Introduction

> **The First Water Law of the West is the Law of Gravity. Water runs downhill. The initial uses of water in the West involved the use of gravity to tap rivers and divert their flows into canals for delivery to farms and mines. This is also known as Newton's Law.**
>
> **The Second Water Law of the West is the original law of Los Angeles…[and] states that 'water runs uphill to money.' The development of energy technologies to lift water against the pull of gravity is the basis for modern Western civilization. Los Angeles pioneered the effort to defy gravity with money in the early 1900s with its Owens Valley Aqueduct…Phoenix, San Francisco and Denver also utilize massive pumping and diversion systems to transport water from great distances in defiance of gravity to serve their growing urban populations.**
>
> **—Hugh Holub, 1999**

Societies throughout history have used laws to define, control, and sanction the use of natural resources for their benefit – water being no exception, and perhaps all the more so because of its absolute non-substitutability. Water, however, is a law-defying entity. As Holub's first two Water Laws of the West make clear, even Newton's Law, long used to the advantage of farmers, miners, and other water users, may be superceded when societal ambition and ingenuity dictate necessary (Lebel et al. 2005). Today, we are beginning to realise the limits of our legal measures to manage water. Holub's laws were written with reference to the water saga that has long endured in the American West (Reisner 1993), but apply with little modification to numerous societies that have made similar valiant attempts to support livelihoods, economies, and political regimes on arid landscapes, often with remarkable success, and as the historical record indicates, equally often with phenomenal failure (Tainter 1998, Diamond 2005).

Perhaps nowhere has the need to reform the way water is managed and even conceived been more apparent than in South Africa in the last decade. In a country where history has been so prominently shaped by unevenly distributed natural resources (Figure 1.1), the nation's leaders seized an opportunity at the close of the apartheid era to overhaul the previous water law and replace it with one of the most progressive pieces of water legislation in the world to date. The enactment of National Water Act No. 36 of 1998 signaled not only the end of an era of resource

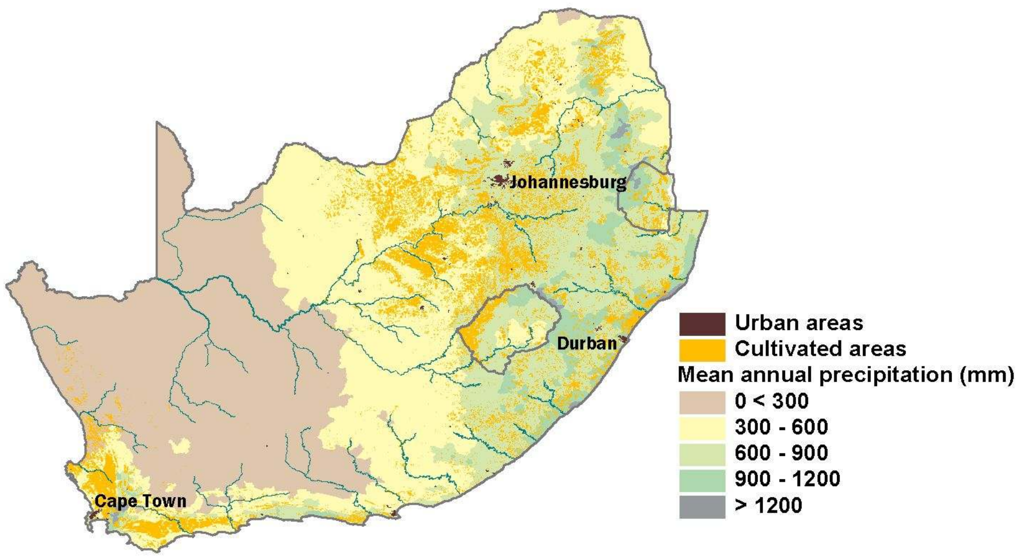

Figure 1.1. South Africa, with major rivers, cities, urban and cultivated areas, and mean annual precipitation.

management but the beginning of a commitment to ecological and social sustainability, abolishing all water rights except for two: the right of every citizen to an adequate, safe supply of water for domestic needs and the right of ecosystems to the water required for their continued functioning (DWAF 2004*a*). Together, these rights constitute the Reserve, the unconditional first priority in water allocation. The Act also strives for efficiency, so that scarce water resources beyond the Reserve are used for the collective benefit of the nation's present and future generations.

Four years after the Act was passed, the World Summit on Sustainable Development was held in Johannesburg. To showcase South African water policy for the benefit of international visitors, the Department of Water Affairs and Forestry took out a billboard ad in a prominent location. The ad showed the image of a smiling African child standing at a tap, while beneath the image ran the newly-adopted slogan of the department: "Some, for all, forever," a reference to the Water Act's three core principles of efficiency, equity, and sustainability. Here was a very appealing concept: the department's new law would serve the 'triple bottom line' of the people, the economy, and the environment. It was a concept that everyone could buy into, and few could argue against.

As of early 2006, major parts of the new water policy await implementation, and many questions about how to do it remain unanswered. Moving from legislation to action on the ground must extend beyond a paradigm shift in thinking to the establishment of new institutional arrangements, demonstrable progress on the significant backlog in service delivery especially in the rural population (DWAF 2004*b*), and an improved understanding of the complex relationships between hydrology, ecology, and society. This amounts to an enormous task, and while the new Water Act is a significant piece of legislation, concerns are expressed that an enabling environment for implementation of the law does not yet exist, necessary partnerships among and between institutions and communities are not being forged, and the Act's vision is not being effectively communicated (MacKay et al. 2003).

We now know that water cannot be governed by physics alone. Managing water sustainably is a question of biological and physical processes, but it is every bit as much a question of social ones (Pahl-Wostl 2002). In this thesis I propose that water management in South Africa – which encompasses its water resources, ecosystems and their services (Daily et al. 1997), people they support, and institutions that govern them – is a social-ecological system: a coupled, inseparable system of human beings and nature. However, social-ecological systems theory, increasingly embraced by those working at the interface of social and natural science problems, has not been fully brought to bear on the challenges that South African water management faces now and may encounter in the future. I then argue that a social-ecological systems perspective is needed to understand the true nature of these challenges. Below I elaborate on this perspective before outlining the thesis structure and the approach adopted in each chapter to support this argument.

A Social-Ecological Systems Perspective on Water Management

Science and broader society have traditionally treated social systems and ecosystems as distinct, according to one of two general views (Westley et al. 2002). One is that ecosystems are part of social systems – 'natural' patches within a human-dominated matrix. The other is that social systems are part of ecosystems, with ecosystems comprising all life, among which the human species has come to dominate. Each view tends to draw from a unique disciplinary paradigm, and each may be used to support different approaches to conservation and development problems (Norgaard 1994).

A growing volume of case studies and examples (e.g. Gunderson and Holling 2002, Janssen 2002, Berkes et al. 2003) suggests that each of these views has limits when called upon to provide sustainable solutions to such problems. The first view, that ecosystems are contained within social systems, may arrive at an assumption that managers can control ecosystems. Much management in industrialised nations has been based on a 'command-and-control' (Holling and Meffe 1996) approach that supports the idea that humans can and should dominate, tame, or triumph over nature. A counterargument is that all ecosystems, no matter how much humans influence them, are partially but inherently beyond human control. This is because ecosystems behave as complex adaptive systems (Walker et. al. 2002), which tend to be non-linear, uncertain, unpredictable, and adaptive to change. Their complexity emerges from simple rules (Lee 1993), the ability to self-organise (Holling 2001), and the interaction of slow variables – the governing structures and processes that drive system behavior – with rapidly changing ones (Gunderson and Holling 2002). Complex systems are able to shift between alternative states; state change is often characterised by thresholds that are difficult to predict (Scheffer and Carpenter 2003). When a critical threshold is passed, recovery to the previous system state is often extremely difficult (Scheffer et al 2001). Such dynamics explain the severe resource collapse or degradation that has been observed in large complex systems such as the Columbia River Basin (Lee 1993), the Everglades (Light et al. 1995), and the Western Australia agricultural region (Allison and Hobbes 2004), all of which have been guided by command-and-control management approaches.

The second view, that social systems, as a construct of the human species, are contained within ecosystems, may conclude that humans, though a remarkably successful species, are just like any other (Pinker 1997), and therefore, human control over and custody for ecosystems can be relinquished. The likeness of humans to other life forms is not debated here; the salient argument against this view is that the human species, though only one of many, has made an indelible and profound mark on global ecosystems and human well-being (MA 2005). Some liken the current scale of human domination to a new geologic era, the 'Anthropocene' (Meybeck 2003), in which the modern human species – *Homo economus* (O'Neill and Kahn 2000) – has appropriated primary production (Vitousek et al. 1997), freshwater (Vörösmarty and Sahagian

2000), and biodiversity (Pimm et al. 1995) as no other species has done before. The continuation of these activities, and the unprecedented scale of their effects, does not bode well for future human (or other) generations (MA 2005). Furthermore, some challenge the 'just another species' view on the grounds that nature has intrinsic value and a right to exist beyond any human needs or desires for it (Noss and Cooperrider 1994).

Where sustainability is concerned, a more meaningful position is likely to lie somewhere between the two views – one that suggests a more complex relationship between humans and ecosystems, appreciating that while humans are at least partially at the mercy of ecosystem complexity, they have tremendous impact on natural systems, and recognising this, are capable of better management. Such a relationship is not novel in human history; case studies show how recognition of the fundamentally coupled nature of social-ecological systems has allowed some societies to manage their resource bases sustainably, sometimes for centuries (Berkes et al. 2000, Dietz et al. 2003). At present, however, such a position does not feature prominently in the positivist tradition of Western science (Berkes et al. 1998) or conventional resource management (Holling and Meffe 1996).

In South Africa, water management has been dominated largely by the first view (Rogers et al. 2000), though elements of the second also persist. Undoubtedly, a more holistic perspective is required to achieve the efficiency, equity, and sustainability principles of the Water Act. This is a call echoed by water researchers and practitioners across the globe (Pahl-Wostl et al. 2002, Folke 2003), but it is often guided by incomplete understanding on the ground. For example, Integrated Water Resources Management, which focuses on coordinated management of water resources to achieve social, economic, and sustainability goals, is often an attempt at such holism, but at other times is a mere buzzword that obscures underlying perceptions about human-water relationships (Chikozho 2005, Moench 2005).

Water is an especially challenging resource to manage because of its tight links to other ecosystem components, land use, economies, culture, and fundamentally, ethics (Acreman 2001). The South African Water Act clearly acknowledges these links and trade-offs in a 'water and society' system context, but recent dialogue regarding the creation of new water institutions has suggested that this context is not always being appreciated in practice (Rogers et al. 2000). In academic and research circles, different aspects of social-ecological systems theory are reflected in the current water management discourse and analysis. These focus on the role of adaptive management (Rogers et al. 2000, MacKay et al. 2003), the incorporation of value systems in monitoring programmes (Rogers and Biggs 1999), limits of biophysical research (van Wyk et al. 2001), and governance mismatches (Pollard and du Toit 2005). Despite this, the theory needs continued development and application to the South African context, individual efforts need to be synthesised, and greater investment made in communication with those responsible for implementing water policies. This thesis is an attempt to respond to these needs by pushing social-ecological systems thinking in several new directions in an arena where its application has been limited thus far.

Thesis Structure: Hypothesis, Key Questions, and Approach

My hypothesis is that a social-ecological systems perspective makes a unique contribution to our understanding of water management in South Africa, and particularly to the current transition underway. To explore this, I identify five key questions that flow from this premise (Table 1.1), and use a variety of approaches and methods to address them in the next five chapters. Two chapters (2, 3) of this thesis draw on the experience of the Southern African Millennium Ecosystem Assessment (Biggs et al. 2004, Bohensky et al. 2004, van Jaarsveld et al. 2005 – see Appendix A), part of a global initiative to provide information to decision-makers about the relationships between ecosystem services and human well-being (MA 2003, MA 2005). To a large degree, the scientific basis of the Millennium Assessment is rooted in social-ecological systems theory, though in itself it was not a theoretical exercise intended to support or test this theory, an issue I return to in a later chapter (6).

Two chapters (4, 5) use an agent-based modelling approach that was developed for this thesis to explore the evolution of interactions between water resources and water users in a spatio-temporal environment that represents South Africa. Agent-based modeling has its origins in the arenas of artificial intelligence (Ferber 1999) and social science (Epstein and Axtell 1996) but is becoming widely applied to natural resource management research that adopts a social-ecological systems perspective (Bousquet and Le Page 2004).

Table 1.1. Thesis structure.

Chapter	Key Question(s)
1 Introduction	How can a social-ecological systems perspective contribute to our understanding of South African water management?
2 Evaluating responses in complex adaptive systems: insights for water management from the Southern African Millennium Ecosystem Assessment (SAfMA)	What factors characterise effective management responses - those that maintain ecological and social resilience - in complex systems?
3 Future ecosystem services in a southern African river basin: a scenario planning approach to uncertainty	How can scenarios of possible alternative futures aid our ability to deal with uncertainty in complex social-ecological systems?
4 Decentralisation and its discontents: redefining winners and losers on the South African 'waterscape'	Does the decentralisation of water management in South Africa lead to 'better' outcomes, or does it simply redefine winners and losers?
5 Learning dilemmas in a social-ecological system: an agent-based modelling exploration	How do certain social-ecological system conditions enable or constrain learning? Does the Water Act create optimal environments for learning?
6 Discovering resilient pathways for water management: two frameworks and a vision	Can existing social-ecological systems frameworks help to discover resilient pathways for South African water management and achieve the vision of the Water Act?
7 Synthesis	How can a social-ecological systems perspective contribute to our understanding of South African water management?

In order to understand why certain systems of water management in southern Africa have succeeded or failed in the past, and the likelihood of future successes and failures, water management responses need to be viewed in a complex adaptive systems context. In **Chapter 2**, I investigate whether certain factors characterise effective management responses – those that maintain ecological and social resilience – in complex systems. Water management in South Africa needs to be understood in light of the dominant paradigms of past and present that have enabled or constrained people's options for managing water. I present a conceptual framework of responses in complex social-ecological systems to evaluate different interventions to manage water. The framework consists of three interconnected scopes or spatial and temporal domains: the scope of an impact, the scope of the awareness of the impact, and the scope of the power or influence to respond. I suggest that these scopes must be at least mostly congruent for a response to be effective. I then assess the validity of this suggestion by evaluating water management responses in the Gariep and Zambezi River basins that formed part of the Southern African Millennium Ecosystem Assessment. Fundamentally, this chapter seeks to gain a better understanding of past water management responses, and is a logical basis for the questions explored in the following chapters of the thesis which essentially focus on the future.

Many uncertainties influence the future of water management in South Africa, and are not easily controlled by actors in the system. In such situations, scenarios, as plausible narratives describing alternative futures, have shown great potential to stimulate thinking and debate. For this reason, scenarios have been used widely in business and political contexts, where they have frequently been instrumental in achieving major strategy changes and paradigm shifts. In **Chapter 3**, I review a scenario planning exercise as an approach for identifying social-ecological management decisions that are robust to high levels of uncertainty about future ecosystems and their services. I then discuss the objectives, approaches, and findings of a scenario analysis in the Gariep River basin in Southern Africa. I also look more closely at the key findings of this analysis, why they emerged from the scenarios, as well as the shortcomings of this exercise and how it could be improved for future use. Scenarios show greatest potential when designed to address a focal policy issue, and could therefore play an important role for dealing with uncertainty surrounding the South African water management transition.

The new water management paradigm in South Africa entails an unprecedented decentralisation process for this country. Social-ecological systems theory suggests that democratic decentralisation is an effective management response because it transfers decision-making authority to local actors who presumably have the most relevant information about their water resources, and it also minimises risk by promoting a diversity of water management strategies. Yet in reality, few examples exist of successful decentralisation experiments for natural resource management. In **Chapter 4** I ask if decentralisation leads to ‘better’ outcomes in social-ecological systems, or simply redefines winners and losers. I pursue this question with the use of an agent-based model of decision-making in the South African water sector called the WaterScape. I compare the outcomes of actors’ decisions for achieving the three Water Act principles of efficiency, equity, and sustainability under three dominant water management paradigms and under a decentralised system that allows collective learning. Given that water management must occur at multiple scales, I explore to what extent decentralised decision-making is appropriate.

Learning is important in a social-ecological system so that actors can capture information and detect key patterns. Because social-ecological systems are dynamic, actors must be able to learn and adapt. While in Chapter 4 I ask whether the Water Act principles are more likely to be achieved when learning is allowed, in **Chapter 5** I extend this line of questioning and ask what causes agents to learn, and conversely, what prevents them from learning. I propose that water management in South Africa, as a social-ecological system, is challenged by ‘learning dilemmas,’ in which human perceptions combined with social-ecological conditions affect the capacity, understanding, and willingness required to learn. In South Africa, learning how to manage water has been affected by water’s high temporal variability, scarcity, and lack of access to ‘learning networks’ through which relevant, timely information can be obtained. Learning is also affected by the indicators selected to measure the effectiveness of different management strategies. I use the WaterScape model presented in Chapter 4 to investigate social-ecological conditions that encourage or constrain learning by agents in the South African water sector. I explore how variability, water stress, and spatial heterogeneity, together with indicator selection affect learning ability. I then ask, given these conditions, what can be done to enhance learning, and how can management ensure that optimal conditions for learning are maintained or created?

In **Chapter 6** I investigate the concept of resilience in water management. Resilience – defined as the amount of change or disturbance a system can withstand and still maintain its essential structure, function, and identity (Rappaport 1968, Holling 1973, Levin 1999, Cumming et al. 2005) – as it applies to water management is poorly understood, yet it is a critical issue to the successful implementation of the South African Water Act over the long term. Because a social-ecological system undergoes continuous change, the concept of resilience needs to be viewed with respect to particular system configurations rather than to the system itself. It is therefore useful to identify resilient "pathways" for the system that can guide future management actions. A growing body of theory and associated frameworks exist to improve understanding of resilience, but its relevance to management, and specifically for the example in this thesis, is unclear. I evaluate the potential of two existing frameworks – the conceptual framework of the Millennium Assessment and the "panarchy model" of Holling that has played a pivotal role in current resilience theory – to help water managers discover resilient pathways that are likely to align with a common vision for the South African water sector. I then identify features of the framework that may require modification as well as gaps in the vision, with the practical example of South African water management ultimately serving to strengthen social-ecological systems understanding.

In **Chapter 7**, I revisit the hypothesis presented above: can a social-ecological systems perspective contribute to our understanding of water management in South Africa? I attempt to answer this in a synthesis of the arguments made in the five main thesis chapters. I then discuss some of the expected implications of this work for water management and research in the future.

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