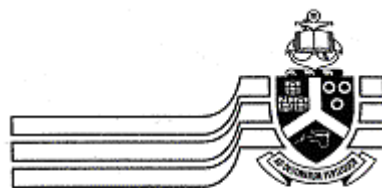


**A SOCIAL-ECOLOGICAL SYSTEMS PERSPECTIVE ON WATER
MANAGEMENT IN SOUTH AFRICA**

by

Erin L. Bohensky

**Submitted in partial fulfilment of the requirements for the degree Doctor of Philosophy
(Environmental Ecology)
in the faculty of Natural and Agricultural Sciences**



University of Pretoria
Universiteit van Pretoria

July 2006

A social-ecological systems perspective on water management in South Africa

Student: Erin L. Bohensky

Supervisors: Professor A. S. van Jaarsveld¹ and Dr. Berndt Janse van Rensburg²

Departments: ¹Centre for Invasion Biology, Department of Botany and Zoology,
Stellenbosch University, Private Bag X1, Stellenbosch 7602 South Africa

²Department of Zoology and Entomology, University of Pretoria, Pretoria,
0002

Degree: Doctor of Philosophy (Environmental Ecology)

Abstract

Conventional approaches to water management have traditionally treated social systems and ecosystems as distinct, and to a large degree have failed to achieve outcomes that are simultaneously efficient, equitable, and sustainable. 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, where a tremendous opportunity for change has been created in the form of the National Water Act of 1998. In this thesis I propose that water management in South Africa – which encompasses its water resources, ecosystems and their services, people they support, and institutions that govern them – is a social-ecological system: a coupled, inseparable system of human beings and nature. Using a combination of approaches, I demonstrate that a social-ecological systems perspective is needed to understand the true nature of these challenges. First, drawing from the experience of the Southern African Millennium Ecosystem Assessment (SAfMA), I construct and apply a framework for evaluating past water management responses. Second, I review a scenario planning exercise as an approach for identifying robust decisions amid high levels of uncertainty about future ecosystem services. Third, I use an agent-based model to explore the evolution of decision-making and learning by water managers under alternative paradigms. Lastly, I compare the ability of two existing frameworks to increase understanding of resilience as it applies to South African water management. Results of this work indicate that: congruence of impacts, awareness, and power is key to achieving effective water management in South Africa; future water management planning needs to take account of cross-scale trade-offs; decentralisation holds most promise when supported by a national policy framework but which allows for local learning; learning may be constrained by temporal variability, water stress, access to learning

networks, and use of inappropriate indicators; and the concept of resilience may provide a mechanism for uniting social and ecological research on water management. As most past water management failures have resulted from a misunderstanding of social-ecological system dynamics, work of this kind can make a significant contribution at this pivotal point in South Africa's water management history.

Declaration

I, the undersigned, hereby declare that this thesis, submitted for the degree of Doctor of Philosophy (Environmental Ecology), is my own and original work except where acknowledged. This work has not been submitted for a degree at any other tertiary institution.

Erin L. Bohensky

Disclaimer

This thesis consists of a series of chapters that have been published in, or prepared for submission to, a range of scientific journals. As a result formatting styles differ and overlap may occur to secure publishable entities.

Acknowledgements

Funding for this research was provided by a grant to the Southern African Millennium Ecosystem Assessment from the Government of Norway and administered by the United Nations Environment Programme. The University of Pretoria and Stellenbosch University provided logistical and administrative support.

I am grateful to my supervisor, Professor Albert van Jaarsveld, for all of his support and insight over the past years. Thanks also go to co-supervisor Dr. Berndt Janse van Rensburg for useful advice along the way, and my ‘quasi-supervisor,’ travel companion, and all-around good friend Belinda Reyers. Cheers to everyone in the lab in its various incarnations from Pretoria to Stellenbosch, particularly Jen Jones and Aimee Ginsburg for ‘lectures,’ and Marinda Dobson and Mari Sauerman for efficiently handling finances and other logistics.

The opportunity to work on the Millennium Ecosystem Assessment while conducting my research and to interact with the SAfMA team was a uniquely enriching, and at times, highly entertaining experience. In addition to Albert and Belinda, thanks are due to Tim Lynam, Christo Fabricius, Oonsie Biggs, Bob Scholes, Connie Musvoto, and honorary SAfMA member Marcus Lee, and many others in the larger MA family.

I am indebted to John Murphy for a dynamic exchange of ideas and tireless enthusiasm for helping me build the WaterScape model, and to Ann Kinzig for hosting my visit to Tempe, Arizona in July(?) 2004.

I am grateful to CIRAD for the opportunity to participate in a short course in agent-based modelling at the University of Pretoria in 2003, and especially to the instructors, Christopher Le Page, Pierre Bommel, and Louise Erasmus, and a lively group of participants.

I thank the South African Department of Water Affairs and Forestry for providing access to the Water Situation Assessment Model, the organisers and instructors of a training course on its use, and Anne Beater for subsequent support. Numerous individuals in the South African water sector provided insight, information, and feedback on this work as it evolved.

I was fortunate to travel widely to present this work, and received excellent feedback from audiences of presentations and seminars given at the following: International Young Scientists' Global Change Conference, Trieste, Italy (2003); "Bridging Scales and Epistemologies: Linking Local Knowledge with Global Science in Multi-Scale Assessments," Alexandria, Egypt (2004); Society for Conservation Biology, New York (2004); South African Society of Aquatic Sciences, Midrand, South Africa (2004), "Water Resource Management for Local Development: Governance, Institutions, and Policies," Loskop Dam, South Africa (2004); the Programme for Land and Agrarian Studies at the University of the Western Cape, South Africa (2005); and CSIRO's Davies Laboratory, Townsville, Australia (2006).

Several people kindly read drafts of chapters: Duan Biggs, Harry Biggs, Jen Jones, John Murphy, Belinda Reyers, and Dirk Roux, in addition to several anonymous reviewers.

Of course, I owe a special thanks to my family: Anita Bohensky and Richard Pfeiffer, Megan Bohensky, and Richard Bohensky for all of their love and encouragement across the miles, and no less to my surrogate family in South Africa, Harry, Rina, Oonsie, and Rory Biggs – and most of all, Duan, for his friendship, enthusiasm, support, and love during the journey.

Lastly, credit is due to Marc Reisner for a fascinating and at times horrifying account of water politics in the U.S. (*Cadillac Desert: The American West and its Disappearing Water*), which provided early interest in the subject, and Hugh Holub for a humorous, but still horrifying, summary ("Western Water Law: A Really Dry Subject"), which provided additional inspiration.

Table of Contents

Abstract.....	ii
Declaration.....	iv
Disclaimer.....	v
Acknowledgements.....	vi
Contents.....	viii
List of Figures.....	x
List of Tables.....	xiii
Chapter 1. Introduction.....	1
Chapter 2. Evaluating responses in complex adaptive systems: Insights on water management from the Southern African Millennium Ecosystem Assessment (SAfMA).....	15
Chapter 3. Future ecosystem services in a Southern African river basin: A scenario planning approach to uncertainty.....	45
Chapter 4. Decentralisation and its discontents: redefining winners and losers on the South African ‘waterscape’	68
Chapter 5. Learning dilemmas in a social-ecological system: an agent-based modelling exploration.....	101

Chapter 6. Discovering resilient pathways for water management: two frameworks and a vision.....	135
Chapter 7. Synthesis.....	162
Appendix A. Background paper on Southern African Millennium Ecosystem Assessment by van Jaarsveld et al. (2005).....	172
Appendix B. Class diagram depicting agent classes of the WaterScape model.....	173
Appendix C. Description of attributes of entities in the WaterScape model.....	175
Appendix D. Translation of scenarios for use in WaterScape model.....	180

List of Figures

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

Figure 2.1. The Southern African Millennium Ecosystem Assessment study area and its nested, multiscale design.

Figure 2.2. (a) Near congruence of impact, awareness, and power scopes. (b) Incongruence of impact, awareness, and power scopes.

Figure 2.3. Water supply augmentation, illustrated by cumulative storage dam capacity in South Africa from pre-1900 until 1997.

Figure 3.1. Change in production or condition of ecosystem services in the four regions of the Gariiep basin from 2000 to 2030 under (a) Policy Reform and Market Forces scenarios, and under (b) Local Resources and Fortress World scenarios.

Figure 4.1. Spatial and social entities in the WaterScape model.

Figure 4.2. Ecological feedbacks in the WaterScape model.

Figure 4.3. Value added in Rands per m³ at initialisation and after 100 years under five scenarios.

Figure 4.4. Mean dissatisfaction index value at initialisation and after 100 years under five scenarios.

Figure 4.5. Proportion of catchments in WMA that are ecologically transformed at initialisation and after 100 years under five scenarios.

Figure 4.6. Dominant scenario selected after 100 years under two learning algorithms.

Figure 5.1. (a) Map of South Africa depicting international boundaries and Water Management Areas (WMAs). (b) Visual representation of WMAs in the CORMAS program.

Figure 5.2. Schematic of major relationships governing an actual and perceived environment in a social-ecological system.

Figure 5.3. Ecological feedbacks in the WaterScape model.

Figure 5.4. The mechanics of learning as represented in the WaterScape model.

Figure 5.5. Sequence of indicator change.

Figure 5.6. Sequence of activities in the model.

Figure 5.7. Strategy selection when all agents use the efficiency indicator (Rand value per cubic meter of water use).

Figure 5.8. Strategy selection when all agents use the equity indicator (human reserve deficit).

Figure 5.9. Strategy selection when all agents use the sustainability indicator (decline in present ecological management class from initial value).

Figure 5.10. Strategy selection by agents when indicators are randomly assigned and fixed.

Figure 5.11. Strategy selection by agents when agents are allowed to change indicators.

Figure 5.12. Strategy change when agents use the three single indicators, randomly-assigned fixed indicators, and changing indicators.

Figure 5.13. Indicator selection by agents with changing indicators.

Figure 5.14. Hydrological variability (mean hydrological index value), water stress (ratio of demand to supply) and size (number of water units) of five water management areas.

Figure 5.15. Strategy selection by agents in: a) most variable and water-stressed (Lower Vaal); b) least variable (Thukela); c) largest (Lower Orange); d) smallest (Berg); and e) least water-stressed (Mzimvubu) WMAs using randomly-assigned fixed indicators.

Figure 5.16. Strategy selection by agents in: a) most variable and water-stressed (Lower Vaal); b) least variable (Thukela); c) largest (Lower Orange); d) smallest (Berg); and e) least water-stressed (Mzimvubu) WMAs using changing indicators.

Figure 5.17. Strategy change by agents in five WMAs using randomly-assigned fixed indicators.

Figure 5.18. Strategy change by agents in five WMAs with changing indicators.

Figure 5.19. Selection of equity indicator by agents in five WMAs.

Figure 5.20. Selection of efficiency indicator by agents in five WMAs.

Figure 5.21. Selection of sustainability indicator by agents in five WMAs.

Figure 6.1. A possible pathway of water use, based on past, present and suggested future ecological management classes.

Figure 6.2. Conceptual framework of the Millennium Ecosystem Assessment.

Figure 6.3. Adaptation of the MA conceptual framework to depict two iterations of South African water management.

Figure 6.4. The panarchy model (Holling 2001) is comprised of four ecosystem phases (r , K , Ω , and α) and the flow of events between them.

Figure 6.5. The panarchy model of the adaptive cycle is used to depict the dynamics in South African water management during the previous (iteration 1) and current (iteration 2) eras.

List of Tables

Table 1.1. Thesis structure.

Table 2.1. Characteristics of the Gariep and Zambezi basins.

Table 3.1. Key bifurcations in drivers of change that distinguish four scenarios of future ecosystem services and human well-being.

Table 4.1. Scenario assumptions and rules.

Table 4.2. Economic efficiency, equity, and sustainability of water use on WaterScape at beginning and end of 100 years under five scenarios.

Table 4.3. Valued added (millions of Rands) by each sector at beginning and end of 100 years under five scenarios.

Table 4.4. Gini coefficients for sectoral consumption at beginning and end of 100 years under five scenarios.

Table 6.1. Water management in South Africa: a timeline of events.