts influence them to form these views/ perceptions?</u>

Even though most of the participants indicate that their farming practices are independent of the media, the above systems thinking, and specific lack thereof, is echoed in media coverage of the floods and drought.

<u>- Which specific sources (both printed and oral) do they recall?</u>

No media sources were reported. However, the farmers indicate that they rely heavily on formal knowledge and interpersonal communication when they need information. The experimental farm in the area was identified as a major source of information by the farmers, and are also a source for the media.

<u>- Which perceptions are more diffuse?</u>

The most prolific issue that was revealed by the participants was the need for dams, in the light of more erratic seasons and sporadic rainfall. To further this, some participants indicated that this change in rainfall combined the steep catchment meant that dams were the future of conserving water.

2. What are the relationships between the below factors and farmers' perceptions and conceptions about the water conservation in catchments?

- Environmental communication

As stated above, the participants trust sources of formal knowledge and do not rely on the media for information. However, when probed, most participants were interested in environmental topics in the mass and agricultural media publications. These topics include Water conservation and purification, Sustainable farming practices and Invasive Species management.

- Interpersonal communication

Farmers rely heavily on their community through formal organisations. This includes farming associations and commodity specific study groups. In accordance with diffusion of innovation theory, farmers depend on opinion leaders for adaptations. What has been found with this community, is each farmer playing to their passions and strengths on a certain topic and then allowing the other farmers to learn from them. An example: a farmer taking an interest in geology, becoming an expert in analysing soil and acquiring knowledge from various sources, including journal articles, textbooks, experiments and the internet. The other farmers then go to this farmer for advice about geology-related issues and practices.

- Local ecological knowledge

Even though the farmers in the area are extremely adaptive, the family farmers are still passionate about their heritage and attribute their basic understanding of farming to their upbringing. Furthermore, some farmers indicated that they inherited their love of nature from their fathers and growing up in the area on the farms.

The farmers who didn't inherit their farms or grow up on farms criticized the family farmers for their stubborn adherence to traditional farming practices that aren't environmentally friendly. The research, however, did not turn up any evidence to support this theory.

- Financial considerations

This appears to be one of the main determinants to pro-environmental practices. If environmentally friendly farming practices are framed in terms of their economic benefits as well, such as optimizing water usage to save on pumping and electricity costs, it is more likely to be employed.

3. How do the perceptions and conceptions measured above inform the farmers' behaviour?

The farmers, as indicated by their NEP scores, have pro-environmental views mixed with business-minded traits. Farming has become a business, which makes economic approaches to adaptations necessary. The perceptions have informed the practices, in that most farmers employ water saving irrigation practices and clear their Invasive Alien Plants. The motives behind these adaptations appear to be primarily economic and then environmental. The cost of water, because of the input costs of dams, pumps and electricity has risen to a level which requires the farmers to optimize their water usage as much as possible.

Most of the participants try to clear their invasive alien plants, but lack the funds to do so adequately. A possible reason for this could be that the increased water yield will be experienced by downstream users, and they will not see economic return on their investment. Contrary to this, a lot of the farmers have installed center pivot irrigation with moisture probes, irrigating at night and using a lot less water. The farmers had all optimized their water usage if it was economically viable to do so.

Chapter 4: **Discussion**

The above findings will be analysed in accordance with the literature reviewed. Relationships between perceptions of water conservation and environmental communication, interpersonal communication, local-ecological knowledge and financial considerations will be explored. These will try to be reinforced by analysing the behaviours measured, and examining what the main determinants of these behaviours were.

Chapter 5: **Conclusion and Recommendations**

The main findings will be outlined and the implications of the research for research and in practice. This will include recommending a restructuring of the NEP scale for the South African agricultural context. Research into the framing of the environment and its role in the misunderstandings in communities will be suggested, as well as using opinion leaders to encourage environmentally friendly farming practices.

References

Binder, C. R., Hinkel, J., Bots, P. W. G. & Pahl-Wostl, C. 2013. Comparison of Frameworks for Analyzing Social-ecological Systems. *Ecology and Society,* 18**,** 26.

Braune, E., Adames, S. & Fourie, F. 2014. *20 Years of Groundwater Research, Development and Implementation in South Africa 1994-2014*, Water Research Commission.

Kilbourne, W. E. 2006. The Role of the Dominant Social Paradigm in the Quality of Life/Environmental Interface. *Applied Research in Quality of Life,* 1**,** 39-61.

Le Maitre, D. C., Versfeld, D. B. & Chapman, R. A. 2004. The impact of invading alien plants on surface water resources in South Africa: A preliminary assessment. *Water SA,* 26**,** 397-408.

Lotter, D. 2009. *Case study: Climate change implications for water and land use within the agricultural sector of the Garden Route* [Online]. SA Risk and Vulnerability Atlas. Available: http://www.rvatlas.org/casestudies/study06.php 2015].

Meier, K., Kuusemets, V., Luig, J. & Mander, Ü. 2005. Riparian buffer zones as elements of ecological networks: Case study on Parnassius mnemosyne distribution in Estonia *Ecological Engineering,* 24**,** 531-537.

Pauw, J. 2009. Challenges to sustainability in the Garden Route: Water, Land and Economy. Nelson Mandela Metropolitan University: George Campus.

Pleasant, A., Good, J., Shanahan, J. & Cohen, B. 2002. The literature of environmental communication. *Public Understanding of Science,* 11**,** 197-205.

Pollard, S. & Toit, D. d. 2008. Integrated water resource management in complex systems: How the catchment management strategies seek to achieve sustainability and equity in water resources in South Africa. *Water SA,* 34.

Ralston, S. J. 2011. *Environmental Communication as Deeply Pragmatic* [Online]. Hazleton: Pennsylvania State University. Available: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1865480 2014].

Rowntree, K. M. & Wadeson, R. A. 1999. A hierarchical geomorphological model for the classification of selected South African rivers. Pretoria, South Africa: Water Research Commission Report No. 497/1/99, Pretoria, South Africa.

Schachtschneider, K. 2013. Building resilient landscapes by linking social networks and social capital to ecological infrastructure. *P2: River and impoundment rehabilitation.* Council For Scientific and Industrial Research.

Stephens, P. H. G. 2014. PRAGMATIC ENVIRONMENTALISM: TOWARDS A RHETORIC OF ECO-JUSTICE. *Ethics & the Environment,* 19**,** 123-131.

Trautmann, I. 2014. SmartAgri project launched. *Agriprobe.* Elsenburg: Western Cape Government.

Wilhelm-Rechmann, A., Cowling, R. M. & Difford, M. 2014. Responses of South African land-use planning stakeholders to the New Ecological Paradigm and the Inclusion of Nature in Self scales: Assessment of their potential as components of social assessments for conservation projects. *Biological COnservation,* 180**,** 206-213.

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Thesis Title : Development role players' knowledge of ecological infrastructure in Eden District, South Africa

This WRC project co-funded a number of Abigail's theses chapters. The focus of her thesis and major findings to date are documented.

Key messages

- Role players in development processes in Eden were able to identify buffering to coastal storms as a key function of coastal foredunes. They understand the function of coastal foredunes as ecological infrastructure.
- Ecosystem services that were clearly identified were those that are visible and/or tangible such as tourism, coastal protection and dunes as a wildlife refuge.
- Ecosystem services that were not well identified were those that are less visible and/or tangible such as water catchment and purification.
- Engineers and environmental assessment practitioners were the most proficient while the planners were the least informed. Participants of this study were aware that foredunes offer ecosystem services but they demonstrated a general lack of knowledge regarding the number of services provided by dunes.
- Coastal defence was the primary adaptation identified. The consequences to adaption ranged from dune erosion to compounded risk.
- All respondents in this study recognised that a holistic approach is essential in responding to global environmental change.
- They agreed that integrated proactive approaches are needed which do not only consider coastal defences, but also include improved governance coupled with stakeholder awareness raising and facilitation between governance and implementation.
- These views concur with previous studies and models that most coastal developments in Eden are at high risk of property damage.
- The main obstacle to proactive adaptation voiced by participants is the lack of awareness of environmental change among professionals and its effect on social-ecological resilience. Another obstacle expressed was the complex and time-consuming application processes clients have to endure in order to follow legal prescriptions. The complexities of legislation and the effects this has on social-ecological resilience were also identified as an obstacle.
- Legislation still allows the modification of development that has been historically constructed on these dunes. This shows that it is not only these role players who need to be convinced of the need to integrate ecological infrastructure into development planning, but to also include developers, property owners and law makers.
- In order to create a resilient coastal community in Eden District Municipality the following actions are recommended:
    1. Develop a database were all ecological information about the Eden District coastline can be stored. This database should include information from experts who conduct environmental impact assessments. Allowing role players of the development processes to access it will cut down on time and financial constraints that leave property owners frustrated.
    2. Conduct sediment movement studies. Map areas of coast that are experiencing accretion or erosion. Include this information in the biological database.
    3. Use the information stored in the biological database to plan and holistically design coastal defences. These designs should make allowances for different types of infrastructure to be used according to the need, including the use of current ecological infrastructure combined with engineering synthetic natural infrastructure.
    4. Create coastal care-taker communities which include and focus on property owners with seafront property. These care-taker communities can be used as platforms for knowledge

exchange and provide opportunities for engagement and participatory mapping of at risk and damaged sections of coastline.

5. Ensure municipal managers are involved in care-taker communities because much seafront land is owned by and should be managed by the local authorities.
6. Use projects, such as Working for the Coast, that are already established to monitor and report illegal hardening and development of coastal properties. More serious actions should be taken against property owners who work outside of the law.
7. In cases where historical land rights allow the further development of coastal foredunes, additional by-laws and levies should apply. These can include stricter rules for the design and control of storm water; setting building lines further from the high water mark; preventing landscaping of dune areas on the seaside of properties; encouraging the use of known dune ecosystem services before hard structures are used to replace ecological infrastructure; and increased levies that can go toward the continued rehabilitation and monitoring of coastal foredunes.

While these recommendations do not address all of the obstacles identified by participants they will promote communities within the Eden District Municipality that are resilient to the risks presented by climate change.

Coastal disasters have been increasing in intensity and frequency around the world causing loss of life and millions of Rands' worth of damage to infrastructure. Coastal communities are growing as more people are drawn to urban areas. These people depend on the services the coastal ecosystem provide but through degradation and land use change the supply of services is reduced. The ability of these communities and landscapes to bounce back from disturbance has been severely hampered. As a result communities are looking for ways in which they can protect their lives and their assets and become more resilient. Through development planning structures such as coastal foredunes, that offer a buffering capacity against storm surges, can be used to strengthen the resilience of coastal communities. The type of defences used in communities would be dependent on the knowledge of the decision makers.

Between 2003 and 2008 the southern Cape region suffered damages amounting to ZAR2.2 billion due to severe weather events, in some cases isolating the city of George, in the Eden District Municipality, due to damages to road infrastructure. Most of the damage occurred along the coast, to dwellings built on coastal foredunes. These events confirmed what developers had known for decades: development on coastal foredunes is associated with extreme risk to climatic events. The provincial authorities have developed climate change adaptation plans and coastal setback lines while insurance providers are conducting private studies to determine the extent of risk to property. Despite current advances being made on adaptation plans the coastal strip of the Eden District Municipality has been developed beyond recognition leaving millions of Rands of infrastructure at risk.

This study explored the discourses and practices that are present in development processes regarding ecological infrastructure (in its buffering capacity for risk reduction) as an option for adaptation to global environmental change in the coastal areas of Eden District. Ecological infrastructure was defined as "*the network of natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas, which together enhance ecosystem health and resilience, contribute to biodiversity conservation and benefit human populations through the maintenance and enhancement of ecosystem services. Green infrastructure can be strengthened through strategic and co-ordinated initiatives that focus on maintaining, restoring, improving and connecting existing areas and features as well as creating new areas and features*". The aim was to identify what knowledge and practices are presently being employed in development processes regarding ecological infrastructure (in its buffering capacity for risk reduction) as an option for adaptation to global environmental change, in the coastal areas of the Eden District Municipality.

Qualitative data collection and analysis techniques were used. Following purposive and snowball sampling, in-depth interviews were conducted with 27 environmental assessment practitioners, developers, planners, regulating officials and architects active in the study area. Content of interviews was analysed according to pre-identified themes (Table 1) with the aid Atlas.ti software, recording the frequencies of responses in each theme. Descriptive statistics was then applied to the coded frequencies. Data were supplemented with quotations from interviews.

Table 1. Topics and interview questions used during interviews with 27 role playes in coastal dune development in Eden

TOPIC	QUESTIONS ASKED
Key ecological drivers of dune system:	• In your opinion, what are the natural drivers of coastal dune systems? • What benefits can be gained from coastal dune systems?
Key issues, vulnerabilities and threats:	• How do human activities affect the natural drivers/processes of coastal dune systems? • Please describe an example of where human activities have affected natural coastal processes? • What are your views on climate change? • How will climate change affect the Eden coastline? • What risk rating would you give the Eden coastline?
Best practice for development and disturbances:	• If a client approached you with a job to develop on a dune what process would you follow? • How would you/do you protect natural processes? • In what way do you adapt your practices to incorporate ecological infrastructure? • Where to from here (new developments, protecting existing developments)?
Perceived obstacles for sustainable adaptation to global change	• What is preventing you from using ecological infrastructure as an adaptation?

The study area included the local municipalities of Mossel Bay, George, Knysna and Bitou (Figure 1). The study area is limited to the coastline extending from Visbaai in the west to Nature's Valley in the east (Figure 1.)

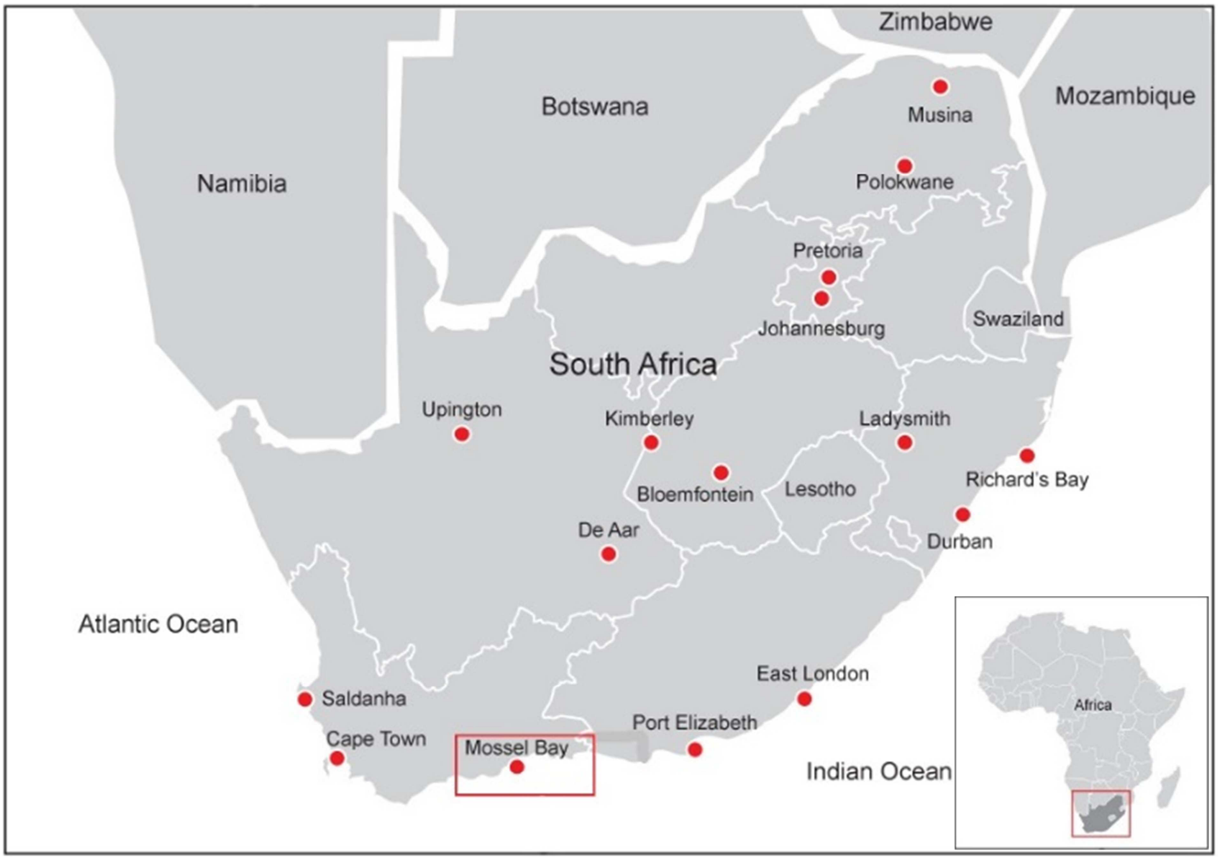

Figure 1. Study area

In Eden, dole players in development processes are aware of the complexities surrounding coastal social-ecological systems and understand the role foredunes play as ecological infrastructure within this system. Those who lack knowledge are aware of their knowledge gaps. Participants believe the study area is at risk due to human impacts and overall, participants felt that there is a general lack of awareness with regard to issues affecting our coastline, compounded by the absence of an enabling environment brought about by a lack of finances and time.

Following an social-ecological systems framework, the interactions between resource users, resources, public infrastructure providers and public infrastructure can be diagrammatically represented (Figure 2).

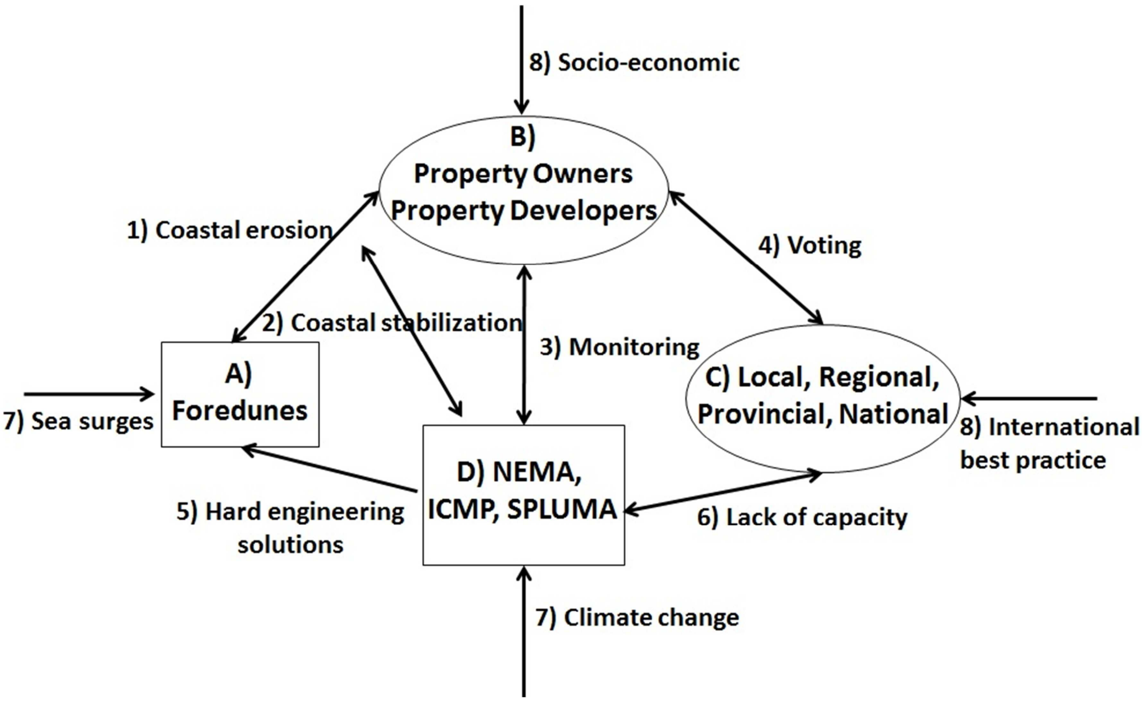

Figure 2. A conceptual model of a social-ecological system, A) resource/environmental system; B, C, D) components of social systems; 1-6) interactions and feedbacks between components of social and ecological systems; 7) external biophysical disturbances; 8) external socioeconomic disturbances (Anderies et al. 2004).

There was a rapid increase in the number of suburbs in Eden developed from the 1950s to 1970s with a peak in the 1960s (Figure 3). While the promulgation of environmental legislation played a role, it is noteworthy that there was still development of coastal dune areas at Cola Beach, Sedgefield, after the enactment of the National Conservation Act in1989 as well as within Mossel Bay Local Municipality after the enactment of the National Environmental Management Act in 1998 when two private estates, Nautilus Bay and Moquini Coastal Estate, were developed.

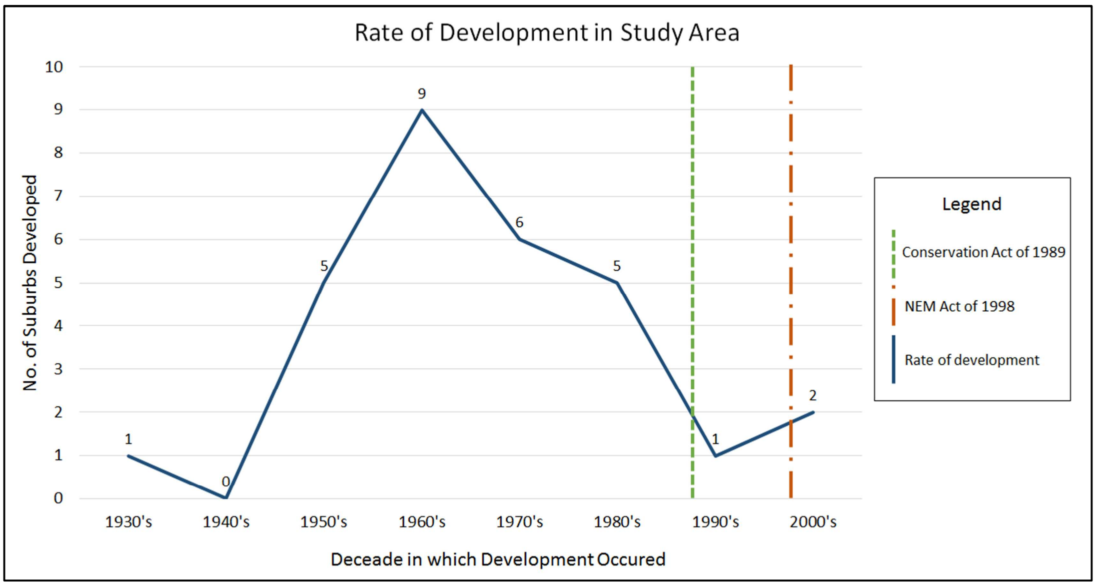

Figure 3. Number of new suburbs developed per decade along the Eden coastline, determined from aerial photographs

Respondents were very aware of the coastal protection services offered by coastal dune systems, and were more aware of the regulating and supporting services than provisioning services (Table 2).

Table 2. Frequency of responses recorded per code by professional group within the theme 'ecosystem services'

ECOSYSTEM SERVICES	Developer	Planner	Architect	Engineer	Environ Prac	Regulator	TOTAL	% of total (n)
Number (n =)	**1**	**4**	**4**	**6**	**7**	**5**	**27**	
Coastal protection		2	2	4	7	2	17	**63.0%**
Wildlife refuge		2	2	2	3	2	11	**40.7%**
Recreation			2	2	4	1	9	**33.3%**
Tourism			3	1	3		7	**25.9%**
Water catchment		1	1	1	1		4	**14.8%**
Erosion control	1				2		3	**11.1%**
Water purification				1	2		3	**11.1%**
Raw materials				2			2	**7.4%**
Carbon sequestration							0	**0.0%**
Total responses	1	5	10	13	22	5	56	
% of total responses	1.8%	8.9%	17.9%	23.2%	39.3%	8.9%	100%	
Ave number of responses per professional	**1.00**	**1.25**	**2.50**	**2.17**	**3.14**	**1.00**	**2.07**	**23.0%**

The average number of responses per professional group are highlighted (yellow = average # responses; green = above average; red = below average). The percentage of participants who identified the same services and drivers are recorded in the far right column and list from most in common to least in common

Participants had a good overall understanding of how coastal foredunes form and what drives their formation, showing they understand the importance of maintaining ecological infrastructure. Most participants mentioned multiple drivers (three, on average) (Table 3).

Table 3. Frequency of responses recorded per code by professional group within the theme 'drivers'

DUNE DRIVERS	Developer	Planner	Architect	Engineer	Environ Prac	Regulator	TOTAL	% of total (n)
Number (n=)	**1**	**4**	**4**	**6**	**7**	**5**	**27**	
Prevailing winds	1	2	2	4	6	3	18	**66.7%**
Seasonal wave action	1	1	1	5	5	3	16	**59.3%**
Sand mobility corridors	1	2	1	2	6	3	15	**55.6%**
Dune vegetation	1	2	1	5	3	2	14	**51.9%**
Ocean currents			1	3	3	2	9	**33.3%**
Organic material			1	1		1	3	**11.1%**
Total responses	4	7	7	20	23	14	75	
% of total responses	5.3%	9.3%	9.3%	26.7%	30.7%	18.7%	100%	
Ave number of responses per professional	**4.00**	**1.75**	**1.75**	**3.33**	**3.29**	**2.80**	**2.78**	**46.3%**

The average number of responses per professional group are highlighted (yellow = average # responses; green = above average; red = below average). The percentage of participants who identified the same services and drivers are recorded in the far right column and list from most in common to least in common.

Participants were not fully aware of the risks to development linked to global climate change. Risk dialogues centred around future expected impacts (44%) and past mistakes (25%) (Table 4).

Table 4. Frequencies of various risk discourses held by development industry role players in Eden

RISK DISCOURSE	Developer	Planner	Architect	Engineer	Enviro n Prac	Regulator	TOTAL	% of total (n)
Number (n=)	**1**	**4**	**4**	**6**	**7**	**5**	**27**	
Impacts are expected		2	3	4	1	2	12	**44.4%**
Past mistakes, current issues, future plans	1	1		1	3	1	7	**25.9%**
Impacts can be controlled				1	1	1	3	**11.1%**
Governance, entitlement					2	1	3	**11.1%**
It's part of life			1				1	**3.7%**
No risk		1					1	**3.7%**

The most common response to perceived threats was that of coastal defences in response to damage from sea storms . Setback lines were also identified, together with adapting legislation (Table 5).

Table 5. Frequency of participants' responses within the theme 'responses to perceived threats'

RESPONSES TO THREATS	Developer	Planner	Architect	Engineer	Enviro n Prac	Regulator	TOTAL	% of total (n)
Number (n=)	**1**	**4**	**4**	**6**	**7**	**5**	**27**	
Coastal defence				4	7	3	14	**51.9%**
Setback lines		1	2	1	2	2	9	**33.3%**
Legislation		2	2	1	2	1	8	**29.6%**
Infrastructure planning		1		2	1	2	6	**22.2%**
Dune stabilisation	1	1	1	1	2		6	**22.2%**
Insurance		1			1	1	3	**11.1%**
Adhoc setback lines					2		2	**7.4%**
Disaster management		1				1	2	**7.4%**
Research						1	1	**3.7%**
Desalination					1		1	**3.7%**
Total responses	1	7	5	9	18	11	52	
% of total responses	1.9%	13.5%	9.6%	17.3%	34.6%	21.2%	100.0 %	
Ave number of responses per professional	**1.00**	**1.75**	**1.25**	**1.50**	**2.57**	**2.20**	**1.93**	**12.6%**

The average number of responses per professional group are highlighted (yellow = average # responses; green = above average; red = below average). The percentage of participants who identified the same responses to threats and consequences thereof are recorded in the far right column and list from most in common to least in common.

Participants also understood that these responses could have unintended consequences, for example:

- construction of sea-walls which shift wave damage to other properties
- stabilization of mobile sand dunes, thereby preventing sand movement to beaches and causing their conversion to rocky shores;

- manipulation of river mouths to prevent flooding of properties upstream, but disrupting natural ecological processes and causing siltation of estuaries
- desalinization plants which disrupt sand movement along the seabed

A schematic representation (Figure 4) puts coastal development at the centre of the problems being faced. Black arrows show the environmental disturbances (blue boxes) effecting coastal development. In response to these disturbances (blue arrows) public infrastructure providers adapt as best they can with current information and knowledge. This has resulted (red arrows) in maladaptations (red fill boxes), such as desalination and mouth manipulation, that have created further risk of coastal erosion (red outline and text) through disrupted sediment movement (red outline). The blue arrows pointing away from the coastal development box show direct responses to issues arising with coastal development. Dune stabilization (maladaptation), as a result of houses being covered by sand, has resulted in the creation of increased risk from fire as well as disrupted sediment movement. Positive adaptations (green boxes) include sediment research and the development of integrated development plans Coastal erosion was identified as a risk created by maladaptation in response to disturbances. This is the risk that has put infrastructure and lives in vulnerable positions and has created a positive feedback loop. This loop is the on-going drive from property owners to protect their properties that ultimately enhances the effects of coastal erosion. The coastal erosion risk has not only created maladaptations but has also resulted in numerous positive adaptations. Planned retreat, setback lines and lack of insurance encourage property owners to leave coastal fore-dunes and build houses in other areas that are governed by integrated development plans.

The adaptations frequently recommended by participants in coastal defence, governance, coastal development and development planning (Table 6). They recommended that coastal defences should include a combination of soft and hard structures, and be adopted over extensive stretches of coastline rather than piece-meal. Governance-related recommendations were to improve spatial development frameworks, prevent further development on dunes and improved coordination of activities between authorities.

Table 6. Adaptations recommended by development role players in Eden

RECOMMENDATIONS	Developer	Planner	Architect	Engineer	Environ Prac	Regulator	TOTAL	% of total (n)
Number (n=)	**1**	**4**	**4**	**6**	**7**	**5**	**27**	
Coastal defence				5	3		8	**29.6%**
Development planning		2	1	1	2		6	**22.2%**
Governance		1	2		1	1	5	**18.5%**
Coastal development				1	2	2	5	**18.5%**
Infrastructure planning				2	1		3	**11.1%**
Public awareness					2		2	**7.4%**
Setback lines		1			1		2	**7.4%**
Total responses	0	4	3	9	12	3	31	
% of total responses	0.0%	12.9%	9.7%	29.0%	38.7%	9.7%	100.0 %	
Ave number of responses per professional	**0.00**	**1.00**	**0.75**	**1.50**	**1.71**	**0.60**	**1.15**	**16.4%**

The average number of responses per professional group are highlighted (yellow = average # responses; green = above average; red = below average). The percentage of participants who identified the same recommendations and obstacles are recorded in the far right column and list from most in common to least in common.

The size of replacement buildings should be restricted and special levies for frontal properties should be considered, to enable municipalities to take preventative action.

Participants identified a number of obstacles to proactive coastal adaptation. They felt that there is a general lack of awareness with regard to issues affecting our coastline. Most participants mentioned that a specific group or individual (client, local authorities, people, council, community, developer, and officials) was unaware of the complexities of the issues affecting the coastline that "they just think in terms of their own little box" often resulting in a knock-on effect of the consequences (Table 7).

Table 7. Obstacles to proactive participation mentioned by participants

OBSTACLES	Developer	Planner	Architect	Engineer	Environ Prac	Regulator	TOTAL	% of total (n)
Number (n=)	**1**	**4**	**4**	**6**	**7**	**5**	**27**	
Lack of awareness		2	4	1	5		12	**44.4%**
Lack of enabling environment		3	1	3	3		10	**37.0%**
Lack of finances		1		3	3	1	8	**29.6%**
Long time scales		1	1	2	2	1	7	**25.9%**
Legal precedent set			1	1	4		6	**22.2%**
Lack of experts		1	1	1	2		5	**18.5%**
Lack of enforcement	1	1		1			3	**11.1%**
Hierarchy of policies						1	1	**3.7%**
Total responses	1	9	8	12	19	3	52	
% of total responses	1.9%	17.3%	15.4%	23.1%	36.5%	5.8%	100.0%	
Ave number of responses per professional	**1.00**	**2.25**	**2.00**	**2.00**	**2.71**	**0.60**	**1.93**	**24.1%**

The average number of responses per professional group are highlighted (yellow = average # responses; green = above average; red = below average). The percentage of participants who identified the same recommendations and obstacles are recorded in the far right column and list from most in common to least in common.

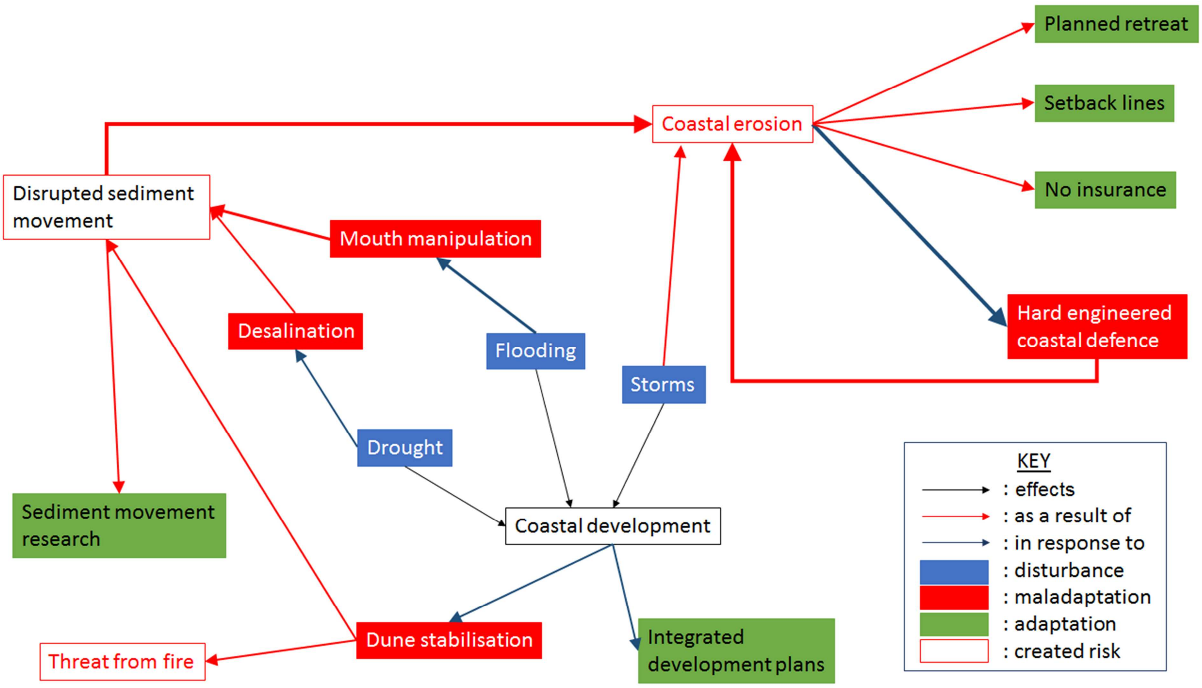

Figure 4. Schematic summary of adaptations and consequences as elicited from interviews showing cause and effect. It puts coastal development as the centre of the problems being faced. Black arrows show the environmental disturbances (blue boxes) effecting coastal development. In response to these disturbances (blue arrows) public infrastructure providers adapt as best they can with current information and knowledge. This has resulted (red arrows) in maladaptations (red fill boxes), such as desalination and mouth manipulation, that have created further risk of coastal erosion (red outline and text) through disrupted sediment movement (red outline). The blue arrows pointing away from the coastal development box show direct responses to issues arising with coastal development. Dune stabilization (maladaptation), as a result of houses being covered by sand, has resulted in the creation of increased risk from fire as well as disrupted sediment movement. Positive adaptations (green boxes) include sediment research and the development of integrated development plans Coastal erosion was identified as a risk created by maladaptation in response to disturbances. This is the risk that has put infrastructure and lives in vulnerable positions and has created a positive feedback loop. This loop is the on-going drive from property owners to protect their properties that ultimately enhances the effects of coastal erosion. The coastal erosion risk has not only created maladaptations but has also resulted in numerous positive adaptations. Planned retreat, setback lines and lack of insurance encourage property owners to leave coastal fore-dunes and build houses in other areas that are governed by integrated development plans.