EXPLORING CURRENT AND EMERGING IRRIGATION AND DRAINAGE MANAGEMENT TO REDUCE THE IMPACT OF EXTREME EVENTS AND MITIGATE DROUGHTS AND FLOODS

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

Effective water management has become an important part of sustainable economic development worldwide. In areas dependent on agriculture for livelihoods and local economic development, an integrated approach to catchment management is key in ensuring long-term availability of high-quality water. Agriculture in South Africa is also faced with an increase in irregular rainfall patterns as a result of climate change, affecting infiltration rates of water, and severity and frequency of flooding and drought events. This, and other factors have led to the establishment of hard infrastructure in rivers to protect private property from flood damage but also undermines already established ecological infrastructure, which is often integral in regulating water flow, sediment deposition, nutrient filtration, and maintenance of biodiversity. These issues are often compounded by other issues like excessive water abstraction, pollution from agricultural runoff and effluent from human settlements, and invasion by alien fauna and flora.

This study takes a participatory research approach to identifying the opportunities and barriers in the Berg River Catchment, regarding innovation in irrigation and drainage practices aimed towards informing integrated management of the catchment. Different engagement tools have been employed to ensure the incorporation of varied perspectives and knowledge of the social-ecological system. Internationally applied practices are used as inspiration to draw out and evaluate context specific interventions for the Berg River

The Berg River Catchment is an important component of the Berg River Water Management Area (WMA), which supports the various water uses of 7 economically intensive municipalities, including the Berg River, Saldanha Bay, Swartland, Drakenstein, Stellenbosch, Witzenberg, and City of Cape Town municipalities. As such, the Berg River Dam and the Wemmershoek Dam in the upper reaches of the river are important reservoirs for consistent supply of water to these municipalities but also pose significant environmental threats associated with reduced flows affecting the ecological reserve, disrupting sediment flows, and loss of natural flooding regimes. Reductions in the ecological reserve invariably also leads to increased concentrations of nutrients and other pollutants in the main channel, which (in addition to increased salinity from the soils towards the West) affects agriculture and industrial activities downstream. These effects would naturally be buffered by the influence of clean water and natural flow regimes provided by tributaries.

By consolidating the outcomes of continuous engagements with local stakeholders, this report details stakeholder perceptions regarding the management of the Berg River Catchment. Recommendations arising from the identified influencing factors, opportunities and barriers were well aligned between the various stakeholders and could be broadly grouped as interventions in i) innovation, ii) implementation and coordination, and iii) policy, legislation and information sharing.

We propose a continuation of efforts to rehabilitate and invest in ecological infrastructure in the Berg River Catchment. Through prototyping interventions which integrate ecological infrastructure and built infrastructure to support agricultural productivity, ecological function and disaster risk reduction, we aim to support and address local and provincial priorities. Specific research questions have been highlighted and we commit to continue facilitating knowledge creation and exchange. We aim to build stronger relationships with and between stakeholder groups active in the Berg River Catchment, and create the space for new collaborative relationships and partnerships to emerge.

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The Department of Science and Technology, the South African National Biodiversity Institute, the Department of Environmental Affairs and Development Planning, the Berg River Irrigation Board, BlueScience, Cape Nature, the City of Cape Town, the Centre for Scientific and Industrial Research, the Department of Water and Sanitation, LandCare, Stellenbosch University, University of Cape Town and WWF-SA.

LIST OF ABBREVIATIONS AND ACRONYMS

WMA	Water Management Area
WCWSS	Western Cape Water Supply System
DEA&DP	Department of Environmental Affairs and the Development Planning
MIT	Massachusetts Institute of Technology
WARMS	Water Authorisation Registration and Management System
DWA	Department of Water Affairs
DWS	Department of Water and Sanitation
ZAR	South African Rand
WWTW’s	Waste -water Treatment Works
BRIP	Berg River Improvement Plan
IPCC	International Panel on Climate Change
WWF	Worldwide Fund for nature
REC	Recommended Ecological Category
PEC	Present Ecological Sate Category
MUCP	Management Unit Control Planning
UCPP	UMzimvubu Catchment Partnership Programme
UCT	University of Cape Town
SANBI	South African National Biodiversity Institute
SWSA	Strategic water source areas
MMP	Maintenance Management Plan
M&E	Monitoring and Evaluation
CMA	Catchment management Agency
CMF	Catchment Management Forum
RQO’s	Resource Quality Objectives
DAFF	Department of Agriculture, Forestry, and Fisheries

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. PREAMBLE

This study draws on several engagements facilitated by Living Lands in an attempt to understand and co-develop approaches for integrated catchment management in the Berg River catchment. This study was conducted in recognition of the fact that irrigation and drainage practices in the Berg River Catchment are informed by the local socio-ecological system and has a major impact on the management of the catchment. This report provides an overview of what might, and might not be applicable in the Catchment, rather than being a prescriptive manual on innovation in irrigation and drainage practices in the Berg River Catchment. In this regard it represents a 'work in progress', aimed at demonstrating there is a need to interrogate and prototype innovative interventions in the field of irrigation and drainage practices to enable successful integrated catchment management.

2. BACKGROUND AND RATIONALE

The Berg River Catchment forms part of one of South Africa's 19 Water Management Areas (WMA's), the Berg River WMA. The primary river, the Berg River, originates in the Boland Mountains North of Cape Town, from which it flows towards St Helena Bay on the West Coast and discharges into the Atlantic Ocean. The river and its tributaries also form part of the Western Cape Water Supply system, connecting various water sources to the major municipal areas in the region. Outside of the major Cape Town Metropolitan, the principal land use surrounding the Berg River is agriculture. The river provides water for approximately 600 farm units where production of grapes, livestock, and deciduous fruit is an important economic driver for the province. The Berg River has 19 tributaries feeding into the main channel which discharges a volume of 931 Mm^3/a. The river originates in mountain ranges that are underlain by Table Mountain Sandstone, giving rise to nutrient-poor, acidic soils. Towards the west, the soils are derived from Malmesbury Shale, which is a parent material to more saline soils. Groundwater quality in these two sections of the catchment are also significantly different, with groundwater from the Table Mountain Group and the Cape Granite Suite Aquifers typically being of better quality than that of the Malmesbury Group and the Klipheuwel Group Aquifers (DEA&DP, 2012). The region receives most of its annual rain during the Winter months (June-August) and, under natural conditions, undergoes regular flooding during this period; during the period of April to September, the region receives 80% of its annual rainfall (Görgens & de Clerq, 2005).

Effective water management has become an integral part of sustainable economic development worldwide. South Africa is ranked as the 30th driest country in the world and requires continuous monitoring of and development of innovative approaches to water resource management. The agricultural sector in the Western Cape has considerable potential to drive economic growth, job creation and social development (OneCape-2040, Western Cape Government). The need for effective and efficient water management in agriculture is common knowledge but an apparent lack of common understanding and access to information is a major barrier to employing adaptive mitigation practices, leading to uncoordinated, isolated, and often less effective catchment management interventions. In the face of current trends in climate change, it is becoming more and more pertinent that catchment management includes consideration of all the various drivers to the functioning of a catchment, including hydrological, ecological, economic, and social drivers.

Rehabilitation and maintenance of ecological infrastructure is important to catchment functioning and delivery of ecosystem services such as provision of clean water, flood attenuation, and drought protection. Management of such infrastructure may only be effective if the social systems along the catchment are understood and taken in to account. Agriculture, as a water-intensive sector in South Africa, and often a driver of change, could potentially play an important role in successful catchment management through practices such as improvements in irrigation efficiency and effective drainage management. Threats to livelihoods, however, often culminate in unsustainable farm management interventions. Climate change presents a major threat to agriculture in South Africa, as rainfall becomes less predictable and more often arrives in shorter, more intense spells causing severe flooding, erosion, and damage to property. Flooding is a highly destructive natural phenomenon and often leads to anthropogenic flood protection measures, including building of infrastructure such as levees. This invariably reduces the storage capacity of the floodplain and confines the river to a singular channel, which has potential for even greater destruction during higher intensity floods. Economically and environmentally sustainable management of catchments is necessary in order to successfully adapt to climate change (Loos & Shader, 2009). This report aims to consolidate the major opportunities and barriers perceived by stakeholders to the successful, integrated management of the Berg River Catchment.

3. OBJECTIVE

This study was borne out of a collective recognition that management of the Berg River Catchment for human and ecological well-being requires strategic planning which involves bottom-based approaches to information gathering and project implementation. The goal of this project was **to explore innovative interventions needed to enable integrated catchment management in the Berg River Catchment**. This was done through a desktop assessment of literature on international and local water management systems, related to irrigation and drainage practices, and a discussion of such programmes in the context of the Berg River Catchment. The desktop research was supported by information gathered through attending workshops, conducting Dialogue Interviews and facilitating learning events. Dialogue Interviews were conducted with various local stakeholders to ascertain what the challenges, opportunities and barriers are to the implementation of innovative interventions in the Catchment. The different views of stakeholders were consolidated to determine the scope for innovation in the management of the catchment and the factors that influence implementation.

4. RESEARCH APPROACH

Participatory Research

This study employs a participatory research approach. Participatory research methods are aimed towards planning and conducting the research process with those people whose daily reality and actions are being explored. Consequently, the intention of the inquiry and the research questions are developed and informed out of two perspectives; that of science and of practice (Bergold & Thomas 2012).

Involving a broad base of stakeholders in the study process enables one to incorporate varied perspectives and knowledge of the social-ecological system. The incorporation of diverse knowledge helps to identify the potential unintended negative consequences of any interventions and ensure that these consequences are minimised and if possible avoided. Through interacting with each other and the research team, the unconscious tacit knowledge embodied in the stakeholders is revealed and incorporated. This is the social information that is not generally known and that the stakeholders often do not realize they themselves or others have. The collective involvement of the stakeholders in the process, the incorporation of this tacit knowledge, and the collective interrogation of the assumptions related to e.g. innovation in artificial irrigation and drainage practices in the Berg River Catchment enables the researcher to gain a holistic understanding of the study area.

The Living Lands approach to participatory research and stakeholder engagement is rooted in Theory U, which is a method of facilitating collective social learning, developed from the MIT U Lab (Scharmer, 2009). Social learning is increasingly recognised as a crucial component of participatory processes aimed at nurturing collective action around common environmental concerns (Cundill & Rodela, 2012).

The Living Landscape Approach

As Living Lands, our vision is "Collaborations Working on Living Landscapes". This vision informs our work and research approach. To expand on our vision; when we speak of *collaborations,* we refer to people working together to solve a common challenge and engage in collective action based on understanding, trust and respect. In our work, collaborations mean working and partnering with farmers, private landowners, businesses, government bodies, schools, universities and other civil society organisations. *Working on*, refers to the fact that we do our work on the landscape and live there as well. We manage ecological rehabilitation projects and innovate to suit the landscape needs. We believe in learning by doing; fail fast and learn faster. We define *living landscapes* as a variety of healthy ecosystems and land uses that are home to ecological, agricultural, and social systems which are managed to function sustainably.

We see ourselves as facilitators on the landscape. We have developed, tested, refined and applied our Living Landscape Approach to all our landscapes in the Eastern and Western Cape of South Africa. This approach, integrating the building blocks of Theory U and the 4 Returns framework, brings bottom-based and top-guided processes together to facilitate social learning and collaboration between local stakeholders. It builds ownership and willingness within collectives and is supported by an integrated effort of the government and private sector to implement and mainstream policies and programmes. A knowledge and evidence base is developed which informs the programmes and policies that arise out of the process.

We embody five different roles on the landscape namely: Landscape Mobiliser, Landscape Facilitator, Landscape Innovator, Knowledge Broker and Business Developer (described in Appendix A).

The Theory U Methodology

Theory U allows for a deeper integration and understanding of systems that are foreign to oneself. This helps us and the stakeholders with whom we work, to immerse in experiences on deeper levels which then trigger greater emotion and action. Theory U was developed by the Presencing Institute at the Massachusetts Institute of Technology (MIT) for leading profound change. The process provides opportunities for all stakeholders to engage on a deeper level of reflection on the socio-ecological system, to identify and create viable community-based responses through theoretical perspective and practical social technology. This addresses underlying social problems on an individual, community and institutional level and informs behaviour to better reflect the values of inclusion, fairness and opportunity. We believe that when processes are developed in such a way, they reflect the truth of each system. Focusing on the interior state of the intervener allows results of a higher quality to emerge. Theory U acts as a framework; as a method for leading profound change; and as a way of being, through connecting to one's more authentic and higher aspirations.

We are guided in our work by the steps of the U with five primary stages;

1. Co-initiating: creating a common-intent.
2. Co-sensing: observing and learning from the system in which we are working.

3. Co-strategising: reflecting on how we become part of the story of the future and plan ahead rather than holding on to the story of the past.
4. Co-creating, prototyping interventions and innovating on the landscape, and
5. Co-evolving by developing a strategic and holistic landscape plan.

This process is by no means linear and can include multiple iterations of the U through time.

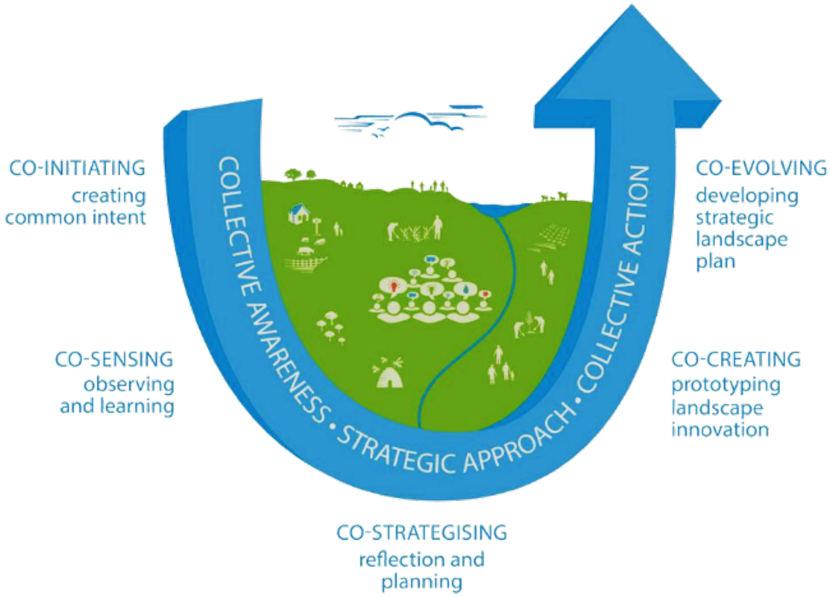

Figure 1: The Theory U framework, developed by Sharmer (2009) and employed in our current Living Landscape approach to management of social-ecological systems

The 4 Returns Framework

Commonland is an international foundation that believes landscape restoration offers tremendous untapped opportunities for sustainable economic development. Living Lands is a proud 4 Returns partner organisation. We develop and implement interventions with the intention to result in
4 Returns: the return of inspiration, social capital, natural capital and financial capital. This enables long-term sustainability of projects to build a collective sense of place and move beyond the 'project lens'. Projects initiate action towards a broader landscape vision. This vision is where we focus our energy and ensure succession towards a Living Landscape. The business component is as crucial as the rest - we believe that as a Not-for-Profit Company we need to be the bridge between business, social and ecological thinking.

Figure 2: The 4-returns framework employed by Commonland, advocating that ecological interventions should be designed to return social capital natural capital, financial capital (investment), and inspiration to those who interact with the environment

Engagement Tools

Different engagement tools are employed depending on the specific stakeholders who are being engaged, the intended outcome and the context of the engagement. For this study, additional Dialogue Interviews were conducted, and project meetings were held. Prior to, and during the timeframe of this study, several Workshops and Learning Journeys were facilitated by Living Lands in the Berg River Catchment. Below is a short description of the different types of engagements employed.

Dialogue Interview

To allow for an increased level of trust and transparency between Living Lands and landscape stakeholders, Dialogue Interviews are conducted with key stakeholders which helps to create a generative field of connections and collaboration. These are one-on-one meetings where a generative conversation is created to allow for the interviewee to reflect on aspirations, challenges and needs and how they relate to and engage with the community and the landscape. Subsequent group meetings and workshops are then informed by the expectations and reflections of stakeholders collated from Dialogue Interviews.

Outcomes of a Dialogue Interview:

- Provide insights into questions and challenges that the interviewees face;
- Promotes common understanding
- Begin to build a generative field for the initiative you want to co-create.

Initial Questions:

- What are your current challenges, and how can we support these activities and help you realise it?
- What criteria do you use to assess if activities have been successful?
- If I were able to change two things in the current catchment management system within the next six months, what two things would create the most value and benefit for you?
- What barriers in the current systems or other issues have hindered progress?

Group gatherings

Two types of group gatherings are employed to facilitate knowledge exchange, namely; Workshops and Learning Journeys. Workshops are aimed to bring focus around a specific challenge to prototype solutions and innovation. It generally takes place at one location, which is centrally located and runs for about 3 hours.

Learning Journeys allow participants to fully immerse themselves, explore and experience first-hand, the various dimensions of the realities they are trying to understand and influence. Participants usually visit different sites which tell a story and deepen the understanding a topic. These journeys are generally half a day and allow participants to break-through old patterns of seeing and listening by stepping into a different and relevant perspective and experience. The aim is to gain a systems perspective as well as create an environment to build relationships with and between key stakeholders.

A Learning Journey is conducted by following the following key steps:

A. Site Selection.
B. Identifying key questions.
C. Participants write down key assumptions.
D. Reflection/debrief exercise afterwards: What is it that we saw that confirmed our assumptions and what changed our assumptions? What we noticed about the system and ourselves? What new ideas were generated?
E. Sense interests of stakeholders and determine if scope exists for further project development.

A Learning Journey provides for the following:

1. To see and understand reality with new eyes.
2. Allows generation of new ideas.
3. Building relationships with others - the key to instrumental prototypes of new ideas.
4. Produces a mindset shift within a system that is much more profound and effective than a workshop.

Both workshops and Learning Journeys are spaces where all opinions and ideas are respected. Principles that guide these group gatherings are; everyone has valuable knowledge to share of their context, nothing is right or wrong and everyone is responsible for their own learning.

5. SITUATION ASSESSMENT OF THE BERG RIVER CATCHMENT

The Berg River Water Management Area

South Africa is divided into 19 Water management Areas (WMA's), including four in the Western Cape, of which the Berg River WMA covers the southwestern corner (Cole et al., 2018). The country has a mean Falkenmark water stress indicator of 921 cubic centimetres per person per year ($cm^3/c/a$), while the Berg River WMA has an indicator of 193 $cm^3/c/a$. By comparison, most European countries operate on more than 1700 $cm^3/c/a$ (and more than 30 000 $cm^3/c/a$ for Norway and Iceland) (Lallana & Marcuello, 2004). South Africa is thus relatively stressed for water and needs to continuously find new ways of efficient water management. Breaking regions up into WMA's aims to promote a coordinated approach to water management but requires continuous engagement to be effective.

Through the WMA, the Berg river supports a large proportion of South Africa's GDP and, as such, needs to be managed appropriately to ensure the maintenance of appropriate water quality and quantity. The Western Cape has recently been subject to a severe drought that underlined the importance of effective catchment management and the need for a multisectoral approach to addressing water related issues in the region.

Socio-economic system

Water usage in the Berg WMA has been detailed in the Water Authorisation Registration and Management System (WARMS) which is housed by the Department of Water and Sanitation (DWS). An analysis done by Cole et al. (2018) on the WARMS database that focuses on the heavy water usage sectors of agriculture, freshwater aquaculture, mining, and agri-processing showed great disparity in the socio-economic benefits of water between different areas. The City of Cape Town, for instance, was reported to create 932 jobs per million cubic meters of water per annum (Mm^3/a) which accounts for an income of R187/m^3/a, while the Stellenbosch Municipality provides about 7 jobs per Mm^3/a at R9/m^3/a. The average for the Berg WMA is set at 177 jobs per Mm^3/a at R184/m^3/a. Out of all the sectors, the most jobs in the region are produced through Agri processing (633 jobs/ Mm^3) and the highest income per unit water is produced through mining (R57.52/m^3).

Table 1: Indicators of water-use efficiency in the Berg Water Management Area (WMA) (source: Cole et al., 2018)

Municipality	Residential per capita water use (L/c/d)	Municipal water losses (%)	Jobs per million cubic metre in heavily water-dependent sectors (Mm^3/a)	Total income per cubic metre in heavily water-dependent sectors (ZAR/m^3/a)
Bergrivier	138	13	114	79 ± 26
Saldanha Bay	112	18	786	239 ± 80
Swartland	107	15	234	102 ± 32
Drakenstein	106	11	41	18 ± 6
Stellenbosch	152	18	7	9 ± 3
Witzenberg	107	10	112	15 ± 5
City of Cape Town	125	14	932	187 ± 62
Berg WMA	124	16	177	184 ± 61

The Berg River Catchment is highly stressed for consistently supplying large volumes of water of high quality to support the local and international markets attached to its functioning. Recent droughts have underlined the importance of effective catchment-scale interventions and management approaches to the long-term well-being of the system and its dependents. This is exacerbated by marked decreases in water quality as a result of increased urbanization along the upper reaches of the catchment, including its tributaries, which could invariably lead to health issues of primary water users and could have a significant long-term impact on the export potential of agricultural goods produced in the region.

Water quantity and quality

Water quality in the Berg River has deteriorated with time, largely as a result of establishment of informal settlements next to the main channel and its tributaries. It has been reported that the poor water quality in the Berg River has a significant impact on agriculture in the region, which currently amasses total exports to the value of R7 billion annually (55-60% of the country's total exports) (Pengelley et al., 2017). The declines in water quality have led to economic risks for the region by, in some cases, not meeting international quality standards (DEA&DP, 2012). In addition to the economic impact of reduced water quality, the quality of life of all surrounding the river is affected as domestic and recreational use are limited and can lead to illness.

Other sources of pollution in the Berg River, as identified in the Berg River Improvement Plan (BRIP; DEA&DP 2012) include wastewater treatment works (WWTW's), nutrients from agricultural runoff, natural soil salinity, and industrial wastewater.

A prominent threat to water security in the Berg River WMA has been identified as invasive alien trees, mainly from the Acacia and Eucalyptus genera. Invasion in the province leads to significant losses of water annually. Additionally, natural ecological infrastructure is severely compromised by presence of invasive trees, especially in riparian zones where natural vegetation is responsible for flood attenuation, nutrient filtration, and erosion control. Another threat to the availability of water in the catchment is potential unsustainable water usage practices for irrigation purposes. Specifically, infrastructure built along the stream channels to limit the width of the river either to allow farming further unto the floodplain or to reduce flood risk. This typically reduce the capacity of the riparian zone to absorb the river's natural flow, leading to faster through-flow of water, causing further erosion in the stream and affects long-term water availability. Irrigation on farmland also has a massive impact on the Berg River's water availability, accounting for 47% of the total water usage in the catchment, second only to industrial use (Bronckhorst et al., 2016).

It is widely agreed that releasing large quantities of water through alien clearing and storage in dams would not necessarily address the issue of water security if water quality is not improved. The levels of inorganic nitrogen and phosphorus have been reported to increase more than 10 times from the upper Berg River to the lower reaches, while these levels have been found to fluctuate by more than 1000% between season as a response to fluctuations in diffuse and point-source pollution (Fell, 2017). A significant increase on phosphate levels have also been observed over the past two decades, which could be exacerbated by a decrease in river flow, effectively leading to an increase in nutrient concentrations (De Villiers, 2007). These issues have been raised prior to the building of the Berg River Dam, which has been cited as a possible cause for decreased flow year-round. Recent discussions with stakeholders suggest that the environmental release from the Berg River Dam has not been administered as previously indicated. According to the original design of the dam, environmental flow will be tailored to seasons (due to seasonal rainfall in the region), where releases of $4m^3/s$ will be released during the winter months but up to $160m^3/s$ during high rainfall events; summer releases are not specified. During the recent drought, the entire ecological reserve was allocated to human consumption, leading to drying up of the parts of the river.

Irrigation and drainage

Agriculture in South Africa accounts for about 63% of all water usage (Donnenfeld et al., 2018), most of which is for irrigation. In the Western Cape, agriculture is also a major water use activity but more so in the Breede, Gouritz, and Olifantsdoorn WMA's. In the Berg River WMA, agriculture accounts for approximately 47% of the total water usage, due to the heavy residential water usage in the City of Cape Town (Bronckhorst et al., 2016). The high proportion of water allocated to residential use is as a result of the Berg River WMA catering for two-thirds of the population of the Western Cape. It has to be noted too that, through absorbing 47% of the available water in the WMA (and a portion of the Breede River WMA via the WCWSS), the City of Cape Town contributes 75% of the GDP of the province and 11% of the national GDP (Pegram & Baleta, 2014). Agricultural land in the Western Cape covers an area of 11.5 million ha (12.4 % of the national agricultural land) and produces between 65 and 70% of the country's total agricultural outputs.

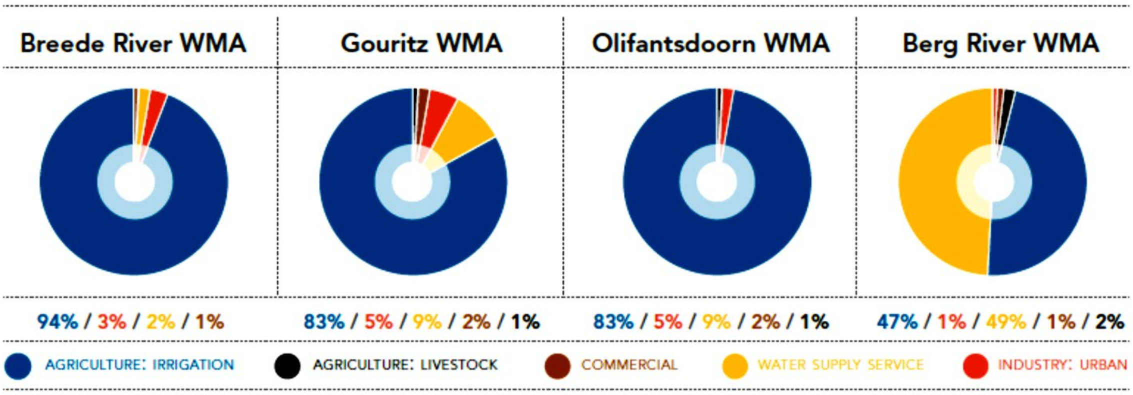

Figure 3: Proportion of water allocated to various uses in the Western cape WMA's (source: Bronckhorst et al., 2016)

However, non-revenue water (water lost in the distribution system) has been cited as a major driver of the great consumption of water in SA and it has been estimated that the non-revenue water through agriculture will, by 2035, account for 58% of the national withdrawals (Donnenfeld et al., 2018). Additionally, Donnenfeld et al. (2018) reported that 60% of South Africa's rivers are currently overexploited, while only a third of the country's rivers are deemed to be in a good condition. Additionally, the Intergovernmental panel on Climate Change (IPCC; 2014) forecasted an increase in drought conditions in the Western parts of South Africa as a result of declining annual rainfall and further population increases.

Efficient irrigation, however, does not in isolation improve farm productivity and protection of water resources. Effective drainage systems are important to maintain soil and river health. Artificial drainage in agriculture is a practice to improve the natural drainage conditions and has been practiced for many years. The purpose of agricultural drainage is to remove excess water and salts from the soil in order to enhance crop production. In some soils, the natural drainage processes are sufficient for growth and production of agricultural crops, but in many other soils, artificial drainage is needed for efficient agricultural production. In South Africa drainage was introduced in the late fifties and various approaches and techniques have been developed. Approximately 500,000 ha of the total world's agricultural land is being lost out of production every year due to poor drainage. In South Africa an area of 16 000 000 ha is being cultivated and 1 700 000 ha is being irrigated (Van der Stoep & Tylcote., 2014), of which only 10% is drained regularly (Reinders et al., 2016). It is estimated that more than 240 000 ha is affected by rising water tables and salinization problems appear to be expanding (Reinders et al., 2016). Sufficient drainage has a multitude of possible benefits for agriculture, including better root development, soils cater for a wider variety of crops, more efficient use of fertilizers and pesticides, and reduced denitrification (due to aeration of soils) (Ritzema et al., 1996).

There are two main types of drainage, namely surface and subsurface drainage. Surface drainage is the removal of water that collects on the land surface to create more favourable conditions for plant growth preventing long periods of ponding without excessive surface erosion (Figure 4). This type of drainage is affected by the topography and vegetation. Typically, structures used in subsurface drainage include land levelling, open storm water drains, contour banks, and artificial waterways.

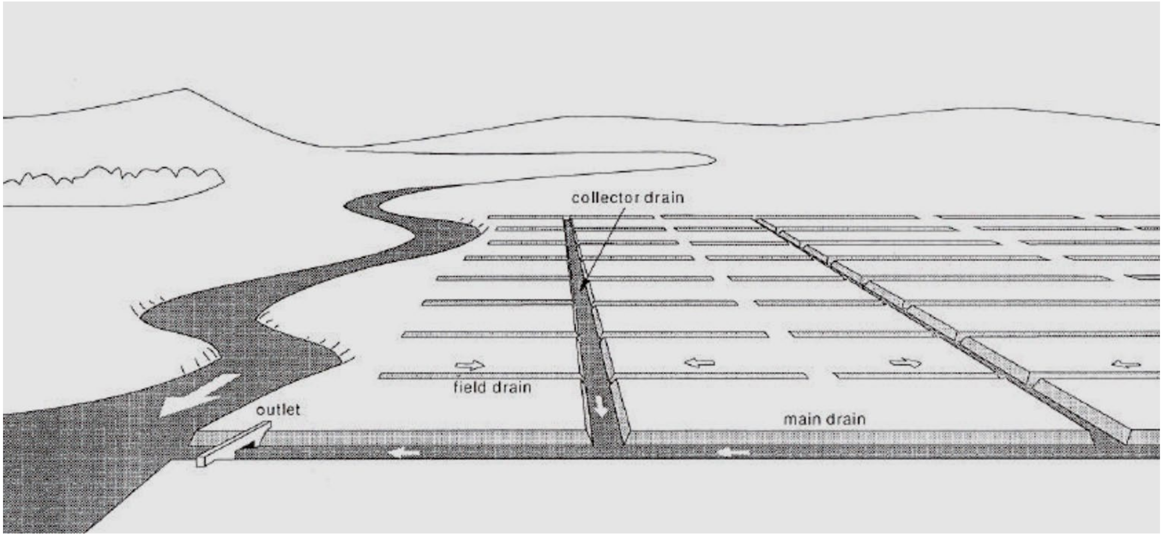

Figure 4: Simplified diagram of a typical surface water drainage system to remove excess surface water (Source: Ritzema et al., 1996)

Subsurface drainage can be defined as the removal of groundwater and salts from below the surface (Figure 5). The main objective of subsurface drainage is to manage the underground water table (Ritzema et al., 1996) The source of water accumulating below the surface may be long term irrigation, percolation from precipitation or topographic movement of water from higher elevation. Any form of drain designed to control or lower the ground water is considered subsurface drainage.

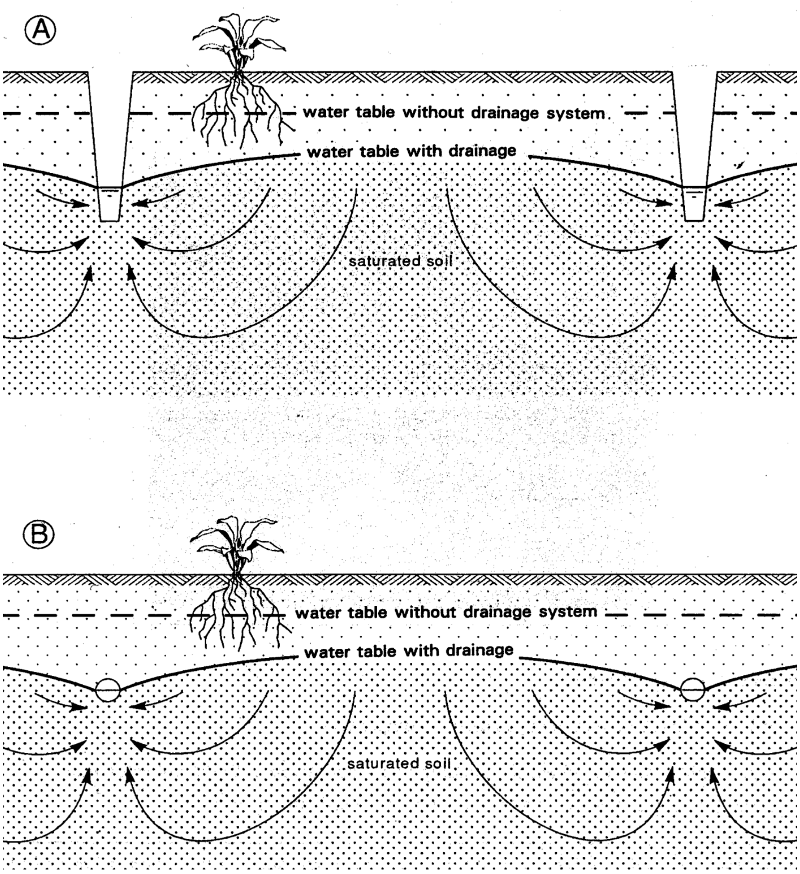

Figure 5: Subsurface drainage systems can be classified into open drains (A) and pipe drains (B) (Source: Ritzema et al., 1996)

According to Reinders et al. (2016), surface runoff contributes significantly more to water quality issues in rivers than subsurface drainage. Although implementation of subsurface drainage systems (Figure 5) is costlier, it has been shown to significantly improve crop yield (Ritzema et al., 1996). It has also been suggested that shallow water tables are most often responsible for salts accumulating in the topsoil layers (Scheumann & Freiseman, 2002; Smedema & Shiati, 2002).

Given the high volumes of water allocated to irrigation in the province and in the country, irrigation remains a field of great interest for improvements in efficiency. The Berg River main channel has stretches of irrigation-intensive cultivation of grapes and stone fruit, while some areas practice dryland wheat farming. While dryland agriculture has been hailed as an important part of the future of food production, it has also been shown to assist in the increased salinity in the Berg River, due to the high soil salt contents in the areas surrounding the lower Berg.

Innovation in irrigation and drainage systems has thus become necessary to ensure water and food security for the coming decades. Irrigation efficiency has, however been a point of contention due to confusion with measurement accuracies.

The most important considerations for improved irrigation efficiency and catchment management are related to:

- Lawful use of allocated water
- Water and energy used for irrigation needs to be reduced significantly
- Adoption of a systems approach
- Implementation of novel technologies for water management
- Consideration needs to be given to the volumes of non-recoverable and recoverable fractions of used water as to reduce the non-recoverable fraction, while increasing the availability and re-use of the recoverable fraction.

Ecology, hydrology and geomorphology

The Berg River is situated in the Cape Floristic Kingdom, which is recognized as a global biodiversity hotspot. The River flows westwards out of the Fynbos Biome into the West Coast region, where the soils become more saline, giving rise to a distinct Strandveld vegetation type. Fynbos soils are characterised by dominant sandstone-derived materials that are well-drained, low in pH and are generally nutrient-poor.

The Berg River has 19 tributaries feeding into the main channel which discharges a volume of 931 Mm^3/a (DWA, 2007). The river originates in mountain ranges that are underlain by Table Mountain Sandstone, giving rise to nutrient-poor, acidic soils. Towards the west, the soils are derived from Malmesbury Shale, which is a parent material to more saline soils. Groundwater quality in these two sections of the catchment are also significantly different, with groundwater from the Table Mountain Group and the Cape Granite Suite Aquifers typically being of better quality than that of the Malmesbury Group and the Klipheuwel Group Aquifers (DEA&DP, 2012). The flow regimes of the Berg River catchment have been altered over time with the construction of the Berg River Dam and development of the Western Cape Water Supply System (WCWSS). Creation of job opportunities in the area through agriculture and agriprocessing have also led to increases in urban populations through establishment of informal settlements, often in close proximity to the main channel or its tributaries. The resulting anthropogenic impacts on these rivers, including infrastructure for flood protection and alterations of natural flow regimes also have significant impacts on the hydrology of the catchment.

Riparian zones are important for ecological functions such as maintaining local biodiversity, flood buffering, nutrient filtering, and can act as climate change buffers. Degradation of such areas directly affects these functions, which then also significantly reduces the societal benefits of riparian zones. More often than not, degraded riparian zones can be rehabilitated to its natural state, suggesting the need for a change in methodology of not only rehabilitation, but management of riparian zones, which incorporates accountability on the side of local landowners for its long-term sustainability.

Functioning freshwater ecosystems also provide services, such as supplying freshwater during droughts and can mitigate serious ecological damage during flooding events. Many water conservation and management lessons have been learned at different scales, from catchment to household in constructed and natural environments. Precipitation patterns are projected to change; where more rain is expected to fall in shorter periods of time, increasing the risk of floods, while dry periods are expected to become longer and hotter, increasing the need for water retention for nature and agriculture. With the current structure of the Berg River, such precipitation patterns may lead to severe problems. Exploring innovative irrigation and drainage practices applied elsewhere, such as in The Netherlands through the Room for the River project, will shed light on the actions that needs to be taken towards a healthy social-ecological Berg River system.

Due to the semi-arid nature of the Western Cape Province landscape, conservation of freshwater ecosystems has become more and more important. The Western Cape is fortunate to still have some near-pristine mountain streams and upper foothill rivers. However, many of the lower lying ecosystems such as rivers and wetlands in the rural and mostly agricultural landscape, have been altered to a completely degraded state, often resulting in impoverished water quantity and quality. When freshwater ecosystems reach this degraded state, they also lose their ability to provide ecosystem services, such as water provisioning and mitigation during severe flooding events. According to the CapeNature State of Biodiversity Report of 2012, 45% of the province's rivers and 71% of the wetlands in the Western Cape are threatened (either Critically Endangered, Endangered or Vulnerable), compared to 51% and 65%, at the national level. Lowland river ecosystem types and floodplain wetlands are the most threatened river and wetland ecosystem types. This is particularly concerning, as they are also the least protected of the river and wetland ecosystem types.

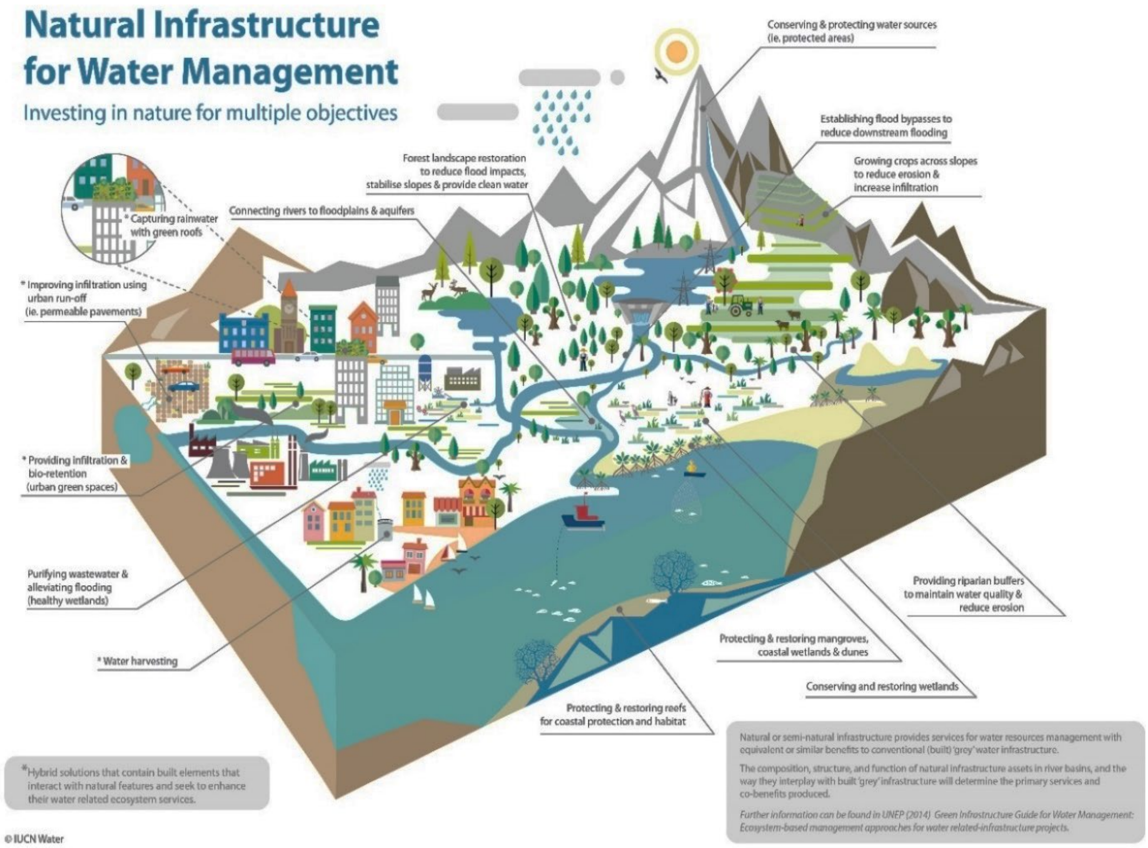

Figure 6: The value of in-tact ecological infrastructure (source Cohen-Shacham et al., 2016:)

To maintain ecological integrity of the Berg River, it is essential that the ecological reserve from the Berg River Dam be maintained. The ecological reserve is the water made available for maintaining an appropriate flow of water downstream to support the ecosystems around the river. The ecological reserve is also important for downstream agriculture and industry as these are dependent of water from the main river channel. It has been suggested that the diminishing water levels of the Berg River have exacerbated the issues of salinity downstream. Mismanagement of various upland areas and tributaries have also led to the pollution of the main channel, which has over time lost its capacity for nutrient filtration due to invasion by alien plants, encroachment of agriculture into the floodplains, and destruction of riparian vegetation and wetlands. Responsible catchment management and maintenance of ecological infrastructure are highly important to maintaining catchment integrity and are responsible for the long-term sustainability of water supply to farmers, local communities, and industry.

Compounded to degradation, climate change also has the potential to change rainfall regimes with showers becoming more isolated and often more intense. These events have two major impacts: 1) More intense floods cause significant erosion and damage to infrastructure, and 2) The inability of the riparian zone to capture and store water leads to high volumes of losses in shorter amounts of time.

Figure 7 shows the effect of levees on the flowing patterns of the river, confining its flow to a single channel and isolating the original riparian zone and floodplain. Well-managed ecological infrastructure could serve as a natural buffer against flooding, protecting soil and absorbing destructive floods. Flooding has been identified as one of the world's most destructive natural phenomena and has prompted the creation of levees along river banks to contain water during high-flow times. In doing so, the storage capacity of the floodplain is significantly reduced and, in some cases, could be completely removed.

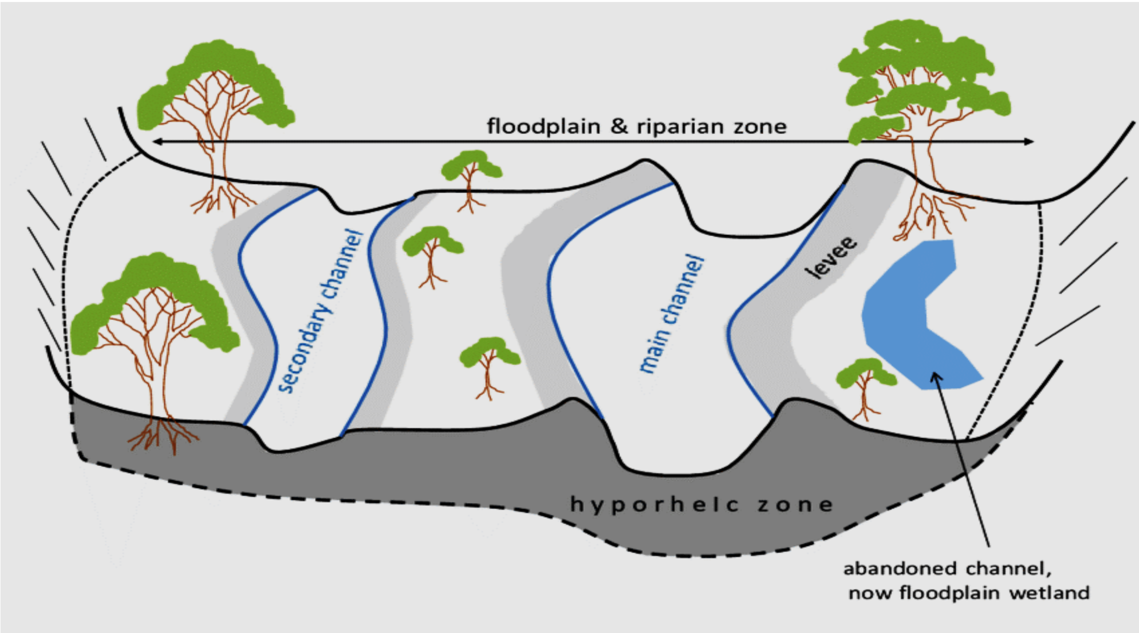

Figure 7: Three-dimensional view of a river channel, showing the riparian zone and the floodplain as part of the catchment system and the confining effect of levees on the main channel (Wohl et al., 2016)

In addition to the loss of water due to diminished storage capacity of the floodplain, soil is also lost as a result of the increased intensity of floods and the debris could accumulate elsewhere where it can do damage to infrastructure (Opperman et al., 2009). Finding innovative ways of adapting to changing climatic variables is becoming increasingly important in maintaining food and water security and preserving ecological infrastructure. Economically and environmentally sustainable management of floodplains is necessary in order to successfully adapt to a changing climate (Loos & Shader, 2009).

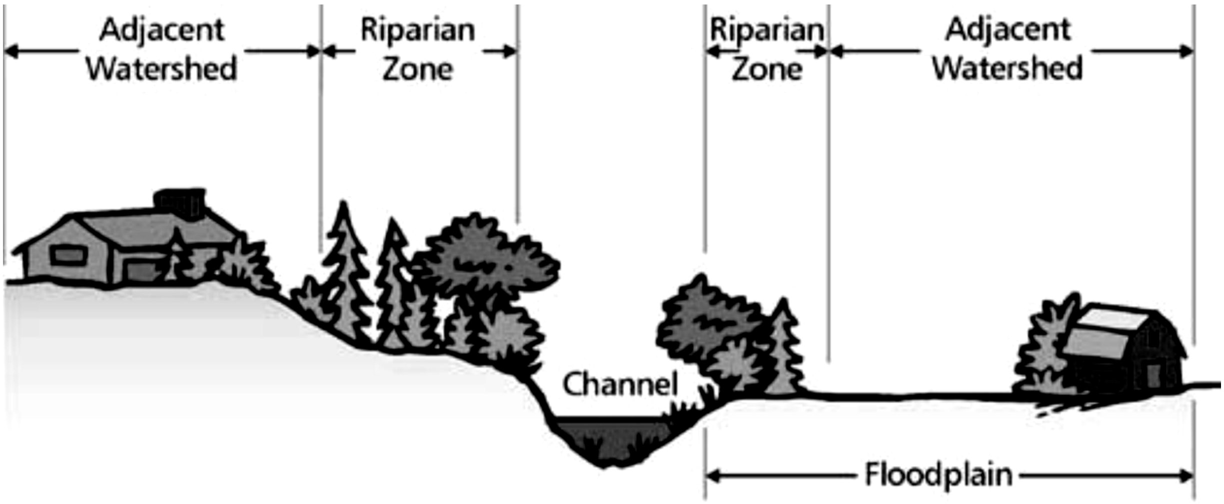

Figure 8: Cross-sectional view of the floodplain showing its different components and its position relative to the watershed/catchment boundary, the river channel, and the riparian zone (Source: https://fortress.wa.gov/ecy/publications/publications/92br003.pdf)

Farming along the Berg River, like elsewhere in the world, has significantly reduced the floodplain extent in an effort to reduce the effect of high flows on crop production. Floodplains have ecological importance due to the biodiversity they harbour but also due to its ecosystem services such as water filtration, retention and flood attenuation (Loos & Shader, 2016). Floodplains have, however been disconnected from river systems through residential development and agricultural activities. Shown in Figure 8, the riparian zone and floodplain are responsible for various functions in the catchment, including:

- A mechanism for connecting organisms via the lateral corridor
- Moving and exchange of sediments and nutrients
- Improving and maintaining water quality
- Mitigating flood intensity by dispersing the energy of moving water
- Mitigating drought through soil water retention and sustaining base-flows

6. CATCHMENT MANAGEMENT INTERVENTIONS

Various initiatives are being trialled and implemented worldwide to address the issues of integrated catchment management, including the Room for the River initiative (The Netherlands) and the Sustainable Conservation Groundwater Recharge initiative (USA, California). The potential to farm floodplains has also become a well-studied concept in several settings (Jones, 2010; Verhoeven & Setter, 2010). These initiatives recognize the importance of a fully functional riparian zone to the overall ecosystem health and for the provision of ecosystem services. This provides good insight of the various scales of catchment management practices in response to different challenges. They also recognize the anthropogenic component to catchment management.

The Room for the River project

The Room for the River project's goal is to give the river more room to be able to manage higher water levels, naturally. Measures are taken to give the river space to flood safely. Moreover, the measures are designed in such a way that they can improve the quality of the immediate surrounding and enable water retention. The methodology employed by this initiative follows an adaptive management approach, acknowledging the complexities of river systems and the need for specific management solutions to each situation. Thus, to make room for the increased flow of rivers, the methods could include widening of the flood zone, deepening of the original stream bed, creating additional high-flow channels, creating temporary water storage areas, relocating and strengthening dykes previously employed to confine river flow, and removing obstacles in the river.

This approach of catchment management is designed for systems too confined for the large volumes of water flowing through it. Though large volumes of water do not consistently flow down the Berg River, the catchment receives strong seasonal rainfall, which leads to periodic flooding and damage to infrastructure during the wet winter season. Channelling of sections of the Berg River for farming purposes has been identified as an unsustainable practice and this methodology could possibly be employed to reduce the effects of seasonal flooding on river banks and to ensure longer water availability.

The Sustainable Conservation Groundwater Recharge project

This project aims to expand the rate of groundwater recharge beyond the limits of dedicated recharge basins by encouraging farmers to apply available floodwater on their active farmland in ways that do not compromise crop production. The initiative is built up of several programs which are designed to increase water availability for farmers and local communities. These programs include:

- **Accelerating restoration:** This program engages with local conservation authorities to fast-track restoration of degraded areas in order to minimize further degradation and to promote better water conservation.
- **Waste Not:** Seeks to maintain agricultural production while employing innovative methods of farming that allows for efficient use of resources.
- **Water for the Future:** Promotes integrated water management practices through building and maintaining partnerships between various stakeholders.
- **Plantright:** This is an initiative to remove alien plant species from riparian zones and replanting with local species.
- **The Leopold Conservation Award:** This is an incentive program that rewards responsible farming practices that conserve water, air, and wildlife, all contributing towards building resilience in the face of climate change.

The programs under this project have great potential to be implemented wider and in a greater variety of settings. This is mainly because the interventions are not confined to areas/times with an over-abundance of water. These programs can be suitably adapted to fit the issues currently being experienced in the Berg River. In fact, some of these are already present in some shape in many South African settings, including the "Working for-" programs by the South African Government, and WWF's Conservation Champions Program. Rehabilitation is generally done by implementing agents, while integrated water management practices of the Berg and Breede rivers are promoted through platforms such as the Freshwater Forum and the Upper Breede Collaborative Extension Group.

Farming the floodplain

Figure 9 depicts three distinct scenarios which a channel can potentially go through in relation to its exposure to agricultural activities. The first scenario (a) shows a pristine riparian zone which, with time, gets converted to agricultural land (b). Because the floodplain is not conducive to pure agriculture, a hybrid approach is recommended (c). This approach allows for the planting of water-tolerant crops in or next to the floodplain while conserving key aspects of the riparian zone. Farming in the floodplain thus creates an incentive for farmers and landowners to protect a buffer zone next to the river that could directly improve their livelihoods (Jones, 2010).

This approach to farming and water management is a big shift from the traditional methods of channelling water by building levees and, in the short to medium term, will likely not provide much returns. However, a major driver behind channelizing is the limited access to suitable farming land, in which case the fertile soils of the floodplains are already in use for cultivation. In such cases, ecological infrastructure could potentially be rehabilitated to act as a buffer, instead of a rigid levee.

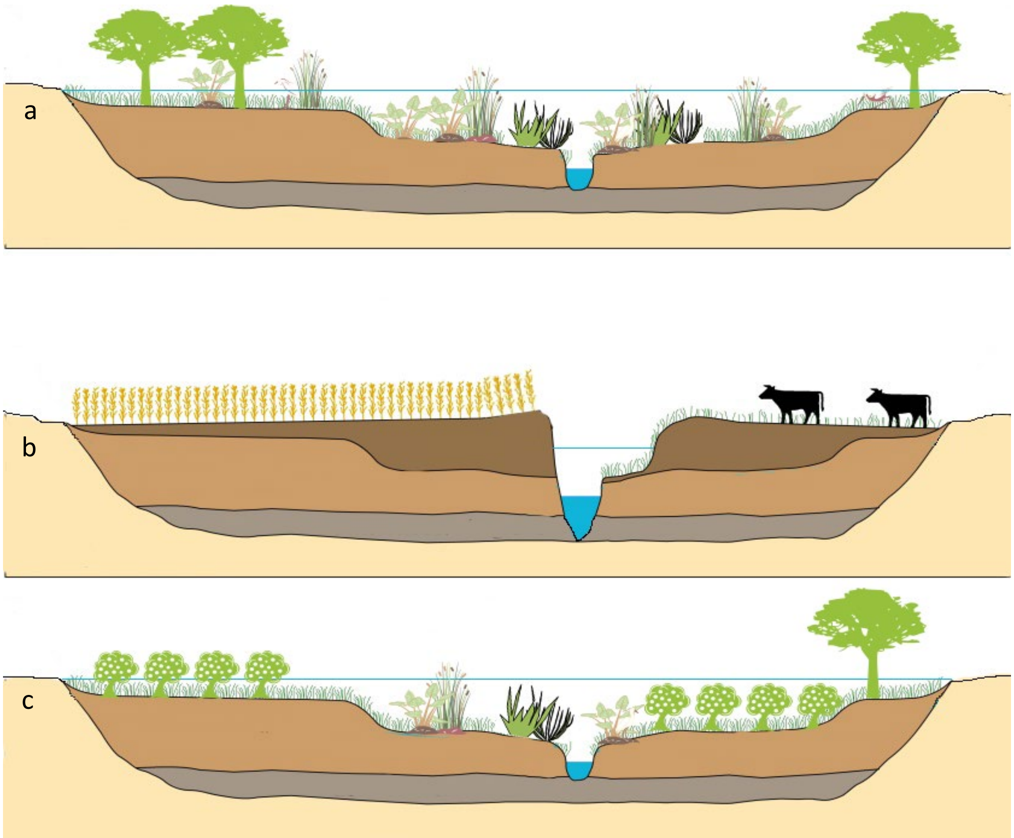

Figure 9: Diagram showing a pristine floodplain (a), a floodplain supporting agriculture (b), and one where a buffer zone of natural riparian vegetation is protected while agricultural crops are planted in the remainder of the floodplain. The blue line indicates the potential floodplain. (Adapted from Booth and Loheide, 2010).

Interventions in the Berg River: Influencing factors

The importance of developing case-specific management interventions is evident from work done previously in the Berg River, in collaboration with Rountree and Powrie (2016). The two sites evaluated for rehabilitation in the Upper Berg River, namely; Botmansdrift (Hermon) and Tweerivieren (Franschhoek) showed considerable differences in their intervention possibilities as a result of their proximity to the Berg River Dam**.** This is also due to the effects of historic disturbances and the impacts on the different sites.

The Tweerivieren site is located 7km downstream of the Berg River Dam, where the Wemmershoek tributary meets up with the main channel. The floodplain here has been channelized but would have been a well braided wetland system in the past. The area is now confined to one single stream, which is likely wider and significantly deeper than in the past. Deepening would occur as a result of sediment deposition behind the Berg River Dam wall and severely reduced sediment transport downstream from the dam. Ideal rehabilitation interventions proposed here were to remove the berms upstream of the wetland to allow for braided flow, reopening the secondary channels, and elevate the main channel and allow the area to be flooded via large releases from the dam. As these interventions would require large-scale engineering activities and would be very expensive, it was suggested that mitigating activities such as alien tree clearing (and follow-up clearing) and rehabilitation focussing mainly on the planting of Palmiet (*Prionium serratum*) would be the best course of action.

The Botmansdrift site is situated about 60km downstream of the Berg River Dam and is not as heavily affected by the dam as other areas upstream. The area was, however, also heavily invaded by alien trees (mostly Eucalyptus), which have been managed successfully. The largest impact on this site was from invasive alien trees, while floods and fine sediment deposition are still reduced because of the Berg River Dam. A small section of this site also has a berm to protect agricultural land. To adhere to the DWS Ecostatus requirement of a Recommended Ecological Category (REC) of B (only slightly modified from its reference condition) the site requires complete removal of alien tree species, improved water quality to near its pristine state, and for the geomorphology, and the natural wetland and riparian flora and aquatic fauna to represent reference states. This would also need to consider other factors of river health such as alien fish and re-introducing natural flow regimes/patterns. The differences in management interventions required for the two wetland sites and their challenges are shown in Table 2.

Through these case studies, it is apparent that decision-making requires thorough consideration of various factors impacting on management interventions for any site. Also evident is the effect of tributaries on the main channel and its management, more so where the effect of large dams is quantifiable. Importantly, the landowners, as stakeholders, will have a significant impact on the success and development of the project. Such analyses of the site, its disturbances, physical variables, and social systems are key in informing its management. All these will inform the project objectives and the potential for the intervention to meet those objectives.

Table 2: Differences between two sites relatively close to each other in the Upper Berg River and some factors affecting its possible management interventions (adapted from Rountree & Powrie, 2016)

Variable	Tweerivieren	Botmansdrift
Ecological sensitivity	High	High
Present Ecological Sate Category (PEC)	D	C Wider part of the site is D due to upstream alien invasion

Variable	Tweerivieren	Botmansdrift
Default estimated Recommended Ecological Category (REC)	B	B
	Opportunities and Constraints	
Land Ownership	>10 properties with several owners	1
Biophysical processes	Berg River Dam is less than 7km upstream. Sediment is limited by dam wall; promotes erosive processes that have been exacerbated by historic channelling of the river.	Dam is more than 60 km upstream. Tributaries help lessen its impact. Erosion further upstream and below the dam also enhances deposition/ sediment supply.
Flooding	Severely reduced due to dam	More natural due to tributaries.

7. OUTCOMES OF STAKEHOLDER ENGAGEMENTS

Living Lands have been engaging with stakeholders in the Berg River Catchment since 2014. For this study, a focus is placed on engagements which have taken place in the last two years (2017 and 2018), to inform the current understanding of stakeholder perceptions. These engagements form part and feeds in to the ongoing Research, Development and Innovation Catchment Platform project funded by the Department of Science and Technology, the Water Research Commission and the Department of Environmental Affairs. Cross-pollination and capacity building through knowledge exchange is essential in socio-ecological systems such as the Berg River Catchment.

As described in Section 4, different engagement tools are employed depending on the specific stakeholders who are being engaged with, the intended outcome and the context of the engagement. The intention and outcomes of the meetings Living Lands has convened, facilitated and participated in, in 2017 and 2018 are summarised in Table 3.

Figure 10: Learning Journey's bring people together outside of their usual context and allow participants to fully immerse themselves, explore and experience first-hand, the various dimensions of the realities they are trying to understand and influence.

Table 3: List of meetings Living Lands has convened, facilitated and participated in, in 2017 and 2018 to better understand the complexities of the Berg River Catchment and build relationships with the various role players - engagements form part and feeds in to the ongoing Research, Development and Innovation Catchment Platform project

Meeting	Date	Involvement	Intention	Outputs/Outcomes
Invasive Alien Plant mapping meeting, Stellenbosch	7 March 2017	Convened	To enable use of the Management Unit Control Planning (MUCP) tool for the Stellenbosch Invasive Alien Plant Management Plan.	Data and information were shared in the group and a guideline was given for feeding in to the ACRABE Community of Practice.
Stellenbosch University Research Day	26 May 2017	Participated	Share active research being conducted through the Conservation, Ecology and Entomology department.	Established connections with Stellenbosch based researchers active in the Berg River Catchment.
Berg River Improvement Plan meeting	1 June 2017	Participated	Feedback on planned tasks.	Understanding of the progress of the BRIP and the challenges faced.
Water Hub Launch	2 June 2017	Participated	Launch of the new biofiltration cells at the Water Hub	Identified research needs and opportunities for prototyping innovation in the Upper Berg.
Action Based Research meeting	14 July 2017	Facilitated	Build a common understanding between key role players regarding needs on the landscape and complementary activities.	An informal space to network, build trust, stimulate collective action in the Berg River Catchment
Role of Soil Health in Riparian Rehabilitation Success	25 July 2017	Facilitated	Develop research ideas towards understanding the role of soil health in contributing to rehabilitation of riparian zones	List of discrete research and implementation questions. Input on current rehabilitation efforts.

Meeting	Date	Involvement	Intention	Outputs/Outcomes
Bridging Waters Future Water, UCT	5 September 2017	Participated	Illustrate how built environment professionals and others are designing with water to ensure sustainable and ecologically viable landscapes.	Understanding of what is meant by valuing water as a landscape architect. Insight to the complementary potential of ecological infrastructure protection and rehabilitation and passive design.
Knowledge Exchange	20 September 2017	Facilitated	Integrative dialogue regarding Strategic Water Source Areas, Alien Clearing and Value-Added Industry (Bio-char). Rudolph Röscher, LandCare Manager of the Cape Winelands District Program, and Dr David Le Maitre, CSIR principal researcher, delivered insightful presentations.	Generative discussion and collective thinking in the group. Multi-level interaction; from MSc student poster presentations to detailed discussion on alien vegetation clearing funding models.
National Biomimicry Workshop	22 September 2017	Participated	Position SA for successful nature-inspired innovations and product development	Constructive networking and inspiration.
Symposium of Contemporary Conservation Practice	6-10 November 2017	Presented	Contribute to the ecological infrastructure dialogue, connect with researchers and practitioners, gain insights through lessons learned discussions	Insights to long-term rehabilitation monitoring. Strengthened relationships, particularly with ERS, SANBI, Ezemvelo wildlife, the Endangered Wildlife trust.
Freshwater Forum	6 February 2018	Facilitated	Kickstart the Ecological Infrastructure action group	Constructive visioning and action plan development. Ongoing
Research Retreat	10 April 2018	Facilitated	Align research agenda’s to that of local, national and international priorities, codevelop nature based solutions in a water stressed landscape	Developed a multi-disciplinary research programme reference document and discussed methods of knowledge dissemination. Joint funding application(s) developed and a network of complementary researchers and practitioners were strengthened.

Meeting	Date	Involvement	Intention	Outputs/Outcomes
CAPE Landscape Initiative Knowledge Exchange	30 July 2018	Facilitated	Exploring social enterprise for the biodiversity economy and discussing context specific examples.	Shared experience to create a better understanding of social enterprise and biodiversity economy, networking and building inspiration.
Riparian Rehabilitation Workshop	22 August 2018	Facilitated	To collect data in a participatory way and promote knowledge exchange around the riparian rehabilitation programme active along the Berg and Breede rivers.	Consolidation of lessons learned in the first two phases of the programme and recommendations for the next phase, ensuring a research component is added.
Water Hub Workshop	6 November 2018	Facilitated	Exploring opportunities for collaborative research at the Water Hub focussed on efficient cities, towns, homes and buildings; Healthier rivers and wetlands; increased food security; and social transformation	To be informed about the facilities and support available at The Water Hub. To understand the research interests and strengths of the Western Cape Research Institutions, explore partnerships and identify research questions.
Dialogue Interviews	Jan – Dec 2018	Conducted	To allow for the interviewee to reflect on aspirations, challenges and needs and how they relate to and engage with the Berg River Catchment community and the landscape	Promotes common understanding and begin to build a generative field for innovation in catchment management practices.

The major impacting factors, opportunities and barriers to integrated catchment management and achieving socio-ecological health in the Berg catchment were discussed in the abovementioned meetings and have been summarised below;

Factors impacting socio-ecological health

Several agricultural and non-agricultural factors have been identified, which impact on the quantity and quality of the water in the Berg River Catchment and the functioning of its riparian ecotone and wetland areas, including:

- The presence of illegal man-made infrastructure in the river channel
- Invasive alien species, including plants and animals
- Destruction of wetlands
- Illegal off-channel streams
    - Impact flow variability needed for the ecological reserve
    - Impact the ecology of the river
- Failure to honour the Berg River Dam ecological releases
- Practices in the farming community are difficult to influence/change.
- Limited knowledge of appropriate regulatory frameworks to guide water usage and management practices make implementation of interventions difficult (process to get permission and advice from DEA&DP, CapeNature and DWS is lengthy)
- Lack of a Catchment Management Forum is seen as a gap between research, implementation, and policy
- Funding for research and implementation is limited
- Users and managers are unaware of all the water losses in the river system, it may be ecological (recharge) or anthropogenic (illegal abstraction)
- Lack of aquatic ecologists active in the highest levels of decision-making
- Non-existent service delivery in informal settlements

The impacts of these factors are exacerbated by the lack of effective coordination of activities at a catchment scale.

Barriers to successful integrated catchment management

- Lack of applicable scientific theory for ecological rehabilitation in the Western Cape river systems
- Connections between different initiatives, projects and programmes are not transparent
- Effects of scaling up rehabilitation activities to catchment scale are unknown
- Expert knowledge is scattered and inaccessible
- Opposing time-scales within research, implementation and policy
- Implementers frustration due to questions not being answered
- Researchers frustration due to funding informing research topics not related to specific questions
- The Western Cape is dense with plans, systems and people which is overwhelming
- The policy - Implementation gap is increasing
- Translational gaps exists, including translating experience to information and wisdom to planning and policy

Opportunities for successful integrated catchment management

- Review and evaluate current ecological rehabilitation methodologies and interventions
- Understand roles, responsibilities and accountability of the key institutions on the landscape
- Establish a quick feedback platform for critical questions to inform action and communicate day to day questions coming from the catchment
- Implement an integrated planning and management approach on an institutional level
- Employ a systematic approach to share lessons learned (e.g. Working for Water review)
- Initiate inter-generational knowledge transfer
- Mapp relevant information (e.g. create Literature review and mind map of relevant reports)
- Achieve end user faith and trust by investing into engagement with landowners (high cost but very high reward)
- Translate experiential knowledge into factsheets
- Identify overlaps of national, provincial and municipal plans
- Work within areas of shared mutual interest and not get held up by mandate limitations
- Bring in and share info about existing collaborations – case study examples e.g. CHEC
- There is a big focus on water and climate, also need to look at soil, air and disaster risk reduction
- Governmental plans to include funding for research

Specific Presentations

Specific information presented by stakeholders, which is crucial to integrated catchment management in the Berg River Catchment have been summarised below

David Le Maitre, CSIR - Protecting the Strategic Water Source Areas for water security under climate change

PDF: http://livinglands.co.za/wp-content/uploads/2017/10/Le-Maitre-Breede-Berg-RDI-SWSA-presentation-Sept-2017.pdf

- Strategic water source areas (SWSA) are of national importance and need to be protected
- The Berg and Breede catchments are strategic water source areas
- Due to climate change the ‘normal’ temperatures, rainfall and vegetation is changing which all impact water quality and quantity
- The alien vegetation in the catchments reduces water flows and is projected to become worse if not managed
- Maintaining and restoring the function of SWSAs is integral for human well-being
- Need to see the landscape as a whole and manage ecosystems holistically for the long-term
- Focus on values and building trust to develop land and water stewardship
- Co-learning, co-design and co-governance are the elements of the new approach

‘The health of our water is the principal measure of how we live on the land’ – Luna Leopold

Supporting resources:

http://www.journeyofwater.co.za/catchments/western-cape

https://www.westerncape.gov.za/eadp/calendar/water-indaba

http://biodiversityadvisor.sanbi.org/wp-content/uploads/2016/08/78-LeMaitre-LocalLevelManagement.pdf

Rudolph Röscher, LandCare - Environmental risks, opportunities and research needs

PDF: http://livinglands.co.za/wp-content/uploads/2017/10/RDI-Knowledge-Exchange-Workshop_20092017.pdf

- Land Care practitioners apply the Land Care approach in engaging with landowners
- Trust has been built in the upper Breede catchment, which enables sustained action on the ground
- Various projects are underway and large extent of alien clearing is taking place

There is a need for further study and intervention under the following themes:

- Agricultural run-off, leaching, pH changes in the rivers
- Biochar as neutralising agent in chicken manure compost used on vineyards
- Effect of off-channel dams in water security and aquifer recharge
- Restoring the sponge function of wetlands
- Dam sedimentation after fire and rain
- Collaborate on EIAs to enable action
- Develop small, medium and micro enterprises in the biodiversity-rehabilitation economy e.g. woodcutters, composting, biochar, environmental education

Supporting resources:

http://www.biochar-international.org/

http://www.nda.agric.za/docs/landcare/landcare.htm

Stuart Hall, Stellenbosch University - Restoring Cape Flats Sand Fynbos following *Acacia saligna* invasion

PDF: http://livinglands.co.za/wp-content/uploads/2017/10/Cape-Flats-Sand-Fynbos_Stuart-Hall.pdf

Key findings:

- Traditional alien vegetation clearing is not effective in restoring Cape Flats Sand Fynbos
- Active intervention is most effective in restoring resilient shrub cover and diversity
- Native vegetation cover takes more than two years to recover after clearing and active sowing
- Heat pre-treatment of seeds may increase or decrease germination depending on specie

Supporting resources:

http://academic.sun.ac.za/cib/news/2017/0130_blaauwberg_nature_reserve.htm

8. STAKEHOLDER RECOMMENDATIONS FOR MANAGEMENT INTERVENTIONS

Through our engagements with various stakeholders involved in the management of the Berg River Catchment, we compiled a list of the key areas where interventions are needed to promote the integrated and coordinated management of the catchment.

Innovation

- *Agricultural practices have room for improvement*

Possibilities exist for the exploration of different irrigation mechanisms and regimes such as precision irrigation systems. Platforms like Fruitlook (Free) can be used to track plants water usage over time and detect water-stressed field blocks, where irrigation can be applied. It is also widely agreed that illegal agricultural practices such as efforts to manipulate channel flow have caused serious issues that hamper efficient utilization of the catchment. The building of berms to minimize flood damage has, for instance, led to reduced capacity of the riparian zone to absorb excess water for slower release, leading to a shortened period of water availability in a catchment that receives strong seasonal rainfall. These infrastructural amendments also may not provide protection against larger floods, where more damage is likely to be done to property. Other practices that left much room for improvement include farming too close to the river and poor protection of topsoil. Drainage practices of agricultural land should also be revisited, especially where soils are known to be saline. Surface drainage has been shown to increase the negative impacts of agriculture on the river draining such areas. Subsurface drainage is, however, an expensive process. Drainage mechanisms should thus be tailored to specific sites within the confines of a predetermined set of parameters.

- *Investigate the feasibility of a pipeline*

According to various stakeholders, irrigation efficiency can be improved significantly through the establishment of a pipeline that feeds agricultural land from below the Berg River Dam downstream towards the West Coast. It has been suggested that the pressure generated by the pipeline would significantly reduce electricity costs incurred on farmers by pumping water from the main channel. The pipeline would provide a consistent flow throughout the year. There would also be less interference with the natural flow regimes of the main channel, as it would not need to be managed for irrigation but will mainly serve as ecological reserve. This would aid in the re-establishment of natural ecological processes and riparian zone recovery and maintenance. Lastly, water quality for agriculture and industry would not be influenced by the surrounding landscape, leading to higher quality produce with fewer inputs. These assumptions have, however not been tested. For instance, the assumption is made that the ecological releases from the Berg River Dam will be more consistent and mimic previous natural flows. Failure to maintain the ecological reserve is likely to significantly further decrease water quality of the river as a result of increased concentration of pollutants. In this case, an argument can be made for the need for well-functioning tributaries to maintain the main channel's natural flow regimes, water quality, biodiversity, sediment deposition, and riparian zone maintenance. The converse effect of ill-managed tributaries on the water quality in the main channel (compounded to the effects of an agricultural pipeline) could, however, be severely reduced capacity of the catchment to function properly.

Implementation and coordination

- *Implementation should be prioritized where there is already an MMP in place*

A Maintenance Management Plan (MMP) is developed to guide the maintenance of specific sites along a river. Such a document can be expensive and take a long time to complete. An MMP has been developed for maintenance of existing infrastructure of the Upper Berg River, including that of districts 1 and 2 (downwards from the Berg River Dam wall to below Wellington, near Simondium). This stretch is currently a low hanging fruit for impactful interventions that can be completed in a relatively shorter time. It has been suggested that, while MMP's are being developed for other areas of interest, the MMP for this stretch should be used to inform its intervention actions.

- *Tributaries should be prioritized*

There is an apparent lack of intervention at a tributary level. It has been re-iterated in interviews that tributaries contribute significantly to water quality issues in the main channel. MMP's could be developed for these localised areas and would guide interventions aimed at integrated catchment management. Tributaries have intrinsic biological value, as they often serve as refugia for indigenous aquatic species, especially the more pristine reaches. Tributaries are also important sites for maintaining ecosystems in the main channel, increasing the productivity, and enhancing the heterogeneity of the network feeding into the main channel (Rice et al., 2008). Where large dams are present (as is the case with the Berg River Dam), tributaries are important buffers to the effects of the dam on the main channel, such as sediment and nutrient deposition behind the dam wall, and disruptions in seasonal flow patterns. Pollution, mismanagement, and disproportionately little focus of interventions on tributaries have led to general deterioration of water quality and quantities. Of particular concern for the water flowing into the Berg River is the Stiebeuel tributary, which flows through an informal settlement in Franschhoek. Future interventions for the Stiebeuel, in particular, are planned by the developing Water Hub in Franschhoek (https://www.thewaterhub.org.za/).

- *Implementation should be done by implementing agents as far as possible.*

Building and maintaining trust has, on several occasions, been flagged as an important part of successful implementation on a landscape scale. Strong relationships allow for accountability and efficient communication. To maximize cooperation from private landowners (and thus productivity), the importance of reputable and trusted implementing agents were highlighted. To increase job creation and the longevity/sustainability of clearing operations, biomass can be processed into various products supporting an economy for value added products. It is recommended that implementing agents are trained in producing such products. This is already done in many instances.

- *Alien tree clearing and riparian zone rehabilitation need to be better coordinated*

A recurring issue in catchments servicing the Western Cape Water Supply System (WCWSS) is the presence of, and water usage by invasive alien trees. This directly affects water availability for household, agricultural, and industrial use, and also impacts on the function of the riparian zone of water filtration and flood attenuation. Coordinated alien clearing and rehabilitation of riparian zones and wetlands will most likely yield the best results. Additionally, monitoring and evaluation (M&E) of rehabilitation successes and failures need to be documented better to improve the efficiency and effectiveness of such efforts and develop best-practice guidelines. Resources need to be allocated to these M&E programmes that allow for proper documentation of processes, interpretation of results, and dissemination of knowledge. Monitoring and Evaluation programmes should thus be expanded to include a "Learning" aspect.

Policy, legislation and information sharing

- *A Catchment management Agency (CMA)/Catchment Management Forum (CMF) is needed*

Currently, the Department of Water and Sanitation (DWS) plays the role of CMA in the Berg River Catchment as there is no existing CMA. The DWS will make use of existing forums to communicate catchment management information. A CMA, as a central body of information sharing between stakeholders from various sectors, allows the opportunity for coordinated catchment management and addresses issues such as possible legislative frameworks for facilitating cooperation. A CMA has access to higher levels of decision-making in government and allows the integration of private stakeholders' needs in such settings. In addition to a CMA/CMF, the establishment of smaller, informal networks for knowledge sharing and communication has proven to be an effective way of coordinating activities towards integrated management of a catchment. Knowledge exchange within and between these networks can be facilitated by individuals who span across such networks, often referred to as boundary spanners.

- *Legislative frameworks for facilitating cooperation of landowners should be communicated*

Our engagements show that implementers are unaware of the legislative frameworks to employ when being confronted with uncooperative landowners. An incentive-based approach has worked in the past for a considerable proportion of private landowners, where significant progress has been made towards successful catchment management. However, some areas have been identified as critical sites for intervention but without the cooperation of the involved landowners. It has been suggested that a legislative approach be employed in such cases, one that is guided by the relevant processes. This is believed to lead to more effective catchment management that includes all relevant landowners and is expected to reduce the impacts of illegal/inconsiderate activities on downstream users.

- *Work in line with the Department of Water and Sanitation Resource Quality Objectives (See Appendix B)*

The Water Resources Classes and Associated Resource Quality Objectives have been determined for the Berg River Catchment and is currently undergoing finalisation, whereafter it will be Gazetted. With this information the Threshold of Potential Concern is set, and the resource can be managed effectively in line with the identified objectives.

9. LESSONS LEARNED WITH REGARD TO THE PROJECT APPROACH.

The intention of this section is to share lessons learned throughout the project, act as a reflection process for the project team and provide recommendations for future activities facilitated by Living Lands and for similar projects yet to be implemented.

The Living Landscape Approach was employed in this study. As described in Section 4 of the report, we are guided in our work by the Theory U framework, with five primary stages; 1) Co-initiating: creating a common-intent; 2) Co-sensing: observing and learning from the system in which we are working; 3) Co-strategising: reflecting on how we become part of the story of the future and plan ahead rather than holding on to the story of the past; 4)Co-creating, prototyping interventions and innovating on the landscape, and 5) Co-evolving by developing a strategic and holistic landscape plan. For this study we touched on stage one, two and three to explore and develop a collective understanding of the need and applicability of innovative interventions related to integrated catchment management aimed at reducing the impact of extreme events and mitigating droughts and floods.

The following key lessons have emerged throughout the study:

1.To ensure interventions are relevant in a changing environment a relational approach is needed.

A relational approach or relationality refers to working to build on, deepen and extend existing inter-personal relationships and collaborative networks (Cockburn et al, In review). The Berg River Catchment is dense with strategies, plans and Communities of Practice. A coordinated effort is needed to prototype and implement new practices. This can also be referred to as ‘Praxis’; working at the research-practice nexus by working as a team of researchers and practitioners through reflective, thoughtful, theory-informed action and transdisciplinary approaches (Ison 2018).

2.To understand a specific challenge and build resilience to extreme events, one needs to live in the catchment and understand the delicate complexities of the social and ecological system.

The author John LeCarré said, “The desk is a dangerous place from which to view the world.” Many efforts to address complex challenges are borne at a desk or in an office, sometimes far away from the physical landscape in question. Through our engagements with residents and other stakeholders of the Berg River Catchment it is evident that it takes time and commitment to build trust and achieve a common understanding of context specific needs and challenges. Introducing new ideas or practices needs to be a bottom-based process where interventions are first prototyped. A prototype explores the future by doing something small, speedy, and spontaneous; it quickly generates feedback from all key stakeholders and allows one to evolve and iterate an idea.

3.Every site is context specific and has different requirements and downstream impacts which need to be taken in to account when planning an intervention.

In depth site analysis is crucial when implementing an innovative intervention such as ‘farming in the floodplain’ (Described in Section 6). Different social and ecological influencing factors are relevant at different sites. After an intervention has been prototyped and deemed successful, careful consideration and planning is needed for up-scaling.

4.Large scale interventions need large scale social engagement.

Ongoing social engagement throughout a project and or programme will ensure that trust which has been built, is kept and risk becomes shared. The 4-returns framework also reiterates the need for a 20-year commitment to ensure succession of interventions and landscape level impact. The need for a ‘warm body’ on the ground was reiterated in workshops and interviews. Enabling effective stakeholder participation takes time and resources but is crucial when implementing long-term catchment scale interventions.

5.*Dialogue Interviews and focused gatherings enable deeper understandings and sharing of personal experiences which can often be lost in larger group settings.*

Dialogue interviews can be used to prepare for projects, workshops, and other capacity building programmes or change initiatives. The purpose of a dialogue interview is to engage the interviewee in a reflective and generative conversation as well as to build rapport and trust. Amongst various one-on-one discussions, Dialogue Interviews were conducted with a diverse set of stakeholders. Making first contact through a Dialogue Interview before a group gathering also enables greater participation during the group event. Enabling a generative conversation may however limit the collection of specific information and finding a suitable time for an interview is challenging and results in unconventional meeting hours. During the first interaction with a stakeholder, it is important to be comfortable with letting the conversation flow organically then during a follow up interaction set a clear intention to ensure specific information is discussed.

10. RESEARCH RECOMMENDATIONS AND NEXT STEPS

Living Lands lives on the landscape, engages with stakeholders and facilitates accessible platforms of integration. Working through partnerships, we commit to continue further engagement with stakeholders and co-develop relevant projects which address the needs on the landscape. This proof of concept study was catalytic in strengthening relationships and creating the space to reflect on the current innovation opportunities related to integrated catchment management in the Berg River Catchment.

We have established a physical presence on the landscape by establishing an office and collaborative learning space in Wolseley, close to the shared watershed of the Berg and Breede River Catchments. To build on the stakeholder recommendations outlined in this proof of concept, and ongoing work as part of the coordination of the research development and innovation platform for ecological infrastructure, we propose a continuation of this study in order to;

1. Prototype interventions which integrate ecological infrastructure and built infrastructure to support agricultural productivity, ecological function and disaster risk reduction.
2. Support and address the local and provincial priorities outlined in plans such as the Berg River Improvement Plan and the Breede River Environmental Resource Protection Plan.
3. Promote 'source to sea' (upstream-downstream) thinking with landowners and residents.
4. Conduct research specified by local stakeholders related to the rehabilitation economy and investing in ecological infrastructure.
5. To build mutual understanding and respect between stakeholder groups active in the Berg and Breede River catchments, and create the space for new collaborative relationships and partnerships to emerge.
6. With stakeholders, develop a monitoring, evaluation and learning framework to inform actions and determine impact.

The proposed work is aligned to the vision of the Western Cape's Freshwater Forum;

By 2070, within the Western Cape, ecological infrastructure as it relates to water security has been rehabilitated, protected and managed through coordinated efforts between government and society, which has empowered a responsive approach by all, to achieve resilience related to environmental resource protection, climate change mitigation and sustainable economic growth.

It is the opportune time to continue this work with the launch of the GEF 6 Ecological Infrastructure for Water Security project. Specific research opportunities have also been highlighted, for example; LandCare Western Cape is planning to donate chippers to farming communities which may result in a growing application of mulch in orchards and vineyards. This creates opportunities for on-site research focused on mulch application, soil moisture measurements, irrigation measurements, the use of Fruitlook and recommendations for a business case which forms part of the rehabilitation economy. On approval by the Water Research Commission we will submit a proposal detailing the continuation of this study which is co-developed with stakeholders active in the Berg and Breede River Catchments.

11. REFERENCES

Bergold, J., & Thomas, S. (2012). Participatory research methods: A methodological approach in motion. Historical Social Research/Historische Sozialforschung, 191-222.

Booth, E. G., & Loheide, S. P. (2010). Effects of evapotranspiration partitioning, plant water stress response and topsoil removal on the soil moisture regime of a floodplain wetland: Implications for restoration. Hydrological Processes, 24(20), 2934–2946. https://doi.org/10.1002/hyp.7707

Bronckhorst, S., Milson, C., Payne, A., Pengelley, C., & Seyler, H. (2016). Water: Market Intelligence Report. GreenCape.

Brown, V. A. (2008, July). A Collective Social Learning Pattern. In EuroPLoP (Vol. 2008, p. 13th).

Cockburn, J., Cundill, G., Shackleton, S., Rouget, M., Wright, D.R., Koopman, V., Cornelius, S.F.A., Zwinkels, M., McLeod, N., Van den Broeck, D., le Roux , J.-P., Cele, A. and Schroder, S. (In Review). Relational hubs for collaborative landscape stewardship. Society & Natural Resources.

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (2016). Nature-based solutions to address global societal challenges. IUCN, Gland, Switzerland, 97.

Cole, M. J., Bailey, R. M., Cullis, J. D., & New, M. G. (2018). Water for sustainable development in the Berg Water Management Area, South Africa. South African Journal of Science, 114(3-4), 1-10.

Collins, K., & Ison, R. (2009). Living with environmental change: adaptation as social learning. Environmental Policy and Governance, 19(6), 351-440.

Cundill, G., & Rodela, R. (2012). A review of assertions about the processes and outcomes of social learning in natural resource management. Journal of environmental management, 113, 7-14.

De Clercq, W. P., Jovanovic, N., & Fey, M. V. (2010). Land use impacts on salinity in Berg River water. WRC Report, (1503/01/10).

De Clerk, W., Jovanovic, N., Bugan, R., Mashimbye, E., du Toit, T., van Niekerk, A., Flugel, W.A. (2013). Management of human-induced salinization in the Berg River catchment and development of criteria for regulating agricultural land use in terms of salt generating capacity. WRC Technical report

De Villiers, S. (2007). The deteriorating nutrient status of the Berg River, South Africa. Water SA, 33(5), 659–664.

DEA&DP (2012). A Berg River Improvement Plan - 2012. Western Cape Government.

DEA&DP (2017). The proposed rehabilitation of the bank of the Berg River on the remainder of farm 811 (Digteby), portions 2 and 36 of farm 811, and erf 6, Simondium, Western Cape.

Donnenfeld, Z., Crookes, C., & Hedden, S. (2018). A delicate balance: Water scarcity in South Africa. Southern Africa Report, 13, 1–24. Retrieved from https://issafrica.org/research/southern-africa-report/a-delicate-balance-water-scarcity-in-south-africa.

Dye, A. (2010). Contribution of unregulated tributaries to the ecological functioning of the main channel of rivers. Snowy River Recovery: Snowy Flow Response Monitoring and Modelling. NSW Office of Water, Sydney.

Fell, J. (2017). An analysis of surface water from an informal settlement, Langrug, Franschhoek: down a slippery slope. MSc, University of Cape Town.

Görgens, A., & De Clercq, W. P. (2005). Research on Berg River Water Management Summary of Water Quality Information System and Soil Quality Studies. WRC Report http://www.westerncape.gov.za/other/2011/9/2011_pero_final_to_printers.pd

Intergovernmental Panel on Climate Change (IPCC), Climate change (2014): impacts, adaptation, and vulnerability, Part B: Regional aspects, Chapter 22: Africa, 1199.

Ison, R. (2018). Governing the human–environment relationship: systemic practice. Current Opinion in Environmental Sustainability 33, 114-123.

Jones, M. (2010). Farming Floodplains for the Future: Final Report 2007-2010. Staffordshire Wildlife Trust.

Lallana, C., & Marcuello, C. (2004). Indicator Fact Sheet (WQ1): Water exploitation index. Copenhagen, Denmark: European Environment Agency.

Lebel, L., Grothmann, T., & Siebenhüner, B. (2010). The role of social learning in adaptiveness: insights from water management. International Environmental Agreements: Politics, Law and Economics, 10(4), 333-353.

Loos, J., & Shader, E. (2016). Reconnecting Rivers to Floodplains: Returning natural functions to restore rivers and benefit communities. American Rivers. River Restoration Program.

Maurel, P., Craps, M., Cernesson, F., Raymond, R., Valkering, P., & Ferrand, N. (2007). Concepts and methods for analysing the role of Information and Communication tools (IC-tools) in Social Learning processes for River Basin Management. Environmental Modelling & Software, 22(5), 630-639.

Naiman, R. J., Bechtold, J. S., Drake, D. C., Latterell, J. J., O'keefe, T. C., & Balian, E. V. (2005). Origins, patterns, and importance of heterogeneity in riparian systems. In Ecosystem function in heterogeneous landscapes (pp. 279-309). Springer, New York, NY.

Opperman, J. J., Galloway, G. E., Fargione, J., Mount, J. F., Richter, B. D., & Secchi, S. (2009). Sustainable floodplains through large-scale reconnection to rivers. Science, 326(5959), 1487-1488.

Pegram, G., & Baleta, H. (2014). Water in the Western Cape economy. Progress report to the Water Research Commission, WRC Project, (K5-2075).

Pengelly, C., Seyler, H., Fordyce, N., Janse Van Vuuren, P., Van Der Walt, M., Van Zyl, H., & Kinghorn, J. (2017). Managing Water as a Constraint to Development with Decision-Support Tools That Promote Integrated Planning: The Case of the Berg Water Management Area. Cape Town.

Reinders, Felix B., Oosthuizen, H., Senzanje, A., Smithers, JC., van der Merwe, RJ., van der Stoep, I., van Rensburg, L. (2016). Developing of technical and financial norms and standards for drainage of irrigated lands, Volume 2; Supporting information relating to the updating of technical standards and economic feasibility of drainage projects in South Africa (Vol. 2). Johannesburg.

Rice, S. P., Kiffney, P., Greene, C., & Pess, G. R. (2008). The Ecological Importance of Tributaries and Confluences. River Confluences, Tributaries and the Fluvial Network. https://doi.org/10.1002/9780470760383.ch11

Ritzema, HP., Kselik, RAL., Chanduvi, F. (1996). Irrigation water management, training manual No. 9; Drainage of irrigated lands. Rome.

Rountree, M., & Powrie, F. (2016). Managing water for the environment Development of rehabilitation plans for river / wetland restoration of selected sites (the Carel Visser / Botmansdrift site near Hermon and Tweerivieren site near Franschhoek) Berg River, Western Cape, South Africa. Cape Town.

Scharmer, C. O. (2009). Theory U: Learning from the future as it emerges. Berrett-Koehler Publishers.

Scheumann, W., & Freisem, C. (2002). The role of drainage for sustainable agriculture. Journal of Applied Irrigation Science, 37(1), 33–61.

Schusler, T. M., Decker, D. J., & Pfeffer, M. J. (2003). Social learning for collaborative natural resource management. Society & natural resources, 16(4), 309-326.

Smedema, L. K., & Shiati, K. (2002). Irrigation and salinity: a perspective review of the salinity hazards of irrigation development in the arid zone. Irrigation and drainage systems, 16(2), 161-174.

van Rensburg, L. D., de Clercq, W. P., Barnard, J. H., & du Preez, C. C. (2011). Salinity guidelines for irrigation: Case studies from Water Research Commission projects along the Lower Vaal, Riet, Berg and Breede Rivers. Water SA, 37(5), 739–750

Verhoeven, J. T. A., & Setter, T. L. (2010). Agricultural use of wetlands: Opportunities and limitations. Annals of Botany, 105(1), 155–163. https://doi.org/10.1093/aob/mcp172

Washington State University, Department of Ecology (2009). Riparian Areas. https://doi.org/10.17226/10327

Wohl, E., Allen, A. O., Mersel, M. K., Kichefski, S. L., Fritz, K. M., Lichvar, R. W., & Vanderbilt, F. B. (2016). Synthesizing the scientific foundation for ordinary high-water mark delineation in fluvial systems (No. ERDC/CRREL SR-16-5). US Army Engineer Research and Development Center (ERDC) Hanover United States.

APPENDIX A: ROLES ON THE LANDSCAPE

Landscape Mobiliser

The Landscape Mobiliser facilitates the bottom-based process.

We seek to be grounded on the landscape with stakeholders guiding our work, so that the work stays deeply rooted in the cause. All decisions with regards to the landscape need to be co-created and made by the people affected on the ground. The Landscape Mobiliser facilitates social learning and social change processes with the stakeholders on the landscapes. This is done by building collective awareness and understanding of the current challenges, aspirations and opportunities for action.

Landscape Facilitator

The Landscape Facilitator facilitates the top-guided process to create an environment for change. This aims to build collaborations and mutual understanding of the various challenges facing the socio-ecological landscape. We therefore work with stakeholders such as government institutions, businesses and downstream water users.

Knowledge Broker

The Knowledge Broker generates and translates knowledge. The goal of the Knowledge Broker is to bridge the gap between theory and practice (Knowing-Doing Gap). Trans-disciplinary research informs our approach to build a strong knowledge base. Research is the voice of the landscape; it can open people's eyes to knowledge that was previously unknown or misunderstood. The Knowledge Broker builds partnerships with universities and other knowledge institutions to improve the knowledge base for socio-eco- logical restoration and innovation.

Landscape Innovator

The Landscape Innovator implements socio-ecological rehabilitation on the ground. We, together with landowners, generate ideas and co-create plans. If the need is there, we can do the job and implement large scale ecological rehabilitation projects. We have a strong 'learning by doing' approach. When we work with landowners and communities during the implementation phase, we work to create additional capacity and long term sustainability. The Landscape Innovator is involved in the day to day work on site and is dedicated to project outcomes, deadlines and project finances as well as always looking for innovative ways to implement projects.

Business Developer

The Business Developer is responsible for the 4 Returns Business Development. In this regard, we work closely with our partner organisation, Grounded. Looking for long term opportunities and financial sustainability, we incorporate the 4 Returns Model of Commonland where applicable. We work with farmers to develop regenerative businesses. These businesses establish a healthier and more profitable balance between nature and agriculture. We explore and develop agricultural models that are markedly more sustainable and more profitable

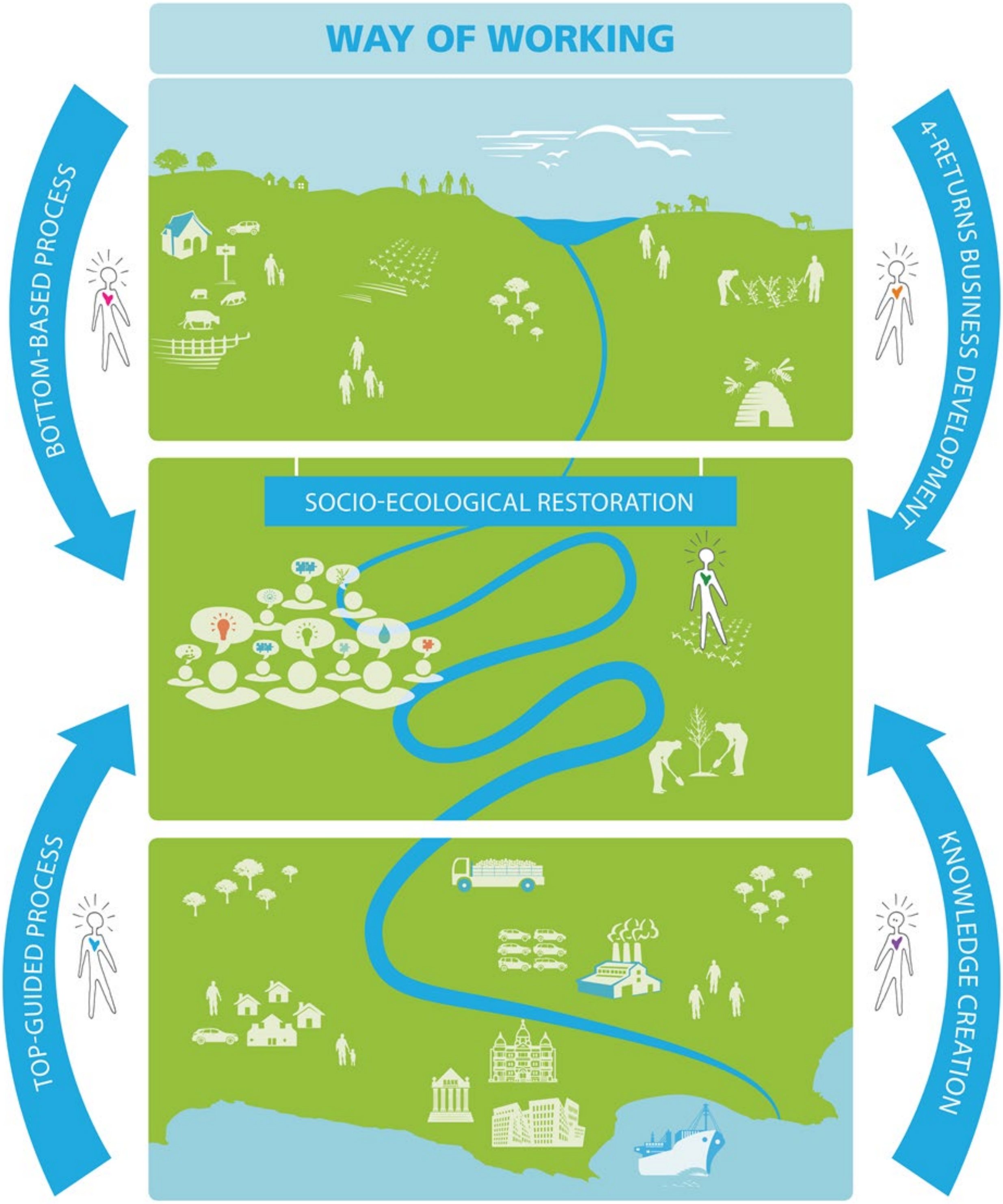

Figure A 1: The Living Landscape Approach illustrating the five roles on the landscape.

APPENDIX B: RESOURCE QUALITY OBJECTIVES

The Water Resources Classes and Associated Resource Quality Objectives have been determined for the Berg River Catchment and is currently undergoing finalisation, whereafter it will be Gazetted. All the documents related to this process is stored at this link: **http://www.dwa.gov.za/rdm/WRCS/**

Assigning the Classes and Objectives

Defined Integrated Units of Analysis (IUA) have been identified based on physical, biological and socio-economic factors. Each IUA represents a similar area requiring a Water Resource Class (WRC). These Classes are therefore broad-scale units to assess socio-economic implications of possible future situations. It also enables reporting on ecological condition at a sub-catchment scale as different WRCs are set for different parts of the catchment. Twelve IUAs have been delineated. Resource Quality Objectives are descriptive broad statements describing overall objectives for the Resource Unit.

IUA Name	IUA Code	Recommended Class
Berg Estuary	A1	II
Langebaan	A2	II
West Coast	A3	III
Lower Berg	B4	III
Berg Tributaries	C5	II
Eerste	D6	III
Sir Lowry's	D7	II
Upper Berg	D8	III
Middle Berg	D9	III
Diep	D10	III
Peninsula	E11	II
Cape Flats	E12	III

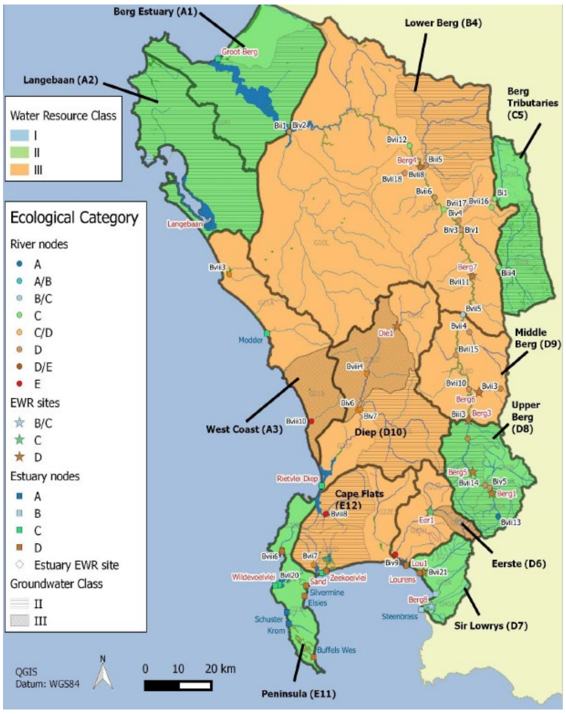

Table B 1: Description of the meaning of each Water Resource Class

Water Resource Class	Description
Class I	Minimally used
Class II	Moderately used
Class III	Heavily used

Table B 2: Guidelines for determining the IUA class based on ecological condition

Water Resource Class	**Percentage (%) of nodes in the IUA falling into the indicated groups**				
	A or A/B	**B or B/C**	**C or C/D**	**D**	**<D**
Class I	60	40	20	1	-
Class II		60	30	5	-
Class III			70	20	-

Resource Units (RUs) are grouped areas e.g. river basins, deemed similar in terms of various characteristics. These Units are used to transfer information between catchments and includes information on groundwater. Nodes are point locations of interest in water resources, including rivers, dams, wetlands and estuaries. Nodes are sited using water infrastructure and aquatic ecosystem attributes and in turn is used to allocate water for the environments and for development.

The DWS Resource Unit evaluation tool was used to select indicators for RQOs based on activities that impact the water resources, such as:

- Dams
- Inter-basin transfers
- Afforestation
- Agriculture
- User requirements
- Conservation and ecosystem characteristics
- Industry
- Ecotourism
- Real Estate

including fitness for use and trajectory of change

Table B 3: Example of Resource Quality Objectives for Node Bvii13

Sub-component	TEC	RWQO	Indicator	Numerical Limits	Present state (50/95%tile) G1H038 Wolwekloof
Nutrients	A	Maintain in an oligotrophic (unenriched) condition.	Phosphate (PO_4-P) Total inorganic nitrogen (TIN)	Median ≤ 0.025 mg/l PO_4-P Median ≤ 0.70 mg/l TIN	PO4 0.005 / 0.005 TIN 0.03 / 0.09
Salts		Salt concentrations should be maintained in an Ideal state for aquatic organisms.	Electrical conductivity (EC)	95^{th} %tile ≤ 30 mS/m EC	EC 3.3 / 4.3
System variables		pH, temperature, and dissolved oxygen are important for the maintenance of ecosystem health.	pH Dissolved oxygen	5 ≥ pH ≤ 7 (5^{th} %tile / 95^{th} %tile) 5^{th} %tile DO ≥ 8 mg/l	pH 5.7 / 6.5 No DO data

With this information the Threshold of Potential Concern is set, and the resource can be managed effectively in line with the identified objectives.