DEMONSTRATION OF HOW HEALTHY ECOLOGICAL INFRASTRUCTURE CAN BE UTILIZED TO SECURE WATER FOR THE BENEFIT OF SOCIETY AND THE GREEN ECONOMY THROUGH A PROGRAMMATIC RESEARCH APPROACH BASED ON SELECTED LANDSCAPES

Deliverable 7: Literature review and final methodology description to assess water resource connectivity and inter-dependency (between surface and ground water, water quality and quantity, water and society, etc) from a landscape perspective

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Project K5/2354
## ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>BEDS</td>
<td>School of Built Environment and Development Studies</td>
</tr>
<tr>
<td>CHAT</td>
<td>Critical Historical Activity Theory</td>
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<tr>
<td>CMA</td>
<td>Catchment Management Agency</td>
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<td>CMS</td>
<td>Catchment Management Strategy</td>
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<tr>
<td>CoGTA</td>
<td>Cooperative Governance and the Department of Traditional Affairs</td>
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<tr>
<td>CWR</td>
<td>Centre for Water Resources Research</td>
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<tr>
<td>DBSA</td>
<td>Development Bank of South Africa</td>
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<tr>
<td>DEA</td>
<td>Department of Environmental Affairs</td>
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<td>DEWATS</td>
<td>Decentralized Wastewater Treatment Systems</td>
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<tr>
<td>DUCT</td>
<td>Dusi uMngeni Conservation Trust</td>
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<tr>
<td>DUT</td>
<td>Durban University of Technology</td>
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<td>DWAF</td>
<td>Department of Water Affairs and Sanitation</td>
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<td>DWAF</td>
<td>Former Department of Water Affairs and Forestry, South Africa</td>
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<td>EI</td>
<td>Ecological Infrastructure</td>
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<td>EPCPD</td>
<td>Environmental Planning and Climate Protection Department</td>
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<td>EWS</td>
<td>eThekwini Water and Sanitation</td>
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<tr>
<td>GIS</td>
<td>Geographic Information Systems</td>
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<td>GWSP</td>
<td>Global Water Systems Project</td>
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<td>IWRM</td>
<td>Integrated Water Resource Management</td>
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<td>KZN</td>
<td>KwaZulu-Natal</td>
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<tr>
<td>LULC</td>
<td>Land use/land cover</td>
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<td>NWRS</td>
<td>National Water Resources Strategy</td>
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<td>PRG</td>
<td>Pollution Research Group</td>
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<td>PRP</td>
<td>Palmiet Rehabilitation Project</td>
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<tr>
<td>SALGA</td>
<td>South African Local Government Association</td>
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<td>SANBI</td>
<td>South African National Biodiversity Institute</td>
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<tr>
<td>SANCIAHS</td>
<td>South African National Chapter of the International Association for Hydrological Sciences</td>
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<td>SASS</td>
<td>South African Scoring System</td>
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<td>SES</td>
<td>Social Ecological Systems</td>
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<td>SIP</td>
<td>Strategic Infrastructure Project</td>
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<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>STELLA</td>
<td>Systems Thinking, Experimental Learning Laboratory with Animation</td>
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<tr>
<td>SWOT</td>
<td>Strengths, Weaknesses, Opportunities, and Threats</td>
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<td>TOR</td>
<td>Terms of Reference</td>
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<tr>
<td>UEIP</td>
<td>uMngeni Ecological Infrastructure Partnership</td>
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<tr>
<td>UKZN</td>
<td>University of KwaZulu-Natal</td>
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<tr>
<td>WESSA</td>
<td>Wildlife and Environment Society of South Africa</td>
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<td>WRC</td>
<td>Water Research Commission</td>
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Definition of terms

Actors: All human and non-human agents who act to shape the physical, social, economic and governance dimensions of the uMgeni Catchment. Power relations between actors vary depending on the power that each actor can exercise.

Agency: reflects on how and to what extent, through power that is exercised, each element is able to shape others.

Discourse: A group of ideas and concepts which give meaning to social and physical ‘things’, which are created and produced by actors through language and then reproduced as they are used in practice (Hajer, 2006).

Materialities: These are the physical elements, including the practices that we engage in that make up the physical and social world. They are the things that ‘just are’, the physical realities, in the context we work in.

Ontology: This is a philosophical term which describes what we know to exist. It also reveals what can be known – in other words what we know to exist based on our scientific and experiential knowledge of the world.

Dialectical approach: In this report this term is drawn from the discipline of geography and refers to how one thing, for example society, is expressed in or connected to another thing, for example, space, but that in turn this second phenomena acts back on or shapes the first phenomena. In this case society is expressed in space, but space in turn acts back on society and reshapes it forming the socio-spatial dialectic. Through dialectics things, such as society and space, continually produce, reproduce and shape each other.

Trialectics: Lefebvre and Soja defined this term as three moments of being which act on and contain each other. Their definition of the trialectics of spatiality referred to the three moments of space which moved from the more objective spatial practices (networks, spatial order), to representations of space (which includes maps and plans), and then on to the more abstract spaces of representation (the space of the imaginary or lived space). These three moments of space are set constantly in relation to each other, shaping and remaking each other.

Water security - “the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability” (UN Water, 2013)

Waterscape - The waterscape is the spatial expression (including the context) of the complex biophysical, socio-political and governance processes that constitute water.
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1 Introduction

This project focuses on the construction of knowledge, through detailed scientific research and social learning, which contributes to the understanding and achievement of sustainable water supply; water related resilient economic growth; greater social equity and justice in relation to water; and the reduction of environmental risk in the uMngeni Catchment. The main research question focuses on how healthy ecological infrastructure can be utilized to secure water for the benefit of society and support the green economy in catchments in South Africa, with the uMngeni Catchment as the case study. This is a complex question as it requires an understanding of the connections and relations between biophysical, social, political, economic and governance dimensions over space and time in the catchment. The study also needs to interrogate whether there is ‘value’ in investing in ecological infrastructure (EI), how this should be done, where the most valuable EI is located, and whether an investment in EI will generate co-benefits socially, environmentally and economically.

The aim and objectives of the project and the composition of the research team demand that a transdisciplinary approach to the research is adopted. The project team consists of academics and practitioners from a range of different disciplines, providing a diversity of skills and approaches through which the main research questions in each case study have been addressed. The project is strongly linked to the uMngeni Ecological Infrastructure Partnership (UEIP) and the general approach has been to provide research support to the UEIP ‘Pilot Studies’ that are being undertaken by some of the uMngeni Catchment municipalities. An action research approach has therefore been employed. This has enabled the research team to link into the stakeholder and social networks which are developing through these pilot studies (see Deliverable 1). The research has included a strong component of participatory engagement and deliberation between the multiple actors involved in each of the four case studies. Collaboration between the research team, municipalities, the private sector and communities has formed part of the knowledge building process through the action research methodology adopted in each case study. Four cases studies have been undertaken for the research. These are termed “Midmar/Mpophomeni”; “Baynespruit”; “Palmiet River” and “Mzinyathi”. A fifth study, the Green Trust/Ecological Infrastructure Investmen project (Jewitt et al., 2015) was undertaken at the catchment scale at the outset of the project. This will be used to triangulate and verify the outcomes of the analysis of the four case studies when they are elevated to the catchment scale as explained in detail in Section 3 of this document.

This report presents the theoretical framework (literature review) and methodology developed to assess water resource connectivity and inter-dependency between water quality, water quantity and society using a landscape perspective. The literature review presents the main theoretical concepts used to frame the study. Due to the transdisciplinary nature of the study and the complex range of questions that emerge when exploring the physical, social, economic and governance dimensions of a catchment in relation to the value of ecological infrastructure, a range of theoretical concepts related to the methodology are presented. The report argues that in order to understand the multiple relations between water, society and ecological infrastructure, both the context of these relations and their spatial expression need to be understood and represented. It therefore adopts Lefebvre’s concept of a trialectic as an overarching theoretical framework (Soja, 1996) to explore water security and ecological infrastructure in the uMngeni Catchment. According to Soja (1996) trialectic thinking is challenging as it requires new epistemologies and it challenges conventional modes of thought. It is not ordered or fixed, but rather is constantly evolving, revealing the dynamic
relations between the elements under exploration. This report constructs the society-water-space trialectic as a way of connecting and assembling the understanding and knowledge that has been produced in four separate case studies in the uMngeni Catchment (see Figure 1). The relations in the three elements of the trialectic are constructed through identifying, understanding and analysing the actors, discourses, knowledge, materialities, issues and spatial connections in each case study. Together these relations, or multiple trajectories, are assembled to form the society-water-space trialectic, which will illuminate the dominant relations in the catchment and hence reveal the leverage points that will have the greatest ability to affect positive change in the catchment.

![Figure 1. The society-space-water trialectic](image)

The methodology outlines how the results from the four case studies can be compared and integrated, given the different approaches and methods adopted in each case study as a result of the flexibility required in action research. In this way the relations between ecological infrastructure, water security, water governance and the green economy in the uMngeni Catchment can be revealed through the society-water-space trialectic.

However, so as to: 1) understand the emergence of the society-water-space trialectic as a framing concept; 2) to explain the methodological approaches adopted in each case study thus far; 3) to propose the methodology to be used to explore connectivity and inter-dependency in the catchment, the literature review expands on a number of different theories and concepts. It first presents current approaches to water resources management and water governance at a global, national, regional and local scale (associated strengths, weaknesses and issues), as these approaches shape water security discourses and approaches at the national and local scale. Transdisciplinary
research approaches are documented and critiqued, as this study involves research undertaken by social and natural/physical scientists in a manner that does not just enable the collation of knowledge from a broad range of sciences, but requires the integration, connection and entanglement of this knowledge. It then presents new approaches to water resources management and governance, introducing the concepts of relational ontologies and dialectics. Here both socio-ecological systems and social-ecological relations are explained and considered in relation to each other. Literature on the hydro-social cycle which has produced a plethora of new research on the political ecology of water is considered, as this body of knowledge stresses the importance of context and power relations in water governance and water security. Finally the relations between society-water-space are explored from a theoretical perspective. A heuristic framework or waterscape configuration, which is the main organizing device for the methodology, is presented. This framework includes identifying actors, discourses, knowledge, materialities, issues and spatial expressions of water-society-space relations in terms of water security and ecological infrastructure. Together these elements of the waterscape configuration are used to construct the society-water-space trialectic.

2 Literature review on approaches to understanding and mapping water-society connections at a landscape scale

2.1 Introduction

The literature presented in this section focuses on approaches to understanding and mapping water-society connections in a landscape. It is therefore not a comprehensive review of literature for all the components of WRC 2354. Literature, which includes conceptualisations of water management and water security, the value of ecological infrastructure, and knowledge on the social, economic, biophysical and governance aspects of water, is presented in other deliverables. This portion of the project outlines current approaches to water resources management; the construction of transdisciplinary research; relational and dialectical ontologies with a focus on socio-ecological systems thinking, socio-ecological relations thinking and the hydro-social model; constructing the society-water-space trialectic; and a heuristic framework or configuration for water security and connectivity.

2.2 Current approaches to water resources management and water governance at global, national, regional and local scales

Over the past 25 or so years, there has been much debate around approaches to water resources management. Integrated Catchment Management, Integrated Water Resources Management (IWRM) and more recently “nexus” thinking have all been proposed and, in places, implemented as approaches to provide water to society and to safeguard the resource base. Water security has been framed as an overarching goal at multiple scales and is defined by UN-Water (http://www.unwater.org/topics/water-security/en/, accessed 15/10/2016) as
“the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability”.

According to the Organisation for Economic Co-operation and Development (OECD), water security is increased through progressive legislation and policy defined across sectors and well implemented with adequate resources; clear strategies that guide sustainable resource use; adequately working built infrastructure; technically sound and innovative practices, including using ecological or green infrastructure as a ‘technology’, which are developed through the engagement between multiple stakeholders within both formal and informal institutions at multiple levels; good governance with clearly defined political, institutional and administrative rules as well as holding decision-makers accountable for water management; and a focus on the resilience and sustainability of water-society relations and the landscapes within which they are produced, including awareness of current and future water risks (OECD, 2015).

Current approaches to water resources management and water governance intended to achieve water security at global, national, regional and local scales recognise that there are both formal and informal organizations that are active in this arena (Stuart-Hill and Schulze, 2010). Formal organizations are easier to recognize and are well researched and documented. Informal organizations are equally important, but are often less visible. It is therefore essential that the methodologies adopted to study water security and the role of ecological infrastructure enable both formal and informal institutions, their practices and the connections between them, to emerge.

The Bonn Declaration on Global Water Security (GWSP, 2013, p.2) strongly supports the formation of strategic partnerships between scientists, public stakeholders, decision-makers, and the private sector to “develop a broad, community-consensus blue-print for a reality-based, multi-perspective, and multi-scale knowledge-to-action water agenda” based on the following six recommendations:

1. Make a renewed commitment to adopt a multi-scale and interdisciplinary approach to water science in order to understand the complex and interlinked nature of the global water system and how it may change now and in future.
2. Execute state-of-the-art synthesis studies of knowledge about fresh water that can inform risk assessments and be used to develop strategies to better promote the protection of water systems.
3. Train the next generation of water scientists and practitioners in global change research and management, making use of cross-scale analysis and integrated system design.
4. Expand monitoring, through traditional land-based environmental observation networks and state-of-the-art earth-observation satellite systems, to provide detailed observations of water system state.
5. Consider ecosystem-based alternatives to costly structural solutions for climate proofing, such that the design of the built environment in future includes both traditional and green infrastructure.
6. Stimulate innovation in water institutions, with a balance of technical- and governance-based solutions and taking heed of value systems and equity. A failure to adopt a more inclusive approach will make it impossible to design effective green growth strategies or policies.
These recommendations, which argue for participatory governance, and include the integration of multiple forms of knowledge, are closely aligned with the objectives of this research project. Pahl-Wostl et al. (2015, p.1) expand this focus by arguing that there is the need at the national level for “adaptive and effective governance and the respect of good governance principles in water-related sectors”. They state that issues regarding the “lack of institutional capacity and high levels of corruption” are “central factors - more important than the state of economic development” in water management. As a result, the building of institutional capacity is critical for good water governance. In particular, South Africa faces multi-dimensional pressure on water governance as the country needs to ensure social transformation and economic growth, while addressing the risks of poverty, inequality and climate change. It is this increased pressure which makes understanding and implementing the integrative role of institutions and water governance processes at a national and sub-national level challenging (Adger, 2006; Stuart-Hill and Schulze, 2010).

The research conducted in the uMngeni Catchment therefore not only contributes to water governance in South Africa, but it also reflects on how South African researchers are contributing to global debates and the global body of knowledge on water governance.

### 2.2.1 Water resources management and governance in South Africa

National, provincial and local government legislation and policy frames water management and governance in South Africa. This framing reflects the approaches being adopted for water management and governance by the state. At the national level, South Africa is governed by the National Water Act (No. 36 of 1998), which “requires that a National Water Resources Strategy (NWRS) be established that sets out the policies, strategies, objectives, plans, guidelines and procedures and the institutional arrangements for the protection, use, development, conservation, management and control of water resources for the country as a whole, and [to] establish and define the boundaries of water management areas taking into account catchment boundaries, socio-economic development patterns, efficiency considerations and communal interests. According to the National Water Services Regulation Strategy, “DWAF as the national regulator will be concerned only with high-level performance and with outcomes, not the detailed processes”, focusing on social regulation including access to and affordability of services, drinking water quality (in association with Department of Health), environmental health regulation, water resources regulation and economic regulation including price, value for money and efficiency. The NWRS is binding on all authorities and institutions exercising powers or performing duties under the National Water Act,” (Blackhurst et al., 2002, p.i).

The NWRS builds on Catchment Management Agencies (CMA’s) as being critical to water governance. Originally, it was intended that Catchment Management Agencies would be formed by drawing together multiple actors to manage and co-ordinate water resources at the catchment scale, but that vision has shifted in recent years and now reflects a more pragmatic, but less representative approach driven by DWS. In 1999, shortly after the promulgation of the National Water Act, 19 catchment management agencies (CMAs) were planned for across South Africa (Meissner, Funke, and Nortje, 2016) to manage water resources at the catchment level as defined by hydrologic boundaries, typically primary catchments. The delivery of water services, on the otherhand, was considered to be part of the detailed planning, management and regulation of water
and hence in 2000 it was delegated to Water Services Authorities (WSA’s) who typically act at a municipal and local scale. In many instances WSA’s are local municipalities, but also include bulk water suppliers (water boards) such as Umgeni Water and Rand Water (Figure 2).

Figure 2. An overview of formal water resources management institutions and their interrelationships in South Africa as envisaged in 1998. These are indicative and do not necessarily reflect recent amendments (Mazibuko and Pegram, 2006)

In the past the Department of Water and Sanitation (DWS, previously DWAF) assumed the role of a water services provider. Water boards, according to the 1994 White Paper on Water Supply and Sanitation, were intended to be the primary regional agent of water supply and sanitation services. At that time, water boards, bulk water suppliers for municipal and industrial use, served as a link between the National and local levels of government (Department of Water Affairs and Forestry, “White Paper on Water Supply and Sanitation Policy”). Therefore, the proposed National Water Services Regulation Strategy (2008) shifted the role of the national government department from provider to regulator and referee (Sutherland et al, 2014). This was done in an attempt to close the regulatory gap in the country (Tissington et al 2008). As pointed out in the NWRS2, most water boards were established for pragmatic reasons, and while performance standards are high, reasons now exist for change, such as weak municipal performance in water and sanitation, unclear responsibilities at the regional and local levels and governance and performance-related issues.

Further complications arise as a result of the fact that municipalities report to the Department of Cooperative Governance, while the water boards report to the Department of Water Affairs. Consideration is now being given to the idea of converting existing water boards into Regional Water Utilities (Department of Water Affairs, 2013).
Under South Africa’s progressive policies, water is considered a social good and a critical part of the transformation and development of the country (Tissington et al. 2008; Sutherland et al. 2014). However, the delegation of the provision of services to the local scale has resulted in a decline in both technical and financial support from the national level (Tissington et al. 2008). This has created the space for well-capacitated municipalities such as eThekwini Municipality to take the lead and show innovation in water governance but it has also had a significant impact on municipalities or broader WSA’s that lack capacity (Sutherland et al., 2013). Each WSA has to produce a Water Services Development Plan to progressively ensure efficient, affordable, economical, and sustainable provision of water services (i.e. water and sanitation services). It deals with socio-economic, technical, financial, institutional and environmental issues as they relate to water services (Tissington et al., 2008). The delegation of water service provision to the local level without fiscal support from national government has placed pressure on municipalities to be “financially self-sufficient in terms of service provision and to recover service related costs from all areas, including poor communities (Tissington et al. 2008, p 2). This neo-liberal cost recovery approach to water delivery therefore means that water is framed as an ‘economic good’ (Sutherland et al., 2014). Balancing the management of water resources as both a social and economic good is challenging and is reflected in the pressures and risks that emerge around water security in South Africa. A report prepared by Centre for Applied Legal Studies (CALS), the Centre on Housing Rights and Evictions (COHRE) and the Norwegian Centre for Human Rights (NCHR) argues that there are nine main ‘fault lines’ in water service delivery at the local level (Tissington, et al, 2008, p 2). These include:

- Eliminating Backlogs and Improving Levels of Service
- Free Basic Services (FBS)
- Indigent Policy as the FBS Targeting Mechanism
- Tariffs
- Credit Control Enforcement – Water
- Disconnections and Restriction Devices
- Financial and Technical Assistance
- Water Quality
- Water Demand Management (WDM)
- Public Participation

Shortly before the National Water Resources Strategy 2 was finalized in 2013, the 19 water management agencies, were consolidated into nine water management areas as of 2012 (Meissner, Funke, and Nortje, 2016). The decision to reduce the number of CMAs from 19 to nine was due in large part to the delay experienced in setting up these agencies. Additional reasons for this reduction included ‘reconsideration of the management model and viability assessments related to water resources management, funding, capacity, skills, and expertise in regulation and oversight, and an effort to improve integrated water systems management’. By 2012 only two of the original 19 existed, (Department of Water Affairs, 2013; Meissner, Funke, and Nortje, 2016).

While CMAs operate a fairly broad scale of water resource management, additional water management institutions exist at the local level in the form of Water User Associations (WUAs). However, unlike CMAs, the primary purpose of the WUAs are to “operate at a restricted localised level, and are in effect co-operative associations of individual water users who wish to undertake water-related activities for their mutual benefit. A WUA may exercise management powers and
duties only if and to the extent these have been assigned or delegated to it. Although water user associations must operate within the framework of national policy and standards, particularly the national water resource strategy, the Minister may exercise control over them by giving them directives or by temporarily taking over their functions under particular circumstances. Existing irrigation boards, subterranean water control boards and water boards established for stock watering purposes will continue in operation until they are restructured as water user associations,” (Republic of South Africa, National Water Act, 1998, p.45).

Catchment Management Forums, although initially established to assist planning and implementation of the CMAs (Boakye and Akpor, 2012), provide a platform to address critical issues within relevant local sub-catchments (Karar and Seetal, 2000). In regards to IWRM these forums provide the space for local citizens to participate in water resource management (Boakye and Akpor, 2012; du Toit and Pollard, 2008; Karar and Seetal, 2000). Public participation can be difficult for many reasons and therefore an analysis of the strengths, opportunities, weaknesses and threats of the CMFs can help to provide a clearer understanding of the CMFs value. As Karar and Seetal (2000) pointed out, the forum’s strength and value arises from the water sector’s interconnectivity amongst institutions, capacity to plan and implement water resource goals for South Africa, enabling legislation that drives the CMAs, and existence of a natural resource database for each forum. Weaknesses include poor information sharing and disparities amongst stakeholders, lack of commitment from stakeholders, lack of clearly defined responsibility or funding sources. Opportunities for the forum include involvement of natural resource stakeholders in positions to influence decisions or provide support, capacity building of natural resources management, improved networking between role-players, obtaining clarity for definition of roles and responsibilities, promoting the sharing of information for effective water resource management (Karar and Seetal, 2000).

2.2.2 Summary

While South Africa’s water resource management holds promise, there are challenges that must be overcome in order to improve this valuable resource overall. A review of the SWOT analysis performed by Stuart-Hill and Schulze (2010) provides insight that can assist in moving forward. As pointed out in this SWOT analysis, strength lies in the established restrictions in allocation and licensing as well as the regular review cycles for policy documents such as the NWRS and the CMS. On the other hand, weaknesses include a ‘shortage of skills and capacity and a lack of implementation efforts’ as well as policy enforcement. These are mirrored in Sutherland et al’s (Sutherland et al, 2014) critique of the difficulties facing water services authorities.

This section has provided a broad overview of water governance approaches in South Africa. The following sections present the conceptual framing of the methodology to be adopted in assessing water resource connectivity and inter-dependency from a landscape perspective. The NWRS adopts a broad and strategic view of water resources, focusing on the overall management of the resource following an IWRM approach. This enables South Africa to embrace ideas of ecological and built infrastructure as mutually beneficial for integrated water resource management (Jewitt et al., 2015). Although most IWRM approaches recognise that water resources are complex with processes and interactions between multiple components and actors across different spatial scales, it reflects an incomplete, but pragmatic approach to fully integrated catchment or landscape management. As part of an allied project supported by the Green Fund, Jewitt et al. (2015) developed a framework to
guide investments in ecological infrastructure in the uMngeni Catchment, aimed at enhancing water service delivery and catchment level water security. The study adopted a social-ecological systems approach “to enable better understanding of the relationships between different project components and how these interact with governance systems in the uMngeni catchment and the potential investments in EI” (Jewitt et al., 2015 p.vi) and provides a catchment level cross-reference for the focused approach to exploring connectivity between different elements developed through this Deliverable.

### 2.3 Transdisciplinary research

The main research problem, the aim and objectives, and the composition of the research team for the WRC 2354 project, requires that a transdisciplinary approach be adopted as the overarching methodology for this study. Transdisciplinary research has emerged as a response to the need for research (and science) to: be relevant and help to resolve ‘real world’ problems, most especially ‘wicked problems’ (Vogel et al, 2016; Bhaskar et al., 2010); address complex social-ecological problems in open systems by drawing on multiple ways of knowing (Max-Neef, 2005; Bhaskar et al., 2010; Vogel et al, 2016); and be able to integrate and synthesise knowledge about these problems in ways that leads to socio-ecological transformation (Max-Neef, 2005; Hirsh Hadorn et al., 2008; Bhaskar et al., 2010; Vogel et al, 2016).

According to Bhaskar (2010) epistemological transdisciplinarity requires drawing knowledge from already existing disciplinary fields leading to creative interdisciplinary work. The WRC 2354 researchers align with Bhaskar’s view that this does not mean the end of disciplinarity, or the emergence of ‘post-disciplinarity’. Disciplinary knowledge still matters. Indeed, feedback from engagement with researchers from other disciplines can strengthen a discipline. It is how knowledge is connected and assembled in a transdisciplinary manner which is critical. For this epistemological shift to occur, Bhaskar (2010) and Stone-Jovicic (2015) suggest that the community of researchers will need to learn to communicate effectively and produce ‘cross-disciplinary’ understanding. It is argued in this report that the heuristic framework or configuration developed for this project, as well as the society-water-space trialectic, offers one way of achieving this goal. The social learning that occurs through this process also contributes to the achievement of transdisciplinarity. According to Bhaskar et al (2010, p ix) “the resulting concept of a laminated system pinpoints the meshing of explanatory mechanisms at several different levels of reality and possible orders of scale”. The critical realist perspective developed by Bhaskar et al (2010) questions both positivism and social constructivism (the main disciplinary fields of researchers in the WRC2354 team) as they exclude certain types of knowledge and do not employ the multidimensional methods and analysis required. It also raises the importance of including a political economy perspective (Naess, 2010). Both the configuration and trialectic developed in this research programme aims to address these concerns. According to Bhaskar (2010, p 11)

“epistemologically, for the successful pursuit of such interdisciplinary work, we need in addition both transdisciplinarity, involving the potential creative employment of models, analogies and insights from a variety of different fields and disciplines; and cross-disciplinarity, involving the potential to empathize with and understand and employ the concepts of disciplines and fields other than one’s own”.

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Following Bhaskar (2010), the project team has recognized that merely pooling the knowledge of the different disciplines of the team members will be not be adequate to achieve the project goals. Rather, an approach of “synthetic interdisciplinary integration” of both the knowledge and process will be undertaken. This will enable a collaborative process of deployment of ideas, models and practice with multiple actors, thus producing and using knowledge for transformations in policy and practice as well as strengthening the different disciplines represented by team members (Lotze-Sika, 2014 pers. Comm; cited in Deliverable 1).

Max-Neef’s (2005) transdisciplinary pyramid, which reflects weak transdisciplinarity, is helpful as it reflects on the multiple levels at which transdisciplinary work occurs.

He argues that in order to develop transdisciplinary understanding and knowledge, it is essential to work from what we know exists, to what we are capable of doing, through to what we want to do and finally to what we must do, or how we do what we want to do. This means that researchers need to travel from an empirical level towards a purposive or pragmatic level, continuing through a normative level, ending up at the level of values. According to Max-Neef (2005, p 9) “any multiple vertical relations including all four levels, defines a transdisciplinary action”. Strong transdisciplinarity deepens the notion of integration by “recognising simultaneous modes of reasoning, the rational and the relational” (Max-Neef, 2005, p 10) challenging binary thinking and reductionism and rather moving towards dialectic and relational thinking or the connections between rational and intuitive understanding. The three pillars of transdisciplinarity as outlined by Nicolescu (1998) are levels of reality; the principles of the included middle; and complexity (Max-Neef, 2005). First, our understanding of reality is shaped by our ‘scientific understanding’ of objects and physical states; our subjective experiences; and our construction of that world, particularly through language, which explains why discourse analysis is useful (see section 2.4.2. Socio-ecological relations ) (Rodriguez, 2004; Max-Neef, 2005). This leads to the concept of multiple truths, or multiple knowledges as “what appears to be increasingly evident is that we can no longer assume that there is just one reality, fully describable and understandable in terms of pure reason” (Max-Neef, 2005; p 12).
The second pillar refers to the ‘included middle’, which challenges the binaries or dualisms created in science, including mutually exclusive pairs of things, such as reason (A) and emotion (non-A), matter (A) and spirit (non-A), wave (A) and particle (non-A). This is difficult to achieve as by their very nature and definition these concepts are ‘opposites’. However the axiom of the ‘included middle’ tries to find the ‘space’ in between, where A and non-A can both exist in relation to each other, or be both A and non-A and hence non-contradictory (Max-Neef, 2005). This led Max-Neef (2005, p 9) to define the first law of transdisciplinarity: “the laws of a given level of reality are not self-sufficient to describe the totality of phenomena occurring at that same level” of reality. The ‘included middle’ really acts as a middle space, where researchers, each with their own knowledges, work through an “iterative process, to cross different areas of knowledge in a coherent manner, and generating a new simplicity” (Max-Neef, 2005, p 13). Dealing with complexity, or the ‘chaos’ of non-linear processes is the third pillar of transdisciplinarity. New epistemologies and ontologies need to be developed to integrate social understanding, politics, economics and environmental risk in a world experiencing rapid global and local change. We need to be able to know, as well as understand (Max-Neef, 2005).

However, as Max-Neef (2010) and Bhaskar (2010) argue, disciplinarity and transdisciplinarity both need to remain and be seen as complementary as “the transit from one to the other, attaining glimpses from different levels of reality, generates reciprocal enrichment that may facilitate the understanding of complexity” (Max-Neef, 2005, p 15). Transdisciplinarity is a new and emerging imperative that continues to evolve. There is a great deal that still needs to be learnt and understood. This WRC project contributes to this learning by integrating the research conducted by scientists and practitioners from multiple disciplines across four different case study sites in the uMngeni Catchment. Transdisciplinarity is as Max-Neef (2005, p 12) argues “both a tool and a project” and it is used in this way in this research too.

Having outlined the thinking and approaches associated with transdisciplinarity, the report now presents new ways of conceptualising water, society and space using relational ontologies and dialectics.

2.4 New approaches to understanding connectivity in water resources management and governance: relational ontologies and dialectics

The binary of society and the environment, or culture and nature, have been challenged by new relational ontologies. Ostrom (2009) argues that the multiple ways in which different scientific disciplines, using different concepts, languages and methods to describe and explain environmental challenges has confounded attempts to resolve them. New approaches that integrate and connect the social, economic, environmental and political need to be adopted. Two approaches, socio-ecological systems theory and socio-ecological relations theory are presented here as frameworks to explore the complexity and interconnectedness of the relationship between society and the environment.
2.4.1 Socio-ecological systems
A socio-ecological system (SES) is defined as “an ecological system intricately linked with and affected by one or more social system” (Anderies et al., 2004, p 18). SES theory has foundations in Garret Hardin’s (1968) economic perspective of resource use theory explained in the ‘Tragedy of the Commons’, which led to the development of resource economics by Clark (1976, 1980, cited in Schluter et al., 2012, p 225) and Dasgupta and Heal (1979, cited in Schluter et al., 2012, p 225). This was followed by Ostrom’s (1990) work surrounding institutional roles for common-pool resources.

An SES approach is holistic and acknowledges the interconnected relationship between society and the natural environment (Jewitt et al., 2015). Biophysical and social elements and their interactions, including natural resource governance aspects, can be illuminated in SES frameworks (Jewitt et al., 2015). Ostrom (1990), Stuart-Hill and Schulze (2010) and Diaz et al (2015) argue that the complex interdisciplinary nature and integrated knowledge of the biophysical/ecological system and the socio-economic system, including governance, cannot be adequately understood through simplified analytical models. Rather they need to be explored through interdisciplinary frameworks. SES thinking constructs frameworks for understanding and assessing the interactions and connections between society and the environment (Diaz et al 2015). Ostrom (1990) stressed, that it was important to develop a framework as opposed to a definitive model to be able to understand the basics of how complex, dynamic systems work. Thus, the common-pool resource framework evolved, as small system experiences were transferred to global systems, introducing new issues (Ostrom et al., 1999). This set a precedent for community-based resources management (Berkes, 2004), and the eventual link between social and ecological systems explored by Berkes and Folke (1998) and Anderies et al. (2004). Ostrom (2009, p 419) argues that “all humanly used resources are embedded in complex, social-ecological systems...composed of multiple subsystems and internal variables within these subsystems at multiple levels”. System’s thinking has been developed further to incorporate resilience thinking. A systems approach now places emphasis on the ability of a society or management system to build capacity for learning and adapting and considers resilience as an emerging property (Gunderson and Holling, 2002; Berkes, 2004).

In understanding why some systems are sustainable or resilient and others are not, the identification and analysis of relationships among multiple levels of these complex systems at different spatial and temporal scales is essential (Ostrom, 1999, p 7–9). This means that different elements of the system need to be dissected and analysed. Given their different disciplinary bases, this requires different philosophical and theoretical framings and methodologies. Ostrom (1999) developed a framework that reveals the relationships between four first-level core subsystems of an SES, as well as connected social, economic and political settings and related ecosystems. SES thinking proposes that the elements of the system are interdependent and interact, but that each element needs to be understood in its own right. Each element has sub-systems which also interact, and it is through these “action situations” that interactions between actors result in outcomes. This reflects that context matters in SES approaches. Ostrom (2009) identified subsystems (resource systems, resource units, governance systems, and users) with ten second-level variables that are potentially important to social-ecological system sustainability (system size, system productivity, system predictability, resource mobility, collective-choice rules, number of users, leadership/entrepreneurship, norm/social capital, knowledge of SES/mental models, importance of resource) as shown in Table 1 below. The established SES framework described above can be operationalized to identify opportunities and trade-offs in achieving sustainability (Leslie et al, 2015).
SES frameworks can be used for building scenarios, particularly when system dynamics modelling is employed.

Figure 4. Ostrom’s (1999, p 420) SES with its four first level systems

Scholars working on SES argue that concepts, technology and methods are still being developed to address complex system problems or ‘wicked problems’. Systems are dynamic and unpredictable and are “non-linear in nature, cross-scale in time and in space, and have an evolutionary character” (Ostrom, 2007, p 8). Critical feedback loops, which offer opportunities for interventions, also occur across temporal and spatial scales. Thresholds are revealed in feedback loops. Integrated and interdisciplinary modes of inquiry are required to develop understanding.
Table 1 First level elements of the SES (Source: Ostrom, 2009, p 421)

<table>
<thead>
<tr>
<th>Resource systems (RS)</th>
<th>Governance systems (GS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS1 Sector (e.g., water, forests, pasture, fish)</td>
<td>GS1 Government organizations</td>
</tr>
<tr>
<td>RS2 Clarity of system boundaries</td>
<td>GS2 Nongovernment organizations</td>
</tr>
<tr>
<td>RS3 Size of resource system*</td>
<td>GS3 Network structure</td>
</tr>
<tr>
<td>RS4 Human-constructed facilities</td>
<td>GS4 Property-rights systems</td>
</tr>
<tr>
<td>RS5 Productivity of system*</td>
<td>GS5 Operational rules</td>
</tr>
<tr>
<td>RS6 Equilibrium properties</td>
<td>GS6 Collective-choice rules*</td>
</tr>
<tr>
<td>RS7 Predictability of system dynamics*</td>
<td>GS7 Constitutional rules</td>
</tr>
<tr>
<td>RS8 Storage characteristics</td>
<td>GS8 Monitoring and sanctioning processes</td>
</tr>
<tr>
<td>RS9 Location</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resource units (RU)</th>
<th>Users (U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RU1 Resource unit mobility*</td>
<td>U1 Number of users*</td>
</tr>
<tr>
<td>RU2 Growth or replacement rate</td>
<td>U2 Socioeconomic attributes of users</td>
</tr>
<tr>
<td>RU3 Interaction among resource units</td>
<td>U3 History of use</td>
</tr>
<tr>
<td>RU4 Economic value</td>
<td>U4 Location</td>
</tr>
<tr>
<td>RU5 Number of units</td>
<td>U5 Leadership/entrepreneurship*</td>
</tr>
<tr>
<td>RU6 Distinctive markings</td>
<td>U6 Norms/social capital*</td>
</tr>
<tr>
<td>RU7 Spatial and temporal distribution</td>
<td>U7 Knowledge of SES/mental models*</td>
</tr>
<tr>
<td></td>
<td>U8 Importance of resource*</td>
</tr>
<tr>
<td></td>
<td>U9 Technology used</td>
</tr>
</tbody>
</table>

Interactions (I) → outcomes (O)

| I1 Harvesting levels of diverse users | O1 Social performance measures (e.g., efficiency, equity, accountability, sustainability) |
| I2 Information sharing among users | O2 Ecological performance measures (e.g., overharvested, resilience, bio-diversity, sustainability) |
| I3 Deliberation processes | |
| I4 Conflicts among users | O3 Externalities to other SESs |
| I5 Investment activities | |
| I6 Lobbying activities | |
| I7 Self-organizing activities | |
| I8 Networking activities | |

Related ecosystems (ECO)

| ECO1 Climate patterns | ECO2 Pollution patterns | ECO3 Flows into and out of focal SES |

*Subset of variables found to be associated with self-organization.

Ostrom (2007, p 8) argues that SES frameworks will support researchers in developing answers to three critical questions that are evidence based and coherent:

1. What patterns of interactions and outcomes—such as overuse, conflict, collapse, stability, increasing returns—are likely to result from using a particular set of rules for the governance, ownership, and use of a resource system and specific resource units in a specific technological, socioeconomic, and political environment?

2. What is the likely endogenous development of different governance arrangements, use patterns, and outcomes with or without external financial inducements or imposed rules?

3. How robust and sustainable is a particular configuration of users, resource system, resource units?

The study performed by Leslie et al. (2015, p 5979) offers further insight through application of “the social-ecological systems framework for comparative analysis of coupled systems, particularly in data-poor and developing nation settings”.

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Figure 5. A Multitier Framework for Analyzing a Social-Ecological System. Straight arrows are causal links, curved arrows are feedback loops (Source Ostrom, 2007, p 8).

Analysis conducted within an SES framework therefore replaces the view that “resources can be treated as discrete entities in isolation from the rest of the ecosystem and the social system” (Berkes and Folke 1998, p 2). SES thinking suggests that complex interactions and feedbacks between human and natural systems must be considered (Lui et al, 2007) through the measuring of ecological variables, social/human variables and also variables that link natural and human components. As reflected in the methodology section below, working on SESs requires integrating methods, tools and technologies from both the biophysical and social sciences as well as mapping techniques that reveal the power of spatial analysis, including GIS and remote sensing. SES research should also be context specific and longitudinal and reflect on legacy affects where traces of older systems can still be seen (Ostrom, 2007).

However, we argue that the place of politics and the historical/contextual reading in SES is weakly developed. It has also been argued that the SES origin in institutional studies results in limited consideration of the biophysical components in the system and reflects inadequate knowledge of these and their inter-connections (Epstein et al., 2013). Furthermore, while the socio-economic and political setting is considered important, it does not form part of the interdependent interactions within the system, and therefore the critical role of power, space and time in shaping SES outcomes is not always revealed.

Thus, the SES approach is critiqued for its limited focus on socio-political and ecological relations, and for its weak theorisation of the social elements, especially the complexity of social processes (Armitage and Johnson 2006, Armitage, 2008, Leach 2008, Crane 2010, Hatt 2013, Fabinyi et al, 2014). Socio-ecological relations thinking, which emerged within political ecology, offers a way of integrating historical, social and political dimensions in to socio-ecological relationships.
2.4.2 Socio-ecological relations

The theoretical understanding of socio-ecological relations has been largely constructed within political ecology with its diversity of theoretical and methodological approaches (Basset and Peimer, 2015). The main concepts that frame socio-ecological relations thinking are:

- the concept that ecology or biophysical systems are a social relation;
- the use of dialectical approaches; a focus on power relations; and
- an emphasis on the non-equilibrium of socio-ecological systems.

Landscapes, in this research the case studies in the uMgeni Catchment, are “contained and are constituted by their relations to other things...they are always becoming something else, precisely through their relating” (Robbins, 2012). These approaches “share a common interest in questions related to the politics of natural resource management, access, and control, environmental knowledge, and their interactive effects on livelihoods and environmental change dynamics” (Bassett and Peimer, 2015, p 158). This understanding is useful and relevant to the aims and objectives of WRC 2354. In their review of the social-ecological relations literature, Bassett and Peimer (2015) argue that there are three main approaches: the environmental/social dialectic; environmental constructivism; and the co-production of socio-nature (Castree, 2003; Braun, 2008) that form part of socio-ecological relations thinking. These are outlined in Box 1.

Box 1. Bassett and Peimer’s three main approaches in socio-ecological relations thinking

<table>
<thead>
<tr>
<th>Three main approaches to socio-ecological relations thinking</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental/social dialectic</td>
<td>The environmental/social dialectic explains environmental change (e.g. soil erosion) and vulnerability to variability (e.g. drought; market shocks) in relation to the social relations of production and exchange. This perspective combines a structuralist view of society with a positivist view of ecology. More recently positivist ecology with its ‘return to a steady state’ ideas has been questioned leading to non-equilibrium ecology, where temporal and spatial scales really matter. This reflects a political economy approach which analyses how social relations and politics of underdevelopment shapes environmental outcomes. This reading of the environmental/social dialectic by Bassett and Peimer (2015) needs to be extended as it does not adequately reflect dialectical thinking (See Soja, 1989; Sutherland, 2016): the environment shapes social and political relations and social and political relations shape the environment. Here both society and space shape each other, just as environment and society shape each other in the society-environment dialectic (see Braun, 2008).</td>
</tr>
<tr>
<td>Environmental constructivist approach</td>
<td>Environmental constructivist approaches adopt a post-structural framing of environment-society questions. This framework is helpful as it first raises the question of whose environmental narrative or history is being told. This then reveals that certain accounts of environmental change, with their certain</td>
</tr>
</tbody>
</table>

1 Bassett and Piemer (2015) provide a very useful review of political ecology and socio-ecological relations thinking and approaches.
forms of legitimate knowledge, reinforce power and social injustice (Brosius, 1999; Hajer, 1995; Dryzek, 1997). These narratives, which often simplify complex systems and ‘cause and affect’ relations, “assign blame, establish expertise, and stabilize uncertain biophysical processes through management processes aimed at returning to the ‘steady state’ are very revealing (Forsyth and Walker, 2008; Bassett and Peimer, 2015). This approach supports the idea of careful historical readings of the landscape to determine whose environmental histories or relations are dominant. It also questions the scientific validity and representations of environmental change, supporting participatory approaches where multiple knowledges, most especially local knowledge, are used to construct a more complex and rich narrative of the landscape. This reduces the dominance of approaches that focus on expertise, problem closure and stable or fixed management approaches that justify ‘restoration’ or return to a ‘normal state’ (Bassett and Peimer, 2015). Participatory environmental governance emphasises transparency, openness, democratic institutions and accountability.

Braun (2008) provides useful insights on the challenge of conducting empirical research which reflects relational thinking. This approach includes attempts “to understand the ways in which non-human nature resists its incorporation into particular political economic and spatial forms” thereby acting and shaping politics, practices, technologies and socio-environmental and economic outcomes (Braun 2008, p 668). All elements, both biophysical and human therefore come together through their relations, to produce a collectivity or assemblage. Bakker (2004; 2005) and Sutherland et al’s (2015) research on water provide examples of such an approach. Non-human nature, including water, is drawn in to the analytical frame not as a backdrop or a resource, but rather as constitutive of social and economic life (Braun, 2008). Some philosophers and geographers even propose a single ontological plane, where all things share their existence and ability to shape the assemblage or collectivities that emerge (Latour, 2005; Bingham, 2006). This means that

“this plane also cannot be reduced to mechanistic interactions or universal law-like processes, such as found in reductionist approaches that imagine that visible dynamics can be understood in terms of the predictable interaction of elements of...
the system. Rather, emergence must be understood as a property of the whole that is not shared by, or reducible to, its constituent parts” (Braun, 2008, p 669).

This therefore challenges socio-ecological systems thinking, which while it focuses on interdependencies, considers elements of the system as reducible, constituent parts. Stone-Jovicich’s (2015) review of critical political ecology and systems thinking is very helpful in this regard.

Relational thinking focuses on how particular assemblages or collectivities “are constituted through particular practices of articulating with others” (Bingham, 2006, p 487), thereby highlighting the importance of agency, both in terms of humans and non-humans. For example, Prudham’s (2005) analysis of the biological characteristics of the Oregon forests, which challenged the workings of capital, revealed how the forests had shaped technologies, the nature of work, labour relations and politics in the region. However Braun (2008, p 668 -667) argues that with all the efforts to insert the non-human “in to the analytical frame as a constitutive element of social and economic life” these studies still reflect a modernist ontology of considering distinct elements within the pre-fixed ontological category, or “already constituted structural unity” of the economy. Moving away from distinct categories is very difficult to achieve, however transdisciplinary approaches and an awareness of relational ontologies helps to shift in that direction.

Discourse analysis employs a social constructivist approach. Knowledge and policy is constructed by social actors through diverse, diffuse and complex social relationships and interactions which emerge as epistemic notions, policy vocabularies and discourses (Keeley and Scoones, 2000). A discourse is “an ensemble of ideas, concepts, and categories through which meaning is given to social and physical phenomena, and which is produced and reproduced through an identifiable set of practices” (Hajer, 2006, p 67). Language is therefore a powerful way of not only describing the world but also creating or producing it (Sim, 2015). Discourses reflect the different policy positions actors adopt in their construction of environmental problems (Keeley and Scoones, 2000). According to Dryzek (1997, p 8) discourse is defined as “a shared way of apprehending the world. Embedded in language, it enables those who subscribe to it, to interpret bits of information and put them together into coherent stories and accounts”. Hajer (1995) states that discourse analysis reveals the content of what is being stated, the context within which it is constructed, the social practices (including scientific investigation) in which it is produced, the actors producing it and the ability for it to transform understanding and shape social reality. Discourse analysis has both theoretical depth and practical applicability and hence it is a powerful means of identifying critical framings of environmental problems (Hajer, 1995; Sim, 2015).

Epistemic notions are broad concepts or ideas that frame policy formation. They reveal a regularity of thinking, which is not always overtly evident and which emerges and remains in place at particular moments in time (Martel, 2016; Sim, 2015). Storylines are short narratives or crisp statements that capture and frame knowledge, enabling actors to draw their knowledge in to policy debates. Once established they can often be taken as ‘truth’ and become stabilised and powerful. Ecological carrying capacity is a good example of a storyline. According to Hajer (1995, p 62) they provide actors with “a set of symbolic references that suggest a common understanding”. Discourses are broader framings than storylines, but that perform a similar role in policy formation. Discourse coalitions are “an ensemble (1) of a set of storylines; (2) the actors who utter these storylines; and (3) the practices in which this discursive activity is based” (Hajer, 1995, p 65). Discourse coalitions are formed when actors collectively subscribe to a particular storyline or broader discourse, reproducing this discourse and stabilising it, resulting in discourse structuration where the discourse becomes embedded and institutionalised and hence starts dominating understanding of the world (Martel, 2016; Sim, 2015).
Adopting a relational approach requires that the constitutive, or productive force or power of all things in social, economic, environmental and political life is recognised. This power is revealed in how these elements relate to or shape each other. Through these multiple relations the ‘life’ of the catchment is assembled. Rather than bounded spaces, catchments can be considered “as ‘polyrhythmic’ assemblages composed of multiple networks stretched across space and time in which humans and nonhumans are inextricably entangled (Amin, 2002; Smith, 2003)” (Braun, 2006, p 644). As Bingham argues “the world is made up of particular assemblages of humans and nonhumans, that are constituted through particular practices of articulating with others” (Bingham, 2006, p 487). Agency therefore really matters as it reflects on how and to what extent, through power that is exercised, each element is able to shape others in the assemblage. It remains a challenge to identify and analyse non-human agency. Actor network theorists with their hybrid approaches have made the greatest contribution to this field of knowledge. Braun (2008, p 670) states that “for many years, geographers [and others] have struggled with this question, uncertain how one can attribute agency to non-human entities”. He argues that Deleuze and Guattari’s concept of *agencement* is most helpful as it uses two main ideas: that of ‘layout’ and ‘coming together’ of disparate elements and their ability to produce an effect, thereby reflecting the “capacity to act with the coming together of things” to be a precondition for agency (Braun, 2008, p 671).

Lorimer (2006, p 540) argues that “biodiversity is not something ‘out there’ waiting to be measured, but is the discursive and material outcome of a socio-material assemblage of people, practices, technologies and other non-humans”. The approach adopted in WRC2354 reflects that the practical understanding of catchments, water governance and ecological infrastructure will emerge from the complex, messy and situated practices of water governance in the uMngeni Catchment. Hinchcliffe et al (2005, cited in Braun, 2008, p 672) on their work on conservation biologists in Birmingham remind us that to be effective, an environmental scientist “must first learn to be open to different ways of knowing and registering the presence of different animals” since things may ‘not show up’, either because they do not afford themselves to our witnessing, or because we have not learned to be affected by them”. The methodology developed in this report attempts to create a framework that will open up spaces for multiple ways of knowing, thereby supporting both transdisciplinary and social-ecological relations approaches. This is critical given that the environmental spaces we work in are not static but are always being reconstituted and are always in construction.

Critical realist political ecology extends these ideas further as it explores environmental change through complex and contingent interconnections between the social and biophysical realms, recognising that there is a real biophysical world out there (Forsyth, 2003), which exists independently of human understanding and which can never be fully apprehended (Stone-Jovicich, 2015). Stone-Jovicich (2015, p 4) provides a review of Bunkers (1984; 1985; 2003) research on environmental degradation. Bunker’s results show how

“They are the physical and biological characteristics of specific natural resources, in combination with topographic and hydrological features of the landscape and climatic conditions, have structured (and continue to do so) both local and global dimensions of the world system, which has driven the environmental destruction of the Amazonian rainforest.”
Materiality therefore matters as much as discursive formation (or social construction of environmental issues) and hence contingent conditions need to be identified. Stone-Jovivich (2015, p 25) cautions that “natural scientific explanations of environmental change and degradation are argued to provide only limited insights into actual complex biophysical processes and, as such, can exacerbate environmental crises and social injustices”. Post-structuralist approaches are therefore essential. Forsyth (2001, p 2) emphasizes that extensive empirical interdisciplinary research should “reconstruct new and more effective science for environmental policy that is both biophysically more accurate than existing conceptions, and socially more just” and that “the adoption of environmental science without acknowledging how it is affected by social and political factors undermines its ability to address the underlying biophysical causes of perceived environmental problems” (Forsyth 2003, p 2). Adopting a socio-ecological relations approach helps to illuminate, or bring to the fore, these critical ideas, which will enhance our understanding of the complex uMngeni Catchment. The Human Development Report (2006) and Loftus (2009) have highlighted that it is impossible to understand the production of a water crisis unless it is acknowledged that this is a result of specific relations of power. Young (2006) argues that “cross-level interactions among scale-dependent regimes can result in patterns of dominance, separation, merger, negotiated agreement, or system change” and hence understanding power at different scales is essential.

One of the frameworks that has emerged more recently in political ecology and which focuses on water is the hydro-social cycle (Cook and Bakker, 2012; Linton and Budds, 2013; Budds and Sultana, 2013). This framework theorizes the social and political aspects of water, by connecting society and water, and enables a reflection on the ‘political projects’ which shape the construction of water over time. There is a well-established body of literature on the hydro-social cycle and its application in understanding water ‘projects’ across the world. The hydro-social cycle is useful as it is a relational-dialectical approach to water (Linton and Budds, 2013). Linton and Budds (2013, p 170) “conceptualise the hydro-social cycle as a socio-natural process by which water and society make and remake each other over space and time”. They argue that “unravelling this historical and geographical process of making and remaking offers analytical insights into the social construction and production of water, the ways by which it is made known, and the power relations that are embedded in hydro-social change” (Linton and Budds, 2013, p 171). This approach therefore challenges the dualism of society and water and hence will be employed in the analysis of the water-society-space relations in the uMngeni catchment.

Staddon (2015) has applied the concept of the hydro-social cycle to construct an urban hydro-social transition model which maps out transitional moments in the construction and production of water (see Table 3). This research and its mapping out of moments of change is extremely useful in the research being conducted in the uMngeni Catchment, as it reminds us of the value of a historical and geographical perspective or of understanding the role of context.
2.4.3 Summary

In this section two approaches that consider the interconnectedness and relations of the biophysical and social environment have been presented. These two approaches will each be used to inform the construction of interconnectivity in the case studies and in the broader uMngeni Catchment. The research team will work through both frameworks in each case study to discover what they reveal based on the analysis undertaken using the heuristic framework (see section 3). This will also be conducted for the analysis and synthesis of knowledge in the broader uMngeni Catchment, which will be assembled using knowledge from the four different case studies.

2.5 Mapping and Modelling relations between society, water and space

Mapping and modelling are important tools for the synthesis of connectivity in the uMngeni Catchment. Mapping and visualization methods allow one to represent a perceived reality in a way that allows this understanding to be shared. Techniques and tools for mapping and visualization vary depending on the desired information. Presented here are a sample of techniques and tools that have been identified for further investigation. While these tools offer a variety of options, their actual capability and applicability will be investigated further as we move towards Deliverable 14.

The use of the term “mapping” is intentional. It is intended to portray the need to understand spatial knowledge in all its forms and in its broadest sense i.e. social space, conceptual space, local vs national space etc. It furthermore has strong links to capacity enhancement, social change, governance and other aspects and is strongly linked to understanding catchment connectivity. It also provides the opportunity for development of unique visualization.

One of the most commonly used methods for spatial expression involves the use of maps to visualize relative space. As Crampton (2001) points out, Robinson (1952, p 13, cited in Crampton, 2001, p 691) revolutionized map ideology with emphasis that function drives form. From this point, maps evolved over time to become more than a communication tool, but rather used in power relations,
from maps being stable, concrete information to ‘exploratory mapping environments where knowledge is constructed,’ (Crampton, 2001, 691). Maps have the power to inform, but as Hartley (1988) pointed out, and echoed by Crampton (2001, 702), maps can also be used to silence; ‘the map contributes to disempower constituencies such as the poor (Yapa, 1996) or for example differential access to GIS, the Web and online mapping (Crampton, 1999), or how the map speaks for others by subjugating knowledge.’

Maps, graphics, and images have an ability to make spatial relationships visual. One primary aim for this ability, known as Geographic visualization (GVis), ‘is the geographical desire to find spatial patterns in the data,’ (Crampton, 2001, 703). The nuance being less emphasis on physical or material realities within real space, but rather visual representations of relations or interconnectedness amongst actors. While focusing only on the spatial patterns between actors allows one to draw conclusions regarding interconnectedness, the disconnection from physical or material realities may in some instances cause for a loss of additional information that could be retrieved if overlaid with biophysical data.

2.5.1 Examples of integrated mapping methods

Various mapping software tools have been applied in attempts to build connections between the biophysical (materialities) and non-biophysical aspects of the landscape and also potentially revealing those that may be hidden. Mapping methods and software include a variety techniques including relational mapping, stakeholder interest intensity tables, probability-impact analysis (Bourne and Walker, 2005), network level techniques, individual level techniques which uses statistical analysis (Calvet-Mir et al. 2015), and other recent innovative approaches such as the sphere of influence (Levine, 1972), the stakeholder circle (Bourne and Walker, 2005), aggregate causal loop diagrams, and social network maps, CMap, Google Fusion Tables, MS Excel’s Powermaps and more accepted approaches such as Google Earth and GIS.

Social network mapping methods include: stakeholder interest intensity tables, probability-impact analysis (Bourne and Walker, 2005), network level techniques, individual level techniques which uses statistical analysis, STATA 12 for Windows (Calvet-Mir et al. 2015), and many others.

Stakeholder interest intensity can be conveyed using a table such as shown below or further developed using graphical imagery as depicted with the stakeholder circle mentioned later.
<table>
<thead>
<tr>
<th>Stakeholder Interest</th>
<th>Stakeholders Vested Interest Intensity Index (VIII) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>For colleagues and COP:</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
</tr>
<tr>
<td>Develop team’s skill base</td>
<td>VH H N N L VL H VH L N</td>
</tr>
<tr>
<td>Enhance workplace environment</td>
<td></td>
</tr>
<tr>
<td>Family-friendly policy</td>
<td></td>
</tr>
<tr>
<td>Demonstrated lessons learned</td>
<td></td>
</tr>
<tr>
<td>Exemplar of better practice</td>
<td></td>
</tr>
<tr>
<td>High-profile/strategic project</td>
<td></td>
</tr>
</tbody>
</table>

Vested Interest (v) levels  
5 = Very high, 4 = High, 3 = Neutral, 2 = Low, 1 = Very low

Influence impact levels (i)  
5 = Very high, 4 = High, 3 = Neutral, 2 = Low, 1 = Very low

Vested interest-Impact Index (VIII) = √((v/i)/25) eg if Vested interest (v) level = 4 (high) and Influence impact levels (i) then VIII = √(4*4/25) = √(16/25) = 0.80 = high

**Figure 6 Stakeholder interest intensity table (Bourne and Walker, 2005)**

Visualisation techniques include relationship or power maps, the sphere of influence (Levine, 1972), the stakeholder circle (Bourne and Walker, 2005), aggregate causal loop diagrams, and social network maps just to name a few. For example, Rowlands et al (2013) mapped influence and understanding in relation to ecological infrastructure (see Figure 6 and Figure 7) providing a foundation for further investigation of stakeholder connectivity within the uMgeni Catchment.

**Figure 7 This power map illustrates the interactions of organizational stakeholders within the uMgeni Catchment, with respect to the regulation of ecological infrastructure (Rowlands et al., 2013).**
The sphere of influence approach was developed by Levine, a sociologist, in 1972 as a network representation technique. This tool can be utilized to visually represent networks, which, in turn, may assist in revealing hidden subtleties of relationships between various actors (Levine, 1972).

Figure 8 Example of a sphere of influence diagramme (Levine, 1972).

While the sphere of influence is not a representation in biophysical space, neither is the stakeholder circle presented below. However, both methods focus rather on the relational aspects between the actors. The stakeholder circle provides a nodal graphic which could easily be incorporated into spatial software i.e. Geographic Information Systems (GIS). This visualization tool is able to depict the power and influence that stakeholders have for a project and, being nodal, could easily represent such information spatially. Presented in Figure 9 is an example of a stakeholder circle, including details of each stakeholder’s representation. It is able to represent a single powerful stakeholder, by showing the stakeholder’s ability to kill the project. Another interesting depiction possible by such a visual tool is that it shows multiple smaller stakeholders, acting in unison, could heavily influence a project. Furthermore, the distance to the project is represented by the various levels of concentric circles. Colour shading within the circle can represent homogeneity, with the colour density representing the degree of impact (Bourne and Walker, 2005).
Figure 9 The stakeholder circle, developed by Bourne and Walker (2005), allows the user to depict stakeholders of a project or spatial landscape.

The stakeholder circle offers a slight resemblance to connectograms used to map cortical networks (Irimia et al., 2012). These techniques may offer additional alternatives for mapping representations and network connectivity.

2.5.2 Modelling Tools
Aggregate causal loop diagrams can help to convey and display feedback loops. This technique is used in system dynamics modelling, a field with roots in 'strategic decision making, feedback thinking, computer technology and computer simulation (Maani & Cavana, 2007)' (Holmes et al., 2014). The use of system dynamics has been increasing in the international water sector as a form of quantitative policy analysis (Holmes et al., 2014). Presented in Figure 10 is an example of a causal loop diagram.

Figure 10 This aggregate causal loop diagram depicts balancing feedback loops
Advanced visual programming tools, such as STELLA (Systems Thinking, Experimental Learning Laboratory with Animation) and VENSIM, are capable of performing quantitative analyses (Holmes et al., 2014) as the software allows the user to input mathematical functions for qualitative analyses, while visual representations are similar to the causal loop diagram shown in Figure 10.

Social network analysis methods used by Calvet-Mir et al., (2015) include the use of advance software such as UCInet6-Netdraw for Windows (Calvet-Mir et al. 2015).

![Communication network using visualization software UCInet6-Netdraw for Windows.](image)

‘Note: The size of the nodes indicates the indegree and the shapes indicate the sex (circle for women, a triangle for men, and a square for institutions). In addition, the following colors are used to denote the various categories: red (local administration); green (park managers); yellow (park employees); blue (agricultural sector); orange (scientific sector); purple (civic sector); pale green (conservationist sector); pale blue (leisure sector); pale yellow (environmental education/tourist sector); brown (forestry sector); pink (accommodation and restaurants); pale pink (other enterprises); and white (others),’ (Calvet-Mir et al.)

2.5.3 “New Generation” Mapping and Modelling Tools

Advances in computing, networking and bandwidth availability have led to a plethora of tools which are now able to utilise this power. These mapping tools or software can assist with mapping the connections between actors. While some have been introduced above such as UCInet6-Netdraw for Windows, another option includes CMap used to ‘construct, navigate, share and criticize knowledge models represented as concept maps’. CMap allows one to easily create visual representations that can be shared across a server. In some ways it is similar to a brainstorming map (ihmc, 2014).

While visualization tools are helpful, application of such tools in conjunction with a biophysical map can increase usefulness as well as draw out additional information. Tools that have a biophysical aspect include: Google Fusion Tables, Google Earth, Microsoft Excel’s Power Maps, and GIS. Heat maps, through which concentrations of categories of information can be depicted, spatially or in other ways, and the methods used to produce them will require further investigation in the project.

Google Fusion Tables offer spatial integration through the use of a Google Maps interface. Informational text boxes allows photographic images along with text for spatial points on a
biophysical map. These are often underpinned by the satellite data and tools developed to display within Google Earth.

Figure 12 Examples of Google Fusion Tables. Left to right: (Marshall, 2011) (Google, 2016)

Microsoft Excel’s Power Mapping function allows for the integration of data tables created in Excel with mapping software for visual representations in space. Examples of finished products are provided in the graphics below.

2.6 Towards an heuristic framework to assess water resource connectivity and inter-dependency (between surface and ground water, water quality and quantity, water and society, etc) from a landscape perspective

The use of a heuristic framework or configuration to assess water resource connectivity and inter-dependency enables the researchers to analyse the data collected in each case study, drawing out the critical elements that shape society-water-space relations. The elements of the configuration are:

- actors (both human and non-human),
- discourses (including ‘scientific facts’),
- materialities (physical realities and contingent conditions),
- issues and critical risks,
- knowledge, and
- spatial expressions of society-water-space relations.

Focusing on such aspects using simplistic heuristic methods for complex environments has proven more accurate in some cases than overly complex analytic models (Gigerenzer and Gaissmaier, 2011). The benefit of applying such a method for various case studies allows the researcher to focus on dominant characteristics for each study site and effectively address multiple locations (Gigerenzer and Gaissmaier, 2011). Considering the complexity of socio- ecological relations, a heuristic framework presents an analytical frame that enables varied environments to be studied, resulting in multiple examples for comparative studies. However, in order to do so, it is critical to formalize a heuristic framework so that predictions can be tested and compared (Gigerenzer and Gaissmaier, 2011). This deliverable presents the heuristic framework that will be be applied to the various case studies for comparative analysis.

According to Colvin et al. (2008) and Stuart-Hill and Schulze (2010, p.130) IWRM needs to be reshaped “according to current spatial and temporal settings, putting learning, reflexivity and adaptation into the centre of implementation’ (Stuart-Hill and Schulze, 2010). It is therefore critical that the heuristic framework established for this study focuses on spatial and temporal settings with emphasis on learning, reflexivity and adaptation. In a similar way, McFarlane (2008, 2011), Sultana (2013) and Sutherland et al (2015) have argued that the waterscapes of South African and Indian cities are produced by an assemblage of actors, technologies, policies, discourses and infrastructure. Murdoch (1998) extends this by suggesting that the effects of both power and resistance amongst actors and discourses are entangled in space, and hence an analysis of ‘spaces’ – as a reflection of an urban configuration – has the ability to reveal these power relations, which resonates with Soja’s (1989) concept of the socio-spatial dialectic.

Section 2 has presented the main concepts to be developed and used in identifying and understanding the connectivities and interdependencies in the uMgeni Catchment, starting with the current international discourse and the history of water management in South Africa, in particular. The need for a transdisciplinary approach highlighted the need for a framework. New relational ontologies and dialectical approaches were discussed to integrate socio-ecological systems and socio-ecological relations. Relating this to the biophysical world, tools were discussed to capture and represent these new methods. Lastly, the broader heuristic framework was touched upon to draw out the critical elements that shape society-water-space relations. The following section draws on this literature and outlines the methodology. Outlining a comprehensive and ‘fixed’
The methodology is not appropriate at this stage given the transdisciplinary and action research approach of this study. It is argued here that as the methodology is applied, which by its very nature is innovative, experimental and still in the making, it may shift or draw in new approaches and tools. Section 3 presents a detailed methodology to begin the process of producing an assembled society-water-space trialectic for the uMgeni Catchment.

3 Methodology

Research has been conducted in four case study sites within the uMgeni Catchment on the physical, social, environmental, economic and political dimensions of water quality, water quantity, ecological infrastructure and environmental services and their relations. This research is not ‘even’, as research teams have adopted different approaches and methodologies in conducting their research in each case study site. However, the main research questions which are common across the case studies provide a basis for comparison through which the data and information collected through the four case studies can be compared. Barrett and Peimer (2015) provide a useful review of the multiple methods that can be employed in socio-ecological research. Many of these methods have already been applied in the research conducted in the case studies for this project, including multi-sited participant observation, ethnographic methods associated with action research, interviews with main stakeholders over long periods of time, analysis of texts, emails, personal interactions and scientific reports, analysis of settings within which interactions take place, and spatial-temporal analysis (Barrett and Peimer, 2015). Both structural-dialectical approaches and social constructivism are employed as research methods in the study of socio-ecological relations, along with the positivist biophysical data collected (Robbins 2012, cited in Bassett and Peimer, 2015) and hence these approaches are applied here too. The biophysical method employed will depend on the biophysical process being explored and includes various aspects of water quality monitoring and modelling, wetland and riparian studies, catchment restoration options, etc as reported in preceding project Deliverables.

WRC 2354 has thus far focused on the detail of each case study, running the risk of focusing too much on building up knowledge at the local level, leading to the ‘Achilles heel of localism’ (Bryant and Bailey, 1997; Stone-Jovicich, 2015). This implies that the results and patterns in the data cannot be generalised. However the configuration and trialectic developed here, address this concern as the critical elements in the catchment, drawn from the different case studies, will be integrated in the trialectic and will reflect more generalizable themes, patterns, interventions and principles, thus addressing the aims of the Deliverable and project as a whole. The overall approach is summarised in Figure 14 and explained in more detail below.
The knowledge produced through this process, which will now reflect a catchment level understanding, will be triangulated against and verified by the fifth study which was conducted at the catchment scale, namely the Green Trust or Ecological Infrastructure Investment project. Scenario planning, with a broad range of water governance stakeholders who work in the catchment at multiple scales, will also be undertaken using the system models developed. This will serve to ground truth the system models and provide insight about the best pathway to follow using ecological infrastructure to ensure the greatest benefits from the financial and social investments.

There are two stages to the methodology. The first stage produces a water security configuration for each of the four case studies that have been conducted in the uMngeni Catchment. These will be produced by the specific research teams working in each case study. The second stage will produce a series of actor maps and SES relationship schema for the uMngeni Catchment, which will be used, in combination with the case study configurations to produce the water-society-space trialectic (see Figure 1 and Figure 15).
3.1 Case study research

Detailed data collection and action research has already been undertaken for each case study. The fifth case study on investment in ecological infrastructure is not an action research project and so its application to the configuration framework will be through its validation of the catchment level understanding that is generated through the systems dynamics modelling. It is also acknowledged that there is not comparable data at every level across the case studies, however the data can be used to generate the detail and data on the elements of each configuration and it is these elements that will be compared.
### Table 3: Description of the four case studies

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Description</th>
<th>Focus of research</th>
<th>Research team</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midmar/Mpophomeni</td>
<td>The Midmar dam provides water to half of the provinces population, yet water quality is compromised as a result of contamination from sewerage, solid wastes, industrial effluent and agricultural activities (SANBI and Wildlands Conservation Trust, 2015).</td>
<td>Through a partnership led by the uMgungundlovu Water Service Authority, efforts are focused on restoring key areas around the dam, emphasising investments in ecological infrastructure (SANBI and Wildlands Conservation Trust, 2015).</td>
<td>UKZN, WESSA, DUCT</td>
</tr>
<tr>
<td>Baynespruit</td>
<td>The Baynespruit, a tributary of the Msunduzi River, runs through the city of Pietermaritzburg and is subjected to illegal discharges of industrial effluent, illegal dumping and poor storm water and sanitation infrastructure (SANBI and Wildlands Conservation Trust, 2015).</td>
<td>Research in the Baynespruit is focused on investments in ecological infrastructure through the construction of artificial wetlands, restoring riparian zones to prevent soil erosion, and controlling alien invasives (SANBI and Wildlands Conservation Trust, 2015).</td>
<td>UKZN, DUCT</td>
</tr>
<tr>
<td>Palmiet Rehabilitation Project</td>
<td>Small catchment in the urban core of eThekwini Municipality, fast rising river prone to flooding, high levels of pollution due to range of land uses (residential – high middle and very low income including informal settlements; industry; nature reserves; landfill site; social facilities including schools and visitor centres)</td>
<td>The development of a community of innovation, comprised of a range of actors from civil society, business, research institutions and the eThekwini Municipality to address water security issues and environmental risk in the catchment</td>
<td>BEDS, UKZN, Civil Engineering, UKZN, DUT, PRG, River Watch, EPCPD eThekwini Municipality.</td>
</tr>
<tr>
<td>Mzinyathi</td>
<td>Rapidly densifying peri-urban area on the rural periphery. Mzinyathi has lower water flow due to Inanda Dam and droughts, environmental services and rivers in the area are under threat due to uncontrolled and rapid densification</td>
<td>Research being conducted in the community in association with the Inkhosi and izinduna on environmental change and the impact of dual governance and different planning systems</td>
<td>BEDS, UKZN</td>
</tr>
</tbody>
</table>
The main research questions, namely what are the water governance arrangements in the case study; what are the critical water security (both quality and quantity) issues; and what is the role and value of ecological infrastructure in addressing water security have already been explored in each case study using a range of methodologies. Researchers have conducted scientific assessments on water quantity and quality and the status of ecological infrastructure, collected quantitative data, mapped the case study area and the river and collected qualitative data on socio-ecological relationships. The research teams did not adopt the same approach in each case study as the contexts of the case studies varied and the research is action research. As a result the research methods were tailored to explore the issues that arose as the action research, and collaboration with practitioners and the state, unfolded. The case studies need to be compared and synthesised even though the same methodologies were not employed in each site. Critical contemporary urban research argues that cities do not have to be similar or be researched in the same way for comparisons between cities to be made (Robinson, 2006; McFarlane, 2011). Rather, the processes in cities or the research questions asked about cities need to be ‘followed’ and identified, and it is the urban processes that emerge that then are compared. In this research, while researchers have adopted different approaches in each case study, the governance, society and water processes and questions they have ‘followed’ through their research have been the same. By analysing these processes using a waterscape configuration, which captures, explores and explains the different elements of these processes, similar knowledge for each case study will be produced. This will be analysed and compared to produce the society-water-space trialectic (including an embedded SES), with its levers for change, for the uMngeni Catchment.

Researchers for each case study will construct and produce a waterscape configuration for the case study. This will include the following elements as illustrated in Figure 16:

![Figure 16 The case study waterscape configuration.](#)
Context

The historical and geographical context of each case study, which includes its environmental, social, economic, and political characteristics will be presented for each case study. Characteristics that are common to all case study sites will be drawn out for use in the uMgeni Catchment SES model and social ecological relationship schema as well as for use in the trialectic.

Actors

Multiple actors at different scales, who are embedded in both formal and informal institutions and who act both within and beyond-the-state, produce waterscapes or water configurations within particular social, economic, environmental and political settings (Dierwechter, 2006; Swyngedouw, 2005; Sutherland et al, 2015). The main actors engaged in each case study will be identified and mapped. Examples of how this mapping will be undertaken are presented in Section 2.5.

Prell et al. (2009) discuss the value of social network analysis as a means of actor mapping. Limitations exist for such robust techniques, including influence derived from other sources such as statutory bodies for example (Prell, Hubacek, and Reed). A power mapping of actors, including ‘missing actors’, will be undertaken showing both the power relations between actors, as well as their relations and clustering in relation to the three main research questions. According to Stone-Jovicich (2015) the detailed mapping of diverse actors and how their relationships are formed, negotiated, sustained and reshaped provides empirically rich understandings of social learning, power relations in a catchment and the potential for co-management relationships and transformation.

Discourses

The dominant discourses, which are constructed by actors, using both scientific and experiential knowledge, will be identified for each case study. The storylines and discourses are identified by reading through all the case study documentation and texts and identifying the storylines and discourses, as well as the underlying arguments which support them. Colour coding is used to highlight similar arguments and storylines so that the dominant discourses in the textual analysis can be identified. These storylines are then entered into a spreadsheet, along with the actors who are producing them, as well as quotes from the actors being recorded. The storylines can then be organised into broader discourses, categories or policy fields. Martel (2016) in his analysis of a spatial planning exercise in the Back of Port in the south Durban basin provides as useful example of this approach, as does Sim’s (2015) discourse analysis of data collected from stakeholders on framing resilience in Durban and Sutherland’s (2016) discourse analysis of society-space-environment relations in Knysna.

The discourses will be identified by analysing the data, both qualitative and quantitative, which has been collected and recorded in each case study. Scientific facts will also be identified and recorded and their relationship with discourses will be explored. Minutes of meetings, transcripts of interviews, scientific reports, scientific presentations and student dissertations will be analysed using discourse analysis, including epistemic notions and storylines, to identify the dominant discourses that have emerged in each case study.

Materialities

The materialities, which are the physical realities and characteristics of each case study site, as well as the contingent conditions, will be identified and described. As Stone-Jovicich (2015) argues, socio-ecological relations are comprised of both discursive constructions and physical material realities.
The materialities for each case study will be mapped and presented in tabular format, and will be drawn from the wide range of spatial data that has been produced in the case studies. The research team will then compare both the similarities and differences across the different case study sites and the critical materialities for the uMngeni Catchment will be identified. These will be included in the model for the uMngeni Catchment.

The materiality and contingent conditions of each space under exploration according to Bunker and others therefore really matters.

**Issues and risks**

Issues and critical risks will be identified and described for each case study. This will be based on intuitive and experiential knowledge of the researchers as they review the discourses, materialities and scientific facts. A risk assessment approach will be adopted where critical risks, which reflect the complex socio-ecological relationships in the catchment will be identified, so that these can be mapped in the SES for each case study and for the whole catchment.

**Knowledge**

The different forms of knowledge collected and produced in each case study will be presented in table format, reflecting on the type of knowledge and what it reveals about the catchment. Knowledge on the case studies will be modelled using a SES approach and system dynamics modelling, where the three main research questions of the study will form the point of departure for each SES model and the inclusion of social ecological relationships identified. Feedback loops and their associated leverage points, or points of intervention, will be identified and described. A socio-ecological relations schema, which draws on the multiple dialectical relations in each case study, and reflects historical and political relations, will be produced.

This modelling will enable main focus areas, risks, themes and levers of change to emerge. These will then be used to assemble the society-space-environment triad, which will also include broad patterns identified from the elements of the configuration (see Sutherland, 2016 for an example in Appendix A). The critical issues and levers will be identified and will be assembled to form the ‘centre’ or ‘nexus’ of the society-water-space triad.

**Spatial knowledge**

Spatial knowledge, which has been produced in the case studies, will be collected and assessed in a spatial analysis workshop for each case study. This data will be described, interpreted and critically analysed, drawing on theory from critical geography to ensure that the power of maps, including what is mapped, what is excluded and how maps are used, is revealed. Space is a not a backdrop or a passive container within which social and environmental life is inserted (Harvey, 2004). Space is produced by socio-ecological relations and in turn it produces socio-ecological relations (Sutherland, 2016). All forms of space: absolute space, relative space, relational space, representative space and representational space (Lefebvre, 1991; Harvey, 1973; 2004) will be considered in the analysis of the spatial knowledge produced in the case studies thus far.

Various mapping methods and a multitude of software are available to produce relational maps (see section 2.6). This process of spatial data analysis will be undertaken at the outset of the process of producing the waterscape configuration. This is because this data will support the production of the other elements of the case study. However, it is presented at the end of the configuration as the spatial data also contains evidence of all the elements of the configuration and hence it has an integrative function. Innovative mapping tools will be explored to determine if an integrated spatial
representation of each case study can be produced. The most likely tool will be GIS where the attribute tables could contain some of the data produced in the configuration.

3.2 The water security heuristic device or configuration

The waterscape configuration, which is an arrangement of elements that are considered critical to understanding water governance, water security and the value of ecological infrastructure in the uMngeni Catchment, will be applied to each case study. The configuration is an ensemble of relationally connected elements: actors; discourses; materialities, issues and risks; knowledge; and the spatial expressions of these elements (Peyroux et al, 2014; Sutherland et al, 2015). The elements of the configuration will be considered in relation to the three main research themes namely water governance systems in the uMngeni Catchment, water security and the value of ecological infrastructure. According to Sutherland et al (2015, p 491) “configurations are context-specific, and are produced by particular socio-spatial and temporal relations” and hence the context of each cases study will be presented as a frame for the configuration.

Actors, both human and non-human, and the relations between them, reveal the politics and power in the catchment. The relationship between the state and its citizens is also revealed through mapping the actors within a water security configuration. Actors construct the meaning and value attached to resources in the catchment and this is revealed through the discourses they produce and reproduce on water governance, water management, water security and ecological infrastructure. Dominant discourses will be identified with discourse coalitions or main themes being mapped out for each case study. However, discursive constructions are not the only productive elements in the catchment. Contingent conditions and the material realities of the catchment also play a significant role in water governance and security. The context of each case study as well as the identification of material characteristics will be included in the configuration. Critical issues or risks in the catchment that have been identified in each case study will be presented as an element of the configuration as they reflect the relations between social constructions of environmental problems, vulnerability and the material realities which underpin risk. Knowledge will be considered in three ways. The forms of knowledge that have contributed to the understanding of each case study will be identified. The knowledge produced in each case study, which reveals the relationships between biophysical and social elements will be represented and modelled as an SES system, and as an assembled social-ecological relations schema. The gaps in knowledge or incomplete knowledge will be outlined. Finally the spatial expression of the different elements of the configuration, in various forms, including absolute, relative, relational and representative space (Lefebvre, 1991; Harvey, 2004) will be presented, analysed and interpreted.

The configuration for each case study will then be re-assembled using system dynamics modelling to produce the society-water-space trialetic for the uMngeni Catchment.

Scenario building will be undertaken in a multi-stakeholder workshop (see Khan et al, 2015). The spatial dimensions will be included as a waterscape is the spatial expression of a water governance configuration (Sutherland et al, 2015).

The actor maps will be connected to the SES models to reveal the role of agency and power in the SES and the relationships which support these. As water resource management shifts from administrative to hydrologic boundaries, there are a number of trade-offs that may affect such an approach including ‘trade-offs between, firstly, (a) the improved fit between the social and the ecological system and (b) the misfit between scales within the social system. Secondly, a trade-off
exists between (a) correct classification along hydrological boundaries (holistic approach) and (b) a feasible size for effective management, meaningful stakeholder participation and financial viability, which may require a splitting and merging of hydrological entities and thus a violation of the hydrological principle’ (Herrfahrdt-Pähle, 2010, p.111). While it is suggested that the aforementioned trade-offs can be met by ‘intense communication, cooperation and coordinated action between the involved organizations’ (Herrfahrdt-Pähle, 2010), actual execution of such efforts requires advanced methods and tools for actor or stakeholder mapping.

As illustrated by Herrfahrdt-Pähle (2010) the complexity that exists for mapping socio-ecological systems is represented in Figure 8 below, with multiple scales including, spatial, institutional, and jurisdictional as well as multiple levels which vary for ecological and social systems.

![Figure 17 Scale versus level illustrating vertical interplay between stakeholders of ecological and social systems](image)

**Figure 17** Scale versus level illustrating vertical interplay between stakeholders of ecological and social systems

### 3.3 Transdisciplinary research

As discussed in the literature review, transdisciplinary approaches will be employed. The main approaches that will be foregrounded will be to identify, respect, acknowledge and integrate different types of knowledge. Researchers will commit to being open to, understanding and drawing different forms of knowledge into their own knowledge formations through engagement and collaboration, as the configurations and trialectic are assembled. A workshop for the entire WRC research team will be held at the end of January 2017 where the methodology will be outlined and specific questions related to the application of the methodology will be explored and addressed. Following this reflection on the methodology the case study teams will each work on the data collected in their case study. This will require that members of each research team (case study based) organise and analyse their own data and knowledge for the configuration and then hold a
series of workshops where the integration of this knowledge for the formation of the configuration will take place for each case study. Once each case study configuration has been finalised two larger research team workshops will be held to explore and analyse the four configurations. System dynamics models (on water governance, water security and the value of ecological infrastructure) will be produced drawing on data from the four configurations, as well as an actor map, for the uMnjeni Catchment, using transdisciplinary approaches, so that leverage points in the catchment can be identified.

4 Conclusion

Deliverable 7 focuses on water resource connectivity and inter-dependency (between surface and ground water, water quality and quantity, water and society, etc) from a landscape perspective. A heuristic device or configuration has been presented, drawing on the literature review. The methods required to produce the configuration have been outlined. The configuration for each case study, with its associated data and knowledge, will then be integrated through the process of system dynamics modelling for the whole catchment. The outcomes of the modelling and the scenario building will then triangulated with the outcomes of the Green Trust/Ecological Infrastructure Investment project. The learning from this process will then be used to construct the water-society-space trialectic for the uMnjeni Catchment (see Appendix A for a society-space-environment trialectic constructed for Knysna). This trialectic illuminates and reveals the interconnections and relations between the different dimensions (physical, social, environmental, economic and political) of water resources management and water governance in the uMnjeni Catchment and ecological infrastructure and environmental services.

The need to build a larger picture or context from site-specific studies is well recognized, and spatial and temporal scaling of the water security configuration in a systemic way will be undertaken in this case study. Through this project, the intention is to learn at a case study level what can be taken to a catchment scale, and then to learn at both a case study and catchment scale what can be taken up nationally in other parts of the country. As such, the literature review and methodology described here provide a sound integrative base for future project deliverables and for similar projects where the incorporation of EI to enhance water security is being considered throughout the world.
5 References


6 Appendix A

1. Example of a society-space-environment trialectic for Knysna (Sutherland, 2016)