DEVELOPING WATER RELATED CLIMATE CHANGE ADAPTATION OPTIONS TO SUPPORT IMPLEMENTATION OF POLICY AND STRATEGIES FOR 'WATER FOR GROWTH AND DEVELOPMENT'

Report to the
Water Research Commission

by

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WRC Report No. 1965/1/15
ISBN 978-1-4312-0636-0

February 2015

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This report forms part of a series of two reports. The other report is *Adaptation to Climate Change – What may it mean for the Water Resources Sector?* (WRC Report No TT 630/15).

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EXECUTIVE SUMMARY

THE PROJECT FROM A CONTRACTUAL PERSPECTIVE

Based on the Terms of Reference of this solicited Water Research Commission (WRC) project, the main objective was to develop a framework that reflects an integrative adaptive management approach in order to facilitate strategy development that takes into account vulnerabilities and impacts of climate change in relation to water planning and management. Furthermore, the study was to reflect on the analysis of climate change-related uncertainties and risks in the context of techniques for integrating long term climate risks into short- to medium term development policy decisions and projects. All the project's activities aimed at developing methodologies that would provide support to the South African water sector in general, but more specifically to the Department of Water Affairs (DWA), in mainstreaming climate change adaptation measures into water resources management.

The specific deliverables requested by the WRC were to:

1. Undertake a comprehensive analysis using state-of-the-art results (including uncertainties and risks) of climate change- related impacts facing water development investments across critical sectors;
2. Provide guidelines for the reduction of uncertainties through improved monitoring and modelling;
3. Develop adaptive integrated management approaches in support of strategies for taking vulnerabilities and climate impacts into account; and to
4. Identify a suitable toolkit for vulnerability assessments and adaption action.

Another key aspect of the Terms of Reference was to try and align the project's activities and outcomes with DWA's Water for Growth and Development (WfGD) Strategy. However, this policy has been relatively dormant since its last public version No. 7 of 2009. The Reference Group of the project therefore advised the project team that, whilst policy linkages were important, the working environment of the project should be kept dynamic just as the South African water policy field is in itself dynamic.

A strong focus in the context of this research project was on vulnerabilities of water resources and especially those impacting on human livelihoods, as well as on feedback and feed-forward mechanisms associated with climate change (**Section B** of the main report). As the climate change (CC) signal for South Africa is projected to be significant in decades to come, this topic of vulnerability emerged as a dominant theme throughout this research report. Specifically, the uncertainties associated with CC are challenging, not only in understanding the impacts and resulting vulnerabilities of climate change (**Section A** of the main report), but also for the design of actual management interventions. Management interventions need to be contextualized within the adaptation research domain and in the overall water governance landscape of South Africa (**Section C** of the main report) if sustainable development is to be achieved.

Because of the substantial increase in complexity of water management and adaptation *per se*, but also because of the challenges of South Africa's governance landscape, this project had to take cognizance of other related on-going and completed research projects and specifically build upon the outcomes of WRC Project K5/1843. Within this present project the uncertainty and mainstreaming work as well as the handbook/reference guide on adaptation which was developed are probably the most closely linked research activities in this regard.

The research team fulfilled the above by producing two final products:

1. A main report made up of 16 chapters, and
2. A user-oriented reference guide / handbook on adaptation in the water sector.

The final products reflect the deliverables as indicated in the Terms of Reference, *viz*.

1. A framework for integrative adaptive management approaches;
2. An update of needs that may assist with reducing uncertainties; together with
3. An analysis of climate change-related risks facing water related development;
4. A toolkit for vulnerability assessments and adaptation actions;

5. Procedures and methodologies to support the DWA and the water sector in general on mainstreaming of climate risks into water management and planning processes;
6. Workshops, progress reports and publications emanating from the project; and
7. A final report on mainstreaming climate change adaptation options.

These 7 deliverables were divided into four main sections covering distinct, but related fields. These are:

Section	Title	Content	Related Deliverables
A	Biophysical information on climate change and discussions on uncertainty	• Update knowledge on climate change impacts in south africa. • Clarify and, where possible, reduce uncertainties related to adaptation options.	2, 7 and (partially) 3
B	Evaluate existing as well as possible future vulnerabilities of different critical water use sectors and society	• Evaluate existing as well as possible future vulnerabilities of different critical water use sectors and society. • Assessment of adaptation activities and options.	3, 7 and (partially) 4
C	Governance and mainstreaming in climate change adaptation	• Create an adaptive and integrated management approach. • Prioritise adaptation activities and options. • Mainstreaming climate change into governmental organisations, institutions and their rules of operation and interaction.	1, 4, 5 and 7
D	Overarching lessons learned and knowledge transfer	• Lessons learned based on the transdisciplinary and adaptive mode of research. • Listing of workshops, scientific publications, popular articles / activities and capacity building initiatives	6 and 7

THE PROJECT'S NARRATIVE AND ITS CHALLENGES

The narrative of this project is multi-dimensional and complex, with the project team itself having to learn to adapt and live with changing parameters and emerging challenges almost on an on-going basis (cf. **Chapter 1** of the main report). These included, *inter alia*,

1. The policy document on "Water for Growth and Development" essentially having been superseded;
2. The 'client' thus changing from the national level, and specifically the DWA, to catchment and more local levels with a focus on champion networks, communities of practice and others;
3. The adoption, by the project team, of a transdisciplinary and a social learning approach to its research activities, which in themselves were new learning paths for the members, with all the above resulting in
4. Four distinct learning cycles within the duration of the project, culminating in an overall systemic design of the project as shown in **Figure ES 1** with 6 Work Packages.

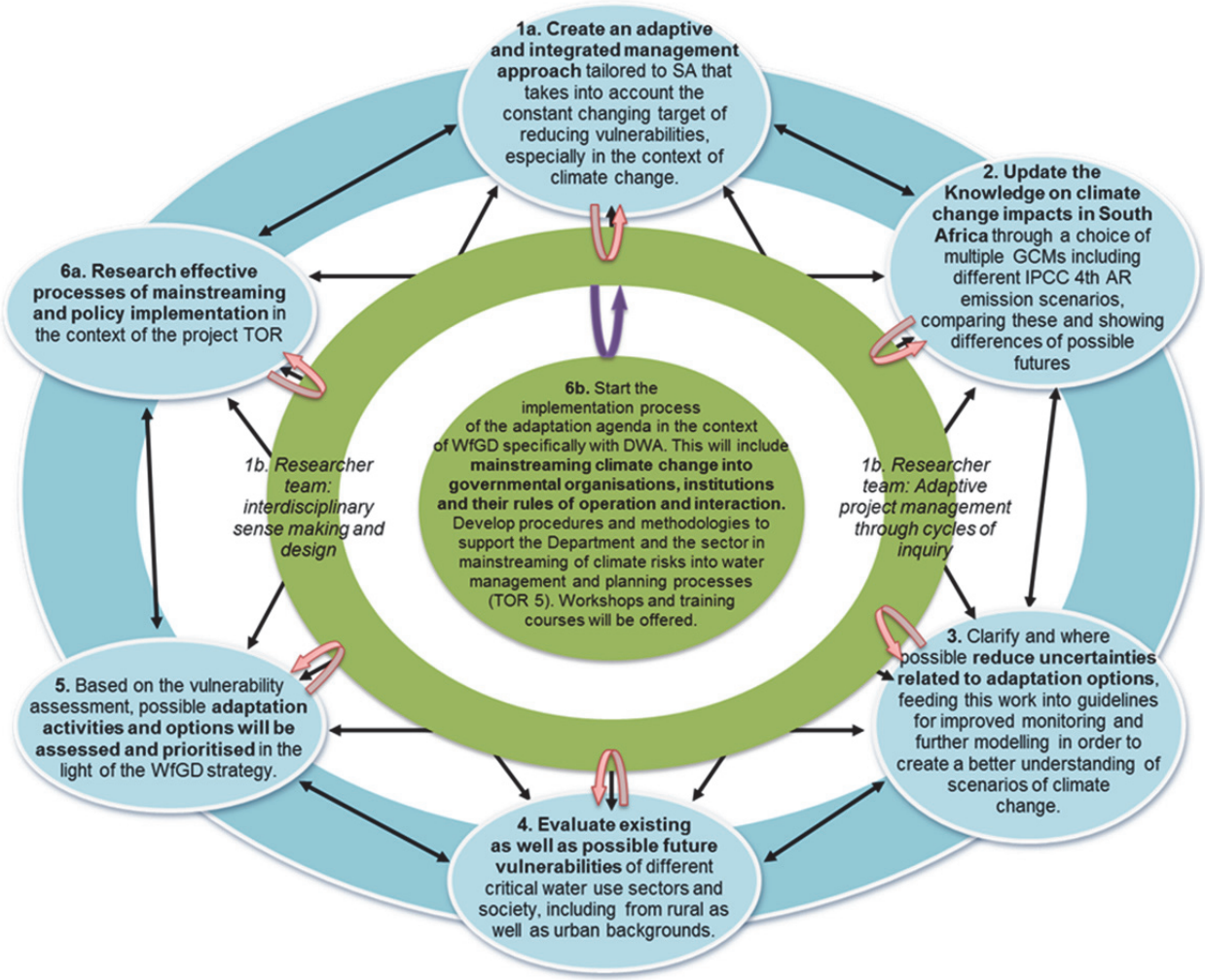


Figure ES 1 The overall systemic design of the project, with the separation into Work Packages

THE MAIN REPORT

The Main Report (this document) is made up of 16 chapters in the 4 sections already mentioned above, with each section covering a common theme. The chapters within each section have been written by the various team members (researchers and graduate students) as self-standing contributions (i.e. with methods laid out and references given) to the project's overall objectives and sub-objectives, with each chapter rigorous in its approach, be it in the biophysical, vulnerability or governance areas. A total of 16 authors made contributions to chapters, and these include inputs from 2 PhD candidates full-time on this project, another 2 PhDs part-time on this project, 3 masters and 2 honours students

Prefacing the Main Report is **Chapter 1 "Setting the Scene"** (S. Stuart-Hill and J. Colvin) in which the Project's narrative and its challenges are outlined, the four learning cycles through which this project evolved are discussed and the research stories and reflections of 8 of the Project team members are narrated.

Section A on ***Biophysical Information on Climate Change and Discussions on Uncertainties*** is made up of a single contribution, *viz*. **Chapter 2 "On Uncertainties and Other Key Issues in Assessing Hydrological Impacts of Climate Change over South Africa: A Perspective"** (R.E. Schulze) which, *inter alia*, asks why climate change should be taken seriously in the South African water sector, before defining uncertainty, elaborating on sources of uncertainty in climate change studies and then reviewing key findings on climate change-related uncertainties from the previous WRC Project K5/1843, which include that

- errors in GCM output for overlapping verification periods vary by GCM, are not spatially uniform across South Africa and differ from variable to variable; that
- errors in GCM output for overlapping verification periods are often largest where the observed record is poor; and that
- when using multiple GCM outputs for hydrological climate change assessments there is no "best" GCM and what may be "best" varies with hydrological variable.

The discussion then moves to "domains" of uncertainty, concluding that "domains of concern" regarding climate change uncertainties are very different to the climatologist compared to the hydrologist. An overview is then provided on expressing uncertainties qualitatively and quantitatively, including a new and robust expression developed in the course of this project, followed by the identification some emerging issues related indirectly and directly to climate change impact studies, and which would affect results and their interpretation, and could affect decisions taken. These include that

- historical means are already highly uncertain
- we have to work with inadequate baseline hydro-meteorological networks in regard to the spatial distribution of stations, the record length and data reliability
- we do not understand well enough the rainfall dynamics of mountain areas which produce our runoff
- key hydrological processes are still missing in frequently used models and these could become important in climate change assessments
- climate change impacts in hydrology are event driven, and that the use of daily time step models is thus imperative, and that
- In hydrological climate change studies, when comparing outputs from differently downscaled GCMs, it is imperative to compare "apples with apples" by appropriate bias corrections to the catchment resolution of choice.

Section B on ***"Vulnerabilities of Water Resources"*** comprises 6 chapters, the first of which, *viz*. **Chapter 3**, titled "**Understanding Links between Water, Livelihoods and Key Hydrological Drivers in Different Communities"** (T. Ngubane and S.I. Stuart-Hill) sets the scene for the section and also for Chapter 7 in outlining some basic concepts around livelihoods (i.e. the ability of individuals to support themselves and others for survival). The chapter then discusses for a rural subsistence farmer, a township and a suburban setting what, respectively for those communities, livelihood assets imply in regard to human, social, physical and natural assets.

Chapter 4 is on "**Vulnerability and Adaptation in the Context of Climate Change and Water Quality Management"** (S.I. Ncgobo) and, as a background chapter to Chapter 5 first provides an overview of, first, vulnerability and adaptive capacity as determinants of adaptation and vulnerability, and secondly, of adaptation in policy development and governance of environmental resources. Thereafter a review continues on evaluating contemporary issues in water quality management, as well as challenges in water quality management and adaptive water quality management. All of this forms the backdrop to discussions on vulnerability and adaptation in water quality management and assessing / managing impacts of climate change on water quality.

This paves the way for **Chapter 5**, **"Towards a Framework for the Adaptive Management of Water Quality under Climate Change"** (S.I. Ncgobo, G.P.W Jewitt, S.I. Stuart-Hill and T.G. Lumsden), which is essentially a fieldwork based case study on modelling climate change impacts on water quality. The chapter is set within a framework of adaptive water quality management, and the simulations performed with the *ACRU*-NPS Model form the basis for the discussion on vulnerability and the potential for adaptive management of nutrients and sediment transport.

The focus changes from issues of climate change, vulnerability and adaptation related to water quality in Chapter 5 to "**Linkages between Selected Hydrological Ecosystem Services, Land Use Changes and Climate Change, as Indicated by Hydrological Responses"** in **Chapter 6** (S. Schütte and R.E. Schulze). In this chapter literature reviews on the concepts of ecosystem services, hydrological ecosystem services, land use within an ecosystem services context and the link between land use and hydrological ecosystem services form the background to the a description of the Mpushini / Mkhondeni Study Area where simulations were undertaken, first without and then with land use changes, and thereafter with climate change scenarios superimposed, with the results interpreted from a perspective of hydrological ecosystem services. Results show that ecosystem services

associated with temperature parameters displayed a higher confidence in the consistency among changes into the intermediate future (2046-2065) from multiple climate models than those related to rainfall parameters, while those in turn showed higher confidence than changes in projected runoff parameters. Another significant result was the amplification of projected changes in runoff compared to those of rainfall.

Chapter 7 on **"Understanding the Links Between Water, Livelihoods and Key Hydrological Drivers in the Communities of Bergville, France and Scottsville: A case study"** (T.F. Ngubane and S.I. Stuart-Hill) links back to Chapter 3, with the emphasis in this chapter on the livelihood backgrounds of different communities, with rural indigenous communities typified by the Bergville area in KwaZulu-Natal; peri-urban communities typified by the township of France near Pietermaritzburg, and urban communities typified by the suburb of Scottsville in Pietermaritzburg. The focus in this chapter was on socio-economic implications on water resources and the challenges related to those.

The theme of vulnerability related to water continues into **Chapter 8**, but now the focus is on **"Climate Change and Food Security: Perceptions of Rural Communities in KwaZulu-Natal and Implications for Food Security Policies"** (S. Shisanya). Undertaken in the uMzinyathi district within the Tugela basin in KwaZulu-Natal and based on 200 detailed household surveys, the key questions revolved around the following:

- What are the emerging climate risks affecting food security of the rural farming households in Tugela river basin?
- What are the levels of household food security in Tugela river basin?
- What is being done at household level to cope with climate risks to reduce impacts on household food security? and
- What policies and investments can be put in place to improve household food security among the rural farming communities?

The results showed that households were concerned about their agricultural climate environment, overall represented by household vulnerability to climate change and this had direct impacts on household food security. Providing farmers with information on good agricultural practice, including water and soil management, had the direct impact of reducing the level of household food insecurity. Such information included coping mechanisms with regard to adverse climatic conditions, hence the need for farmers' access to appropriate extension services. Farmers' preparedness for adverse climate outcomes was necessary, given that out of their experience they knew of some of these outcomes, including outbreaks of crop and animal diseases. Farmers did not have enough resources and needed external support to be able to prepare for these climate related challenges.

Section C on ***Governance and Mainstreaming in Climate Change Adaptation*** is made up of 7 chapters. By way of an overview of this section, its aim was to design a mainstreaming approach that deals with the manner in which climate change actually translates into vulnerability of the individual and the biosphere, as well as what the emerging threats are to society and the economy, in order to inform water management processes and resulting interventions.

In order to design and implement appropriate interventions three key aspects have to be dealt with, *viz*.

- incorporating and adapting to new information,
- promoting vertical and horizontal integration as well as
- undertaking advanced monitoring.

In South Africa climate change has often been mainstreamed into important policy and planning documents, but the research has shown that this is a 'minimum requirement'. What seems to be needed on a very personal level for water managers is the respect for other perspectives, values and priorities as well as the ability to reflect, question, evaluate and learn from what has been implemented. However, so far it is unclear what leverage points for more complex mainstreaming are available. Additionally, this also needs to be seen in the context of a lesser skilled human environment as well as with more fragile organisational structures, such as exist in lesser developed or developing countries. Diverse workshops held and initiatives followed in the course of the project gave the project team some ideas in regard to leverage points, and certainly at the level of key individuals and groups, but it is still unclear how complex issues such as climate change adaptation can be successfully initiated and mainstreamed on a systemic level.

The first of the 7 chapters in this section is **Chapter 9** on **"Mainstreaming Climate Change Adaptation by Preparing for Decision Making in the Water Sector"** (S.I. Stuart-Hill, E. Herrfahrdt-Pähle and C. Pahl-Wostl), in which the key thesis is that Integrated Water Resources Management (IWRM) and Adaptive Management (AM) combine water management and governance approaches for adaptation to climate change. The chapter furthermore outlines the characteristics needed to perform under IWRM and AM and how success can be maintained by bringing knowledge together and reflecting on ones values, which requires leadership in order to take decisions to the final management intervention. A framework for mainstreaming climate change adaptation is proposed, the main tenets of which are that

- Global change, including climate change, is ***why*** we should do things;
- Vulnerabilities as ***what*** we should be doing or prioritising; and
- IWRM and AM as to ***how*** we should approach the design of adaptation options.

Additionally, characteristics had been derived, based on IWRM and AM, in order to perform in an environment of sequential change and periods of consolidation as well as evaluation, which include:

- Dealing with uncertainty in order to increase resilience, with this being expressed through ***flexibility***;
- Enabling change and adjustment, which is expressed through ***responsiveness***;
- Establishing a discourse amongst governmental departments as well as beyond the water sector, which is expressed through ***coordination***; and
- Connecting across levels and scales, which is expressed through ***cooperation***.

In many respects complementary to Chapter 9 is **Chapter 10** titled **"Mainstreaming Adaptation to Climate Change by Taking Organisational Issues into Account for Successful Management Interventions"** (S.I. Stuart-Hill and C. Pahl-Wostl). Following a treatise of more theoretical and abstract issues, it is argued that one should go beyond those because it is essential that policy and strategies should lead to actual management interventions that are implemented - and are adjusted over time. Otherwise, mainstreaming might be successful on a systemic, conceptual and even legislative level, but does not lead to adaptation and change in livelihoods of people in a robust economy, and in resilience of ecosystems. Hence, a management cycle in regard to the process presents itself in 6 essential steps, *viz*.

- Knowing impacts of change;
- Understanding the vulnerabilities (and also risks) which are critical at a certain time and in a certain place;
- Making sense of the above, which results in design and prioritisation of options for adaptation;
- Implementing management interventions for adaptation;
- Managing, monitoring and evaluating the interventions for adaptation; and
- Re-assessing and adapting, based on new knowledge or understanding of climate change and associated vulnerabilities.

Four levels of intensity of mainstreaming climate change adaptation into management are presented, *viz*.

- Understanding and including climate change into the *planning* of the water sector (*minimum*)
- Integrating issues from outside the water sector (*low optimum*)
- Understanding and including climate change impacts on a relevant scale into *decision making and the design of regulations* within the water sector (*high optimum*) and
- Understanding and including climate change into any daily decision making and design of regulations, while simultaneously also integrating issues from all other sectors (*maximum*).

The main skills needed for successful mainstreaming are the need for connection between individuals and organisations, the need for leadership and the need for a capacity to learn.

In **Chapter 11**, **"A Snapshot of South Africa's Water Resource Management Status - What Does This Indicate for Overall Water Governance?"** (S.I. Stuart-Hill and R.E. Schulze) the aim was to gain insights into the *status quo* of day-to-day decision-making realities of South Africa's water managers by conducting 34 in-depth semi-structured interviews, with interviewees from the governmental, consulting, academic and industrial sectors. A questionnaire was developed consisting of four sections, the first two with global questions investigating the integrative and adaptive potential, the second two tailored specifically to the South African case. **Section A** evaluated the enabling environment in regard to policies, the legislative framework as well as financing and incentive structures. The aim of this section was to assess the *status quo* in regard to implementation of the acts and policies as well as the principles of IWRM. **Section B** evaluated institutional roles and management instruments. The first part was to again assess the *status quo* in regard to

implementation of the acts and policies as well as the principles of IWRM, but also to evaluate effectiveness of overall water governance. **Section C** performed a reality check for South Africa in regard to implementation of key policies, transformation and cooperation between sectors while **Section D** dealt with issues of change, leadership, participatory management and adaptation. The aim here was to assess barriers and drivers of change as well as cooperation and beyond the water sector and integrating interests of users and decision-makers from all levels

The results / outcomes of a 4 phase analysis (integration, learning, feedback, adaptive action) showed that the four phases were all distinctively mediocre to weak with fulfilment levels at below 40%. Even Phase, which should reflect well after 15 years of the 'new' National Water Act, and which reflects IWRM as the management approach to be followed, and with many water policies having now been in place for over 10 years, still shows high levels of fragmentation and limited integration. Holistic thinking and decision making approaches were only reflected in a few cases. The learning phase (Phase II) was found to be significantly weaker than the integration phase (Phase I). Although the feedback phase (Phase III) might be surprisingly high with a 37% fulfilment, it has to be relativized due to the fact that the learning outcomes are very limited, and even those are incomplete and partial as they only link certain issues or projects. Overall, learning and feedbacks are not systemic to the management approach and cycle. The final phase of the cycle, which relates to taking adaptive action, was found to be almost non-existent.

Based on these outcomes, the *status quo* of implementation in regard to an integrative and adaptive management approach in South Africa must be regarded as weak overall. It must be assumed that the Policy-Management Cycle within government is not well established and weakens as the issues at hand (integrated learning, reflection, processing new knowledge, participatory activities and feeding back into the system in order to enhance performance and capacity) become more demanding and complex. However, a few individual cases seem to exist, and these might be the pockets of innovation from which the country needs to learn. Additionally, from the different dimensions of capacity which were discussed, the well-known narrative of a skills and capacity crisis in the South African water sector could not be confirmed meaningfully. However, the interviewees confirmed that Human Resources are the area of great capacity deficiency. At least the financial situation and the availability of equipment were seen as remarkably good. What this inquiry has shown is that issues need to be differentiated and broken down into more specific questions, otherwise a proper understanding of the challenges at hand is not possible and any solutions designed would probably not be effective or sustainable.

Another questionnaire based analysis which was conducted, but in this case more catchment specific, is reported upon in **Chapter 12** on **"Understanding the Policy and Management Cycle and the Effectiveness of Tools for Policy Implementation, Using the uMngeni Catchment as a Case Study"** (N. Vilakazi and S.I. Stuart-Hill). The first half of the chapter reviews the literature on water governance, elaborates on water governance capacity and water policy in South Africa (with an emphasis on IWRM), discusses the links between the Water Services Act (WSA) and the National Water Act (NWA) through the Sanitation Business Cycle and concludes with a discussion on the implementation of water policies in South Africa. This is followed in the second half with a case study on the effective implementation of the NWA in the uMngeni Catchment. Background is given on the uMngeni Catchment, on the mixed sampling scheme adopted and on the methodology used with key informant interviews. Results from the key informants' interviews highlighted the following:

- There is need to employ capacity building mechanisms and place the right people in the right positions.
- More financial resources should be allocated in different water institutions.
- The budget for water should be spent in water related expenses.
- There is need to carefully plan and strategize the available integrative policy instruments to enable their proper establishment, i.e. the National Water Resource Strategy, Catchment Management Agencies, Catchment Management Forums and Catchment Management Strategies.
- There is a huge need to fast track the establishment of the CMAs.
- There is need to employ an integrated approach to water management.
- There is a need to develop and establish the necessary water infrastructure, especially in rural areas.
- There is need for DWA National to develop guidelines for monitoring and evaluation of the implementation process of the NWA.

Recommendations emanating from the study include the need for more local stakeholder participation and involvement, better communication and dissemination of information to the local level and the need for more integrative management of water resources and services.

Chapter 13 on **"Exploring Co-Design of Adaptation to Climate Change and Prioritising Interventions"** (S.I. Stuart-Hill, N. Methner, R.E. Schulze and T.G. Lumsden) is introduced by the notion that certain land uses can dominate hydrological responses, and that when climate change impacts are superimposed the joint impacts of land use and climate change can, under some circumstances, be significantly amplified. Within such a highly dynamic landscape of our catchments negotiations need to take place within a process of dialogue, with such dialogue needing to take relevant policy and day-to-day decision making of water managers and other critical stakeholders into consideration. Hence, a space is necessary where local and regional knowledge and needs meet policy guidance and is placed within the 'bigger picture' of water management, and the proposed 'space for dialogue' is that of champion networks, understood here as a group of influential decision makers from relevant organisations as well as water users and stakeholder groups from a catchment.

Two case studies areas were chosen to explore the options and potential scope of such a designed process, these being climatically and socio-economically divergent. One was the Berg catchment in the Western Cape's winter rainfall region, the other is the uMngeni catchment in KwaZulu-Natal representing a summer rainfall region. Both have a significant, but opposite, climate change signal

Two sets of 'champion workshops' were held in each catchment with an additional technical workshop in the uMngeni. Adaptation actions proposed in all workshops revealed 6 recurring themes to emerge, *viz*. governance, mainstreaming of climate change into water management (e.g. regulation, design criteria), infrastructure and technology developments, planning, education / awareness and early warning systems.

Equally important, however, were a variety of 'moments of surprise' that were observed in all workshops held, for example:

- Stakeholders identified re-occurring champion workshops as an opportunity for policy implementation.
- Moments of surprise in the uMngeni were the identification of the headwaters as crucial in all future climate scenarios assessed. Building resilience via natural capital was identified as a key activity.
- Moments of surprise in the Berg were that strong social networks of decision makers and stakeholders existed and that these were accessible, but overall the majority of responsibilities identified pointed to higher levels of governmental actors. Furthermore, law enforcement and monitoring were identified as key activities.
- The technical uMngeni workshop also revealed unexpected outcomes such as the identification of positive impacts of climate change.

In conclusion, adaptation design calls for an enabling environment that gives space for knowledge exchange and learning conversations and that caters for the interplay of systemic, organisational, and individual needs. Such conversations cannot be undertaken without a mix of decision makers and stakeholders because of the uncertainties of development trajectories, as well as limited data and knowledge of the impacts and their interlinkages. It needs to be further highlighted that adaptation design and implementation need to be combined with the necessary budgets and require substantial time commitments over and over again.

An entirely different approach is taken in **Chapter 14** which is titled **"Getting to Grips with Governance and Management of the uMngeni River Basin - An Informal Commentary"** (D. Hay), for this is truly the author's "personal journey" into issues of governance in the uMngeni Catchment. A compelling argument is made for water resource management and governance to take place most appropriately at the scale of the river basin. Hay argues that we also increasingly appreciate that, irrespective of the landscape context, the governance and management of water resources is complex. Water is, by its very nature, a complex substance in being a flux – here one moment and far downstream the next. We appreciate further that as our almost insatiable demand and competition for water resources increases, so does this complexity increase. Then take it to the next level: climate change and the uncertainty that it brings with it will increase the complexity. This leads to a further

proposition, *viz*. that if we are going to intervene effectively to address climate change issues, we are going to have to get those things right that are required even without climate change.

Four early lessons learnt by the author in other research projects, and relevant to this project, were
- that long term research programmes can achieve a depth of understanding that is rarely achieved through short term projects;
- that if the research responds directly and practically to the perceived needs of the user it is likely to be used;
- that what we are dealing with, particularly in a water resource management context, is complex, and we therefore have to engage the complexity and expect the unexpected; and
- fourthly, that one had to engage people.

After providing a 'snapshot' of the uMngeni River Basin and its issues, two possible responses to better management are put forward. First and foremost, there needs to be a paradigm shift in thinking and acting from what could aptly be described as a 'culture of impunity' to one of custodianship and caring and that we require a sustained campaign of 'societal action' where every individual, group, sector and the entire community living in the basin sees themselves as custodians of the basin. Secondly, we need to have the courage to talk truth to power. Many of those who are acting with impunity are the powerful: government, industry, commercial agriculture. They must be accountable and be held accountable for their actions.

Moving into the realm of research; there are numerous concepts, models and frameworks that might guide our thinking about the uMngeni River Basin, particularly as it relates to governance and management, for example:
- The well-being and livelihoods of those who live in the Basin is a top priority;
- The river basin is a complex social-ecological system;
- The river basin is a supplier of ecosystem services;
- Water resources in a river basin are a common pool resource, subject to common property theory;
- Adaptive governance and management is necessary; and
- It is important how we share the benefits that aquatic ecosystem services supply,

and these are expounded upon in the text.

As researchers, Hay asserts that we should be
- growing our knowledge base in institutional and technical areas in support of effective governance and management of the river basin;
- building the capacity of our current and future generation of river basin leaders, managers, practitioners and researchers; and
- acting as a catalyst for collective and coordinated action.

Chapter 15 summarises the approach and context contained in the extended and shorter, glossy versions of the reference guides on adaptation, with the chapter titled **"Managing South Africa's Water Resources in the Context of Climate Change: A Reference Guide to Implement Adaptation Options"** (J. Colvin, B. Scharfetter and C.H. Vogel). Details on the reference guides are given in the section below on ***The Reference Guides / Handbooks On Adaptation***, but in summary Chapter 15 covers topics such as the intended audience for the reference guide, how South Africa currently manages its water resources, framing adaptation to climate change, adaptation as social-institutional learning pathways, how South Africa's water resources sector should be adapting to climate change, who should do what, the role of different actors (with a central focus on innovation brokers and systemic intermediaries) and using the reference guide as a means to engage in effective dialogue on mainstreaming.

Section D, headed "***Overarching Lessons Learned and Knowledge Transfer"*** contains just a single chapter summarizing the integrated lessons learned, commencing with
- **General lessons learned**, such as
  - the need to recognize that environmental systems have biophysical limitations which vary between catchments, regions and nations;
  - transdisciplinary research being an experience that needs to be lived;
  - the need to learn to live with change and uncertainty;

- communication platforms being required to close the considerable communication gap between research and practice; and that
- climate change adaptation builds on the basics, which have to be in place, and that it is as important to "do the right things" as it is to "do things right"; and following up with

• **Biophysical and vulnerability related issues**, for example, that
- climate change uncertainties within the biophysical realm are but one set of uncertainties among many others, such as land use impacts; that.
- outputs from the downscaled global circulation models should be used in hydrological projections with great care and only after first having undertaken the necessary bias corrections when further downscaling is undertaken to Quinary Catchments; that
- climate change and land use impacts should be expressed as changes in ecosystem services, and be taken account of in the land use planning process; that
- vulnerabilities are created by both local and national 'set-ups' and that climate change adaptations therefore need to reflect this 'split' of different scales; that
- climate change impacts should be placed in the context of, for example, rural, urban or township settings, with adaptation needs to suit the local contexts; and that
- climate change education and creating awareness is an on-going learning process, especially in rural areas. Thirdly, there is

• **The governance and management dimension**, emphasising that
- the roles, skills and tools of 'governance' and 'management' need to be differentiated;
- mainstreaming climate change adaptation is a long term and 'messy' process;
- the NWRS, the Reserve determination and water licensing present themselves as bottlenecks within the management and governance system;
- there seems to be lack of insight in regard to South Africa's policy instruments and their interplay;
- innovative management requires agency as well as political commitment, and technical knowledge;
- several innovation brokers in regard to mainstreaming climate change have been identified;
- the voices of the vulnerable in South Africa are critical and they are often not heard;
- leadership by government on all levels is needed for out- and up-scaling adaptation
- framing, or the point of departure, is critical to designing adaptation activities;
- particularly in technical departments of government younger people need to be mentored and capacity as well as institutional memory need to be built up;
- inertia in society often prevails, because basic needs have often not been met;
- holistic visions need to include the social and biophysical systems as well as the feedbacks and feed-forwards associated with them;
- information needs to be tailored to suit the targeted group and must be understandable;
- within their means local communities are trying to live with climate variability and change in their local context, but often a lack of resources is disabling them to bring adaptation to full fruition; and
- care should be taken by development practitioners and government to implement sustainable interventions when addressing the impacts that may come with climate change.

Overarching lessons learned, based on the transdisciplinary and adaptive mode of research, include the following:

- Additional multiple stresses resulting from projected climate change are still difficult to capture, understand and model and they currently can inform decision making only in a limited way.
- Sub-catchment and socio-economic issues are playing a greater role in overall water availability, access and use, and hence are critical when designing adaptation options. Therefore, an adaptive and participatory management style is key to current decision-making.
- Participatory processes, action research approaches and social network building have shown that the complexities of vulnerabilities at different scales, as well as various organisational challenges, cannot be over-emphasised when designing management interventions.
- Issues such as the initial framing of the adaptation challenge are critical for successful adaptation mainstreaming. Essential dimensions thus include,
  - firstly, that a transdisciplinary approach is central to building a co-created adaptation agenda,
  - secondly, the need to embed any adaptation efforts into the existing context in the water history of South Africa (e.g. IWRM to AWRM),

- thirdly, the ability to be able to include elements of self-organisation into processes of adaptive management design that has elements of a 'history of learning' and,
- finally, a collaborative, mutually accepted process to backcast normative futures for future adaptive design.

Other key issues identified in the research that hinder successful adaptation to climate change in South Africa currently are centralised tools which can result in severe bottlenecks for integrative and participatory planning and implementation. Furthermore, the much-needed organisational capacities and individual skills are not displayed in the overall governance system.

This research project has shown that water will need to from an integral part of any decision making, particularly given that South Africa requires a successful development and growth trajectory that is sustainable. Water would need to be accepted as the main limiting resource for development across all levels and sectors.

Knowledge Transfer

Three aspects of knowledge transfer are highlighted:

- Capacity Building through the Award of Higher Degrees
  - 2 PhDs resulted directly from this project, *viz*. S. Stuart-Hill and S. Shisanya;
  - 2 further PhDs have / will result(ed) partially from this project, *viz*. N Methner and T. Lumsden;
  - 3 Masters degrees resulted directly from this project, viz. S. Schütte, S. Ncgobo and N. Vilakazi; and
  - 2 Honours research projects came directly from this project, viz. B Scharfetter and T. Ngubane.
- Capacity Building through Workshop Participation
  - This includes the capacity built with the many participants who participated in the uMngeni and Berg Catchments by enhancing their understanding of climate change and adaptation, and by the capacity built during post-project workshops.
- Publication of Papers in the Scientific and More Popular Literature
  - In total 6 papers have been submitted to scientific journals, some already published and others under review, and a further 3 papers are in preparation.
  - A popular article on the project appeared in "Water Wheel" in 2013.

THE REFERENCE GUIDES / HANDBOOKS ON ADAPTATION

The developments of both reference guides / handbooks on adaptation have been grounded in interdisciplinary dialogue. While there have been asymmetries in this dialogue, the reference guide narrative structures were shaped on a (hypothetical) community of systemic intermediaries, innovation brokers and bridging organisations.

A core feature of the narrative structure of the reference guides is a focus on 'framing', since framing matters in climate change adaptation for several reasons. First, framing and power are closely connected, with the powerful mediating the dominant frames. Yet climate change adaptation requires a focus on the vulnerable. Secondly, therefore, empowering the vulnerable to frame strategies for coping, adapting, or even transforming should be a central theme of building adaptive capacity. Thirdly, framings of adaptation and adaptation practices have evolved substantially over the past 20 years and continue to evolve. It is important, therefore, to understand these reframings so as not to become stuck in outmoded ways of thinking and acting. Specifically, frames have moved from scientific uni-disciplinary to the inter- and transdisciplinary; and from 'out there' to combining 'external' and 'internal' practice. Fourthly, different ways of framing futurities is a critical issue in climate change adaptation, including addressing the tension between shorter-term shocks and longer-term stresses. And finally, 'seeing frames' helps us to contextualise, learn and build reflexivity.

The chapters of the handbook are sequenced as follows:

1. Introduction and Background

Part 1 The Current Situation

2. How Does South Africa Currently Manage its Water Resources?

- Challenges of managing water resources in South Africa
- Recognising the complexity of managing South Africa's water resources
- Taking account of climate variabilities in managing South Africa's water resources
- Water resources as a 'wicked issue'
- The policy response – IWRM
- Implementing IWRM – two case studies
- Why has the South African Department of Water Affairs found it so difficult to implement an IWRM approach?
- Barriers to implementing an IWRM approach (2): Competing stakeholder interests and framings

Part 2 Understanding What is Needed

3. Framing Adaptation to Climate Change

- Introducing an era-based approach to framing adaptation
- Era 1 - Modelling climate change impacts
- Era 2 - Early thinking about vulnerability assessments
- Era 3 - Adaptive capacity
- Era 4 - Adaptation policy assessments
- Major South African climate change policy processes
- Era 5 - Adaptation as a social-institutional learning pathway
- Reframing adaptation - summary reflections

4. Adaptation as a Social-Institutional Learning Pathway

- Introduction
- Adaptation as a wicked issue
- Building adaptive capacity through social learning
- What do social-institutional learning pathways look like?

5. What Might be Required to 'Mainstream' Climate Change Adaptation Within South Africa's Water Resources Sector?

- Raising the profile
- Reinforcing the need for IWRM
- A focus on vulnerabilities
- Ecosystem-based approaches to adaptation
- Developing adaptive capacity - specific adaptation responses
- Adaptive management as a source of adaptive capacity
- New ways of thinking about and planning for the future - short term shocks vs long term stresses
- Shifting from South Africa's current WRM practices to IWRM/AWRM is itself a process of adaptive learning
- Summary

Part 3 Making it Happen

6. Who Should do What? The Role of Different Actors, With a Central Focus on Innovation Brokers and Systemic Intermediaries

- Introduction
- Innovation brokers and systemic intermediaries
- The role of NGOs
- The role of universities
- The role of business
- Major cities as innovation hubs
- What role should DWA be playing?
- An emergent strategy?

7. Conclusions and Recommendations

The focus of the extended reference guides has therefore been on exploring these framings and how this can help diverse actors in diverse positions to support the adaptive management of South Africa's water resources in the context of climate variability and longer term climate change. Particular attention was given to a key group of actors, *viz*. the systemic intermediaries, as these individuals and

organisations have a leading role to play in integrating as well as adapting water resources management practices and governance.

ACKNOWLEDGEMENTS

The Project Team wishes to acknowledge the generous financial contribution to this project from the Water Research Commission and the large measure of guidance and encouragement received from the project's Reference Group, listed below, and under the able chairmanship of Dr Chris Moseki.

Dr C. Moseki (Chair)	Water Research Commission
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CHAPTER 1: SETTING THE SCENE

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1.1 A Brief Introduction

Based on the Terms of Reference of this solicited WRC project, the main objective was to develop a framework that reflects an integrative adaptive management approach in order to facilitate strategy development that takes into account vulnerabilities and impacts of climate change in relation to water planning and management. Furthermore, the study had to reflect on the analysis of climate change-related uncertainties and risks in the context of the development of techniques for integrating long-term climate risks into short- to medium-term development policy decisions and projects. All activities aimed at developing methodologies that would provide support to the water sector in general and more specifically to the Department of Water and Environmental Affairs (DWEA) in mainstreaming climate change adaptation measures into water resources management.

The specific deliverables requested by the WRC were to:

5. Undertake a comprehensive analysis using state-of-the-art results (including uncertainties and risks) of climate change-related impacts facing water development investments across critical sectors;
6. Provide guidelines for the reduction of uncertainties through improved monitoring and modelling;
7. Develop adaptive integrated management approaches in support of strategies for taking vulnerabilities and climate impacts into account;
8. Identify a suitable toolkit for vulnerability assessments and adaption action; and to
9. Take relevant completed and on-going projects into account.

Another key aspect of the Terms of Reference was the alignment of all activities with DWEA's Water for Growth and Development (WfGD) Strategy. However, this policy seems to have been dormant since its last public version No. 7 of 2009. The members of the Reference Group therefore advised the project team that, whilst policy linkages were important, the working environment of the project should be kept dynamic just as the South African water policy field is in itself dynamic. It was also recommended that the project team should take the opportunity to collaborate with the people who are behind the policy rather than focusing on the policy *per se*.

Following the advice of the Reference Group the research team also orientated the research towards development rather than growth. This was guided by the definition of Farley and Daly (2006) which explicitly distinguishes between economic growth, understood as the increase in the rate at which the economy transforms natural resources into economic output and waste, and economic development, which is an increase in human welfare for a given level of resource use. Thus, a strong focus in the context of this research project has been on vulnerabilities of water resources and especially those impacting on human livelihoods, as well as feedback and feed forward mechanisms (cf. **Section B**). As the climate change (CC) signal for South Africa is projected to be significant in decades to come, this topic has emerged as a dominant theme throughout this research report. Specifically, the uncertainties associated with CC are challenging - not only in understanding the impacts and resulting vulnerabilities of climate change (cf. **Section A**), but also for the design of actual management interventions. The latter needs to be contextualized within the adaptation research domain and in the overall water governance landscape of South Africa (cf. **Section C**) if sustainable development is to be achieved.

Because of the substantial increase in complexity of water management and adaptation *per se*, but also because of the challenges of South Africa's governance landscape, this project had to take cognizance of other related on-going and completed research projects and specifically build upon the outcomes of WRC project K5/1843. Within this present project the uncertainty and mainstreaming

work as well as the handbook which was developed are probably the most closely linked research activities in this regard. The research team fulfilled the above by producing three final products:

1. A final report,
2. A comprehensive, full-length handbook, and
3. A shorter more user-oriented handbook.

The final report reflects the 7 deliverables as indicated in the terms of reference:

8. A framework for integrative adaptive management approaches;
9. A report on monitoring and climate change information, updating needs that may assist with reducing uncertainties;
10. An analysis of climate change-related risks facing water related development investments;
11. A toolkit for vulnerability assessments and adaptation actions;
12. Procedures and methodologies to support the DWEA and the water sector on mainstreaming of climate risks into water management and planning processes;
13. Workshops, progress reports, scientific publications and popular articles for public consumption; and
14. A final report on mainstreaming climate change adaptation options.

These 7 deliverables were divided into four main sections covering distinct, but related fields. These are:

Section	Title	Content	Related Deliverables
A	Biophysical Information On Climate Change And Discussions On Uncertainty	• Update The Knowledge On Climate Change Impacts In South Africa. • Clarify And, Where Possible, Reduce Uncertainties Related To Adaptation Options.	2, 7 and partially 3
B	Evaluate Existing As Well As Possible Future Vulnerabilities Of Different Critical Water Use Sectors And Society	• Evaluate Existing As Well As Possible Future Vulnerabilities Of Different Critical Water Use Sectors And Society. • Assessment Of Adaptation Activities And Options.	3, 7 and partially 4
C	Governance And Mainstreaming In Climate Change Adaptation	• Create An Adaptive And Integrated Management Approach. • Prioritise Adaptation Activities And Options. • Mainstreaming Climate Change Into Governmental Organisations, Institutions And Their Rules Of Operation And Interaction.	1, 4, 5 and 7
D	Overarching Lessons Learned And Knowledge Transfer	• Lessons Learned Based On The Transdisciplinary And Adaptive Mode Of Research. • Listing Of Workshops, Scientific Publications, Popular Articles/Activities And Capacity Building Initiatives.	6 and 7

1.2 The Project's Narrative and its Challenges

The narrative of this project is multi-dimensional and complex. We had to learn to adapt and live with changing parameters - almost on an on-going basis. Therefore, some changes had to be made to the project approach, while also keeping to the overall rationale from the Terms of Reference as the canvas on which the project unfolded. The key challenges were:

5. The policy document "Water for Growth and Development" has been superseded; and
6. Based on this it was difficult to approach representatives at the national level in order to develop appropriate approaches and material for implementation.

In discussion with, and the support of, the project's Reference Group it was therefore decided to:

7. use general issues regarding "Water for Development in the South African Context"' as a point of departure, and to
8. change the 'client' from the national level, and specifically the Department of Water Affairs, to catchment and regional level focusing on champion networks, communities of practice and others.

Furthermore, the project team adopted a transdisciplinary and a social learning approach to its research activities. These approaches proved to be very challenging, not least as members of the team themselves went through changes (e.g. two main partners changed organisations during the course of the project). This first team workshop also aimed at understanding the inter-relationships of the various project deliverables as shown in **Figure 1.2.1**. Furthermore, in the section to follow (cf. **Section 1.3**) the team reflected on its own practice and shared personal and joint stories of this adventure and the learning path the members all had been on. Such an approach highlights some of the key challenges, but also opportunities, of inter- and transdisciplinary within the broader water sector in a South African context.

1.2.1 Starting conditions

The 'starting conditions' of any initiative help to shape the pathways that it pursues (**Box 1.2.1**). In addition to the details of a project's objectives, starting conditions of a multi-faceted and multi-institutional project commonly include the history, experience and research traditions of consortium members as well as those of key stakeholders. With regard to the former, two sets of starting conditions were particularly relevant to this proposal, *viz*. the breadth of the various team members' experiences of climate change adaptation work; and the prior experience of one member (John Colvin) in working on integrative and adaptive management approaches in the South African water resources sector through a programme called Watercourse.

Box 1.2.1 Starting conditions matter

'Initial starting conditions' and 'pathway dependency' are both concepts of concern to systems theorists and practitioners (Ison *et al.,* 2011). In complex systems the sensitivity to initial starting conditions of unfolding dynamics is now well known (e.g. Chapman, 2002). Path dependence explains how the set of decisions that are faced for any given circumstance is limited by the decisions that have been made in the past, even though past circumstances may no longer be relevant. In economics and the social sciences, path dependence can refer either to outcomes at a single moment in time or to long run equilibria of processes. In common usage, the phrase implies either (i) that "history matters" or (ii) that "predictable amplifications of small differences are a disproportionate cause of later circumstances". In the absence of contextual appreciation (i.e. what initial starting conditions exist? what is the history of the situation? what are the explicit or implicit 'framing conditions'?), innovations can easily fail.

Important starting conditions include an understanding of both the specific historical, cultural, political, environmental, economic and spatial conditions in which work is being undertaken (Mukute and Lotz-Sisitka, 2012) and the early dynamics taking place within the project team and between project team and the funding body.

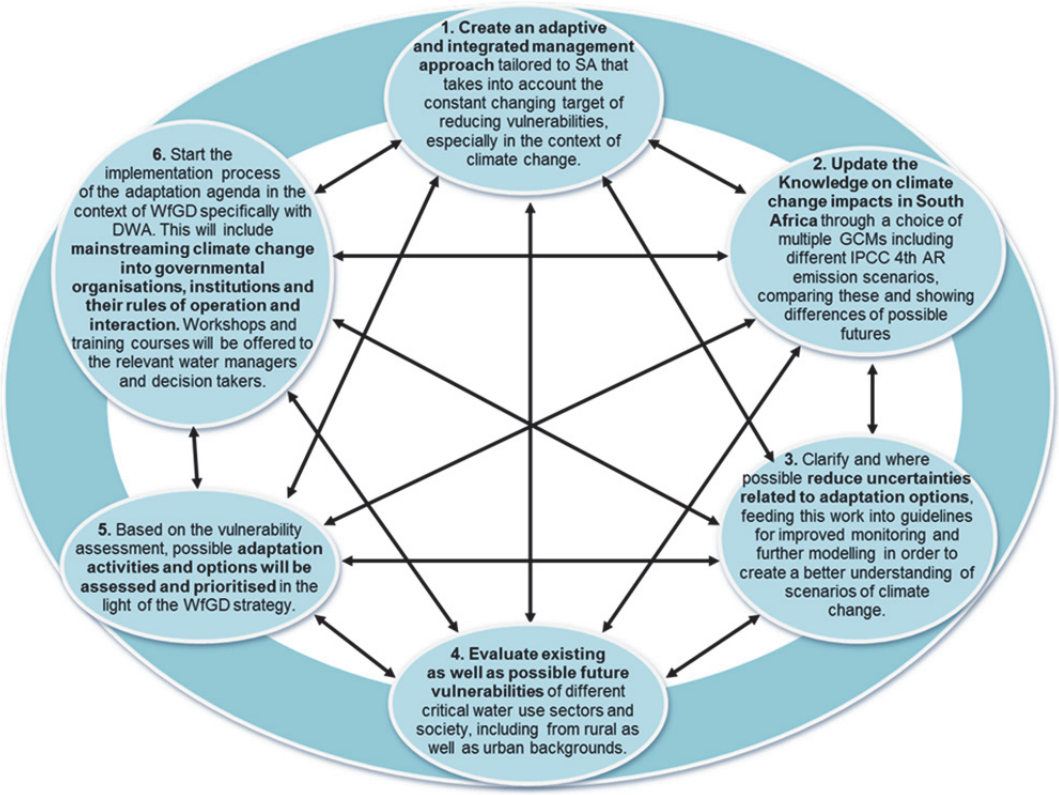


Figure 1.2.1 Diagram showing the six aims (and work packages) of the project and their potential inter-dependencies, as conceptualised at the commencement of the project

The initial project team included a broad range, and in some cases distinguished history, of work in South Africa on:

1. Climate change modelling and downscaling in the water and agricultural sectors (Schulze);
2. Disaster risk management and climate change research (Vogel);
3. Policy and action research experience in integrated and adaptive approaches to water governance (Colvin);
4. Community vulnerabilities, sustainable livelihoods and community-based planning (Chimbuya);
5. Sustainable livelihoods and community empowerment (Shisana); and
6. Consultancy and research in hydrology, water institutions, governance and climate mainstreaming (Stuart-Hill).

Furthermore, several members of the team (Schulze, Colvin and Stuart-Hill) had collaborated on a previous WRC-funded project, *viz*. K5-1843, which had made a significant contribution to developing the building blocks of an "integrative adaptive management approach for facilitation of strategies for taking account of vulnerabilities and impacts of climate change in relation to water planning and management".

The Watercourse programme was the source of a further and important set of start conditions. Undertaken over the 6-year period (2005-2010), the purpose of this programme had been to strengthen capacity for implementing integrated water resource management practices in South Africa in the context of the DWA's National Water Resources Strategy (NWRS, 2004), while also beginning to embed adaptive management practices. The design of Watercourse was based around a series of long-term, linked, multi-stakeholder dialogue processes as a means of enabling stakeholders to "learn their way" towards integrated and adaptive water resources management practices at both local, sub-catchment, river basin and national (policy) levels. The designs for these dialogue processes were based on whole systems principles and enabled the development of consensus and collaborative planning and action across stakeholders with widely differing interests and backgrounds, from traditional communities to commercial farmers and from environmental NGOs to government departments (Colvin *et al.,* 2008; Collins *et al.,* 2008; Colvin *et al.,* 2010a, b; Colvin *et al.,* 2011a, b, c). Key findings of the Watercourse programme were as follows:

In each of the sub-national pathfinders, the whole system methodologies proved effective in bringing together diverse stakeholders from different sectors including research, policy and implementation backgrounds. The dialogue processes helped stakeholders to make sense of their situation and to explore and agree new institutional processes and arrangements that would enable them more effectively to implement the NWRS within their specific contexts. Two of the pathfinders in particular led to significant new agreements, *viz*. for an integrated approach to water resources management in the Inkomati catchment (Colvin *et al.,* 2008; 2011a) and for a new, catchment-wide Water User Association in the Mvoti catchment, based on IWRM principles (Colvin *et al.,* 2010a). However, it proved much more difficult to support sustainable policy learning at the National Department of Water Affairs (DWA), in spite of the many rich and valuable lessons that flowed from the sub-national pathfinders. The national policy environment was much more dynamic than the situations of the sub-national pathfinders, with several changes during the six-year period at Ministerial, Director General (DG) and Deputy DG levels. Furthermore, many key staff left during this period. Thus, despite strong national policy support for the capacity building programme in its first two years, in its later phases policy learning failed to keep track of adaptation and innovation processes more locally, creating significant policy and implementation bottlenecks. The Watercourse work therefore provided the team, *via* John Colvin, with a significant experience of working on water sector reform in South Africa, and specifically on building capacity for integrated and adaptive approaches, and of engaging with stakeholders at all levels of governance over significant time periods. The programme also provided experience in undertaking transdisciplinary research (**Boxes 1.2.2** and **1.2.3**) in the water sector, drawing on action research approaches.

Box 1.2.2 Transdisciplinarity (Source: Swilling, 2012)

Lang *et al.* (2012) define transdisciplinarity as follows:

> Transdisciplinarity is a reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge.[1]

Transdisciplinarity has emerged as a new mode of knowledge co-production *with*, rather than *for*, society in order to deal with complex societal problems that can no longer be approached and solved by mono-disciplinary approaches only (for the most significant contributions see Hirsch-Hadorn *et al.,* 2006; Hadorn and Pohl 2008; Regeer and Bunders 2009; Scholz 2011; Lang *et al.,* 2012). As a new mode of knowledge production, transdisciplinarity has been conceptualised as being capable of producing both practical, useful knowledge for solving real-world problems as well as theoretical, scientific knowledge for better understanding our complex world. Global warming and climate change, natural resource depletion, soil degradation, pollution, food security, increasing poverty as well as water and energy crises are just a few examples of such complex societal problems warranting a transdisciplinary response.

These problems are complex because they are truly planetary-level problems, existing simultaneously at the global and local scales. But they are also complex because they are being produced by both nature and society, and therefore also have far-reaching long-term consequences for both nature and society. These are 'entangled' or 'hybrid' problems that can no longer be approached in terms of the two-world theory and disciplinary divide of separating the 'natural' from the 'social' as supposedly two fundamentally different and unconnected realities that can only be worked on separately by the natural and social science in isolation of society. Attempts to work within this double disciplinary and science vs society divide can only result in the single disciplines producing partial knowledge of these hybrid problems; whereas the need today is clearly for integrated solutions based on integrated knowledge (Morin, 1999).

In order to justify its claim as a new mode of knowledge co-production, capable of producing both scientific and practical knowledge, it has been critical for transdisciplinarity to establish itself within the scientific community as a credible scientific mode of knowledge production. To publicly demonstrate that the process of starting with shared real-world problem statements can be translated into scientific problem statements and research questions, which, in turn, can be worked on and transformed into scientific knowledge, the emphasis has very much been on the discovery, design and production of appropriate transdisciplinary methods that are replicable in different contexts.

[1] Adapted from Bergmann (2011)

Box 1.2.3 Design principles for transdisciplinary research (Source: Lang *et al.,* 2012)

These authors developed an ideal-typical model of the transdisciplinary research process conceptualized as a sequence of three phases. Though the model might indicate a rather linear process, they argue that the individual phases and the overall sequence often have to be performed in an iterative or recursive cycle, also highlighting the need for reflectivity in transdisciplinarity (see, for example, Spangenberg, 2011). The model includes design principles associated with each phase and three cross-cutting design principles (see below). While not explicitly referring to social learning, the three cross-cutting design principles are key elements of effective social learning practice.

Phase A: Collaborative problem framing and building a collaborative research team	**Phase B: Co-producing solution-oriented knowledge through collaborative research**	**Phase C: (Re)-integrating and applying the produced knowledge in both scientific and societal realms**	**General Design Principles**
• Build a collaborative research team • Create joint understanding and definition of the sustainability problem to be addressed • Collaboratively define the boundary/research object, research objectives as well as specific research questions, and success criteria • Design a methodological framework for collaborative knowledge production and integration	• Assign and support appropriate roles for practitioners and researchers • Apply and adjust integrative research methods and transdisciplinary settings for knowledge generation and integration	• Realize two-dimensional integration • Generate targeted products for both parties • Evaluate scientific and societal impact	• Facilitate continuous formative evaluation • Mitigate conflict constellations • Enhance capabilities for, and interest in, participation

1.2.2 The four learning cycles of this project

First learning cycle (October 2010 - July 2011)
During the first year of the project the team invested considerable time and effort in interdisciplinary sense-making and transdisciplinary design. This involved working towards shared understanding and agreement, first on the nature of the project's six work packages and their potential interactions (*interdisciplinary* understanding and practice), and secondly on how the research process could be designed in such a way that it was of practical value to the DWA and potentially also to other stakeholders (*transdisciplinary* understanding and practice).

Two workshops on team social learning were held to support this process: the first at the outset of the project in October 2010 and the second in June 2011. A significant outcome of the first workshop, in which team members met for the first time[2], was agreement to adopt a 'non-traditional' approach to the research process. Rather than first undertaking the research (**Figure 1.2.1**: work packages 1-5) and then engaging with stakeholders through workshops and training (**Figure 1.2.1**: work package 6), consistent with a traditional, linear or 'mode 1' model of knowledge production followed by knowledge transfer[3], it was agreed that work packages 1-5 would progress in an iterative manner, through on-going engagement (work package 6) with a core group of stakeholders, primarily in DWA. This latter approach requires and builds transdisciplinary, i.e. 'mode 2' knowledge co-production practices.[4]

[2] This workshop was attended by: Sam Chimbuya (SC); John Colvin (JC); Refiloe Ntoi (potential researcher); Roland Schulze (RS); Stephen Shisana (SS); Sabine Stuart Hill (SSH); and Coleen Vogel (CV).

[3] Mode 1 knowledge concerns the production of knowledge based on reification of an external, observed reality - sometimes also referred to as 'reliable knowledge' (Nowotny, 2003)

[4] Mode 2 'knowing' is knowledge that is co-produced through a relational process of dialogue between stakeholders – sometimes also referred to as 'socially robust knowledge' (see Gibbons *et al.,* 1994; RELU, 2007; Ison *et al.,* 2011)

This was a significant agreement, as it implied a re-shaping of the design of the entire 3-year project. Specifically, it was agreed that while some initial work should be undertaken within each of work packages 1-5 (with the nature of this research varying according to the specific requirements of each work package), the purpose of this initial work should be to prepare for a series of sense-making interactions with a core stakeholder group, with the intention that further work on each work package, and on their interactions, would be guided by the social learning and knowledge outcomes that took place through each engagement with the stakeholder group. This meant, for example, that rather than presenting preferred interpretations of 'vulnerability assessment', 'adaption options' and 'mainstreaming' to the core stakeholder group, our aim would be to seek to determine key questions, priorities and the research to address these through a co-production process, enabling us to explore a variety of meanings of 'vulnerability assessment', 'adaption options', and 'mainstreaming' with this group, in the context both of their current knowledge practices and of normative futures implied by climate change adaptation. This in turn meant that, for example, the mode 1 research priorities for work package 4 during the first year was to research different framings and meanings of vulnerability assessment, placing these in historical and cultural contexts (Fussel and Klein, 2006; O'Brien *et al.,* 2007; Fussel, 2009).

Work package 6 thus acquired a meta-role in relation to the other five work packages, with initial work within the work package focusing on the outline design of the overall stakeholder engagement process and the detailed design of the initial engagement, including agreement and selection of stakeholders for this engagement. This design work was supported through interaction with the project Reference Group and deepened at the second team social learning workshop in June 2011, when initial work on each of the work packages 1-5 was also shared and discussed.[5]

This second workshop also provided an opportunity to further clarify the overall systemic design of the project, updating the design in **Figure 1.2.1**. As shown in **Figure 1.2.2**, this led to a re-drawing of the diagram in **Figure 1.2.1**, placing aim 6 at the centre of the diagram, and indicating that (through a green rather than blue background) this aim (now re-labelled 'aim 6b')[6] was to be delivered through a mode 2 knowledge co-production process (Colvin *et al.,* 2011: **Chapters 1**, **8**). To support aim 6b, an 'aim 6a' was also introduced, concerned with mode 1 researching of effective processes of 'mainstreaming' and policy implementation in the context of the TOR.

Figure 1.2.2 also shows that as a result of the second workshop we were able to clarify a further knowledge intermediation process (outer green circle) operating between work packages 1-6a and work package 6b. The reason for this further knowledge intermediation is that it should not be taken for granted that in some logical, perhaps even linear, sense, aims 1-6a fit together in a non-problematical and uncontested manner. Rather, it is important to recognise that each aim arises from its own disciplinary domain (or in some cases from multiple disciplinary domains) and that seeing the inter-relationships between the aims necessarily involves interdisciplinary sense-making by the project team (a mode 2 process) - hence aim 1b, now separated out from aim 1a. Furthermore, this interdisciplinary sense-making also functions as an intermediation process between the aims 1a-6a and the sense-making with stakeholders undertaken through aim 6b. Aim 1b also highlighted our agreement as a project team that the flow of knowledge (co)production back and forth across the outer, middle and inner circles became an iterative process, based on cycles of inquiry managed through an adaptive project management approach. In this sense, the management of the project is designed to 'walk the talk' of (and enable us to learn more about) the 'adaptive and integrated management approach' (aim 1a) that we are researching as one of the key elements of 'mainstreaming climate risks into water management processes' (aim 6b).

[5] This second workshop was attended by SC, JC, RS, SS and SSH. Refiloe Ntoi had by then disengaged from the project, while CV was unable to attend due to health reasons. Simphiwe Ngcobo (SN) and Ntombifuthi Vilakazi (NV), two MSc students who had recently joined the project, also attended the workshop.

[6] We also added the additional text: 'Develop procedures and methodologies to support the Department and sector in mainstreaming climate risks into water management and planning processes' to the text of aim 6b, as this TOR deliverable (5) adds an additional requirement not properly expressed in aim 6b.

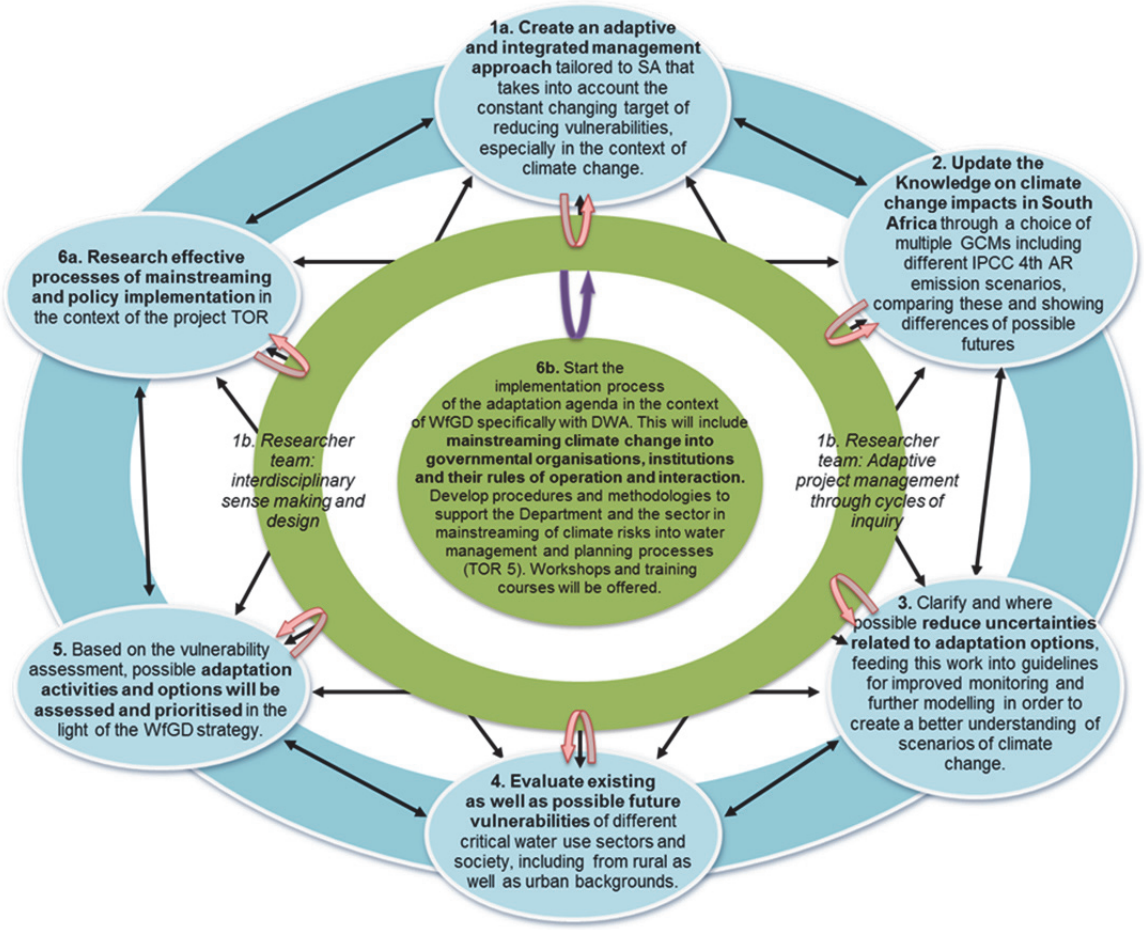


Figure 1.2.2 Redrawing of **Figure 1.2.1**, to further clarify the overall systemic design of the project, with the separation of work package 1 and work package 6 each into two work packages explained in the text

Building on the above, by mid-July 2011 the project team had agreed on a list of stakeholders (primarily, senior members of staff at DWA) to be invited to form a 'core group' at a policy workshop in early September 2011[7], had developed a detailed design for the workshop (Colvin *et al.,* 2011: Annex 2) and had an invitation letter ready to distribute.

In summary, during this first learning cycle the project team developed shared enthusiasm and commitment to a transdisciplinary approach. Social learning among team members helped them begin to understand what such an approach might mean in practice, as reflected in the plans and preparations for the first stakeholder workshop, while conceptually, the approach was represented and refined in the systemic diagrams shown in **Figures 1.2.1** and **1.2.2**. The culture of the team during this period was collaborative and the project at this point showed considerable promise.

At the same time two potential constraints had also appeared by this point. The first was the temporary withdrawal of CV, a senior member of the project team, from the project on health grounds. This meant that, despite enthusiastic participation in the first team workshop, she had been unable to contribute further to the research process during this period. The second potential constraint was related to the way in which the research team had grown. While at the outset the team consisted of four senior staff (including two professors [RS, CV], one local [SC] and one international consultant [JC]) and four PhD students (SSH [also the project manager], RK, TL and SS), by July 2011 the number of early career researchers on the team had grown, through the addition of two MSc students

[7] Trevor Balzer; Mbangi Nepfumbada; Ndileka Mohapi; Johan van Rooyan; Smangele Mgqubu; Thoko Sigwaza; Peter van Niekerk; Dr Beeson Mwaka - all senior staff at DWA; Zachariah Masuma (Department of Environmental Affairs); Chris Moseki (WRC).

(SN and NV)[8]. This introduced a potential structural tension within the project team, between the focus of senior team members on inter- and transdisciplinary working, and that of the six PhD and MSc students who were required to pursue more focussed academic type research.

Second learning cycle (August 2011 - January 2012)
In late July 2011 the project experienced a significant setback. The project's Reference Group, at its first meeting in February 2011, had discussed and enthusiastically supported a transdisciplinary research approach for the project. In July 2011 arrangements were made to meet with the DWA to explore the proposal for a transdisciplinary project approach and make arrangements for a policy workshop planned for September 2011. However, owing to a tender for a project[9] and subsequent discussion that revealed there were potential overlaps with our project (WRC K5/1965), further engagement activities with the DWA were postponed. Although a public service provider (PSP) was subsequently appointed to manage the other project, no further opportunities for engagement arose between the project team and DWA or the PSP.

Project team members were significantly 'thrown' by this development as (i) it highlighted our own failure to ensure this key element of stakeholding in the project at a sufficiently early stage and (ii) it had significant implications in terms of a re-think of our own project focus and approach. Mirroring the wider landscape of climate shocks and stresses, this development thus called for the project itself to 'walk the talk' of adaptation (aim 1b) and marked the end of the first and the start of the second cycle of project learning, requiring at least a 'double loop' reframing (Argyris and Schön, 1978).

In reviewing options for moving forward, opinions were divided within the team as to whether or not to submit a bid in response to the DWA call. In the end it was agreed that on member of the team (JC) would submit an independent bid, but "in association with project K5/1965". In other words, if successful, the bid team would collaborate with K5/1965 in order to deliver to both sets of objectives, while also maintaining appropriate boundaries between them.

The bid development process itself contributed significantly to two of the aims of K5/1965, in that it rapidly progressed (i) analytical thinking on 'effective processes of mainstreaming and policy implementation' (aim 6a) and (ii) design thinking on how to 'create an adaptive and integrated management approach tailored to South Africa that takes account of the constant changing target of reducing vulnerabilities, especially in the context of climate change' (aim 1a). A key element of the

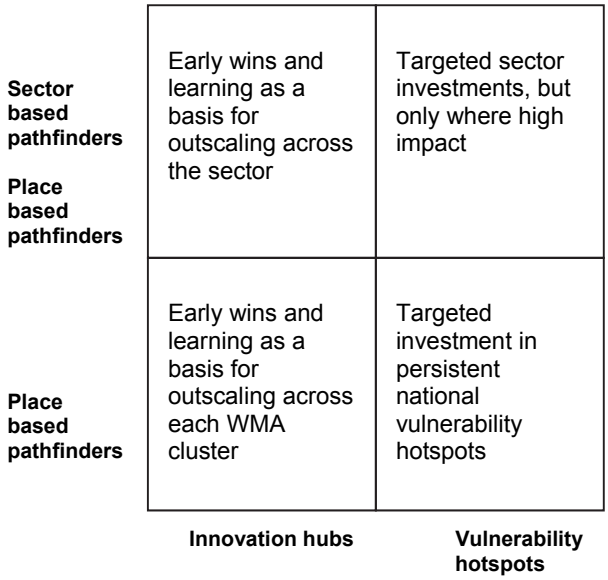


Figure 1.2.3 A framework for investment in adaptation through pathfinding, based on the concept of innovation hubs and vulnerability hotspots

[8] However , the role of RK and TL in the project was unclear. While they did not attend team meetings, it was assumed that they supported RS in the climate change modelling work.

[9] DWA Tender WP10550: Appointment of a Professional Service Provider for the "Development of a Climate Change Response Strategy for The Water Sector"

mainstreaming approach that was presented in the bid reflected a need to move away from traditional top-down approaches, which have often been "data-hungry, time-consuming to prepare, with analysis disconnected from action and, where action is foreseen, inflexible" and towards more open, participatory and flexible processes (Maxwell, 2011) based around a learning approach. Thus the bid proposed a series of pathfinders that were located within both innovation hubs and vulnerability hotspots (**Figure 1.2.3**), reflecting a strategy of learning from places and sectors where innovation was already happening (**Box 1.2.4a**), while also investing in those places or sectors that are most vulnerable (**Box 1.2.4b**).

Box 1.2.4a An 'innovation hub' can be defined as a set of institutional arrangements where adaptive capacity is already well developed, and could serve as a hub for potential outscaling. With respect to place (social geography), arrangements should involve collaborative partnerships and multi-stakeholder networks, reflecting the principles of the new IWRM institutions (such as CMAs and WUAs) set out in the first National Water Resources Strategy. Examples include:

- *the Shared Rivers Initiative in the lowveld*, where there is a concerted effort to improve implementation of current institutional arrangements (with a focus on catchment management strategies), to apply adaptive management practices and to combine expert and participatory modelling practices (Pollard and du Toit, 2010; 2011);
- *the payment for watershed services/second economy pathfinders in the Upper Thukela, Upper Mzimvubu and Baviaanskloof watersheds*, where there is a focus on exploring new institutional arrangements with local stakeholders, in the absence of catchment management agencies, based around the value to the local economy of managing ecosystem services under a range of climate change scenarios (Mander, 2008; Mander *et al.,* 2010);
- *the Berg River/Cape Town 'problemshed',* where there are multiple, interlinked stakeholder networks seeking to address intractable issues of water quality, water resources, agriculture, urban development and climate change adaptation, through engagement with a range of formal and informal governance systems (Callaway *et al*., 2009; Colvin, 2010; Methner and Ernstson, 2011).

Box 1.2.4b A 'vulnerability hotspot' describes an area (social geography) or a sector where vulnerabilities are particularly strong and adaptive capacity particularly weak. While the benefit to cost ratio of investing in innovation hubs is far higher than that of investing in vulnerability hotspots, there may also be important grounds for carefully targeted investment in tackling a limited number of vulnerability hotspots, particularly as a basis for learning what works (prior to outscaling).

The independent member's bid was unsuccessful and no feedback was given on the quality of the bid. During the waiting period of 5 months the team therefore moved into a period of uncertainty, during which it was decided to plan for both positive and negative outcomes to the bid process. The latter generated a series of seven options which fell into three clusters: those where the DWA remained as the primary stakeholder focus; those where the stakeholder focus was broadened to a partnership that included the DWA; and those that took a more systemic focus (**Table 1.2.1**).

In summary, this second learning cycle, in strong contrast to the first, was characterized primarily by independent activities within the project team. As these individualized practices became more embedded within the project, it also became increasingly unclear where and how PhD and MSc work was contributing to the project and where it was being carried out outside the boundaries of the project. As RS noted in a conversation following the second meeting of the Reference Group in November 2011: "we need to become much better at distinguishing where PhD and MSc projects are contributing to this project and where they are not".

Table 1.2.1 Summary of options for progressing K5/1965 during the remainder of the project January 2012 - March 2013

The DWA remains the primary stakeholder focus	Focus broadens to a specific partnership	More systemic focus
(a) Seek to re-engage the DWA head office in the co-production process originally proposed in July 2011	(d) Work with an existing stakeholder partnership (including the DWA) whose work is directly relevant to this project	(f) Map observed adaptation activities across the South African water resources sector
(b) Focus on a DWA regional office rather than on the DWA national office	(e) Invest in a climate adaptation leadership training and development programme	(g) Focus on one or more case studies, where adaptive and integrated water management approaches are already emerging
(c) Develop a series of briefings for DWA staff, backed up by 'think pieces' and academic papers		

Third learning cycle (February - September 2012)

The failure of the individual member's bid to the DWA in late January 2012 led to the unintended consequence of further institutionalizing individualized research practices. At the same time the project came under pressure from the WRC to 'deliver stakeholder workshops'.[10] Despite the original focus on the national Water for Growth and Development strategy it was therefore agreed with the WRC that, given the difficulties experienced in engaging with the national DWA office, the project should seek engagement through workshops at a provincial and even more local level. In this context, it was decided that SSH would focus her efforts on further workshops with 'climate change adaptation champions' in the uMngeni and Berg catchments, while JC would develop an engagement process in the Eastern Cape, reflecting a combination of options (see **Table 1.2.1** above). This led to discussions with Rhodes University to develop a community of climate change adaptation leadership practice, which could draw on their extensive networks, on-going projects and established reputation within the Eastern Cape water sector. An outline design for the programme was developed, which would develop material derived both from the research work undertaken through K5/1965 and potentially also from training and development materials developed and tested in other contexts[11] (**Box 1.2.5**).

Box 1.2.5 Summary of the proposal to develop a community of climate change adaptation leadership practice in the Eastern Cape

The purpose of the work in the Eastern Cape over the 12-month period September 2012 - August 2013 was to explore/scope, as an adaptation option in itself, the development and co-researching of a community of leadership practice in the province, which would focus on the practical understanding and implementation of climate change adaptation options in the water sector. The precise extent of what might be achieved over this 12-month period would be determined by the unfolding dynamics of the inquiry, but we might expect within this period to have:

- Understood how such an initiative might build on and complement current and planned water-focused inter- and transdisciplinary work at Rhodes;
- Agreed the purpose and linked to this, a spatial and sectorial focus for the community of leadership practice, including:
  - how many and which layers of governance it should embrace;
  - what kind of sectorial diversity it should embrace (given that the 'water sector' can include

[10] Early on in the project, the WRC had requested that 1/6th of the budget was set aside specifically for the purpose of supporting 'stakeholder workshops'.

[11] During 2012 I developed and tested a range of relevant materials to support stakeholder learning about climate change adaptation processes and options, including through the 3-week Global Climate Adaptation Partnership (GCAP) Academy Foundation Course on Climate Change Adaptation (August 2012) and through a consultancy with the WWF Network (January - October 2012) to support the development of effective practices of learning for adaptation.

everyone);
  - potential learning links, if any, between provincial and national policies and strategies;
- Agreed upon a design for the development of the community of leadership practice (a 'learning system design'), including:
  - a broad outline of content and activities;
  - a programme structure, for example, a series of eight 2- or 3-day workshops every 3 months, interspersed with practical learning assignments;
  - an approach to accreditation, if any; and
  - a programme for facilitators/researchers/ 'faculty';
- Convened the first, exploratory meeting of the community of leadership practice, for example, as a 3 to 5-day 'short course';
- Ensured that, as far as is appropriate, this short course highlights and/or draws on the main research themes within K5/1965, including:
  - updated knowledge on climate change impacts in South Africa through a choice of multiple Global Climate Models;
  - an understanding of uncertainties in relation to adaptation options;
  - an understanding of existing as well as possible future vulnerabilities of critical water use sectors, how these are framed and how these might be reduced;
  - how to assess possible adaptation activities and options;
  - how to develop an adaptive and integrative management response;
- Explored the potential for the development of an on-going community of leadership practice, over an agreed period of time (e.g. 2 years);
- Agreed on a framework for co-researching the development and formative evaluation of this community of leadership practice; and
- Agreed upon an approach to funding this full leadership development 'programme'.

The third project team meeting took place in September 2012, involving further additions to the team, *viz*. a research assistant (Nicholas Davis, ND) and a new MSc student (Stefanie Schütte, SS).

In summary, this third learning cycle was characterized by on-going flexibility and re-organizing by members of the project team, as a response to the difficulties encountered in engaging with the national DWA office. Specifically, relationships and trust were mobilized that had been developed with Rhodes University over the previous two years to put together a proposal that spoke not only to the blunt requirement of 'stakeholder workshops', but also to the more nuanced needs of developing adaptive capacity at a cross-institutional level. However, this willingness and ability to mobilize a creative response following the failure of the individual member's bid to the DWA could not be matched by the level of financial flexibility within the K5/1965 project, which therefore emerged as a significant barrier to effective adaptation of JC's contribution to the project during the third learning cycle. This financial inflexibility was a reflection largely of the contractual agreement between the WRC and the UKZN.

Fourth learning cycle (October 2012 - September 2013)

However, three developments closely following this critical incident opened up new opportunities to reframe the project. First, CV had rejoined the project in August 2012 and discussions rekindled a spark that had been ignited at the first project team workshop in October 2010. Searching again for a double loop reframing of focus for the final phase of the project, CV and JC set out a proposal focusing on the (partially) collaborative development of the project's proposed 'handbook'.

JC co-designed and co-facilitated a workshop within a larger international conference held at the Drakensburg Sports Resort, KwaZulu-Natal in November 2012. The theme of the conference was 'Freshwater Governance for Sustainable Development' and the workshop explored the theme: 'More systemic, more adaptive: The way forward for water governance?'[12] The workshop was framed from a transdisciplinary perspective, drawing on theoretical and methodological pluralism in systemic action research (Midgley, 2011), and the workshop engaged with a number of the core themes of the K5/1965 project, particularly those falling under aims 1a (creating integrated and adaptive management approaches) and 6a (researching effective approaches of mainstreaming and policy implementation). But perhaps, most importantly, the workshop attracted and generated interest

[12] There were five other co-facilitators: Dr Sharon Pollard and Derick du Toit (AWARD), Dr Harry Biggs (SANParks), Professor Ray Ison (Open University and Monash University) and Dr Phil Wallis (Monash Sustainability Institute).

among several key figures from the national DWA office as well as from the wider stakeholder community. This demonstrated not only that there was an appetite for engaging with the complexities of water governance, but also that there was a real interest in understanding the contribution of systemic and adaptive approaches and how these could be made to work in practice. This encouraged JC to position these as core themes within the handbook.

The development of both handbooks, long and short, has been an interesting process, reflecting a move away from transdisciplinary engagement, but with a commitment to ground it in interdisciplinary dialogue. While there have been asymmetries in this dialogue, the handbook narrative structure was shaped according to **Box 1.2.6** as well as its core focus on a (hypothetical) community of systemic intermediaries, innovation brokers and bridging organisations (**Figure 1.2.4**).

Box 1.2.6 Narrative structure of the extended handbook

A core feature of the narrative structure of the handbook is a focus on 'framing' (O'Brien *et al.,* 2010). Framing matters in climate change adaptation for several reasons. First, framing and power are closely connected, with the powerful mediating the dominant frames (Vink *et al.,* 2013). Yet climate change adaptation requires a focus on the vulnerable. Secondly, therefore, empowering the vulnerable to frame strategies for coping, adapting, or even transforming should be a central theme of building adaptive capacity. Thirdly, framings of adaptation and adaptation practices have evolved substantially over the past 20 years and continue to evolve (Fussel and Klein, 2006). It is important, therefore, to understand these reframings so as not to become stuck in outmoded ways of thinking and acting. Specifically, frames have moved from scientific to inter- and transdisciplinary (O'Brien, 2012); and from 'out there' to combining 'external' and 'internal' practice (O'Brien, 2013). Fourthly, different ways of framing futurities is a critical issue in climate change adaptation, including addressing the tension between shorter-term shocks and longer-term stresses (Leach *et al*., 2010; Stirling, 2011). And finally, 'seeing frames' helps us to contextualise, learn and build reflexivity.

The focus of the extended handbook is therefore on exploring these framings and how this can help diverse actors in diverse positions to support the adaptive management of South Africa's water resources in the context of climate variability and longer-term climate change. Particular attention is given to a key group of actors, *viz*. the systemic intermediaries, as these individuals and organisations have a leading role to play in integrating as well as adapting water resources management practices and governance.

The chapters of the handbook are sequenced as follows:

1. Introduction and background

PART 1 The current situation

2. How does South Africa currently manage its water resources?
- Challenges of managing water resources in South Africa
- Recognising the complexity of managing South Africa's water resources
- Taking account of climate variabilities in managing South Africa's water resources
- Water resources as a 'wicked issue'
- The policy response – IWRM
- Implementing IWRM – two case studies
- Why has the South African Department of Water Affairs found it so difficult to implement an IWRM approach?
- Barriers to implementing an IWRM approach (2): Competing stakeholder interests and framings

PART 2 Understanding what is needed

3. Framing adaptation to climate change
- Introducing an era-based approach to framing adaptation
- Era 1 - Modelling climate change impacts
- Era 2 - Early thinking about vulnerability assessments
- Era 3 - Adaptive capacity
- Era 4 - Adaptation policy assessments

- Major South African climate change policy processes
- Era 5 - Adaptation as a social-institutional learning pathway
- Reframing adaptation - summary reflections

4. Adaptation as a social-institutional learning pathway

- Introduction
- Adaptation as a wicked issue
- Building adaptive capacity through social learning
- What do social-institutional learning pathways look like?

5. What might be required to 'mainstream' climate change adaptation within South Africa's water resources sector?

- Raising the profile
- Reinforcing the need for IWRM
- A focus on vulnerabilities
- Ecosystem-based approaches to adaptation
- Developing adaptive capacity - specific adaptation responses
- Adaptive management as a source of adaptive capacity
- New ways of thinking about and planning for the future - short term shocks vs long term stresses
- Shifting from South Africa's current WRM practices to IWRM/AWRM is itself a process of adaptive learning
- Summary

PART 3 Making it happen

6. Who should do what? The role of different actors, with a central focus on innovation brokers and systemic intermediaries

- Introduction
- Innovation brokers and systemic intermediaries
- The role of NGOs
- The role of universities
- The role of business
- Major cities as innovation hubs
- What role should DWA be playing?
- An emergent strategy?

7. Conclusions and recommendations

The development of the extended handbook has been a 'learning process' in itself. To ensure that the handbook is accessible and, indeed, will be taken up, the team then also decided to try and capture the richness in the handbook in a 'shorter' version for practitioners. Mindful that many practitioners are busy, the plan was also to try and 'reduce' this even further into a 2-pager for practitioners.

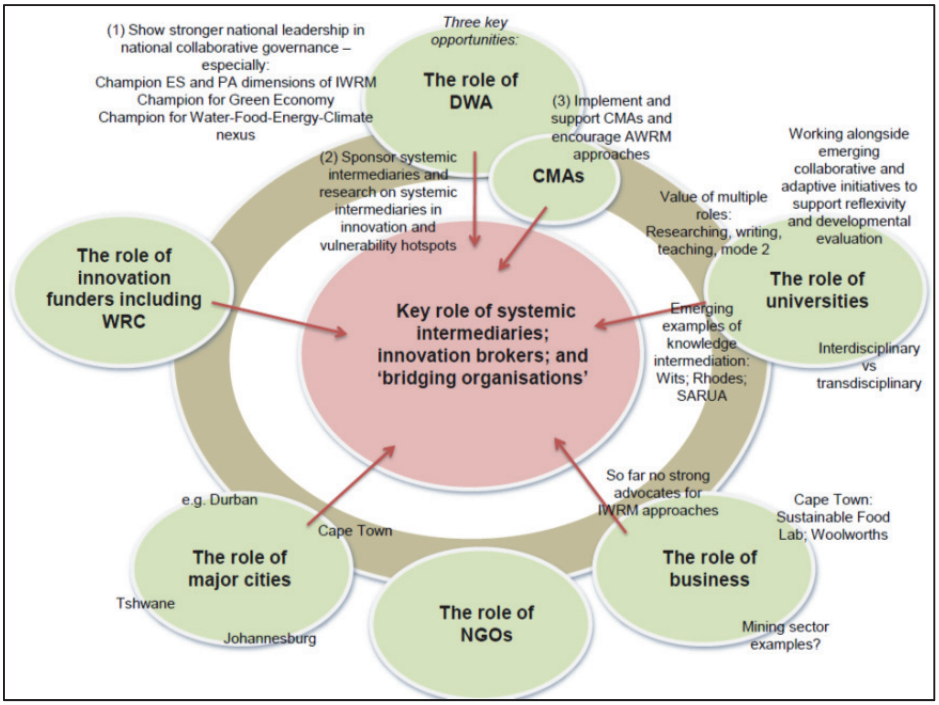


Figure 1.2.4 Intended audiences for the handbook, with a core focus on a (hypothetical) community of systemic intermediaries, innovation brokers and bridging organisations

1.3 Research Stories and Reflections from the Project Team Members

Based on the multi-dimensional learning experiences of the project team within as well as beyond the four learning cycles, the research team decided that it would be useful to include accounts of personal experiences. This should help to aid in laying out other research processes especially when those are of a transdisciplinary and adaptive nature. In the following sections, the research stories of several researchers and students are presented, including some personal reflections. This is followed by a conclusion with some preliminary overarching lessons learned, as well as recommendations for further research. At the end of this final report a section looks specifically at overall lessons learned from the project. This is where some of the issues will be reflected upon once again.

1.3.1 Sabine Stuart-Hill

As the project leader and also principal investigator of this project, I already had a multi-dimensional role to play. This was further complicated by simultaneously being a PhD student on the project. The latter made me appreciate the challenges of doing research in a dynamic project environment as described under **Section 1.2** when at the same time the research itself has its own dynamics that are not always aligned with the aim of the project.

Being the project leader…
At the beginning of this project a considerable amount of my energy had to go into the administrative process of creating the main contract and sub-contracts. And overall, getting the partners on board and committed to the process was delayed due to maternity leave in 2010. The start-up phase took longer than I would have ever contemplated. The challenges in regard to main collaborators moving organisations or even dropping out for some significant time were heavy and challenging, as the project proposal was specifically designed around those partners and their expertise. In South Africa we are very limited with skills and expertise in the sphere of Water Governance and Management Implementation. Thus, 'just getting someone else' with similar expertise to take over was not possible.

Furthermore, it was difficult to strike a balance between an innovative research approach (transdisciplinarity), the criteria of receiving funding from the donor only upon deliverables and the inflexibility of the project proposal/contract. However, with our WRC research manager we were fortunate to have someone who was familiar with adaptive research approaches and appreciated the specific challenges of our project topic and the project team. This made project life much easier.

Being the principal investigator…
Over time I increasingly recognised the unusual design of the Terms of Reference. The project was, and is, actually a hybrid of pure research, action research and consultancy. So, how to do research with a moving target, *viz*. a politically highly influenced field with many hidden agendas? It soon became apparent to me that the Water for Growth and Development programme could not be the key document around which all activities were to evolve (as originally envisaged). A different approach was needed and over time three main themes emerged: information design, vulnerabilities (existing as well as those emerging under climate change) and governance, including mainstreaming of climate change into governance. But how to merge these fully under a transdisciplinary research approach was something I had, and still have, no idea about. My assumption was that each partner in the project had a type of work package that from time to time (annually in our team workshops) we would introduce to each other and from there take knowledge and messages 'home' and incorporate those into our research and adapt approaches, methodologies etc. But at the same time we would stay in contact with our fellow researchers in order to have an adaptive and iterative approach as we were aiming at jointly walking our paths of inquiry. This was, especially with our young and emerging scientists, not possible.

This brings me to the next major challenge, *viz*. the post-graduates who are incorporated into every WRC project. As a post-graduate student, be it as an MSc or PhD candidate, the flexibilities are extremely limited. It almost seems that a project such as this one is partially taken hostage to the WRC's 'capacity building' needs. However, the process over the past 3 years has certainly been interesting and inspiring to the students, but the burden of flexibility and transdisciplinarity ended up being on John Colvin's and my shoulders.

Being a researcher and PhD student on the project…
Additionally, I had the pressure of finishing off my own PhD thesis, which was designed more along the theme of the published WRC project K5/1843, rather than along the theme of this project K5/1965. The latter actually aimed at moving forward from my main PhD outcomes into a joint research venture with my research partners. So in a way I was taken hostage by my own PhD research when trying to contribute in a relevant way to this project's development and write-ups.

However, the team workshops were hugely inspiring and I have gained knowledge regarding what transdisciplinary research is NOT. The needs and commitments for such an approach are hugely challenging and I am not too certain how I would design a similar project proposal. But what would have to be emphasized would be frequent team workshops (lasting 2 days), a joint writing-platform (which would exclude postgrads to a certain extent), a flexible budget and a final one week team workshop to brainstorm and 'bring it all together'. Especially, to distil the overall lessons learned from such a project takes time and much thinking - and that should actually be a learning process in itself!

1.3.2 John Colvin

At the outset of the project, in September 2010, there was growing interest among funders in Theories of Change (ToCs), but this interest was not yet fully mainstreamed. Over the intervening period the value of ToCs has become firmly established and many funding calls now require that a project ToC is stated upfront. One of the values of doing so is that it requires project teams to state explicitly, not only how they will undertake their research, but also how they anticipate that their research and its outputs will lead to positive changes (in terms of outcomes and impacts) for identified beneficiaries. Following emerging good practice, ToCs summarise not only the current situation and proposed long-term changes, but also pathways to impact and the assumptions that underlie these (Vogel, 2012).

In the absence of an agreed theory of change for the project, set out below are some of the assumptions that I brought to this project at its outset (and which I tested at the first project team workshop in October 2010):

1. Based on the experience of working with WRC project K5/1843, investment in social learning processes within the project would enable the progressive development of good interdisciplinary learning and research;
2. Based on the experience of Watercourse, a transdisciplinary research approach (cf. **Box 1.2.2** under **Section 1.2**) would provide the most effective way of building understanding and ownership of water related climate change adaptation options, including integrated and adaptive

management approaches, to support implementation of policy and strategies for Water for Growth and Development, provided that key stakeholders both within and outside of DWA could be engaged in the process;
3. Developing effective transdisciplinary research practice within the research consortium would require additional investment in social learning (cf. **Box 1.2.3** under **Section 1.2**);
4. To achieve its inter- and transdisciplinary aims the consortium would need to take an adaptive management approach to project management. This would enable the research process to be adjusted and adapted in the context of a complex and uncertain stakeholder environment, as well as 'walking the talk' of the subject matter;
5. That sufficient trust and joint understanding had already been established within the team to support the above approaches and to surmount challenges encountered;
6. That the WRC would support the above approach to the research process, including through flexible allocation of funding across the consortium as required.

Reflections on the experience of participating in this 3-year project can be made through a number of different lenses and at a number of levels. First, and in the spirit of first person inquiry, I draw out some of my personal learning through the course of the 3-year project. Secondly, given the focus of the project on integration, I reflect on some of the factors which enabled and constrained effective transdisciplinary practice as the project unfolded, using the lens of Lang *et al.* (2012). Thirdly, given the focus of the project on adaptation, I reflect on the factors which enabled and constrained the adaptive capacity of the project team, using the lens of Marshall *et al.* (2012), together with an emergence lens, drawing on some of the systemic action research perspectives explored at the Freshwater Governance workshop in November 2012. And finally, I will allude tentatively to some of the broader lessons that might be drawn for the role of the university sector in South Africa, as it seeks to adapt and potentially transform its role as a key facilitator of society's wider adaptive response to climate change and that of the water sector in particular.

Personal learning

O'Brien (2013) argues for the value of adaptation from the 'inside-out' as a complementary approach to thinking about and doing adaptation in the world, highlighting the value of reflecting on the perspectives we bring to adaptation research and practice, including our own blind spots. More strongly, she proposes that adaptation from the inside-out can be seen as "a critical part of any adaptation process, for it enables us to deal with complexity, uncertainty and surprises" (O'Brien, 2013). Indeed, from a social learning perspective, it would be surprising if we were to ignore our own reflexive practice as researchers, while urging social learning on others. This, in turn, connects to an action research perspective in which linkages between first, second and third person inquiry are highlighted within an integral practice (e.g. Torbert and Taylor, 2008).

So, turning to my own feelings at the conclusion of this project, I notice a mixture of disappointment, surprise and satisfaction: My *disappointment* is that as a consortium team we were not afforded the opportunity to collaborate with the DWA in a transdisciplinary inquiry into the meaning and practices of climate change adaptation in the context of water resources reform. As a result, we seemingly lost the momentum and motivation to attempt another transdisciplinary inquiry, perhaps focused in a different stakeholder setting and/or more locally. Or perhaps the structural dynamics of the consortium team were such that the pull to more individualized practices (in the context of MSc and PhD projects) proved stronger.

My feelings of *surprise* perhaps point to the main areas of my personal learning and development. I am surprised by the nature of collaborative work around the development of the handbook that emerged during the fourth cycle of learning and in which I participated. I could not have anticipated this at the outset of the project. I have found the writing of the handbook to be not only an intellectually rewarding endeavour, but also one that has provided a space that is rare for me in the consulting world, that is, the opportunity with others to think through and develop a linked set of ideas - a thesis - without the constant need to work with and respond to clients' or partners' thinking and practice. In other words, while transdisciplinary practice is my daily bread and butter (although the research side is often weak), for me, 'mode 1' professorial research and analysis is a rare luxury. This project has provided the space for me to undertake a sustained piece of analysis in a complex field that invites repeated examination and reframing. Indeed, I notice that I became involved in this project (late 2009) at precisely the time (a) that the Watercourse programme was coming to an end and (b) as it was becoming clear to me that the rapidly emerging challenges of climate change adaptation would demand new levels of intellectual insight and discipline within my professional practice. So in a

way, writing the handbook has enabled me to synthesise a five year first person inquiry which has sought to make sense of climate change adaptation in the water resources sector. The inter-disciplinary companionship of Coleen Vogel and Beate Scharfetter in the writing process has furthermore provided a much-valued 'container' within which to pursue this writing.

So - where does the *personal development* lie? Of course, personal development is a holistic process and doesn't take place within the compartments of different research and consulting projects, but rather across these as well as within one's personal life. In this respect, my sister's progressive struggle to live with cancer over the past two years had affected me profoundly. Nonetheless, it is possible to point to some of the ways in which this project has shaped my professional practice on a personal level. First, it has deepened my understanding of emergence (Collins and Ison, 2009) and how I work with emergent processes. This is an area where I consider that I already have considerable mastery, so I am struck by how much the reframing of my research focus through the life of the project from trans- to interdisciplinary (as discussed above) took me by surprise. Undoubtedly, being a team member rather than the team coordinator on this project further reinforced the need for me at various stages of the project to let go of both expectations and assumptions and instead to notice what was emerging and within this, what actions were possible, or at least, 'good bets' worth pursuing.

And secondly, the process of working on the handbook has contributed in a very practical way to building my confidence and experience in the art of interdisciplinary writing. Here, I have again found myself working with an iterative and emergent process, which the 'holding' relationship involving my colleagues has been able to support. More specifically, this holding relationship has contributed to an inquiry-based exploration of the 'form' of the handbook which has been critical to the sense-making (i.e. 'content') of the whole and enabled me to guard against the ways in which this can so easily be overtaken, discounted and devalued by conventionalized academic approaches to forming (see Marshall, 2008, for further reflections on finding form in writing for action research).

1.3.3 Coleen Vogel

Working with the team of the WRC project was a really wonderful, learning experience. I was so enthused after the first meeting (2011), given that we were all committed to transdisciplinarity (TD) approaches. For a number of reasons, however, not least my sudden departure from the University of the Witwatersrand, I had to find a new identity and really find myself and eventually my way back into the team. I thus was not involved until the end, once again, of the project. So my reflections will not be as full as they could be.

1. Transdisciplinary (TD) design and framing is key - the design of the process is still a key issue for me. Unfortunately we could not sustain and actually fully engage a TD approach and perhaps the key lesson of all is that all stakeholders MUST be included upfront, even in the design of the project proposal. Perhaps then we would have had more buy-in and co-evolution and co-design.
2. Patience is also a virtue and much of TD takes simmering, brewing and cannot be done in a short space of time. The process is central. But the funding cycles are not linked to such cycles and best suited to such project designs and hence one races against the clock for 'deliverables' at the risk of a less robust and well-developed end product.
3. The need for knowledge on climate change is huge, and all respondents we have been fortunate to engage with have stated that we need 'easily accessible' texts, 'safe spaces' for engagement.
4. The 'politics of science' and how knowledge is constructed remains key and in this case the changing landscape of the water arena and climate arena, with several knowledge brokers, knowledge leaders, 'power brokers' etc. became key to note and remain sensitive to.
5. Younger, engaged scientists really do 'get it' that is the need for TD, but our system and rewards at the universities do not favour such approaches thus, making it very difficult for the younger scientists to maintain the enthusiasm for such approaches.
6. Working also with a trained expert on social learning and TD (e.g. John Colvin) was hugely rewarding. His external view, informed by years of South Africa's 'internal gazing' on the local water scene, was humbling, informative and really a journey of exploration and self-learning.
7. Finally, it has been great to 'put our money' where our mouths are and really try and design a series of both detailed and more simple, user-friendly sources for a range of audiences. If we can, this process should be extended with further funding from the WRC to complete a detailed social, reflexive process and further development of the process and products!

1.3.4 Roland Schulze

One of the things that I have learned is that there is tremendous local knowledge and tremendous local interest that resides in the people who made up the Champions in the study catchments, which were the uMngeni Catchment and the Berg Catchment. To some extent, within the uMngeni Catchment the thinking amongst the Champions that we interviewed appeared a little more compartmentalised to me than those interviewed in the Berg.

One of the issues we had to look at was to assess uncertainties related to climate change projections. I believe that we need to approach uncertainty assessments in a somewhat more simplified manner than scientists conventionally do. I think what we have achieved in this project is an indicator of uncertainty that is relatively simple, but appears to be very robust.

Another thing that I have learned is that it does not matter if you have been in the hydrological field for decades a project like this always makes us get to know the hydrological system and its linkages better than we did before.

What came out very clearly, is that any errors in the GCM output in the upstream catchments cascades down to the lower parts of the catchments.

Another issue which became clearer and clearer is that the tributaries of a major river system have more uncertainty in their climate change responses than the main stream. In the main stream, with its contributions from many tributaries, certain uncertainties appear to be partially self-cancelling.

A further issue that I experienced in this project was that one needs to sensitise government officials to issues of climate change, and sensitise them again and again. Many seem to be paying lip service to climate change, but at the end of the day there still seems to be a little bit of indifference to the whole issue of mainstreaming climate change into day-to-day decision making. Much of this, in my opinion, appears to come from pre-conceived ideas that they have and an apparent unwillingness to moderate these ideas, as we gain more and more experience on impacts of climate change. I also believe that very often the government officials do not really ask the correct questions on climate change and their mind-sets remain where they are in a comfort zone.

To me a very positive experience of the project was the value that the case studies added to this project, particularly the case study on the Mpushini/Mkhondeni system where, because we were looking very intensely at an actual system, with actual land uses and actual dams and irrigation, we really got to understand much better the hydrological processes and their immediate effects as well as their effects further downstream.

A project of this nature is always enriched by collaboration with other experts. Inevitably, some make tremendous contributions and others less so, and these are things one has to appreciate when one is doing multi-institutional research.

1.3.5 Stefanie Schütte

After spending about 10 years working in the chemical field, mainly involved with production processes, I spent eight years at home bringing up my children, while working part-time in various fields, including conservation, indigenous landscaping, establishing a wildlife residential estate and working on alien plant eradication. This established new interests and when it was time for me to return to work, I realised I wanted to change the direction of my professional life. Being fascinated by the links between environmental processes and ecosystem services and concerned about the effects of land use change, I wanted to pursue an MSc in that field. Choosing a study area that I knew and had lived in for the past nine years, I wanted to study the various ecosystem services that this area provides, including those related to hydrological flows, carbon sequestration and biodiversity. Originally the aim was to do this research for the current land uses, as well as for the proposed land uses, and also include projected climate change. However, soon it became clear that this would be work for many years, so I had to limit myself to ”Linkages between selected hydrological ecosystem services and land use change, as indicated by hydrological responses”, which is the title of my MSc

dissertation. The climate change projections, being beyond the scope of the dissertation is to be included as an added part of the WRC K5/1965 project.

I have concerns about the current drive to land transformation in South Africa, which is being seen as a means to achieve progress from the paradigm of development through growth and increased resource use. This is aimed at improving human well-being, but at the same time the unforeseen negative consequences of land transformation related to human well-being are not understood. During my research, I found a very suitable definition of growth and development. Farley and Daly (2006) explicitly distinguish between economic growth, which they understand as the physical increase in the rate at which the economy transforms natural resources into economic output and waste, and economic development, which is an increase in human welfare for a given level of resource use.

I am grateful for this research opportunity. I learned a great deal in the past two years and was also able to contribute, in my opinion, to very relevant knowledge creation.

1.3.6 Stephen Shisanya

I understood very well that making a decision on my PhD research topic and at the same time to effectively contribute to the WRC project was not going to be easy. This was in terms of having enough time to adequately respond to both research undertakings. I was fortunate in that the decision on my PhD study topic and my contribution towards the K5/1965 project coincided. In discussion with my supervisor, Prof Bogale, we agreed that my contribution to the project would be more effective if it was directly linked to my PhD study. To this end we set up a plan for my study that would address both the project and my PhD objectives. We decided on an overall research topic titled: “Climate Change, Water and Food Security: Perceptions of Rural Communities in KwaZulu-Natal and Implications for Food Security Policies”. This topic articulated well my area of interest while at the same time addressing, to a large extent, deliverable 5: Vulnerability assessments and possible adaptations and impacts on household food security to climate change.

Data Collection
Constructing the actual data collection tool proved to be quite a challenging process that required more time than anticipated. I did develop a number of drafts that were sieved through by my supervisor. Eventually we settled on draft 5 as a suitable tool to capture information that would answer our research objectives. We did develop a questionnaire for households and focus group discussion questions for community stakeholders. At this time we were also careful to phrase our questions in such a manner that the analysis programme (SPSS) would be able to capture and respond effectively.

The initial process for data collection was to find enumerators. One of the critical considerations in this case was that the enumerators should be known to the community. I felt this would allow the community to feel comfortable in answering the questionnaire which itself was quite long and required patience from the respondents. It was also necessary for the enumerators to know when a respondent was misunderstanding the questions since they would have an idea of appropriate answers and could guide the respondents effectively. It was not easy to come across community members with the basic requirements for an enumerator, which was set to be at least a tertiary education. This requirement was critical in the way the questions were to be explained to the respondents. Eventually I settled for non-local, but Zulu-speaking, enumerators from the university (UKZN). The enumerators went through rigorous training on how to administer the questionnaire. Random checks were made on a daily basis for each enumerator to check that what was coming in from the field was of good quality. Even with the university enumerators we still had anomalies such as plot sizes given in centimetres or quantities given in metres. We had to go through the questions over and over again to ensure thorough understanding whenever an anomaly was observed.

Data entry and analysis
After all data were collected (200 questionnaires) and two focus group discussions had been held, data were captured using the SPSS programme for analysis. A lot of data cleaning had to be done and some entries had to be excluded. After satisfactorily capturing data for the SPSS programme, it was time to start making sense out of the captured data. I found it easy to say what I wanted from the data, but it was challenging to come up with statistically sound answers to my questions. I did contact a number of statisticians from the School of Statistics. Many did not have enough time to concentrate

on my case. In many instances some were not able to understand what I wanted to do with the data I had. Some suggested that my data were not adequate to come up with statistical evidence. It was very frustrating until I came across Mr Mathenge who took time to understand my research and we jointly identified the necessary statistical processes. He tutored me on a number of statistical interpretations which I have used in articulating my findings.

Reporting
Reporting has been one of greatest challenges in my research. As much as my PhD and the project work were 'talking to each other', I had to formulate independent papers that would have relevance to both. Although thought had been given to this right at the study inception, it was necessary to start considering who the audiences to the research finds were: academic (UKZN) versus development practitioner (WRC). Ongoing communication with my supervisor was required. Again my desire was to harmonize the two so that I would have depth in reporting to both audiences. We eventually settled for the following paper titles that covered both my study and the project work:

1. Assessing household perceptions and vulnerability to climate change: The case of rural small-scale farming communities in the Tugela river basin of South Africa
2. Farmers' adaptation to climate risk and the impacts on household food security: A case of rural small-scale farming communities in the Tugela River Basin, KwaZulu-Natal, South Africa.

The two papers did form the last two chapters of my thesis.

Conclusion
It was challenging and exciting to be part of the WRC project while working on my PhD. Besides the learning in the context of my research, a greater learning experience was having various audiences. Members of the WRC project team were of real help in contributing and shaping my thinking through critical interaction with my presentations at our meetings. Based on the past 3 years I gained a much deeper understanding of climate change at a community level. Several questions have emerged from the work, more than answers that I could supply and would need to be addressed in future research endeavours.

1.3.7 Ntombifuthi Vilakazi

The main objective of the K5/1965 WRC project was to develop a framework that reflects an integrative adaptive management approach for facilitation of strategies for taking account of vulnerabilities and impacts of climate change in relation to water planning and management. My MSc project on integrative policy instruments for effective implementation of the National Water Act (NWA) was therefore built on the governance and policy implementation component of the bigger K5/1965 project where an integrated approach to water management was the main theme.

In what follows I reflect on what worked well and what did not work well for my MSc project. I have split these reflections into 3 phases of my MSc project, *viz*. initiation, planning and executing phases, closing with lessons learned on the overall K5/1965 project.

Initiation phase
The initiation phase was very exciting for me as I was looking forward to the outcome of my research work. I was also introduced to the project team of the K5/1965. In this phase I undertook intense review of literature related to my MSc project topic and finally identified a research problem on which I wrote a proposal which was presented to the project team of K5/I965 as well as to the UKZN's School of BEEH (now SAEES). Water governance is a broad topic, and hence there is an abundance of literature. It proved to be very challenging to identify only the relevant papers and information. Moreover at that point in time my MSc topic had not yet been clearly defined and hence I felt unsure about what exactly I would be doing.

In future I aim to understand the topic right from the beginning in order for me to know what literature to review and what is expected.

Planning phase
Moving into this phase, the objectives of my study were clearly defined and the research questions were formulated. The research methodology was proposed, but was not clear due to the limited knowledge that I had at the time. However, later in this stage, with the help of my supervisors I was

able to revise my topic, objectives, research questions and methodology and to carry out my research work.

A shortfall at this stage was that I was too optimistic and estimated unrealistic timeframes for my project lifecycle. This resulted in a lot of pressure.

Project Execution
This was the most interesting and exciting phase of the project, as it represents the actual data which were collected from two different groups of participants, i.e. key informants and households. Very important lessons emerged during this phase:

1. The fieldwork was planned to take place in March 2011 but only started in mid-April due to the process of application for ethical clearance from UKZN which had to be granted before data collection.
2. Getting the key informants to participate in the study was partially challenging owing to their many other commitments. Additionally, it occurred that the topic of the interview was sensitive to some people and in that way some people preferred not to be part of the survey and others chose to participate, but remain anonymous.
3. Access to high-income residents was noted as a limitation due to restricted public access to apartment blocks. Access to homes was restricted by access control, gates, high walls, and intercom systems. This made it easy for respondents to indicate that they were not willing or interested in participating in the survey or not responding at all.
4. A large number of residents work during the daytime which also contributed to the high number of non-responses. A number of homes in the suburbs have dogs. This was considered a limitation because interviewers were afraid to approach the homes where there were barking dogs. The above constraints and challenges resulted in the data collection phase taking longer than anticipated.
5. One important thing that I learned during data collection was that ethical consideration of the participants is very crucial when conducting surveys and interviews on a sensitive topic such as water access and usage as well as management aspects. Power issues seem to play a role in many of these fields. Therefore it is very important to assure the participants that all the information be kept confidential.
6. One major surprise for me was that while one would assume that everyone working in water management would have the same goal and vision, based on the NWA and other policies, during data collection I realised that this was not the case. I feel that by not agreeing to participate in water research for no valid reason means that all they care about is the salary and not helping society. To me this also indicates that there might be transparency problems in the actual water institutions.

Experiences in the context of project K5/1965
Being part of the K5/1965 project in my case was meant for capacity building purposes on the 'young water professionals'. I think the project did achieve its objective for capacity building in my case because I learnt a great deal during the project. Even though I participated where I could, i.e. presenting stages of my MSc and sharing some of my thoughts, I was more like an observer and a student. I got to be in the same room with respected people in South African water research and had the opportunity to my share ideas with them.

The K5/1965 project, as well as my MSc project, helped me formulate my own deductions:

1. Various factors affect the level of implementation of the NWA, with integration being the most important actor.
2. The need to change attitude towards water management responsibility is one important factor whose relevance and importance (in implementing the NWA effectively) has not gained enough emphasis, i.e. judging from the fact that many water stakeholders still look at the DWA as the one who should be responsible for water management while I think water management should be everyone's responsibility, including that of children. For example, children (school learners) can be equipped and made aware of water quality issues through programmes such as the Stream Assessment Scoring System which is currently being undertaken by some conservancies such as Kloof Conservancy and I am part of that. Also, the river walk from source to sea by the Duzi Umgeni Conservation Trust was one good and practical way to bring water awareness to society at large.

3. Being part of the project and involving myself in various Catchment Management Forums made me realize that local communities have a better chance of managing their water resources effectively. The local communities know the catchments well and they can take care of them better than anyone else because they are part of their lives and they are easily accessible to them. Hence I came to the conclusion that through allowing and equipping the communities to manage their water resources we can provide a way to achieve a more equitable and sustainable use of water resources.
4. I strongly believe effective water management can help in eradicating poverty. We should consider funded community projects specifically on water (or maybe water-related) that will stimulate the interest of local communities and in that manner create an awareness, thereby helping them to implement water management in their daily routine. (During my data collection I interviewed a community in Noshezi in Pietermaritzburg where there was an agricultural group of disabled people who grew vegetables, but were limited by reason of not having access to water as they are not able to walk to the rivers or community tube wells since they are disabled. The sad part here was that these people have asked for help from their councillor and the municipality, but their concerns were never attended to). If we are serious about eradicating poverty we need to make sure that the government responds to and supports the community projects.
5. Interlinkages between water resource management (NWA) and water services (WSA) needs more recognition and more emphasis in order to draw people's attention as to how crucial it is that they use their water effectively and sustainably.
6. I believe that Social Media can play a much bigger role in bringing awareness with regard to water management and climate change.
7. Communities need to be represented in water stakeholder dialogues to include them in the social learning process and to be bringing awareness as well as to equip them on how they can participate in water management.

Being part of the K5/1965 project was very eye-opening and made me want to involve more people in implementing good change to other people's lives through striving for effective water management at all levels and I hope to contribute towards my wish of getting more people involved in water management.

1.3.8 Thembi Ngubane

South Africa consists of diverse communities that think and behave differently in many ways. My research journey proved this to be true because as I did interviews in the three communities (Bergville, France and Scottsville) I had different experiences and informative sessions with all the participants that were involved. Each community had a story to tell about the area they live in and there was quite a lot of emotion involved for most of them (expressions of sadness and anger). In Bergville (rural area) people spoke of the lack of sufficient water supply, which limits their livelihood and reduces crop yield. Some have stopped growing crops as a result of water scarcity and also because of cattle interference. They suffer from poverty due to the reduction in supplementary food and lack of employment, which makes matters worse. In this case supplementary food comes from harvested crops, therefore reduced crop yields minimize supplementary food and the lack of employment worsens the situation. Regardless of their poor conditions, they still welcomed me into their small homes with warm hearts and humbling smiles. I had an amazing experience in the rural community of Bergville, and being a young female who grew up in a township I learned a lot from the interviews conducted there.

I was born in Umlazi, one of the largest townships in South Africa, and established in 1967. We live near a stream, located just behind our backyard and during intensive rainfall events water always floods our home. Apparently we are located within the floodplain of the Mlazi stream, which is less than 100 m away from my granny's yard. Having a hydrology background I comprehend that houses are not supposed to be built within floodplains for reasons such as the frequent flooding of homes. Nevertheless, it seems that not much can be done since these houses were built during the apartheid era. However, France, formally known as Ambleton, is an RDP township that was established not so long ago and has worse infrastructure related challenges than Umlazi. What is our excuse now? I mean our country is not constrained by apartheid, is it? This community challenged my thoughts in many ways and just by observation I concluded that a lot of work needs to be done in the planning and development of communities in South Africa.

When I jumped off the taxi in France the first thing I could hear was a running tap from one of the houses nearby and as I walked closer I noticed that people were sitting right next to the “running tap”, laughing and chatting and not bothered about the water. As I saw all of this I could not help but think what was going on in their minds, but carried on walking, hoping I would get answers from the neighbours. I learned that this community received free water and very poor maintenance services, and that taps from 5 houses were running continuously. Thousands of litres of purified, clean water is lost just from one house a day. Imagine the millions of houses in different townships that have similar cases. How much clean water are we losing then? As I carried on walking I kept noticing water running over the road and I assumed it came from a burst pipe. I started searching, but could not locate it. So I continued with my journey and noticed that alongside every street, water was flowing, When I asked one of the participants, I was shocked to hear that the area did not have any storm water drainage systems. Sewage and garbage pollution seemed to be an issue that affected this community. Garbage is not collected in this area therefore people dispose of litter in an open space. A lady who stays near the dumping site complained about the amount of litter disposed in her yard during windy and rainy seasons and because of this she makes it her responsibility to burn the litter every now and then. The sewage septic tanks issue would take me the whole day to express. All I could say is that it is hazardous to human health and water sources.

After visiting France, I went on to the formal suburb of Scottsville. Elderly people who have stayed in Scottsville for a long time told their story about the drought that took place in the 1980s and how it changed their lives since. However, young people in the area still do not understand the importance of saving water, particularly the University students. From personal experience that speaks volumes about South Africa’s future. I witnessed a student at the University residence leaving the kitchen tap running while they went to fetch some cooking utensils in their room. This was heart-breaking because the “Save Water” sign was just above the sink and she must have read it so many times, but still the sign meant nothing to her. When I confronted this young lady, I was told to relax and that it was “just water”. One would think that educated young people are the future of this country, but the question is: What future could we possibly have without water? I would not have known this behaviour and attitude that students had towards water if I had not been rejected by homeowners in the Scottsville area. Countless times I went to the different homes hoping to be welcomed, but it seemed more people had contagious sicknesses and could not chat with me. It was only after I was rejected a number of times that I met a nice old lady who told me that people in the area isolate themselves and that she does not even know her own neighbours. What I gathered from this particular middle class suburb was that there was a lack in social skills.

Overall, people perceive water in different ways and there are many clouds of perception around water security. The issues I came across revolved around efficient use of water and pollution, which will lead to South Africa being at risk of facing a water crisis sooner than we think. This calls for an urgent surveillance of communities, especially the informal and under-developed township communities. I gathered that people degrade water because of circumstances, ignorance and lack of knowledge, which are major constraints in the conservation of water in South Africa. We should understand that everyone is accountable for their water because everyone is affected by it at the end of the day.

1.4 Conclusions

Chapter 1 of the final report has highlighted some of the structural difficulties involved in taking a highly dynamic and politicised topic, viz. that of water management under climate change in the context of growth and development, into that of a structured and externally funded research project. The following sections reflect on some of the main issues emerging from **Sections 1.1** to **1.3**.

Reflections on integrative research practice within the project

Moving from reflections on my personal learning to reflections on some of the factors which enabled and constrained integrative research practice within the project, I draw on the lens of Lang *et al.* (2012) in this section (see **Box 3**) in order to further reflect on the arc of inter- and transdisciplinary practice development.

Reflection on the design principles relevant to the first phase of the Lang *et al.* (2012) model (*viz*. problem framing and team building) suggests that during the first learning cycle, there was good investment in three of the four relevant design principles, namely (a) the development of collaborative capacity within the team, (c) work to develop a joint understanding of the boundary research object

and questions, and (d) the emergent design of a methodological framework for collaborative knowledge production and integration, as embodied in the diagram at **Figure 1.2.2**. However, in the absence of effective engagement with the DWA during this phase, it was not possible to apply design principle (b), i.e. the development of joint understanding and definition of the issue to be addressed.

Enabling factors during this phase included the investment in two social learning workshops and a strong mix of relevant expertise, experience and other relevant ''stakes'' needed to tackle the adaptation issue in a way that could both provide solution options and contribute to relevant areas of scientific discourse. This included expertise and experience relevant to each of the aims covered in the **Figure 1.2.2** diagram - a relatively unique constellation in the South African context. As noted previously, two potentially constraining factors also emerged during this first phase, *viz.* the temporary, but early, withdrawal of CV, a senior member of the project team, and secondly, the structural tension within the project team between the four senior staff, with commitments to interdisciplinary collaboration, and the requirements for the four PhD/MSc team members to pursue more independent research. SSH, as the project manager, occupied a unique position in this respect, with commitments both to project integration and coordination and to the independent pursuit of her PhD.

Following the first learning cycle, initially the transdisciplinary and then the interdisciplinary praxis of the project progressively weakened. With regard to the former, despite attempts to engage with key stakeholders and practitioners, it did not prove possible to apply design principle (b), i.e. the development of a joint understanding and definition of the issue to be addressed.

Interdisciplinary praxis also weakened with the fifth interim report to the WRC, which covered the reporting period March - September 2012, consisting primarily of independent chapters from PhD and MSc students, and from RS and JC, with a coordinating narrative from SSH, but with little sense of proper interdisciplinary development. This partly represents the reality of a project seeking to recover from a series of shocks, coping to its best ability, and partly the reality of the PhD/MSc grouping within the project team, which was never designed to develop interdisciplinary practice. Indeed, from the perspective of 'delivery' to the WRC, the relative independence of the PhD/MSc research streams can be seen as constructive, giving the project potentially greater overall resilience than if it had been fully invested in only inter- and transdisciplinary praxis. Thus, while sacrificing the strength of integrative narratives arising from effective inter- and transdisciplinary collaboration across the whole consortium, the project has instead generated a series of outputs which offer a diversity of perspectives on integration, as demonstrated, for example, in the various chapters of this final report to the WRC as well as within the handbook.

Reflections on adaptive research practice within the project

In the context of its commitment to 'walk the talk' of adaptive management (aim 1b), the project team found itself facing a series of challenges to adapt to unfolding dynamics throughout the project, as narrated in **Section 1.2**. Adaptive management, expressed as 'facilitating continuous formative evaluation', is highlighted as a general design principle in the transdisciplinary research model of Lang *et al.* (2012), while Marshall *et al.* (2012), in their analysis of factors that enable or constrain adaptive capacity, highlight the importance of the following:

1. how risks and uncertainty are managed;
2. the extent of skills in planning, learning and re-organizing;
3. the level of financial and psychological flexibility to undertake/effect change; and
4. the anticipation of the need and willingness to contemplate and undertake change.

Further discussion on adaptive management in the context of project aim 1a can be found in Colvin and Stuart-Hill (2011), Stuart-Hill (2013) and in **Chapter 5** of the handbook.

However, the overall experience of adaptive management practice within the project was that, despite initial good intentions, the overall reality was one of adaption through self-organisation rather than through shared reflexive practice. This is not necessarily a bad thing, as the project was still able to meet its aims and indeed, as argued above, may have been more resilient as the result of an emergent process of self-organisation rather through a more integrated and reflexively adaptive approach.

The team had within it many of the skills listed above by Marshall *et al.* (2012). However, as with the

development of inter- and transdisciplinary practice, several factors appeared to constrain the development of shared adaptive practice within the team. Perhaps the main constraint was that, for the PhD and MSc students involved, there was no specific requirement for the practice of adaptive management within their projects. On the other hand, there was considerable freedom for those who wished and needed to practice adaptive management, to do so. And given the early crises that undermined motivation and commitment to undertake inter- and transdisciplinary research within the project, the effective need to undertake shared adaptive management also progressively weakened.

Reflections on the potential for transformation towards transdisciplinary praxis within the South African university sector

There is already considerable investment in the South African university sector as a vehicle for societal transformation. For example, the Department of Science and Technology's Global Change, Society and Sustainability Research Programme signals a commitment to investing in knowledge challenges which are highly relevant to climate change adaptation in the context of the water resources sector, and these include 'Adapting the way we live' and 'Innovation for sustainability'[13].

Reflecting on this focus on societal transformation, a commitment to transdisciplinary research is emerging within several South African universities, including Rhodes, Stellenbosch and Wits, who are demonstrating an increasingly proactive leadership role to the sustainable development of South Africa and the wider region. This commitment to transdisciplinary research praxis is further mirrored in the climate compatible development initiative of the Southern African Regional Universities Association (SARUA) network (SARUA, 2013).

At the same time, a transition of research praxis toward transdisciplinary sustainability research implies severe consequences for current institutional architecture within the university system. As encountered in this project, transdisciplinary science requires new research methods, a suitable training of junior scientists, and specific career pathways beyond disciplinary boundaries - to name but some aspects of science system capacity building. Most of these measures can only be delivered by universities. The fact that the institutional setting of universities has historically developed in the context of disciplinary and mode-1-research-structures presents a significant problem for the further development of a knowledge system suitable to the challenges of a sustainable development (Stephens and Graham, 2010; Jäger, 2011).

This section of the final report has highlighted some of the structural difficulties involved in taking this transdisciplinary turn, specifically in the context of project K5/1965. Some of these were shown to lie outside the university system, reflecting disconnects within the governmental system and structure as well as attendant difficulties in engaging effectively in a genuinely transdiciplinary opportunity for knowledge co-production and capacity building. Yet within our consortium, and reflecting wider patterns within the South African university system, perhaps the most significant limit encountered was that of the current context of disciplinary and mode 1 accreditation structures, preventing early career scientists from training and experiential learning in inter- and transdisciplinary research practices. Accounts of addressing these limitations within universities of the global North tend to focus on the post-doctoral stage of development (Barlow *et al.,* 2011), although a recent account of building career pathways which include transdisciplinary research practices, from a community of Australian researchers, also involved PhD students (Patterson *et al.,* 2013). Set against this, valuable insights are now emerging as to how transitions towards transdisciplinary institutional practices are emerging in other countries, for example within the German science system (Schneidewind & Augenstein, 2012).

While it is beyond the scope of this section to address how these limits might be addressed in the South African context, it seems important for the WRC to consider these limits when commissioning future research/projects that might require an action research, interdisciplinary or transdisciplinary focus.

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SECTION A:
BIOPHYSICAL INFORMATION ON CLIMATE CHANGE AND DISCUSSIONS ON UNCERTAINTIES

Introduction to Section A

One specific focus in Project K5/1965 was to establish information on levels of risk and uncertainty in regard to water related development investments in a future with climate change and increased climate variability. This focus is particularly relevant as water related infrastructure is expensive, has to operate effectively over the long term, is essentially irreversible once in place, has to operate at the extremes of climatic distributions under conditions of floods and droughts, has major societal impacts, both positive and negative, and creates ecological impacts up- and downstream. Because of the above factors possible impacts will have to be assessed more carefully in a future with climate change in which uncertainties abound, as impacts might lead to changes in design, changes in safety, change in operating rules as well as in optimum locations of certain types of infrastructure. An important step in such an evaluation is an assessment of the degree of uncertainty of different hydro-climatic variables at different locations within South Africa and at different times of the year. The research places a focus on scale issues and scenario assumptions. In order to better understand these uncertainties and to use the information gained to clarify and possibly reduce uncertainties when infrastructure related design decisions need to be made or adaptation options are presented, catchment specific climate databases are created from the multiple GCMs used. This section relates to points 2 and 3 of the deliverables framework, as illustrated in **Figure A1**.

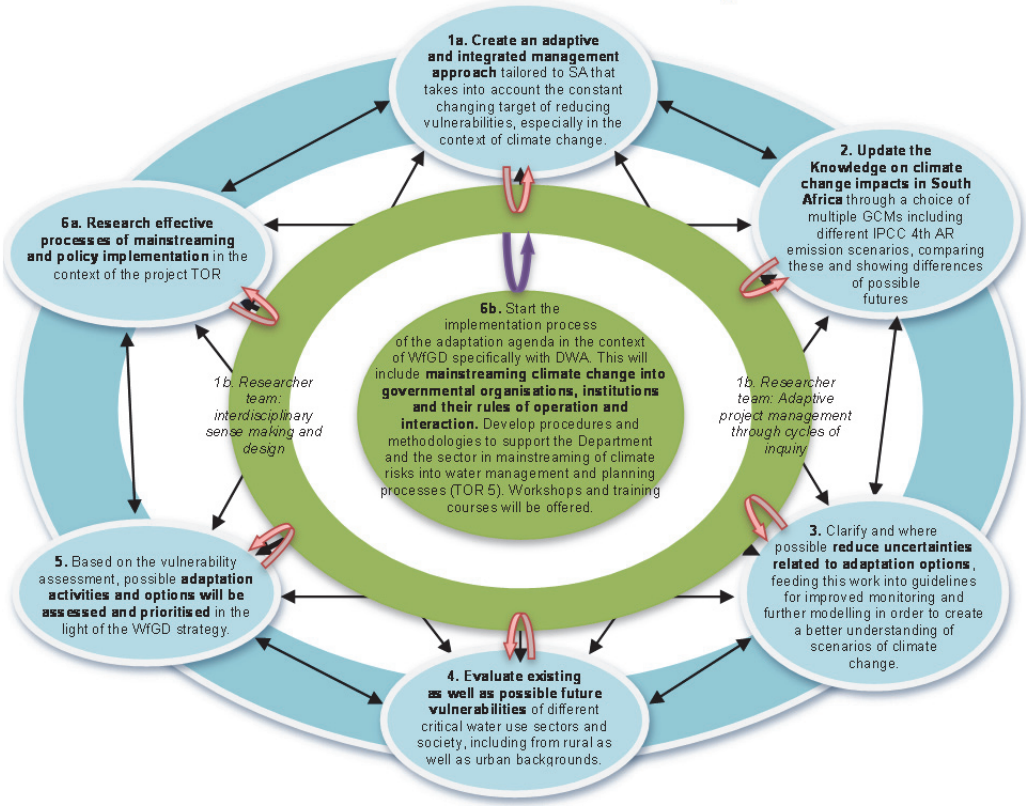


Figure A1 The six project work packages and their inter-relationships, with the diagram showing how the research team intermediates the inter-relationships between the work packages in the outer (blue) circle, and the work package focusing on knowledge co-production with stakeholders (inner green circle), through a process of interdisciplinary sense-making and adaptive project management (middle green circle)

CHAPTER 2: ON UNCERTAINTIES AND OTHER KEY ISSUES IN ASSESSING HYDROLOGICAL IMPACTS OF CLIMATE CHANGE OVER SOUTH AFRICA: A PERSPECTIVE

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2.1 Setting the Scene

2.1.1 Objectives

We live in a time of changing climates in which, rather than continually consolidating knowledge and firming up projections into the future, there is a growing perception and appreciation by, for example, Hewitson (2013) that *inter alia*

- we still have a weak understanding of climatic and, especially, of hydrological stationarity,
- there are limits to climatic (and political, economic, societal …) predictability in the future,
- now, more than before, our projections have to be
  - plausible
  - defensible and, ideally, should be
  - actionable,
- our communications to decision makers have not always been clear and unambiguous, but sometimes possibly jargon-ridden and lacking in clear guidance,
- we may have over-interpreted findings on climate change,
- different agencies of state do not always speak with the same voice in regard to possible impacts of climate change,
- climate science is moving from a possibility into a likelihood space, and that
- we should think beyond our sectors (e.g. water) and rather take a place-based approach in which we integrate and co-explore with other relevant sectors.

These are perceptions and observations to be taken seriously. This chapter touches on some of the above in presenting a perspective related to selected aspects on uncertainties in hydrological impacts of climate change over South Africa. This is done by addressing

- why climate change should be taken seriously in the South African water related sector,
- some fundamental concepts on uncertainty and associated issues,
- key findings on climate change in regard to uncertainty from the previous WRC project K5/1843,
- "domains" of uncertainty questions of climatologists and hydrologists,
- some qualitatively and quantitatively expressions of uncertainties when outputs from only few GCMs are available, including a method developed in the course of this project,
- some emerging issues not related directly to climate change impact studies, but which affect results, their interpretation and decisions, and addressing
- some emerging issues more directly related to climate change impact studies, and which affect results, their interpretation and decisions.

2.1.2 Why should climate change be taken seriously in the South African water sector?

South Africa's water resources, already subjected to high hydro-climatic variability both over space and over time, are a key constraint to the country's continued economic development and the sustainable livelihoods of its people.

In regard to climate change it should be stressed that because

- water is arguably the primary medium through which early (and subsequent) climate change impacts will be felt by people, ecosystems and economies, and because
- a large proportion of South Africa's population is impoverished (thus rendering them particularly vulnerable to impacts of climate change), and

- many of the fragile ecosystems in South Africa (both terrestrial and aquatic) are implicitly or explicitly water dependent,
- it has become urgently necessary to gain a comprehensive understanding of the physical drivers and the hydrological responses of climate change in a South African water sector context in order to
- develop science-based strategies and plans of action to adapt to climate change through an integrated approach to land and water management as the cornerstone to establishing effective resilience to the projected impacts of climate change.

To the above need to be added that

- water-related infrastructure (e.g. dams, irrigation projects, inter-basin transfers, stormwater drains, etc.) is typically a long term investment with a design life of 50 - 100 years, is very expensive, essentially irreversible once constructed and is designed to cope with currently (but not necessarily future) expected extremes of floods and droughts, that
- any changes in rainfall, be they up or down, are amplified in changes of hydrological responses (in the case of year-to-year variability the amplification from rainfall to runoff over South Africa can be 2 - 5 fold; Schulze, 2003), that
- climate change is not going to be experienced evenly throughout the country, with some areas "winners", other areas "losers" and others still are likely to become real "hotspots of concern", that
- climate change does not occur on a "clean sheet" of virgin catchments not yet impacted upon by human interventions on the land and in the channel, but will rather be superimposed onto already water stressed catchments with complex land uses, water engineered systems and a strong socio-political as well as economic historical footprint, and that
- symbiotic links exist between water and
  - human and animal health
  - disaster risk management
  - agriculture - both rainfed and irrigated
  - commercial production forestry
  - many coastal zone processes
  - biodiversity
  - mountain zones - as the water generating zones of South Africa
  - the transport sector
  - the insurance industry
  - the tourist industry
  - the energy sector and
  - our neighbouring countries through transboundary waters in the sense of either water flowing from other countries into South Africa (e.g. Lesotho) or water flowing from South Africa into other countries (e.g. Mozambique) or rivers forming international boundaries (e.g. with Namibia, Zimbabwe, Lesotho).

The above factors render the in-depth understanding of the ramifications of projected climate change on the one hand, and the development of a dynamic, water-related adaptation response strategy to climate change on the other, imperatives for South Africa (Schulze, 2012). To that has to be added that

- climate change from a water viewpoint also has to be considered from a perspective of broader national development agendas (e.g. National Planning Commission; the Presidential Outcomes) in emphasising adaptive land and water management in a holistic, integrative manner (Theesfeld *et al.*, 2011), and that
- the DWA's 2013 National Water Resource Strategy (NWRS2) has placed heavy emphasis on climate change by committing itself to a set of principles, objectives and key issues, which overlap somewhat, but where
  - *principles* imbedded in NWRS2 which are related to climate change include
    * having a sound scientific foundation as basis of all recommendations and actions
    * maintaining a balance between preparedness and over-reaction
    * integrating potential climate change impacts into water resources and water services planning and supply at all levels
    * the DWA committed to providing leadership with strategic partners to drive appropriate strategic responses to minimise the impacts of climate change

    * aligning existing initiatives and institutions to improve effectiveness of the national response
    * elevating climate and water onto appropriate agendas to ensure incorporation into the national agenda and to be managed adequately
    * improving knowledge of climate-water relationships and how these will impact on society
    * protecting / enhancing critical natural infrastructure (ecosystems)
    * planning physical infrastructure for a changing future using a no-regrets / low regrets approach

- with the following *objectives* for a climate change strategy, *viz*.
    * reducing vulnerability and enhancing resilience of communities, people, enterprises and ecosystems to water-related impacts of climate change, particularly for those groups most at risk
    * improving and enhancing water resource management processes to build the required resilience and adaptive capacity
    * integrating climate change considerations into short-, medium- and long-term water planning processes for water resources and services
    * implementing best catchment / water management practices to maximise the degree of water security and resource protection under changing climatic conditions
    * enhancing human, legal, regulatory, institutional, governance and financial resources / capacity to assist with effects of climate change
    * undertaking focused monitoring and research to ensure the efficacy of water adaptation approaches over the long term, as well as
    * ensuring inter-linked climate and hydrological modelling tools that represent the complex inter-related natural systems

- and identifying certain *key issues* in regard to climate change, such as
    * building / strengthening capacity of water sector institutions to function in a context of high levels of uncertainty
    * building the water sector's climate response capability and commitment to timeous action, to avoid inappropriate responses, and ensure the ability to manage water in a context of high levels of uncertainty
    * improving inter-agency collaboration to address climate change, in particular those likely to have overlapping / similar objectives
    * adjusting the water resource planning / management processes to build the required resilience and adaptive capacity in society and ecosystems,
    * strengthening the present rainfall, environmental, hydrological and hydro-geological monitoring systems to support effective climate change detection and effective adaptation, and
    * addressing research gaps in current water sector climate change programmes and water and climate change knowledge.

Overarching all of the above are the recent (2013) updates from the Intergovernmental Panel on Climate Change confirming, *inter alia*, that

- there is new and stronger evidence than before (at very high confidence) of observed impacts of climate change on vulnerable systems such as water, with increasing levels of adverse impacts as temperatures increase; furthermore,
- there is new evidence that observed climate change is likely to have already increased the risk of certain extreme events such as floods and droughts (very high confidence), and it is more likely than not that warming has contributed to the intensification of some tropical cyclones, with increasing levels of adverse impacts as temperatures increase; that
- the distribution of impacts and vulnerabilities is still considered to be uneven, with less-developed areas (such as large parts of South Africa) generally at greatest risk due to both higher sensitivity and lower adaptive capacity, but with evidence also that vulnerability to climate change is highly variable within countries; and that
- adaptation can significantly reduce many potentially dangerous impacts of climate change and reduce the risk of many key vulnerabilities.

2.2 On Uncertainty and Related Concepts

2.2.1 What is uncertainty?

Uncertainty exists where there is a *lack of knowledge* concerning outcomes which may be important in decision making. Such *uncertainty* may result from an *imprecise knowledge of a probability* which can range from poor knowledge to good knowledge, or an *imprecise knowledge of the consequences* which, similarly, can range from poor to good, resulting in a matrix of uncertainties as illustrated in **Figure 2.2.1**. Uncertainty is often linked with *risk,* i.e. where the probabilities a *hazard* (e.g. magnitude of more intense rain) may be uncertain and can range from low to high, and the magnitude of its associated *consequences* (e.g. damage due to increase in flooding) are uncertain and can be low or high, again resulting in a matrix ranging from low risk/low priority to higher risk/higher priority (**Figure 2.2.1**).

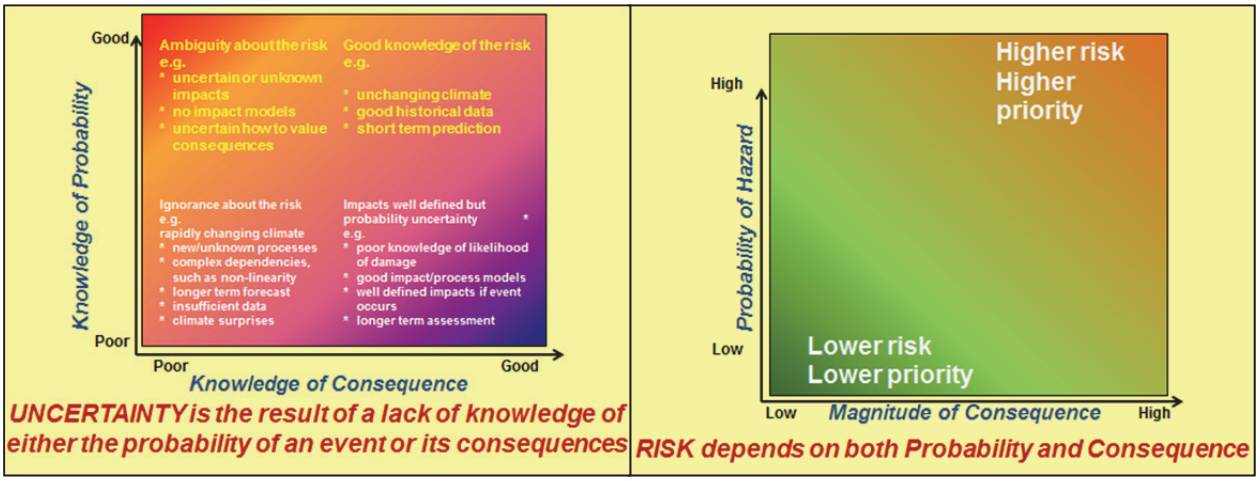


Figure 2.2.1 Some concepts and examples of uncertainty and risk (After UKCIP, 2003)

2.2.2 Sources of uncertainty in climate change studies

Sources of uncertainty in regional climate change prediction

Translating the above general concepts to climate change studies, a point of departure is that interactions between the many processes that govern the Earth's climate are so complex and extensive that quantitative predictions of the impacts of increasing concentrations of greenhouse gases on climate cannot be made with any certainty through simple intuitive reasoning (Shaka, 2008). The result is that GCMs have been developed which are mathematical representations of the Earth's system, and in which physical and biogeochemical processes are described numerically to simulate the climate system as realistically as possible (Jacob and van den Hurk, 2009). However, these GCMs are founded on assumptions of the evolution of drivers of climate change, for example, the distributions of aerosols and greenhouse gases, and their respective concentrations, in the atmosphere (Jacob and van den Hurk, 2009), all of which contain high levels of uncertainty. The GHG concentrations, for example, depend directly upon natural and anthropogenic emissions, which can only be estimated through emission scenarios, developed using so-called "storylines" (e.g. Nakićenović *et al*., 2000) which describe possible developments in global population growth and other aspects of the socio-economic system (Cox and Stephenson, 2007; Jacob and van den Hurk, 2009). These uncertain emission scenarios are then used to drive atmospheric chemistry and carbon cycle models that simulate changes in the concentration of greenhouse gases and aerosols (Cox and Stephenson, 2007). The resulting concentration scenarios are then input into GCMs, which generate climate change scenarios that in turn drive models of the impacts on human and natural systems (Cox and Stephenson, 2007), as illustrated in **Figure 2.2.2**.

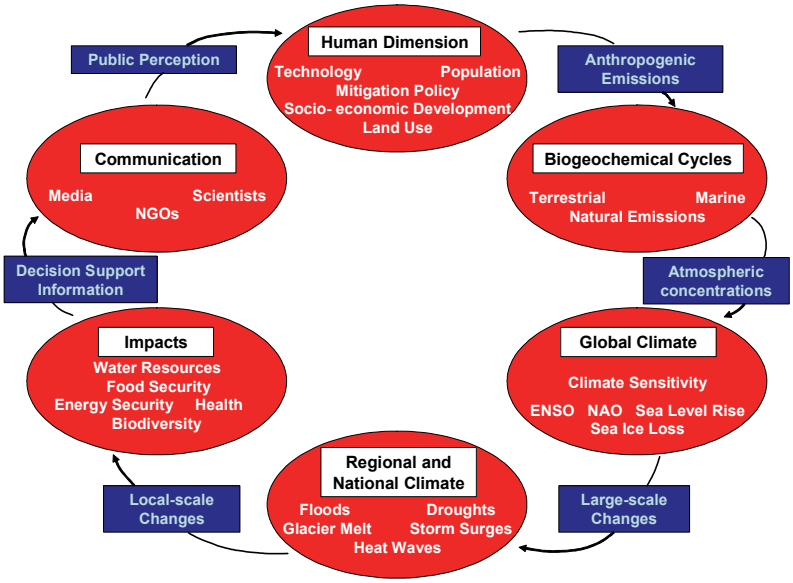


Figure 2.2.2 Sources of uncertainty in regional climate change prediction and their connections (Giorgi *et al*., 2008)

Uncertainties inherent in GCMs

Uncertainties inherent in GCMs have been well documented (e.g. UKCIP, 2003; Cox and Stephenson, 2007; Giorgi *et al*., 2008; Jacob and van den Hurk, 2009). These result in limitations, with GCMs less capable of simulating second order atmospheric processes such as precipitation, compared to those related to first order atmospheric processes, such as surface heat and vapour fluxes (Hardy, 2003). Limitations of GCMs include:

- Failure to simulate individual convective rainfall events, owing to the coarse spatial resolutions of the GCMs, and the smaller spatial and temporal nature of convective rainfall, which poses problems over most of southern Africa summer rainfall region, where convective rainfall is a dominant form of precipitation;
- Difficulty in simulating the intensity, frequency and distribution of extreme rainfall events (IPCC, 2007);
- Tending to simulate too many light rainfall events (< 2 $mm.day^{-1}$) and generally too few heavy rainfall events (> 10 $mm.day^{-1}$), whilst maintaining a fairly realistic mean precipitation (IPCC, 2007);
- Poorly representing major drivers of climate variability, such as the El Niño-Southern Oscillation phenomenon (Hulme *et al*., 2001), which is associated with a broad band of variability throughout southern Africa (Tyson, 1996); and
- Poorly accounting for climatological variables which represent other atmospheric conditions that lead to high magnitude precipitation and flood-producing events.

These factors tend to reduce the accuracy of precipitation output from GCMs. Additionally, projections of means of maximum and minimum temperatures can be quite unrepresentative of daily temperatures at the local scale (Jacob and van den Hurk, 2009) and so, therefore, can any subsequent estimations of potential evaporation. Therefore, there remain limits surrounding the usability of direct GCM output in detailed hydrological studies, where precipitation, temperature and potential evaporation at the local scale are primary inputs into hydrological models.

Even so, outputs from GCMs form the basis for climate change impact assessments. However, as has already been alluded to, a significant discontinuity exists between the output from GCMs (spatial resolutions generally of 10^4 - 10^5 km^2) and the catchment resolution at which local decisions are sought and local adaptation options need to be considered (generally 10^1 - 10^2 km^2; Schulze, 2009). It is due to this discontinuity that GCM output needs to be translated from the coarse to more local scales by the process of regional climate downscaling (Hewitson *et al*., 2005a; Giorgi *et al*., 2008).

2.3 Key Findings on Climate Change-Related Uncertainty from the Previous WRC Project K5/1843

2.3.1 Errors in GCM output for overlapping verification periods vary by GCM, are not spatially uniform across South Africa and differ from variable to variable

In the 2012 study on climate change and water resources over South Africa (Schulze, 2012) an analysis was undertaken to identify *where* in South Africa the errors occurred between the GCM derived and historical variables, and whether spatial patterns of errors varied from hydro-climatic variable to variable. Thus, the spatial error analysis of January (mid-summer) maximum temperatures in **Figure 2.3.1** shows small errors of < 0.5 °C and between 0.5 °C and 1.0 °C (top left and centre maps) to occur for 3 or more GCMs in patches in the east, while errors of 1.0 to 2.0 °C (top right) are found for the majority of the GCMs used in that specific study in the northern third of the region and in patches in the east. On the other hand, large errors in January maxima in excess of 2 °C (bottom left) are found for three or more GCMs in the central parts and what are considered very large differences between GCM and observed, *viz*. > 3 °C, are identified in the south and central areas (bottom right).

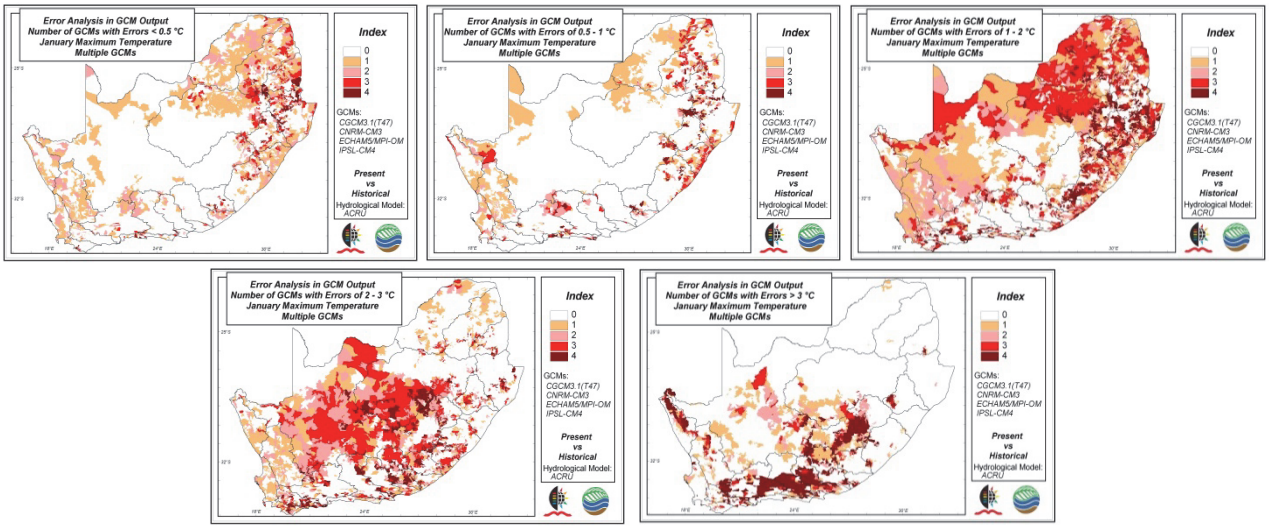


Figure 2.3.1 Spatial comparison of errors of different magnitudes of January (mid-summer) maximum temperatures between GCM derived vs historically observed values (Schulze, 2012)

The spatial analysis for July (mid-winter) minimum temperatures (not shown here, but in Schulze, 2012), on the other hand, displays quite different error patterns across South Africa to those of January maxima for the same categories of differences between GCM derived and historically observed values for an identical time period of 1971 - 1990.

The conclusions reached from the above analyses is that errors between maximum and minimum temperatures are not spatially concurrent and that errors of different magnitudes occur at different locations for both maximum and minimum temperatures. As a summary, the spatially averaged errors from the 4 GCMs used in that particular study, given in **Figure 2.3.2**, show that for January maximum temperatures the major errors are found in the central - south regions of South Africa while for mid-winter minima the largest errors are located in the northern parts. The spatial discrepancies of maximum and minimum temperature errors may have hydrological repercussions in analyses of projected changes in evaporative losses, as an important driver of evaporation is the vapour pressure deficit which is derived from temperature ranges.

In the case of the spatial error analysis of a hydrologically critical rainfall statistic, *viz*. the number of days per annum with rainfall events exceeding 10 mm, areas where small (10 - 20%) and medium (20 - 50%) differences between GCM derived and historically observed values for the same period 1971 - 1990 are found to concur in the southern half and northeastern periphery of South Africa (**Figure 2.3.3** left and centre maps). What appear as larger (50 - 100%) differences occur over relatively small patches, mainly in the southern half of the region.

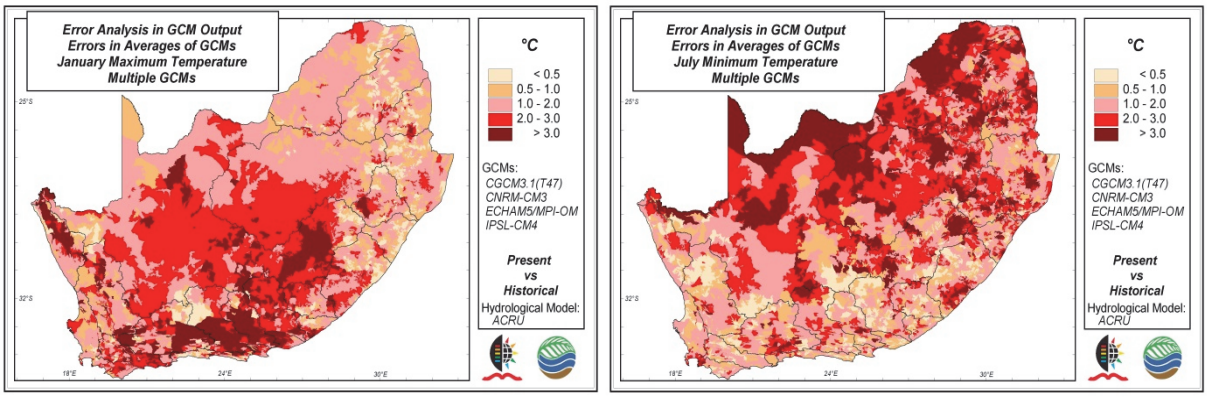


Figure 2.3.2 Comparison of error analyses between January (mid-summer) maximum and July (mid-winter) minimum temperatures (Schulze, 2012)

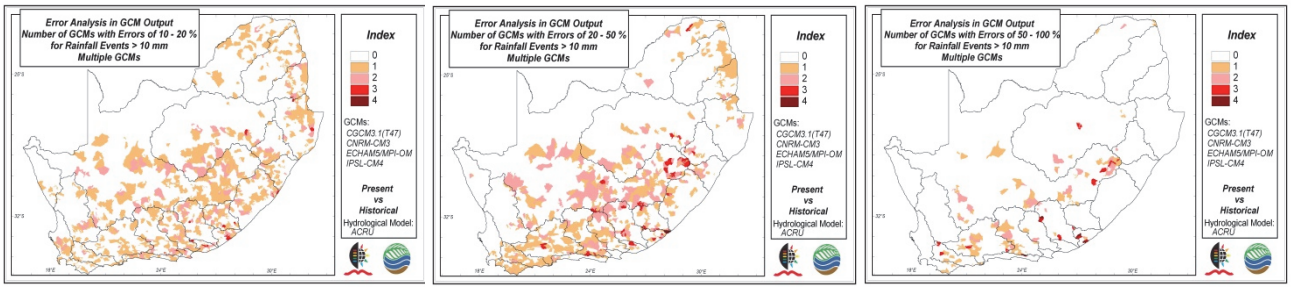


Figure 2.3.3 Spatial comparison of errors of different magnitudes between days per annum with rainfalls >10 mm derived from GCMs vs historical observations (Schulze, 2012)

2.3.2 Errors in GCM output for overlapping verification periods are often largest where the observed record is poor

It is often stated that GCMs do not capture critical hydrological variables well. GCM outputs, however, are "calibrated" against a control of observed data for overlapping historical periods. Significantly, however, in the 2012 WRC K5/1843 climate change study the patches of apparently very large (> 100%) discrepancies between GCM and observed big rainfall events exceeding 10 mm/day overlaps almost entirely with those areas identified by Warburton and Schulze (2005) as having a statistically low reliability of observed rainfall data (**Figure 2.3.4**). While not previously identified and while not quite as discernible to the naked eye, many of the apparent discrepancies between GCM derived and observed temperatures (cf. **Figures 2.3.1** and **2.3.2**) are shown in **Figure 2.3.5** to occur where, when generating a 50 year time series of daily temperatures, station records are short or a Fourier analysis had to be resorted to infill missing station values because there were no stations close enough to be used for infilling.

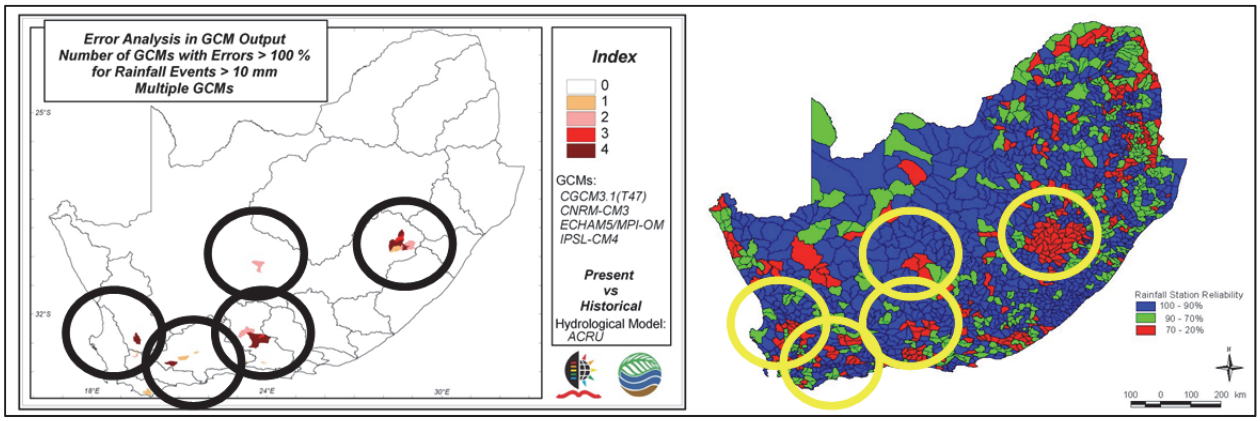


Figure 2.3.4 Example of large errors in GCM output (left: number of days per annum with daily rainfall > 10 mm) occurring where Warburton and Schulze (2005) have shown rainfall observations to have a low reliability (Schulze, 2012)

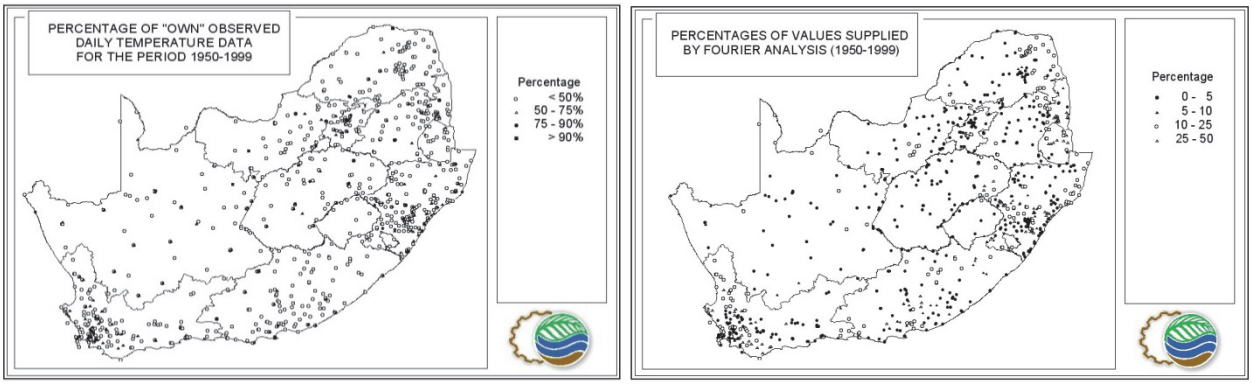


Figure 2.3.5 Percentages of "own" observed daily temperature data at qualifying stations for the common base period 1950 - 1999 (left) and percentages of values having to be provided by the Fourier Analysis in the estimation of daily temperature values for the common base period 1950 - 1999 (Schulze and Maharaj, 2004)

2.3.3 Using multiple GCM outputs for hydrological climate change assessments: There is no "best" GCM and what may be "best" varies with hydrological variable

Considering the vast amount of time and effort expended in producing maps of projected impacts of climate change on hydrological (and other) responses from multiple GCMs with the limited expertise/ resources available in South Africa, a question posed by many and evaluated by Schulze (2012) is whether climate change impact studies could not be simplified by identifying one "best" GCM for a specific region and applying just that one. While the international and local climate change literature warns against the danger of using a single GCM's output (e.g. Hewitson *et al*., 2005b; Schulze *et al*., 2005; Knoesen, 2012) in regard to South African studies) because of the uncertainties remaining in climate change projections (e.g. Cox and Stephenson, 2007; Giorgi *et al*., 2008; Jacob and van den Hurk, 2009), the hypothesis of possibly identifying a "best" GCM for South Africa was nevertheless tested using the 5 GCMs originally available for the study in WRC project K5/1843.

Assuming values of hydrological variables mapped across South Africa and derived from historically observed daily precipitation and temperature to be "correct" (although it has been shown by Lynch, 2004; Schulze and Maharaj, 2004; Warburton and Schulze, 2005; that this is not so everywhere), areas were mapped where a particular GCM's output for a variable performed "best" against values for that variable derived from the historical values for the same time period, *viz*. 1971 - 1990. Areas were also mapped where that particular GCM performed "second best" (on condition that second best was within 2% of another GCM which was the best). In **Figure 2.3.6** the "best" GCM is always shaded in a dark hue of a specific colour (e.g. ECHAM5/MPI-OM in blue) while a lighter hue of the same colour is used where that GCM qualified as "second best".

Two observations are made from the results in **Figure 2.3.6**, *viz*.

- no one GCM dominates as being the "best" or even "second best" over the whole of South Africa, although one or the other GCM might be the "best" over a specific area; and
- for different hydrologically important variables such as reference potential evaporation or rainfall or accumulated streamflows the patterns of where one or the other GCM performs "best" differs quite markedly from one variable to the next; and, in short,
- there is therefore no single "best" GCM for use in climate change impact studies in South Africa.

2.3.4 Some concluding thoughts on previous findings on climate change-related uncertainties

Spatial error analyses showed apparent errors in GCM output to vary by parameter and it was determined that no single GCM was the "best" for all regions within South Africa, nor for all hydrological drivers and responses. Some of the apparent GCM output errors can, in fact, be attributed to errors in the historical datasets which were used as the control in the verifications. The same Quinary Catchments appear to produce outlier results with all the GCMs used, which begs the question of re-checking the historical datasets. There furthermore appear to be regional biases in GCM outputs and subsequent impact studies should therefore consider regional bias corrections to temperature and rainfall output before being used with hydrological models.

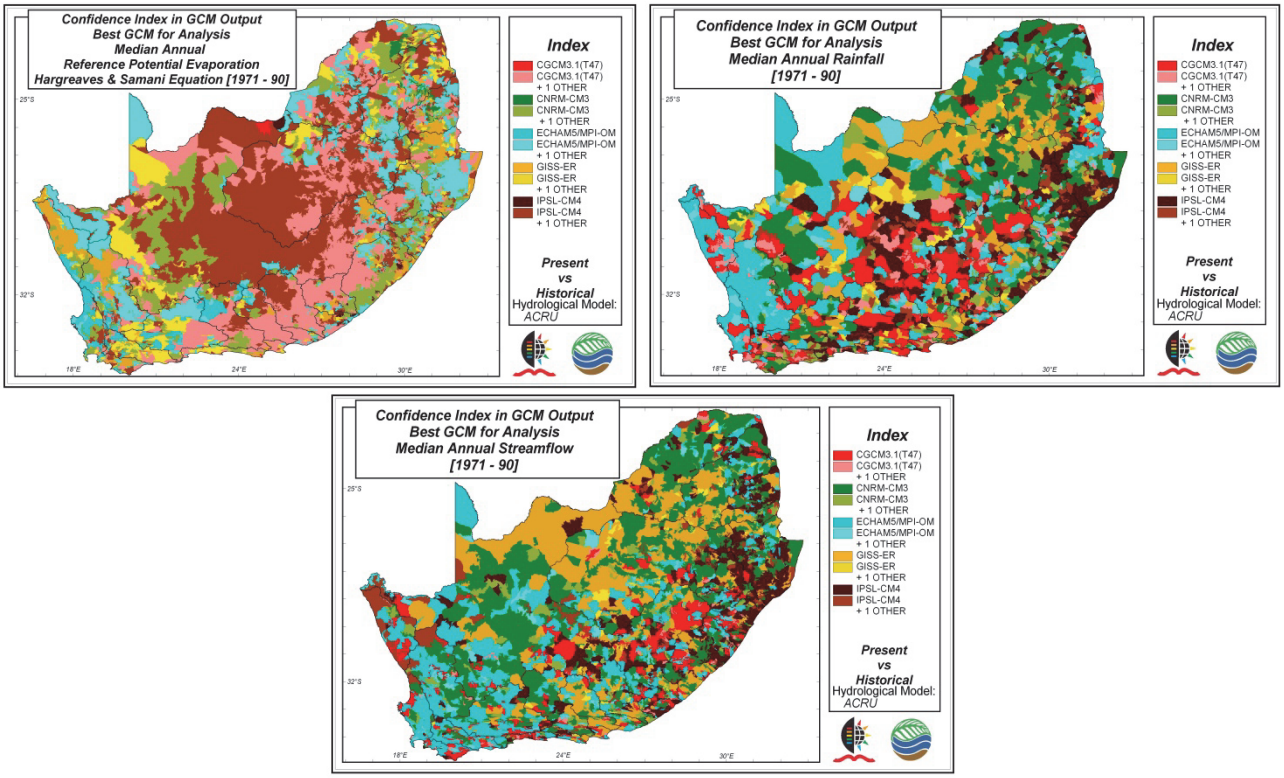


Figure 2.3.6 Spatial analysis of "best" and "second best" GCMs for different hydrological variables (Schulze, 2012)

However, many of these apparent errors and causes of uncertainties may possibly be largely self-cancelling and/or largely eliminated since many climate change impact studies are expressed as ratio changes between projected future and present climates, both derived from GCMs, with these projected changes then mapped as the mean or median of the results from the multiple GCMs used.

2.4 On "Domains" of Uncertainty Questions of Climatologists and Hydrologists

2.4.1 What will need to be considered when climate change impacts are assessed in light of an adaptation strategy?

When potential impacts of climate change on the water related sector are assessed, one will need to evaluate projected changes of *critical* climate variables such as rainfall and temperature (as it manifests itself through evaporative demand) and how, in interaction with one another, they translate to changes in hydrological responses in regard to

- *magnitudes of change*, i.e. how much the change is projected to be and how much impact that can have, where the magnitude of an impact is determined by
  - its scale, e.g. the area or number of people affected and
  - its intensity, i.e. the degree of damage caused, with the most widely used quantitative measures for climate impacts being
  - monetary units such as welfare, income or revenue losses,
  - costs of anticipating and adapting to certain biophysical impacts,
  - estimates of peoples' willingness to pay to avoid (or accept as compensation for) certain climate impacts, or the
  - number of people affected by certain impacts such as food and water shortages, morbidity and mortality from diseases, and forced migration;
- *direction*, i.e. is it a positive or negative change, and what that implies;
- *timing*, i.e.
  - when, in the course of a year, the change is projected to occur and how that affects management decisions, or
  - whether a harmful impact is more likely to happen sooner rather than in the more distant future;

- *rate*, i.e.
  - how rapidly change is projected to occur in years or decades ahead, and
  - how that affects priorities of action,
  - with adverse impacts which occur suddenly (and / or surprisingly) being perceived as more significant than the same impacts occurring gradually, because the potential for adaptation for both human and natural systems would be much more limited in the former case, and
  - with very rapid change in a non-linear system (such as the hydrological system) possibly exacerbating other vulnerabilities (e.g. impacts on agriculture and nutrition aggravating human vulnerability to disease), particularly where such rapid change curtails the ability of systems to prevent and prepare for particular kinds of impacts;
- *location*, i.e. where will it occur first or most severely considering*, inter alia*, income, gender and age in addition to regional, national and sectoral groupings;
- *persistence and reversibility*, i.e. where impacts could become key due to persistence of, say, the emergence of near-permanent drought conditions or intensified cycles of extreme flooding that were previously regarded as 'one-off' events;

and, as has been shown in the various technical chapters in, for example, Schulze (2012), the

- *levels of confidence / uncertainty* of projected impacts in regard to likelihood of impacts and confidence, where
  - likelihood is the probability of an outcome occurring and
  - confidence is either the subjective or a statistically more objective, assessment that any statement about an outcome may prove correct; the
- *potential for adaptation*, which differs between and within regions and sectors, and where the potential considers not only the technical feasibility of certain adaptations, but also the availability of required human resources, the costs and side-effects of adaptation, the knowledge about those adaptations, their timeliness, the (dis-)incentives for adaptation actors to actually implement them, and their compatibility with individual or cultural preferences; and the
- *importance of the system(s) at risk* in regard to the value attached to the system by different societies, be that value related to the uniqueness of a habitat or an ecosystem (e.g. the fynbos biome in South Africa), or livelihoods of many people depending crucially on the functioning of a system (IPCC, 2007).

2.4.2 On "Domains of Concern" regarding climate change uncertainties

In taking cognisance of all the criteria listed above, it becomes a tall order to consider them all in hydrological impacts assessments of climate change in light of the known uncertainties that abound in regard to outputs from GCMs, especially of rainfall and especially also because any errors in rainfall are amplified in estimations of streamflows. However, many issues surrounding climate projections with GCMs are outside of the "control" of the hydrologist and are clearly in the domain of the climate scientists who produce GCMs, with the hydrologist then essentially being at the end of a value chain in having to use the "uncertain output" of the GCMs as "certain inputs" into hydrological impact models. It is for this reason that a distinction is now made between "domains of concern" of the climatologist and those of the hydrologist

2.4.3 Climatologists' domains of concern

Climate modellers are well aware of problems surrounding

- Discontinuities between GCM spatial resolutions of 10^4 - 10^5 km^2 and those of the operational catchment (e.g. Quinary) scale of 10^1- 10^2 km^2
- Uncertainties in GHG emissions
- Updateable model structures (e.g. to higher spatial resolutions)
- Different vertical resolutions of the GCMs
- Pros and cons of ensemble size (super ensembles)
- Cloud radiation interactions
- Dynamical land surface coupling
- Poor parameterization of cumulus convection
- Non-stationarity of key global forcing factors, e.g. El Niño
- Pros and cons of dynamical vs statistical downscaling
- Precipitation being a secondary process in GCMs

and many more.

Hydrologists cannot resolve the above problems. They are clearly within the domain of concern of climate model developers and what hydrologists should do is to assist the climate modeller by identifying hydrologically critical issues for them to address / consider in order to reduce our concern regarding climate change uncertainties.

2.4.4 Hydrologists' domains of concerns

Hydrologists need to rather encourage climate scientists to reduce uncertainties further in regard to

- Rendering any BIAS CORRECTION unnecessary, as hydrologists ask "Bias correction for what?" Is it for means, for extremes, for variability, thresholds of daily rainfall persistencies of wet or dry days, or the El Niños?, with the bias corrections for all of the above not being the same;
- Accounting for local convective events, which in the summer rainfall region of South Africa often play a dominant role in generating stormflows and sediment yield and occur spatially with a degree of randomness;
- Simulating fewer small (< 2 mm/day) events which are generally intercepted by vegetal cover and do not contribute directly to the soil moisture or runoff regimes;
- Better capturing under-estimated temperature minima in winter;
- Better capturing over-estimated temperature maxima in summer;
- Better capturing dry / dry, dry / wet, wet / wet/ and wet / dry sequences which are very important in irrigation scheduling and in determining antecedent conditions ahead of major rainfall events;
- Better capturing extreme events used in design hydrology;
- Better capturing rainfall characteristics in mountainous areas which are the major runoff generating areas of South Africa, and with any rainfall biases in the mountainous regions resulting in amplified errors in runoff, and with this error then cascading downstream; or
- The fact that altitude affects not only rainfall magnitude, but also numbers of raindays.

These (and no doubt others) are hydrologists' concerns in regard to uncertainties in climate change assessments, but resolving them lies within the domain of climate scientists.

2.5 Expressing Uncertainties Qualitatively and Quantitatively

2.5.1 The IPCC approach

When scientists deal with issues of uncertainty it is important that they communicate carefully, using neutral statements and language that minimizes misinterpretation and / or ambiguity.

There are many ways of expressing confidence in results being correct, conversely, of expressing uncertainty in the results. The IPCC published an uncertainty guidance note (IPCC, 2007) that defines a framework for the treatment of uncertainties, together with the appropriate terminology, be the uncertainty expressed

- qualitatively
- quatitatively or
- probalilistically.

In quantitative, i.e. descriptive, terms the table below illustrates the quantitative expression according to the amount of evidence (either theory or observation or by modelling) description from left to right vs the level of agreement (low to high) in the vertical (IPCC, 2007). The terms used here are applied in a relative sense to summarise a judgement, without there being a basis for quantification.

High agreement Limited evidence	…	**High agreement Much evidence**
…	…	…
Low agreement Limited evidence	…	**Low agreement Much evidence**

Quantitatively, according to the IPCC (2007), the terminology used expresses the degree of confidence of being correct, as in the table below, e.g. if correct ~ 8 times out of 10, one would be in the "high confidence" range.

Terminology	Degree of Confidence in Being Correct
Very high confidence	≥ 9/10 chance in being correct
High confidence	~ 8/10 chance
Medium confidence	~ 5/10 chance
Low confidence	~ 2/10 chance
Very low confidence	< 1/10 chance

The third IPCC expression of confidence is a probabilistic one, i.e by likelihood, with the terminology in regard to cerrtainty matched against the probability of occurrence being exceeded, as in the table below.

Terminology	Degree of Confidence in Being Correct
Virtually certain	> 99% probability of occurrence
Very likely	> 90% probability
Likely	> 66% probability
About as likely as not	33 – 66% probability
Unlikely	< 33% probability
Very unlikely	< 10% probability
Exceptionally unlikely	< 1% probability

2.5.2 Expressing uncertainties when outputs from only few GCMs are available: Examples from previous studies

In studies where outputs from many GCMs are available, and the outcomes are all different, the level of confidence or level of uncertainty of results may be assessed by a probability distribution function. However, when results from only a few GCMs are available, simpler indicators have to be used to gain an idea of the confidence which may be placed on the results. Three methods used in WRC project K5/1843 are explained below.

The Index of Concurrence approach

One method of expressing confidence / uncertainty is to pose a hypothesis related to projected change and then to assess how for many of the GCMs used in a study that specific hypothesis was met for each spatial unit, in this case the Quinary Catchment. **Table 2.5.1** shows how the IPCC scale was adapted for the hypothesis approach when used with the five GCMs available for the K5/1843 study, *viz*. CGCM3.1(T47), CNRM-CM3, ECHAM5/MPI-OM, GISS-ER and IPSL-CM4 (cf. **Table 2.5.1**). However, for the more distant future scenario outputs from the CGCM3.1(T47) GCM were not available and **Table 2.5.1** therefore also illustrates how the confidence scale was applied when outputs from only four GCMs could be utilised. Owing to the discrepancy in the number GCMs available for the intermediate and more distant future scenarios, i.e. respectively five and four, comparing the results of the uncertainty analyses from the intermediate future with those of the more distant future may be misleading, and is not recommended. An example of the use of the Index of Concurrence is provided in **Figure 2.5.1**

Table 2.5.1 Scale of confidence levels for the quantitative assessment of uncertainty when using the Index of Concurrence (Knoesen, 2012)

Confidence Terminology	Degree of confidence when 5 GCMs are used	Degree of confidence when 4 GCMs are used
Very high confidence	5 out of 5 GCMs give same signal	4 out of 4 GCMs give same signal
High confidence	4 out of 5 GCMs give same signal	3 out of 4 GCMs give same signal
Medium high confidence	3 out of 5 GCMs give same signal	N/A
Medium confidence	N/A	2 out of 4 GCMs give same signal
Medium low confidence	2 out of 5 GCMs give same signal	N/A
Low confidence	Only 1 out of the 5 GCMs gives same signal	Only 1 out of 4 GCMs gives same signal

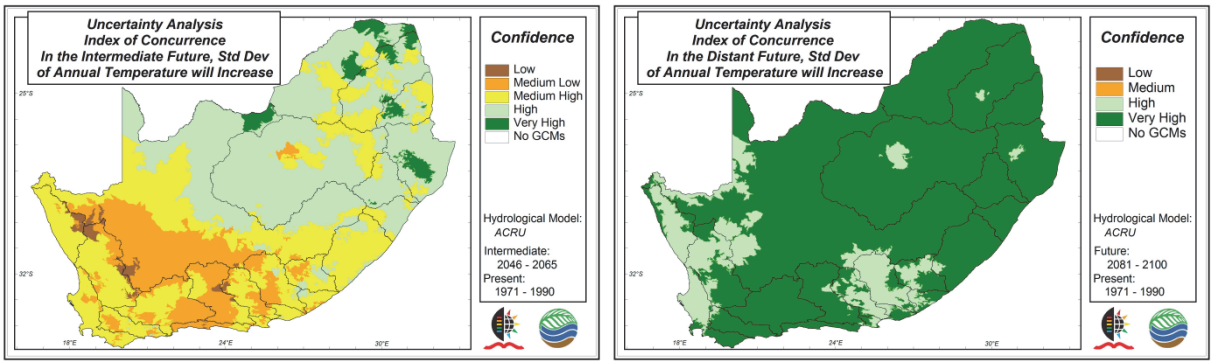


Figure 2.5.1 Example of the Index of Concurrence: Concurrence between multiple GCMs, that in future climates the inter-annual variability of temperatures over South Africa, expressed by the standard deviation, will increase (Schulze, 2011)

The Median of Ratios of Change

Median changes in ratios are computed from output from multiple GCMs, on the assumption that the median of the changes simulated from the various GCMs used in the K5/1843 study would be a better reflection of what might happen in future climates than results from just one or two GCMs. In this index of confidence, therefore, the median of the ratios of change of an attribute between the intermediate future to present climate scenarios from all the GCMs used was mapped, and similarly between the more distant future and present. In the case of results derived from five GCMs, the third ranked ratio was mapped for each Quinary; however, when outputs from only four GCMs were available, the average of the second and third ranked ratios was mapped. An example of the Medians of Ratio Changes is given in **Figure 2.5.2**.

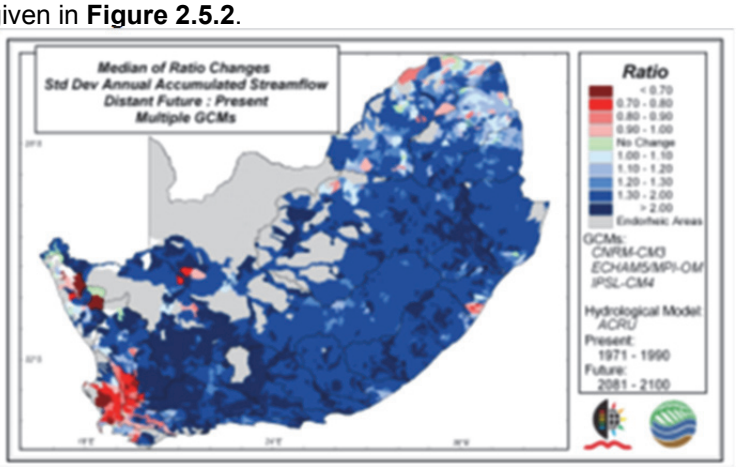


Figure 2.5.2 Example of Medians of Ratio Changes: Medians of ratio changes of more distant future to present of standard deviations of annual streamflows, derived with the *ACRU* model from output of multiple GCMs, with endorheic areas greyed out (Schulze, 2012)

The Index of Consistency of Change
The Index of Consistency of Change (ICC; Schulze, 2011) is a composite statistic which combines

- the consistency of the *direction of change* for a specific indicator when the outputs from the five GCMs are compared (in the case of the intermediate future projection vs present climate), or the outputs from four GCMs in the case of the more distant future, with
- an index of the *degree of dispersion* of the changes between the outputs of the GCMs.

Of the many statistical measures of dispersion tested, the median absolute deviation (or MAD) and the average absolute deviation (AAD) proved useful and robust in quantifying the variability of the GCM ratios, with the absolute deviation of an element of a dataset being the absolute difference between that element and a measure of central tendency, in this instant the median to avoid problems caused by "outlier" ratios.

The ICC is defined as the product of the median absolute deviation and the average absolute deviation, expressed as a percentage, i.e.

$$ICC = 100 * (1 - MAD) * (1 - AAD)$$

where MAD = median (|Xi - median|)
AAD = average (|Xi - median|) for $0.75 < (1 - AAD) < 1.00$

A third simple statistic was used to account for the direction of change derived from each GCM. If all GCM ratios are above (or equal to) unity (i.e. ≥ 1.0), or below unity (i.e. < 1.0), then the ICC value is not adjusted. However, if one GCM ratio is in the opposite direction, then the ICC is reduced by 0.75 to indicate that 3 of the 4 GCMs are in agreement with respect to direction of change. If two GCMs show an increase and two a decrease, the ICC is reduced by 0.50 to indicate the GCMs are not in agreement and the direction of change cannot be determined. On maps the ICC is shown to range from very low to very high, as in the example in **Figure 2.5.3**.

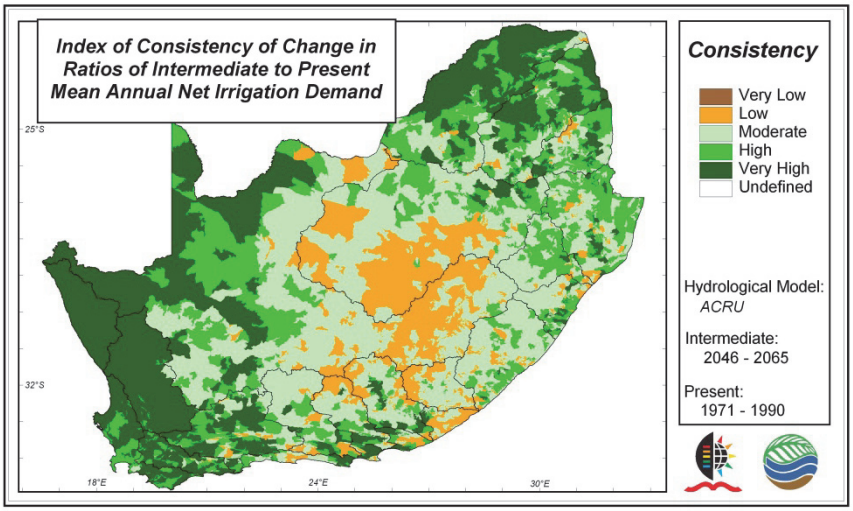


Figure 2.5.3 Example of the Index of Consistency of Changes: Index of Consistency of Changes in ratios of intermediate future to present mean annual net annual irrigation demands, computed with the *ACRU* model from output of multiple GCMs (Schulze, 2011)

Regression analysis
One test of the uncertainty/confidence in GCM output is to regress hydrologically relevant GCM output of a variable against corresponding observed values of that variable for the period over which the observed and GCM values overlap, as shown in **Figure 2.5.4**.

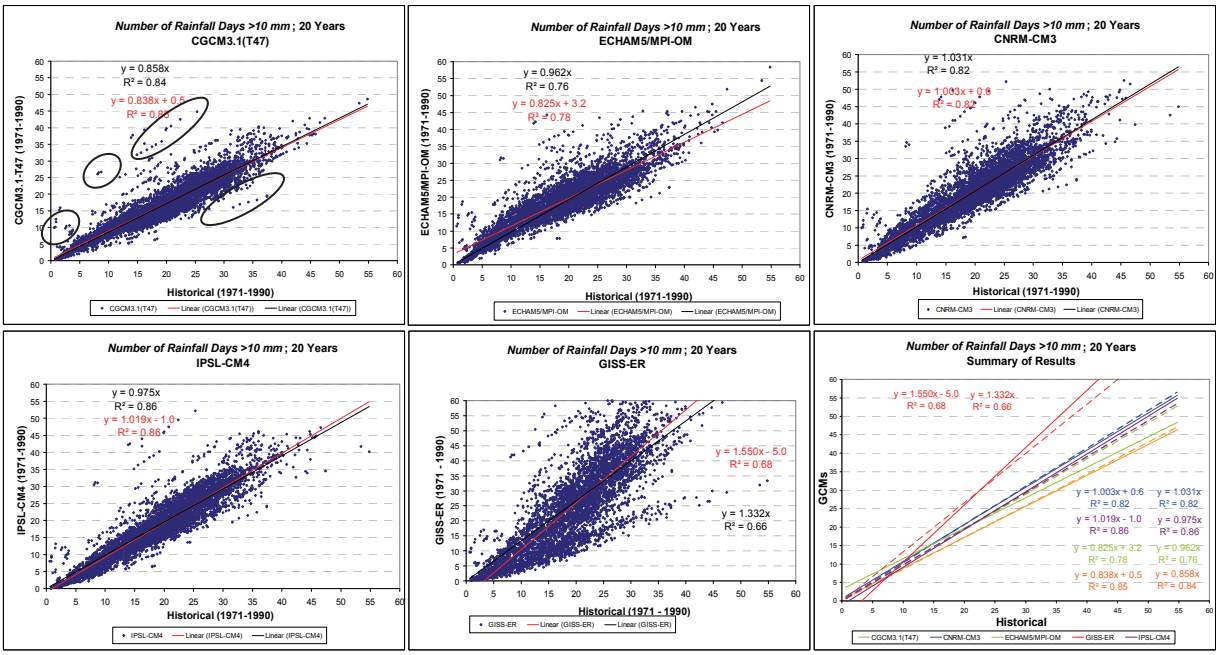


Figure 2.5.4 Scatterplots of GCM derived vs historically observed number of days per year with 10 mm or more of rainfall per day for the 20 year period 1971 - 1990, with each dot representing results from one Quinary Catchment (Schulze, 2012)

Such an uncertainty analysis then takes the form of a verification study and thus implies the following:

- demonstrating that the behaviour (i.e. output) of a simulation model, in this case the output from empirically downscaled GCMs, is consistent with the behaviour of the physical system (i.e. that GCM output reflects the signals of observed values);
- and in doing so, determining if the GCM's output values have sufficient accuracy for the model's intended use, *viz*. to assess projected impacts of climate change on water resources related issues in order to make science informed adaptation strategies.
- It is thus a process to determine if the differences between historically observed and GCM simulated values are sufficiently small (or not) and thereby establishing a level of confidence (or lack thereof) in the climate model (Schulze, 2012).

In such verifications of model output, in this case from GCMs, the assumption is made that the observations against which the verification is made are valid, i.e. that the historical data of rainfall and temperature at the Quinary Catchment scale are "perfect" and contain no errors (Schulze, 2012). This assumption will be tested later in this chapter.

In order to perform verifications on those outputs of the GCMs which were considered relevant to the study by Schulze (2013), hydrologically critical indicators were first selected. For the K5/1843 study those included, *inter alia*, the number of days per year with a rainfall of 10 mm or more (**Figure 2.5.4**), as a test to ascertain whether the downscaled GCMs could capture the significant rainfall events adequately, with 10 mm per day generally being a threshold for stormflows and sediment yields to be generated from a catchment. The relevant values were extracted for each of the 5 838 Quinary Catchments covering South Africa from the daily output files. A similar exercise was undertaken for days with a threshold of 25 mm rainfall. This was done for the overlapping period from 1971 to 1990 of historical daily rainfall and temperature data (i.e. the "observed" data) and output from the 5 GCMs available for that particular study (the "simulated" values). Results from this example are shown either as scatterplots (**Figure 2.5.4**) or in tabular summaries (**Table 2.5.2**; Schulze, 2012), but can also be displayed in map form as residuals from the observed.

Table 2.5.2 Performance statistics on numbers of days per year with rainfall ≥ 10 mm and ≥ 25 mm between outputs from downscaled GCMs vs historical observations, per Quinary Catchment in South Africa (Schulze, 2012)

GCM	Days with Rainfall > 10 mm							Days with Rainfall > 25 mm						
	Regression				Through Zero			Regression				Through Zero		
	Slope	Int	R^2	Rank	Slope	R^2	Rank	Slope	Int	R^2	Rank	Slope	R^2	Rank
CGCM3.1(T47)	0.838	0.5	0.85	1	0.858	0.84	3	0.804	0.1	0.79	2	0.822	0.78	3
ECHAM5/MPI-OM	0.825	3.2	0.78	4	0.982	0.76	2	0.864	0.7	0.75	4	0.956	0.74	3
CNRM-CM3	1.003	0.6	0.82	1	1.031	0.82	4	1.059	0.1	0.78	1	1.066	0.78	2
IPSL-CM4	1.019	1.0	0.86	1	0.975	0.86	1	1.029	0.3	0.78	3	0.993	0.79	1
GISS-ER	1.550	5.0	0.68	5	1.332	0.66	5	1.544	1.1	0.59	5	1.405	0.58	5

When assessing the verifications of the numbers of days per annum with rainfall exceeding 10 mm and 25 mm, the scatterplot in **Figure 2.5.4** and the summary of results in **Table 2.5.2** show clearly that the GISS-ER GCM performs markedly worse than the other four GCMs. That study was subsequently advised through the CSAG in 2010 that the Goddard Institute for Space Studies (GISS) had detected an error in its rainfall generation over certain parts of southern Africa and subsequently that GCM was omitted from further analysis.

2.5.3 Expressing uncertainties when outputs from only few GCMs are available: Example of a method developed in the course of this project

A measure of confidence in the projected changes in a hydrological variable by the various GCMs used in a study is to assess whether there is consistency of change over time amongst the GCMs at a given location, e.g. a Quinary catchment. This is expressed through a Confidence Index (CI) which, for each Quinary catchment, is a measure of the differences/dispersion between the ratio changes of a variable (e.g. of MAP) between the intermediate (or more distant) future and present climates, as generated by the individual GCMs. The CI is computed as the Coefficient of Variation CV(%) of the ratio changes of the individual GCMs, i.e. the lower the value of the CI (i.e. the lower the CV) for a given Quinary the higher the confidence that there is consistency in the changes over time among the GCMs used in an analysis. In the development of this Confidence Index it was shown that it works well irrespective of whether the ratio changes of all GCMs are above 1 (i.e. a change where the future projection gives a higher value than the present) or all below 1 (future produces a lower value) or some GCMs above 1 and others below 1.

$$CI(\%) = 100 * \frac{\text{Standard Deviation (of ratio change in the variable from GCM1, GCM2, GCM3, GCM4…)}}{\text{Mean (of ratio changes in the variable from GCM1, GCM2, GCM3, GCM4…)}}$$

By way of an example, results in **Figure 2.5.5** show that within the bounds of the eThekwini Municipality in KwaZulu-Natal there is considerably more consistency of change among the GCMs used in that study in mean annual rainfall (with relatively low CIs) than mean annual accumulated streamflows (with considerably higher CIs).

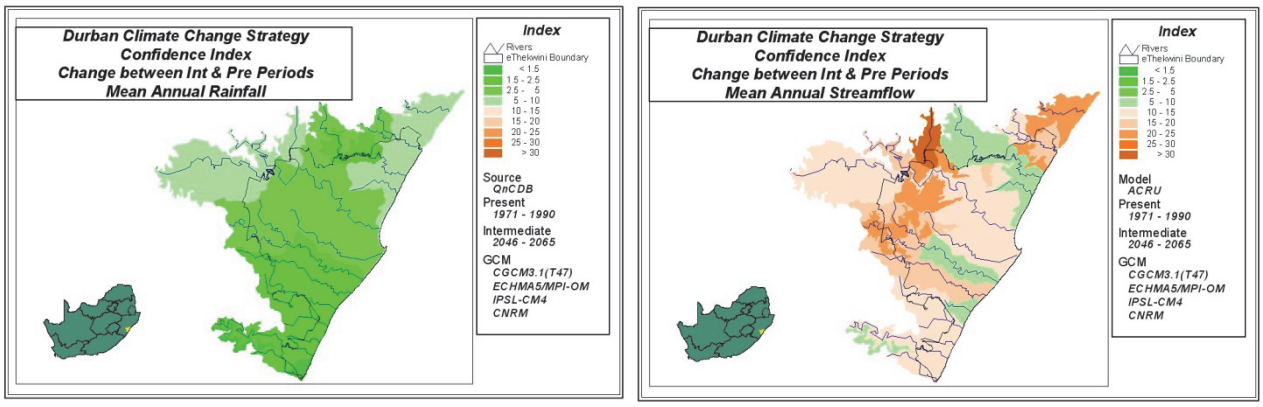


Figure 2.5.5 Example of the Confidence Index showing for eThekwini Municipality that there is more consistency of change from climate projections for annual rainfall than for mean annual streamflow (Schulze and Davis, 2013)

2.6 Some Emerging Issues Related Indirectly and Directly to Climate Change Impact Studies, and Which Would Affect Results and Their Interpretation, and Could Affect Decisions Taken

2.6.1 Historical means are already highly uncertain

Issues around uncertainties of rainfall derived from GCMs must be viewed in light of uncertainties that already abound in the historical record, with the uncertainties associated with the high inter-annual variation of the rainfall and on the relative shortness of the record. Expressed through the Standard Error of the Mean, SE_x ($SE_x = \sigma_x/n^{0.5}$, with σ_x the standard deviation of the observations and n the number of observations), it is shown for various locations in the northern, eastern and southern parts of South Africa (**Figure 2.6.1** left) that for a 50 year historical record the standard error of the mean of annual rainfall is of the order of 5%, but when daily rainfall is used in a hydrological model (*ACRU*) to compute runoff and sediment yield, the standard error of mean annual runoff and sediment yield increases to 11 – 19%. This is a serious error given that licences for production plantation forestry in South Africa are often granted subject to the reduction in streamflow from baseline land cover conditions as a result of afforestation be less than 10% of mean annual runoff.

Given the formula for the standard error of the mean, the error will be even larger for shorter records. The climate change scenarios used in WRC Projects K5/1843 and K5/1965 are for time slices of only 20 (rather than 50) years, and **Figure 2.6.1** (right) illustrates that for the shorter record length the error for estimates of annual rainfall increases to ~ 7% while that for runoff now ranges from 12 to 19%.

Without detracting from the serious uncertainties inherent in rainfall (and thus runoff) estimates from GCMs and differences in these variables produced by different GCMs, the uncertainties already imbedded in the historical record of annual rainfall and annual runoff (be it simulated or observed), let alone when short periods of records are assessed, are already formidable.

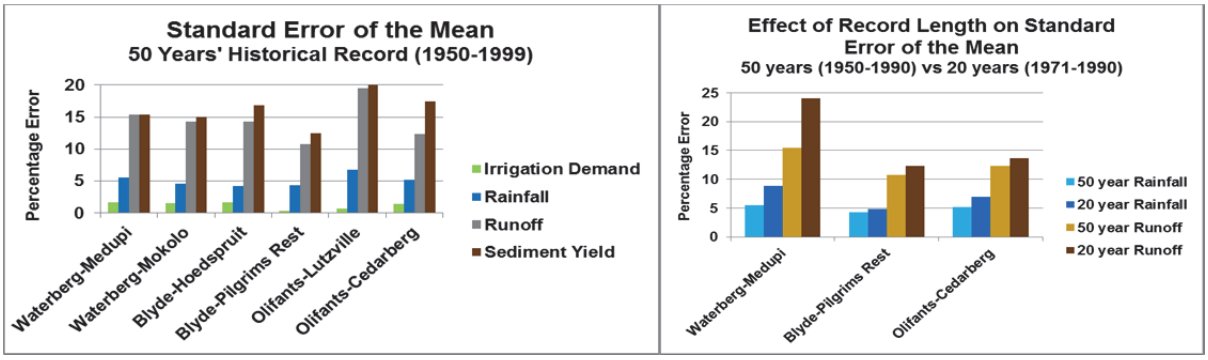


Figure 2.6.1 Examples of high standard errors of the mean from historical records for annual rainfall and runoff (as well as for other variables) for a longer and shorter time period at selected locations in South Africa

2.6.2 We have to work with inadequate baseline hydro-meteorological networks in regard to the spatial distribution of stations, the record length and data reliability

Shown in **Figure 2.6.2** (left) are the locations of all the rainfall stations across southern Africa as identified in a study by Lynch (2004). The quality and length of records from the 12 153 rainfall stations varied greatly, this being of particular concern when they are used for climate change detection or for hydrological modelling purposes or for the design of hydraulic structures. It stands to reason that a long record length increases the range of events captured, including major droughts and floods, allowing extremes to be accounted for in water resources design and planning. At first glance the rainfall station coverage of southern Africa appears highly adequate from **Figure 2.6.2** (left). However, when only rainfall stations with lengths ≥ 50 years of usable records (**Figure 2.6.2**, middle; Warburton and Schulze, 2005) are considered then the coverage is far sparser, with no usable long term rainfall stations in Lesotho, for example, which generates a considerable volume of Gauteng province's water. When mapping rainfall stations with a record length of 75 years or longer (**Figure 2.6.2**, right) the coverage across southern Africa is sparser still. KwaZulu-Natal, at the time of Lynch's (2004) study had only two rainfall stations with a usable rainfall record ≥ 75 years, and Limpopo only three. A usable rainfall record is one for which only a small percentage of values are missing.

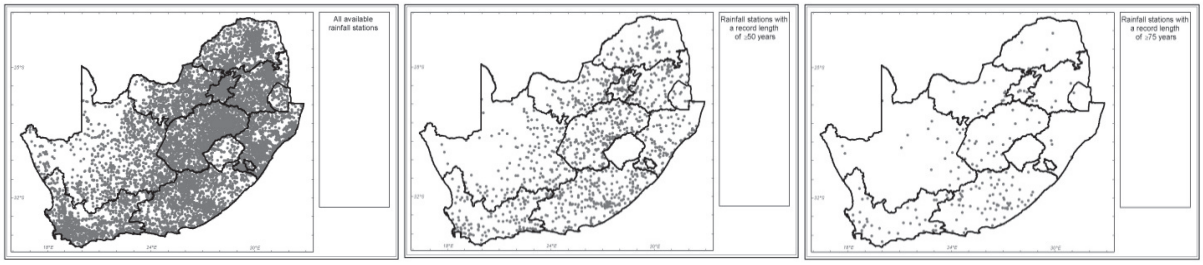


Figure 2.6.2 Location (left) of all available rainfall stations (Lynch, 2004), those (middle) with a record length ≥ 50 years and (right) with a record length ≥ 75 years (Warburton and Schulze, 2005)

The Quinary Catchments Database (Schulze *et al*., 2010), which is the spatio-temporal foundation upon which numerous national, catchment and municipal climate change impacts studies have been undertaken, contains data from ~ 1200 rainfall "driver " stations. **Figure 2.6.3** (left) shows those "driver" rainfall stations (on a backdrop of Quaternary Catchments) which have a record length (observed and infilled) of 75 years and longer, in addition to having a reliability of 95% and greater. These "driver" stations have each been allocated a 35 km radius buffer, representing an area of 3 850 km^2 per raingauge, which is far in excess of the "ideal" area to be represented by one raingauge in a largely convective rainfall region, and considerably larger than the average area of a Quaternary Catchment which is 651 km^2 or a Quinary Catchment, which is 217 km^2. Even if this unrealistically large area were to be represented by a single raingauge, there remain large numbers of Quaternaries (let alone Quinaries) not covered by a high quality "driver" rainfall station over most of Lesotho, much of Swaziland and the Northern Cape. Areas along the Limpopo/Mozambique border are also not represented by "driver" rainfall stations of the highest quality, nor are Quaternaries over much of the Western Cape mountain region. If, however, each raingauge is buffered by a 10 km radius, which would be more representative of an individual thunderstorm cell, then **Figure 2.6.3** (right) shows clearly that the rainfall station network, dense and comprehensive that it might appear (and certainly is by African standards), is not yet ideal for detailed regional distributed hydrological modelling. Added to this is the loss of large numbers of stations (~ 1 000) since the mid-1990s which recorded daily rainfall, which is likely to reduce the network of reliable long term stations when further enhancements of the Quinary Database are undertaken.

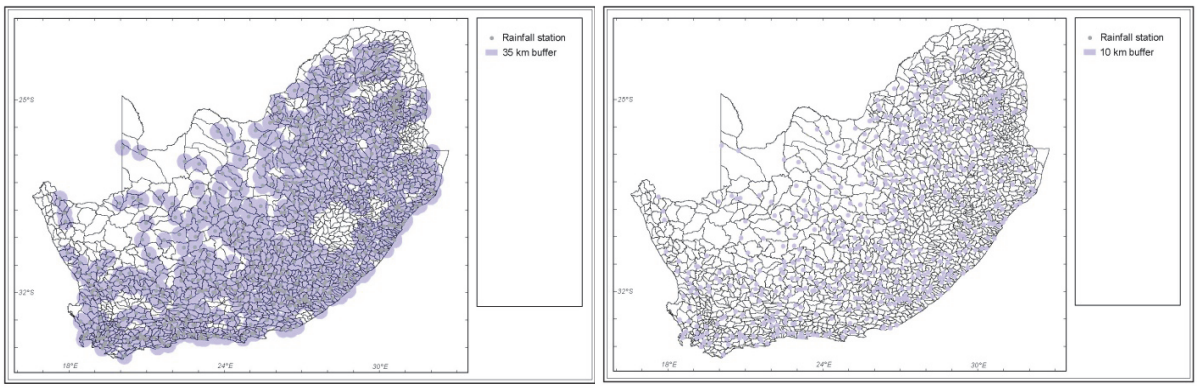


Figure 2.6.3 "Driver" rainfall stations with a record length (observed and infilled) of 75 years or more and a reliability of 95% or more, with a buffer of (left) 35 km radius and (right) 10 km radius (Warburton and Schulze)

As mentioned above, the rainfall record length is an important selection criterion for hydrological research. Another important selection criterion is the reliability of the station's record. The reliability of the rainfall record is the percentage of days in a required data period (e.g. 1950 - 1999) for which there is reliable observed rainfall record. Reliability of the rainfall record is important because a sample error in rainfall will be amplified when the record is used for hydrological modelling to obtain simulated streamflowt. The average reliability of the rainfall stations selected for the Quaternary and the Quinary Catchments Databases was 79.2%, with the highest reliability of a chosen station being 100% and the lowest reliability of a chosen rainfall station being 23.9%. Nearly 50% of the selected rainfall stations had a reliability of 95% or higher. However, the spatial distribution of the reliability of the rainfall stations' records, shown in **Figure 2.6.4**, again reveals large gaps in hydrologically critical areas such as the runoff producing areas of the highlands of Lesotho and parts of the southern Cape mountains as well as in the far north of the country where major economic development is foreseen.

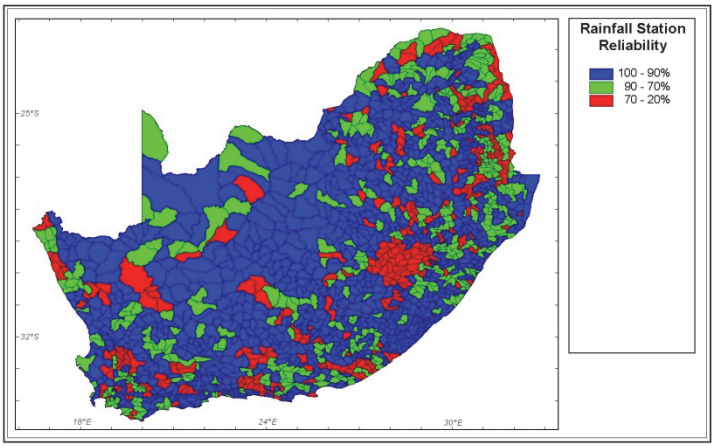


Figure 2.6.4 Reliability of daily rainfall at stations selected to represent each Quaternary Catchment in southern Africa (Warburton and Schulze, 2005)

2.6.3 The "Water Tower" Syndrome: We do not understand well enough the rainfall dynamics of mountain areas

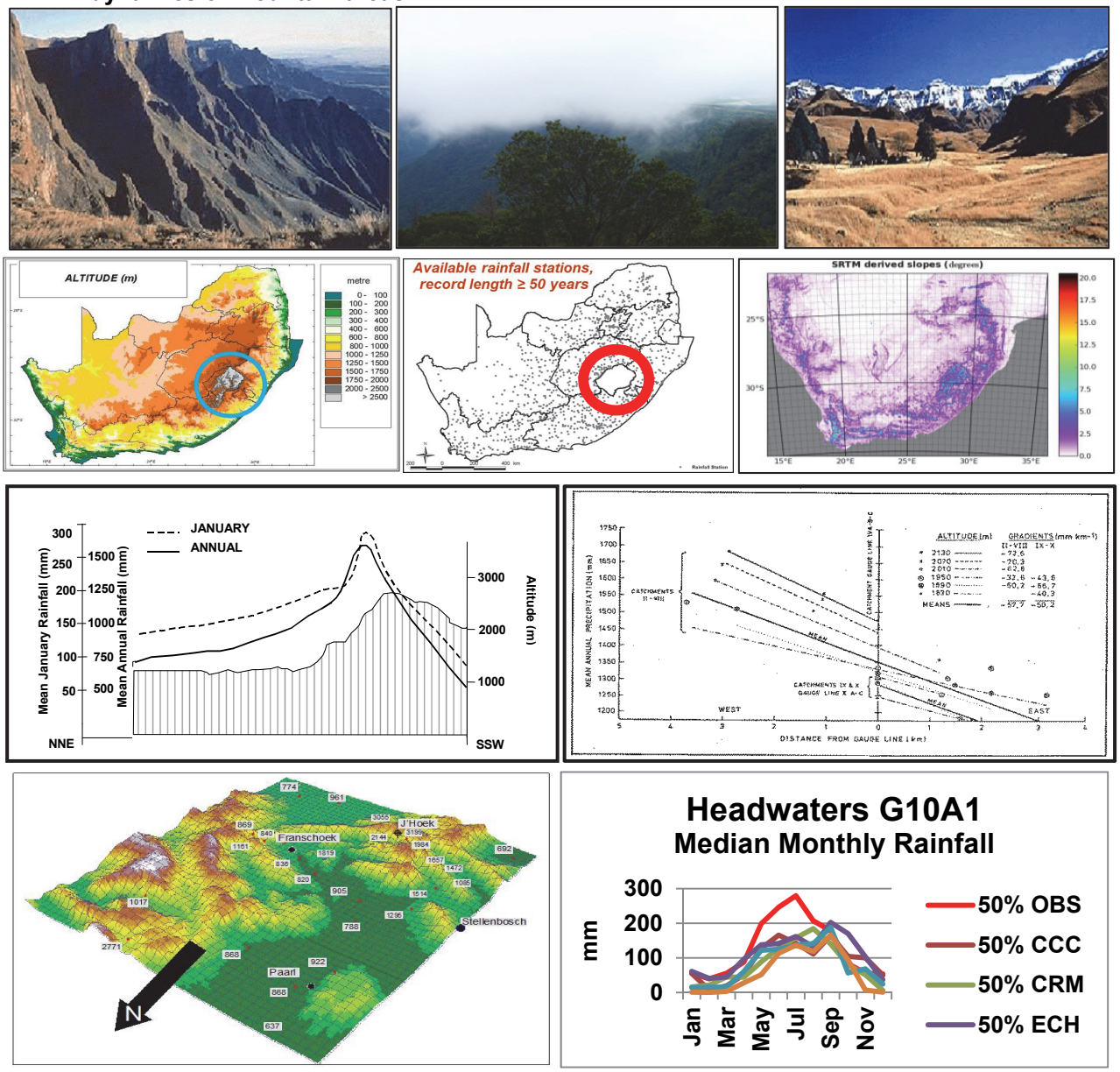


Figure 2.6.5 The complexities of rainfall estimates in mountainous regions (Various sources)

Mountainous areas constitute the primary sources of South Africa's sparse water resources, yet the dynamics of rainfall under current, let alone future climatic conditions, are poorly understood. The composite of pictures and diagrams making up **Figure 2.6.5** illustrate some of the key points of uncertainties and issues in mountain region rainfall dynamics in South Africa, including

- steep gradients (top row, left; middle row, right) forcing up moisture laden air to precipitate out
- these often being associated with shallow soils producing both high and rapid runoff responses
- the usually sparse raingauge network (second row, centre; bottom row, left)
- the unknown influence of fog / low cloud on the water budget (top row, centre), as well as the little known influence of snowfalls (top row, right) on the water budget
- the complex rainfall : altitude relationships with highest rainfalls frequently occurring before the highest altitudes and a rapid fall-off of precipitation on the leeward side of mountains (third row, left), compounded by directional changes in rainfall (third row, right) and
- GCMs often not capturing the high rainfalls in mountainous areas (bottom row, right).

Given South Africa's dependence on mountainous regions as the "water towers" of the country, it is imperative, not only for climate change studies, that better raingauge networks be established / maintained there and that these dynamics be researched in depth

2.6.4 Key hydrological processes are still missing in frequently used models and these could become important in climate change assessments

Channel transmission losses

Much of South Africa is semi-arid to arid and many rivers are either annual in that they flow only for part of the year or even ephemeral in that they discharge into a dry river bed and then, because of vertical recharge into the river bed, may flow only for a short period following heavy rainfalls. Flows generated under such conditions are frequently reduced partially downstream or vanish completely because of channel transmission losses. Such losses can dominate upstream-downstream flow relationships in semi-arid and arid regions characterised by abundant ephemeral streams. This is illustrated by way of the photograph and graphic in **Figure 2.6.6** for the Kuiseb River in Namibia. Given the huge losses downstream, and the magnitude of this problem across the country, a representation of this process needs to be built into commonly used South African daily time step hydrological models. The process representation needs to apply not only to flows into dry river beds, but also to any "pulse" change in runoff of perennial, permanently flowing streams following a stormflow event, as even under such conditions lateral transmission losses into the channel sides can be around 5 - 10%, with the higher the flow change the relatively less the losses.

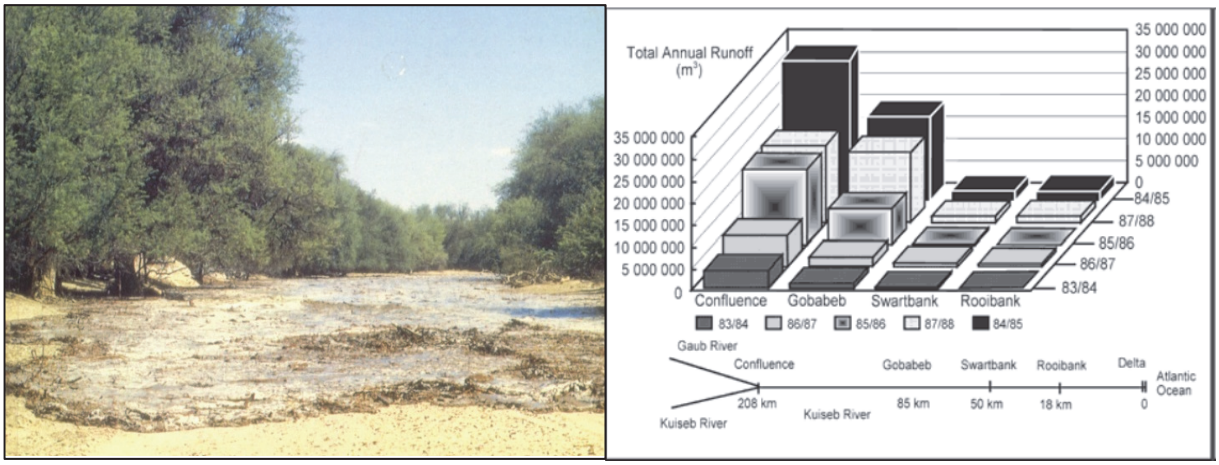


Figure 2.6.6 Examples of channel transmission losses and reductions in downstream flows in the Kuiseb River, Namibia (Jacobson *et al*., 1995)

Modelling the hydrology of endorheic (i.e. internally drained) areas

In addition to channel transmission losses, large areas of the more arid northern areas of South Africa are endorheic, i.e. they have internal drainage with no channels / streamflows exiting the areas (**Figure 2.6.7** left). The endorheic areas are affirmed by the very few, if any, rivers that are shown on the 1:50 000 topographical maps of those areas. This is well illustrated for the Waterberg catchments in Limpopo province in **Figure 2.6.7** (right). Endorheic areas frequently contain shallow pans in which

water accumulates under certain wet conditions and from which water then evaporates again in periods of no sustained rains, so that many pans are dry (with salty surfaces) for large parts of the year and sometimes for several years on end.

The fact that much of the modelling at national level with daily time step models, both without and with climate change considerations (e.g. Schulze, 2008; 2012), has not included the effects on downstream flows of upstream endorheic areas is a shortcoming in the modelling that needs to be rectified in any future simulations, especially now that procedures to account for endorheic areas have recently (2013) become available for the *ACRU* model.

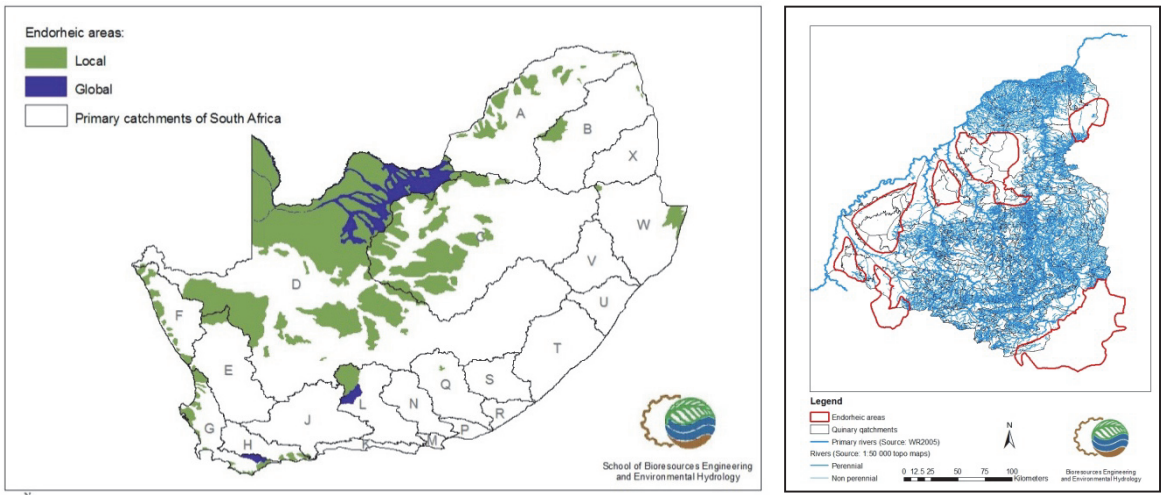


Figure 2.6.7 Endorheic, i.e. internally drained, areas in South Africa (left) and in the Waterberg catchments (right), with the latter illustrating the virtual absence of rivers where internal drainage exists (Sources: Midgley *et al*., 1994; Schulze *et al*., 2011)

2.6.5 Climate change impacts in hydrology are event driven: The use of daily time step models is thus imperative

While there are elements of "push" type alterations associated with climate change, such as gradual sea level and mean temperature rise, the essence of climate change in regard to hydrological responses revolves around changes in "pulse" events through thresholds of short duration (e.g. daily) being exceeded. From a hydrological perspective the impacts of such pulse events cannot be modelled with, for example, a monthly time step model, which does not capture the vertical, horizontal and lateral fluxes and flows, inter-linkages, nor the feed-forwards or feed-backs which are shown in **Figure 2.6.8** and which a physical-conceptual daily time step model can, to a large extent, mimic realistically. Since the major concerns in regard to climate change in hydrology do not revolve only around changes in means, but rather in changes in thresholds, extremes and persistencies, it is therefore imperative that well-structured daily time step models be applied in climate change studies.

2.6.6 In hydrological climate change studies, when comparing outputs from differently downscaled GCMs, it is imperative to compare "apples with apples" by appropriate bias corrections to the catchment resolution of choice

With the large number of downscaled climate scenarios having become available, a number of studies have made inter-comparisons between outputs from GCMs with statements made about matches and mis-matches among the outputs which could have far-ranging repercussions in decision making under uncertainty. As a point of departure the following need to be borne in mind and "reconciled" in terms of protocols to be observed re. GCMs used in such inter-comparisons in order to compare "apples with apples":

- Some GCMs have been downscaled to a raster with variable grid spacing, e.g. 0.5° or 0.45° latitude / longitude using specific geographical projections, while others may have been downscaled to points represented by rainfall and/or temperature station locations (**Figure 2.6.9**). If the 5 838 Quinary Catchments are used as the spatial resolution of choice in hydrological impacts modelling over South Africa, it needs to be remembered that with 499 raster points of a 0.5° raster covering the region, then the climate of each raster point on average "controls" the

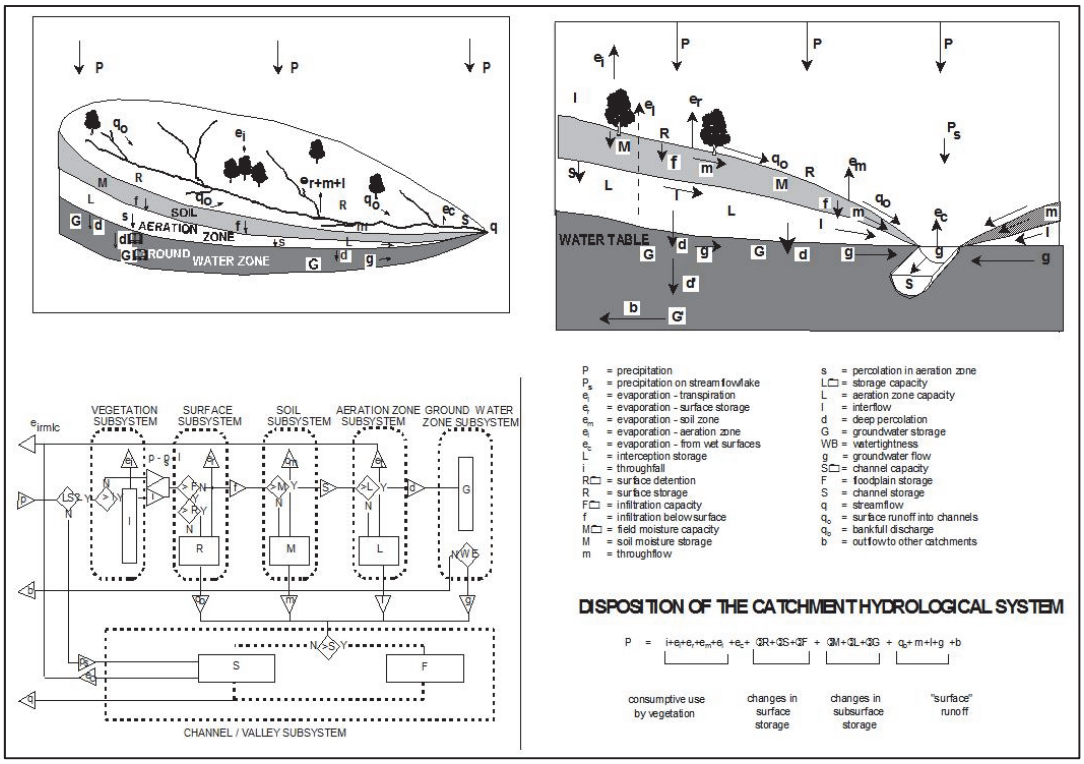


Figure 2.6.8 Processes which need to be captured in hydrological studies of climate change

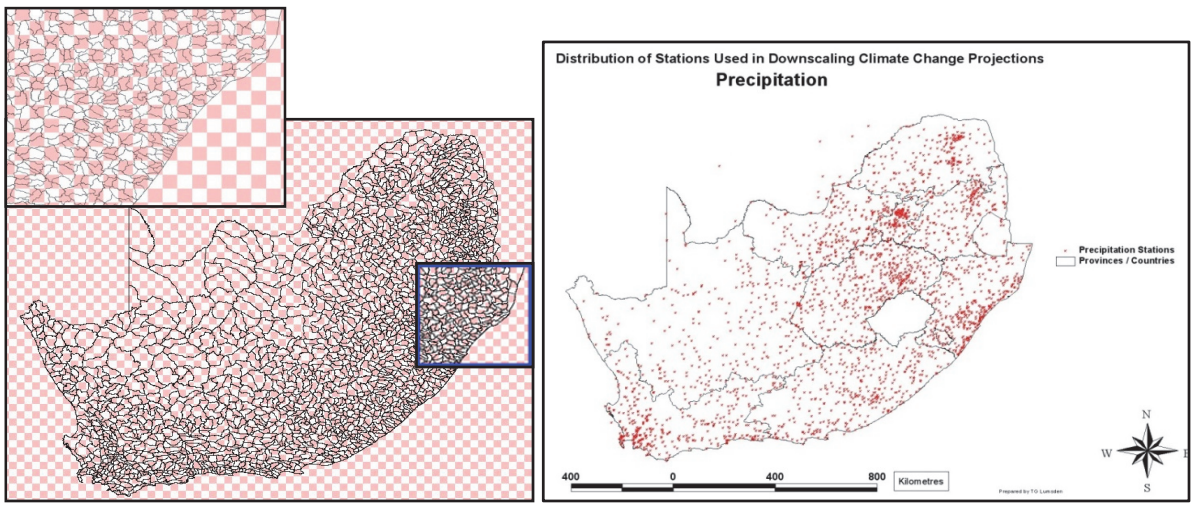


Figure 2.6.9 GCM downscaling (left) to a raster, superimposed over the Quaternary Catchments covering South Africa and (right) to individual rainfall station locations

climate and hence hydrology of nearly 12 Quinaries. On the other hand, with downscaling by CSAG to > 2 000 rainfall station locations across South Africa, each rainfall station would on average service fewer than 3 Quinaries. The number of Quinaries controlled by a raster's or point's rainfall is hydrologically significant as it implies that each of those Quinaries would be assigned rainfall, and hence runoff, on the same day and with the runoff generated from that rainfall event cascading downstream from one Quinary to the next, an excessively large hydrograph may be generated .

- Quinaries are located at altitudes either higher or lower than the representative altitude of raster or station point. Bias corrections from the daily temperature of the raster or station point therefore have to be made to be representative of that of the Quinary. Analyses of the altitude difference between Quinary and a 0.5° raster show that while 49% of Quinary altitudes are within +100 m and -100 m of that of the raster, certain Quinaries differ in altitude by up to +1535 and -1250 m (**Figure 2.6.10**), with resultant maximum temperatures in extreme cases being out by between -11.1 to + 5.5° C and minimum temperatures in extreme cases being out in the range -7.7 to

+6.2° C (**Figure 2.6.11**) when local temperature lapse rates are used. It must be remembered that the extreme cases occur in hydrologically and ecologically sensitive mountainous regions, and this is shown clearly in the spatial depiction of the adjustments in **Figure 2.6.12**.

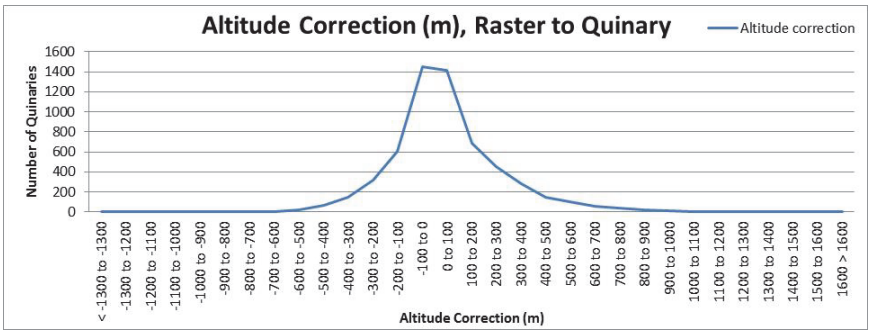


Figure 2.6.10 Frequency diagram showing differences between the mean altitude representing a 0.5° raster and that representing Quinary Catchments

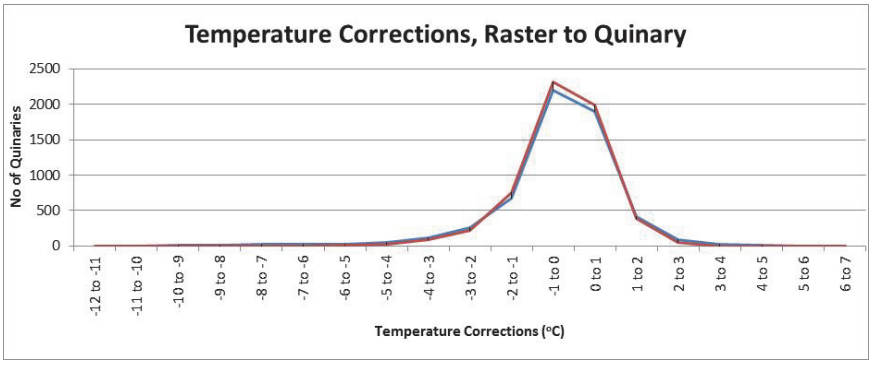


Figure 2.6.11 Frequency diagram showing differences between the maximum (red) and minimum (blue) temperatures representing a 0.5° raster and that representing Quinary Catchments

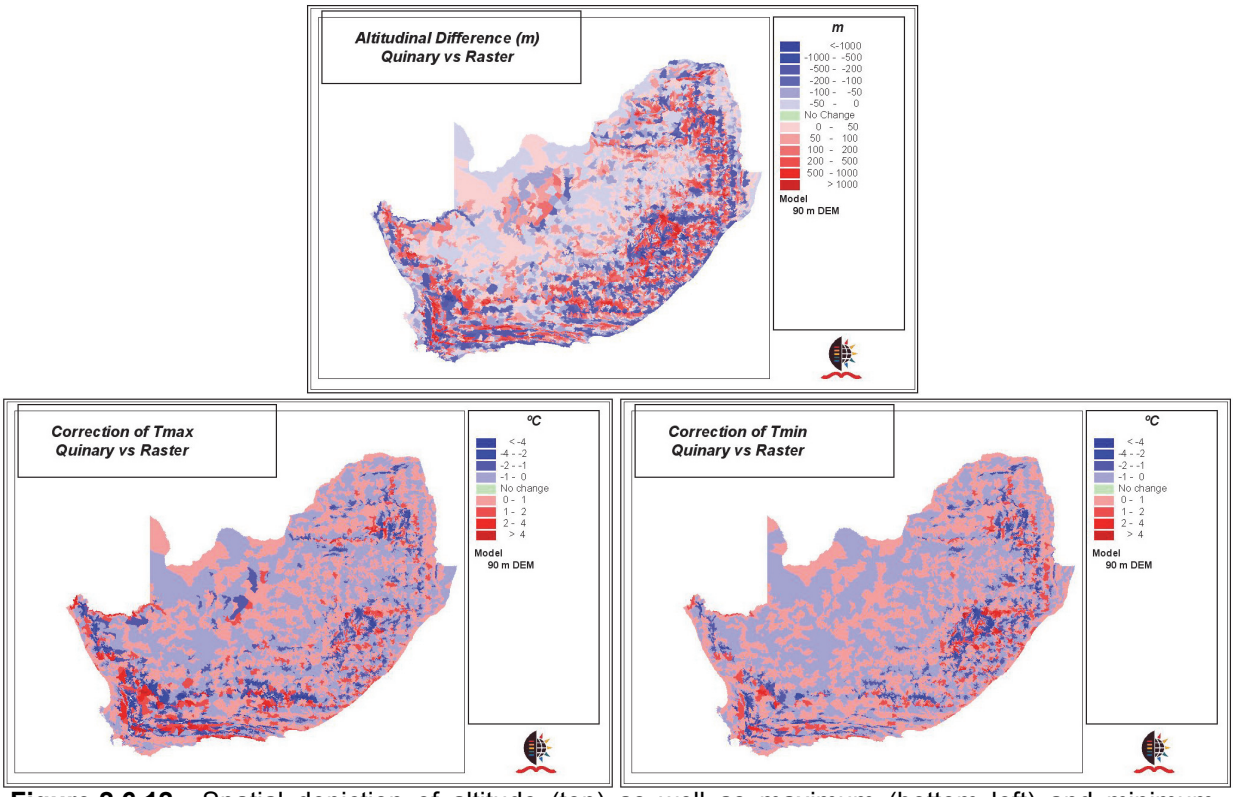


Figure 2.6.12 Spatial depiction of altitude (top) as well as maximum (bottom left) and minimum temperature (bottom right) bias corrections between those representing a 0.5° raster and Quinary Catchments

- Similarly, bias corrections need to be made to the daily rainfalls derived from raster based GCMs in order for those to be representative of the individual Quinaries which are "driven" by rainfall output from a given raster point. What makes rainfall adjustments more complex is that the relationships between rainfall and physiographic variables such as altitude and / or continentality vary throughout the year according to the typical rainfall generating mechanisms (e.g. be they typically frontal vs orographic vs convective) of specific regions (e.g. for the winter or summer or all year regions), and also that these representations vary among the different GCMs. Rainfall bias corrections between a specific raster and the Quinaries it serves therefore have to be undertaken for each GCM separately and for each month of the year separately. Bias corrections also need to be "capped" to a lower and upper threshold in order to remain realistic, and for adjustments when using the *ACRU* model these are capped at 0.5 and 2.0. Mostly the adjustments are between 0.9 and 1.1, implying that the raster to Quinary corrections are in the order of 10% up or down. However, in the non-rainy seasons the adjustments are generally higher, but hydrologically insignificant as an adjustment from, say, 1 mm to 2 mm or 1 mm to 0.5 mm on a given day will not affect runoff generation. Examples of rainfall bias corrections for two GCMs are given in **Figure 2.6.13** for the months of January (mid-summer) and July (mid-winter), showing clearly that while the differences between the GCM are small, the differences between the seasons are significant with, fortunately however, the corrections being less (i.e. around 0.8 to 1.2) in the main rainfall seasons.

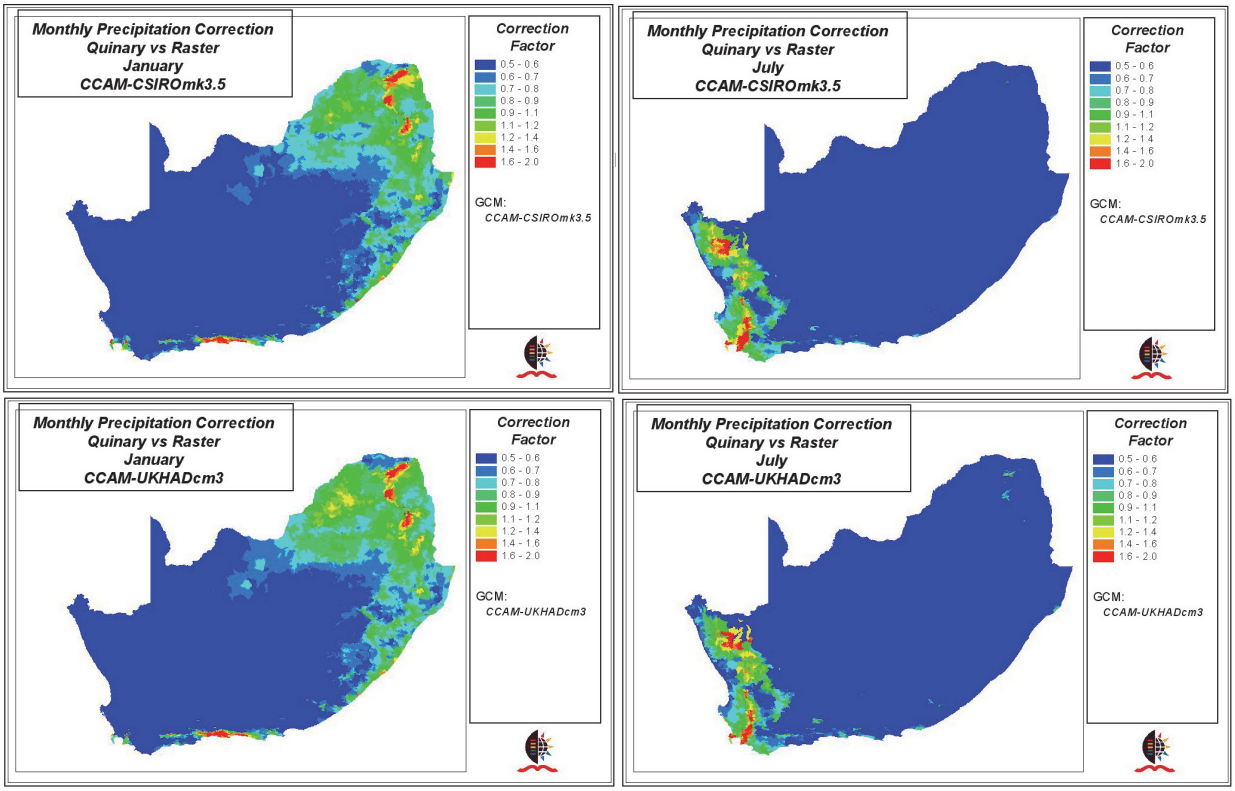


Figure 2.6.13 Spatial depiction of rainfall bias corrections between a 0.5° raster and Quinary Catchments for two GCMs and for a mid-summer (January) and a mid-winter month (July)

2.7 Some Concluding Thoughts on Uncertainties in Climate Change Studies

Uncertainties arise in many components of climate change studies, ranging from the uncertainties of emission scenarios into the future to translating GCM outputs to a desired catchment resolution by various downscaling techniques (each with their pros and cons, and with their attractors and detractors), to those related to impacts models and uncertainties associated with adaptation strategies. It would appear, however, that the concept of uncertainty with which hydrologists have had to grapple with for decades and still make credible decisions (especially in the design of hydraulic structures), has of late become somewhat of a buzzword which is suddenly tending to sow indecision among many decision makers. It should be remembered that the role of science and that of scientists is to reduce uncertainties by obtaining a better understanding of the dynamics of the systems they are operating in, and not to hide behind it.

In this chapter the aim has, *inter alia*, been to

- ***appreciate*** the complexities of climate change science which result in uncertainties,
- help clarify how to ***express*** uncertainties, and
- explain some approaches on how to ***reduce*** unnecessary uncertainties

with some new scientific contributions from this WRC project K5/1965 being an expression of uncertainty through a simple but robust index, and also a methodology to further downscale raster based GCM output to a fine resolution catchment scale and then to effect realistic monthly bias corrections for both temperature and rainfall when converting raster information to that of Quinary Catchments.

2.8 References

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SECTION B:
VULNERABILITIES OF WATER RESOURCES

Introduction to Section B

This section relates to point 4 and partially to point 5 (cf. **Figure B1** below) of the deliverables framework, viz. “Evaluate existing as well as possible future vulnerabilities of different critical water use sectors and society, from rural as well as urban backgrounds”. In **Section B**, different perspectives are taken on existing and possibly future vulnerabilities: In **Chapter 3** the perspective chosen has been the Livelihood Approach, which in the understanding of the authors is most appropriate in order to understand vulnerabilities in the southern African context. In **Chapter 4** and **5** the focus is on the increasingly problematic water quality issues in the Mgnei catchment as well as how these are expected to possibly change under climate change; **Chapter 6** explores the linkages between the natural environment, also called natural capital, and its ecosystem services to humanity, and even without taking climate change into account, vulnerabilities exist. Thereafter, in **Chapter 7**, a step is taken towards interlinking livelihood assets and their direct and indirect impacts on different type of communities. Last, but not least, **Chapter 8** sets its focus on the social system when researching linkages between climate change and food security perceptions of rural communities and implications for food security policies

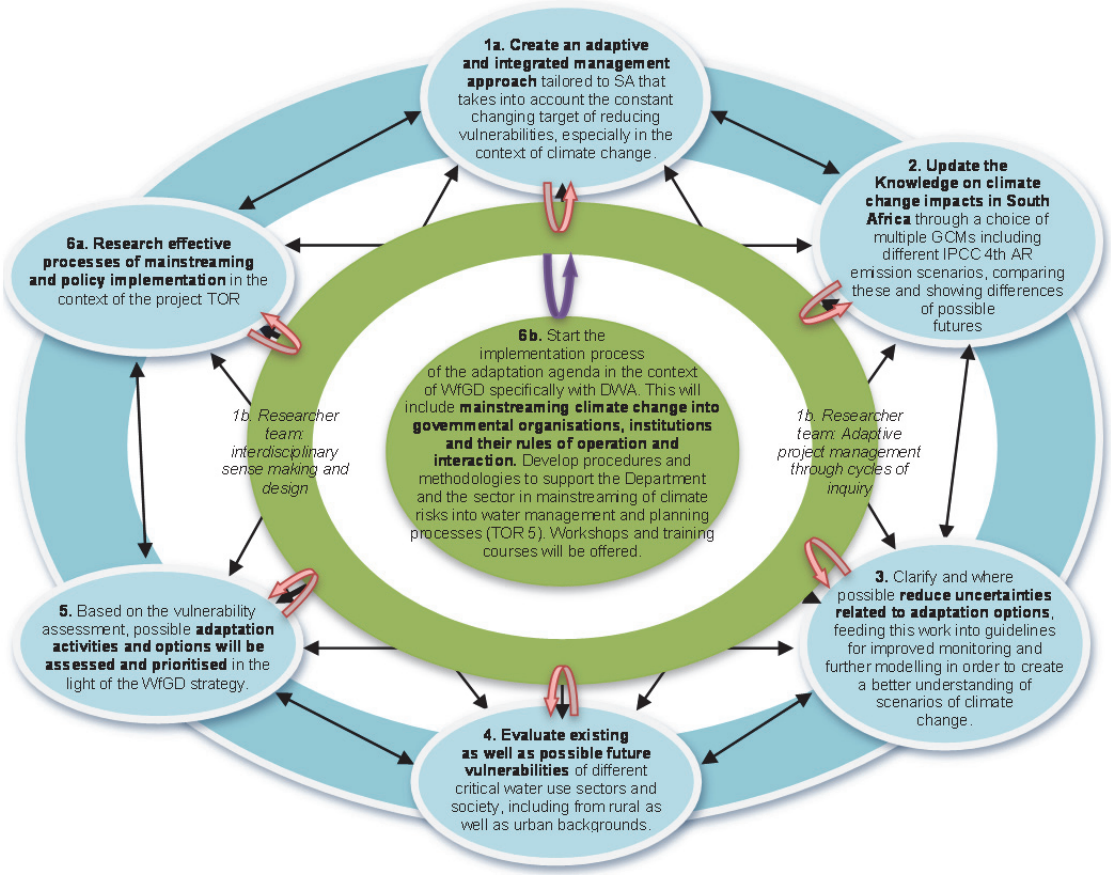


Figure B1 The six project work packages and their inter-relationships, illustrating how the research team intermediates the inter-relationships between the six work packages in the outer (blue) circle, and the work package focusing on knowledge co-production with stakeholders (inner green circle), through a process of interdisciplinary sense-making and adaptive project management (middle green circle)

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CHAPTER 3: UNDERSTANDING LINKS BETWEEN WATER, LIVELIHOODS AND KEY HYDROLOGICAL DRIVERS IN DIFFERENT COMMUNITIES

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3.1 Some Basic Concepts

Water is one of the very necessary resources whose value tends to be undermined in many societies (Van Koppen, 1999). It is required to perform various activities and sustain processes to prolong life. Water resources are essential for economic development at larger scales and to improve and maintain livelihoods at individual levels (Tyler, 2006). Water secure societies endure better capabilities and standards of living that enhance livelihood outcomes as a result. Enhanced outcomes improve local economic statuses and money flows which will help build better resilient structures and adaptation strategies. However, water security is not viewed at household level, nor does it address the issues of conflict of neighbouring regions, but rather plays an important role in assessing how water security limits livelihoods and narrows its activities and strategies (Rijsberman, 2006)

Livelihood here refers to the ability of individuals to support themselves and others for survival (Angelsen *et al.*, 2011). It involves activities that incorporate securing water, ensuring food security, fodder, medicine, shelter, clothing and the ability to continuously attain the above supplies. Livelihoods are strengthened by the availability and accessibility of resources and the ability to work. Working is one of the key aspects (major requirements) of livelihoods, which can be achieved by a combined and cooperative group effort or by individual effort (Muller *et al.*, 2009). The effort exerted by individuals is either beneficial for their own livelihoods, such as small enterprises or subsistence farming, or for other peoples' livelihoods, such as providing customer services, labour and material supply. The overall purpose is to achieve positive outcomes, which involve meeting daily requirements that sustain survival and life thereof (Hebinck and Lent, 2007). Thus, the Livelihood Approach seeks to understand people and their survival strategies and how their different efforts are converted into positive livelihood outcomes, for example small scale farming in water scarce regions (Mulale *et al.*, 2013). According to Adato and Meinzen-Dick (2002), the Livelihood Framework aimed at understanding the rural livelihoods at community and household levels (Grimshaw and Kala, 2011). This framework has now become generic in a sense that it is used to understand urban and peri-urban livelihoods as well, which help recognize the survival strategies that occur within societies of different socio-economic backgrounds, and how these strategies differ (Redwood, 2009). In order to understand livelihoods one needs to study the environment in which people make their living, which gives a good indication of their livelihood capacities (de Satge, 2002). The environment includes the household and the surroundings in which livelihoods are primarily built. The study of livelihoods then looks at the contributing and limiting factors within these environments as well as the survival strategies that the environment contributes (Redwood, 2009).

It has been stated that water security, together with related concepts of access, entitlement and conflicts as they relate to water, are crucial to fully understand the role of water resources in the lives and livelihoods of people (Angelsen *et al.*, 2011). The Livelihood Approach pertaining to water enables one to consider complex ways in which water affects peoples' ability to pursue a livelihood or to cope with vulnerabilities (Chey and Sadoff, 2007). An effective water management strategy coupled with appropriate livelihood assets (**Figure 3.1.1**) is important for a country to achieve paramount social and economic performance (Moser, 1998). In order to improve water availability and ensure overall water security, the focus should be on both resources and municipal services. Poor services and maintenance in communities, especially in rural and peri-urban communities, lead to high revenue losses (Yang *et al.*, 2003). Rural people sacrifice natural assets in pursuit of financial assets. They move from rural communities to seek employment for a better life, which leads to an increase in urban population (Angelsen *et al.*, 2011). Consequently this can lead to an overload in sewage systems that exist, especially in peri-urban areas, because of improper planning and population growth (Watkins, 2009). Most townships are characterized by high density informal settlements where most people cannot afford to pay for services, which leads to illegal connections of piped water and electricity (Gao *et al.*, 2011). Owing to unemployment these societies believe that they are entitled to

free services, which causes conflict between local governments and the people. Local communities often misuse public facilities by damaging or even uninstalling water points, which lead to wasted money wasted as repair bills increase (Mallick, 2013). Degradation of water resources and damaging of municipal water facilities is linked to behaviour and lack of knowledge, which results in negative impacts on water resources (Pervical and Homer-Dixon, 1998). Understanding how water and livelihoods are interlinked, and what impacts need to be considered, can inform water management decisions which can then result in better performance and compliance (De Satge, 200).

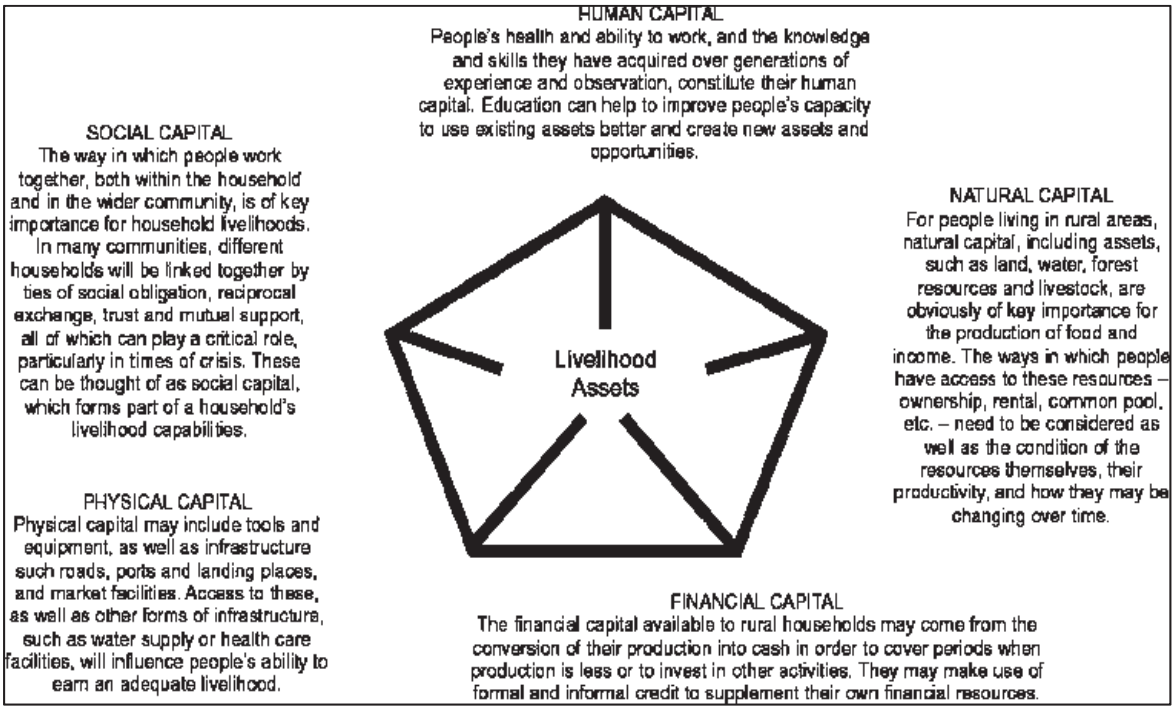


Figure 3.1 Livelihood assets (Source: www.fao.org, 2013)

Water being a necessity for life, investing in it can build opportunities for the diversification of livelihoods, also ensuring its availability to more citizens in the long term (Oumer *et al*., 2013). The earlier alluded to Livelihood Framework includes citizens who live in both formal and informal settlements and it looks at the different habits, customs, behaviour, traditions, skills and resources that occur in those households and communities. It emphasises a focus on household settlements that occur within villages, wards, districts, provinces, countries and the wider world (Hebinck and Lent, 2007). Livelihoods are determined by three aspects, *viz*. capabilities, activities and assets, where the assets can either be tangible (material resources) or intangible (social resources) (Redwood, 2009). Formal and informal livelihoods are invariably intertwined with the asset base from which they are derived and to which they contribute (Grimshaw and Kala, 2011). In order to make a living, people undertake different activities and strategies, which use and depend on various assets and resources available to them. People require specific skills, amounts of time, relationships, tools and materials to be able to grow, find, buy or barter for food; to collect or buy and store water, and to generate income (de Satge, 2002). If people do not own or have access to the assets and resources they need, they will be limited as to how they are able to make a living (Oumer *et al*., 2013).

Livelihood assets enable a better understanding of the livelihood framework and improve knowledge on the requirements for survival. Assets give an insight on which possessions are essential for the livelihoods of different backgrounds (Twyman, 2001). They are defined as useful possessions that can be accumulated, sold or invested to achieve positive livelihood outcomes and benefits thereof (Angelsen *et al*., 2011). The study of livelihood assets is used to examine livelihoods, where observations are made on how they are utilised and what meanings are credited to them. Livelihood assets are a crucial feature required to obtain understanding in the way in which people make a living in their respective households (Redwood, 2009). The assets possessed by different households form the basis for the generation of their income (Moser, 2008). Assets influence households' choice of livelihood strategies and are used as indicators of wealth (Angelsen *et al*., 2011). Livelihoods are best analysed by observing livelihood strategies and assets which people draw upon for survival (Tyler, 2006). Livelihood assets have been divided into five categories, *viz*. human, social, natural, physical

and financial assets. One or more of these assets is displayed in different communities where each has a different significance and meaning (Redwood, 2009: Angelsen *et al*., 2011).

3.2 Human Assets

Human assets are good for capacity building. They involve the improvement of knowledge and skills through learning and education as well as training. This includes informal education and livelihood training skills. An example would be learning about the implications of drinking polluted water (raising awareness) and training on farming techniques that could assist small and large scale farmers (Erenstein *et al*., 2010). Skills training can enable people to become more advanced in their field of expertise and can improve their ability to work, thus increasing income (Watkins, 2009). Education and learning allow a platform for diverse knowledge on the efficient use of water resources at individual level (Angelsen *et al*., 2011). In areas where there is a lack of service provision or maintenance of water infrastructure, people within the community could be trained to fix and repair pipes and taps. Consistent training can encourage the presence of skilled plumbers who can assist in maintaining the existing facilities (Erenstein *et al*., 2010). Human assets influence job creation which is divided into upstream, midstream and downstream employment. In the water management sectors, where upstream employment involves technicians and planners such as engineers and community developers, midstream employment would involve material supplies and downstream employment involves self-employed plumbers. Educated people pursue professional careers and have higher positions in the work industry, hence their salaries are more advanced (Grimshaw and Kala, 2011). While health care is also important for human capacity building, in rural areas health care centres are often limited because of limited skills and farmers' lack of health care information and knowledge (Grimshaw and Kala, 2011).

3.3 Social Assets

Social assets are related to the way people communicate within a household and in the wider environment (Angelsen *et al*., 2011). Rural communities often receive help from their neighbours when they have experienced disturbances or shocks such as drought. During this period the unaffected region helps reinforce livelihoods of the affected households which enables the sharing of assets between people. Social assets can also assist in communication between high authorities and with local communities to manage local issues (Grimshaw and Kala, 2011). Local government usually provides temporal assets for those communities who are in need, thereby assisting these communities to regain and enhance their livelihoods after disturbances. A peaceful and happy community is one that emphasises effective communication which reduces conflicts.

3.4 Financial Assets

The financial capital distinguishes the poor people from people who are well off. Financial capital produces financial stability and promotes well-being in a community. It is the most important asset that influences the other types of assets and limits asset-building in poor societies (Grimshaw and Kala, 2011). An important financial indicator is the proportion of total expenditures that are made on food and other goods and the payment of critical services (Grimshaw and Kala, 2011). Livelihood objectives are, overall, achieved through financial income which can be divided into low, medium and high levels of income (Angelsen *et al*., 2011). The community's socio-economic backgrounds are indicated by their financial assets and characterized by this aspect.

3.5 Physical Assets

Physical assets incorporate infrastructure and produce goods that are required to support livelihoods (Grimshaw and Kala, 2011). Infrastructure enables communication, transportation through road and railway networks. Goods are transported successfully to other regions which contributes significantly to the local economy. Infrastructure helps people meet their basic needs and become more productive. However, infrastructure might have negative impacts on the physical environment as it alters the hydrological processes (Redwood, 2009). Producer goods include tools and equipment which are used to function more productively (Angelsen *et al*., 2011).

3.6 Natural Assets

The natural asset section includes access to land, water and other natural resources such as forests (Redwood, 2009). Rural societies refer to land as their key asset because it is used for agricultural purposes and for their cattle to graze (Angelsen *et al*., 2011). Forests produce wood that is used for energy in rural areas and it is used to produce timber. Water is a natural resource that is required for economic, industrial, domestic and environmental uses (Twyman, 2001). All livelihoods need water for beneficial outcomes. However, these sources can be mistreated and lead to unhealthy and polluted environments. An example of this would be water sources that pass through urban and peri-urban areas generating risks to both people and ecosystems (Angelsen *et al*., 2011). One of these risks is water pollution, which greatly affects both agricultural producers and water users. It also poses threats to existing water resources and causes challenges for water resources management (Grimshaw and Kala, 2011).

3.7 Concluding Remarks

Reflecting on the above, vulnerabilities emerge from two different systems, the natural and the human system. As is well known, these two are closely interlinked and create significant complexities in identifying and understanding them. Vulnerabilities increase when the environmental ceiling, including a changed climate, is reached, or if the social foundation is insufficient. The natural (i.e. natural system) as well as the social capital (i.e. human system) need to be developed and integrated for humanity to live in a safe and just space, as shown in **Figure 3.2** (Raworth, 2012).

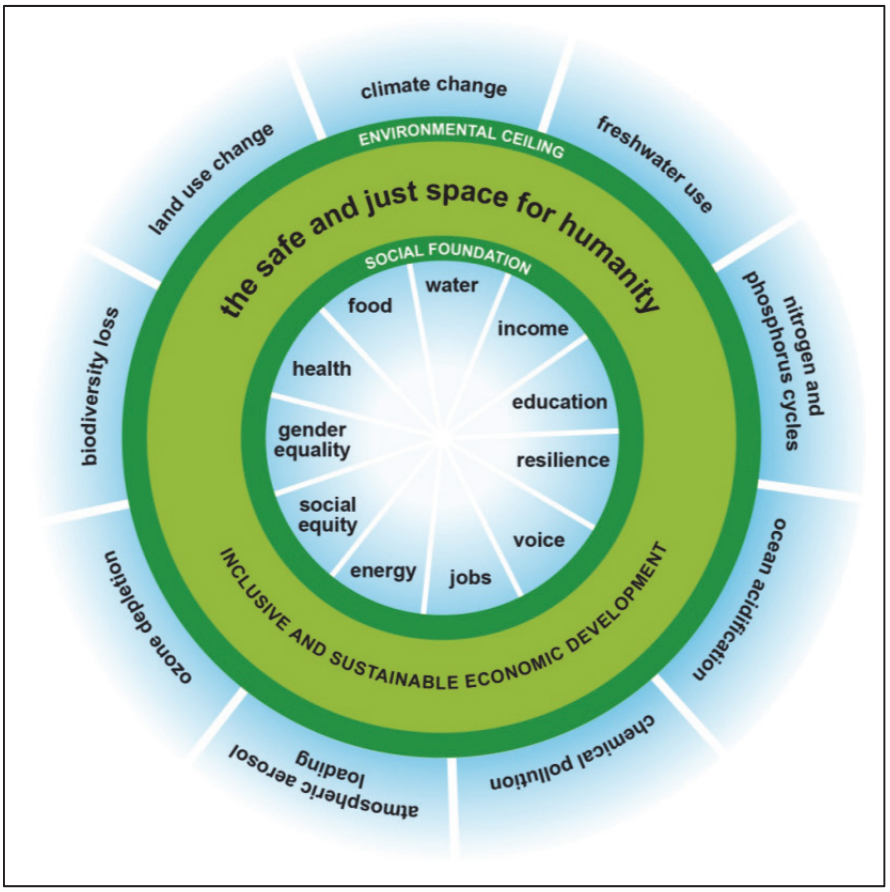


Figure 3.2 A safe and just space for humanity-based on the social foundation and an environmental ceiling, based on the planetary boundaries set out by Rockström *et al*. (2009) (Source: Raworth, 2012)

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CHAPTER 4: VULNERABILITY AND ADAPTATION IN THE CONTEXT OF CLIMATE CHANGE AND WATER QUALITY MANAGEMENT

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This section is taken in part from Ngcobo, S.I. 2013. Projected impacts of climate change on water quality constituents and implications for adaptive management. Unpublished MSc Dissertation, University of KwaZulu-Natal

4.1 Introduction

The climate change discussion has seen the formalised concepts of vulnerability and adaptation become profoundly embedded in the global change agenda. This is not surprising, as climate change is anticipated to induce pressures on aspects such as environmental health, food security and economic stability through its projected impacts on water resource systems (IPCC, 2001; Droogers and Aerts, 2005; IPCC, 2007; Heltberg *et al*., 2009). It is widely acknowledged that the impacts of climate change will affect all water users (IPCC, 2001; Schulze, 2005; Haines *et al*., 2006; Sadoff and Muller, 2007; IPCC, 2007; Bates *et al*., 2008) with the spectrum of affected users being determined by their individual ability to effectively respond to such changes (Paavola, 2008). In the context of adaptation and vulnerability, the developing world is considered to have more limited adaptation capacity and to be highly vulnerable to the impacts of climate change (Desanker and Magadza, 2001; IPCC, 2001; Paavola and Adger, 2005). This is, as Heltberg *et al*. (2009) and Paavola and Adger (2005) indicate, due to the high dependence on climate-sensitive economic sectors, geographic exposure and low-income status characteristic of the developing world. Consequently, the most adverse climate change-related impacts are anticipated to occur in the developing regions of the world, of which South Africa is a part (Bates *et al*., 2008). This serves to highlight the importance of understanding vulnerability and adaptation concepts for application in the most sensitive (i.e. highly exposed and least adaptive) regions of the world, including South Africa. Based on the above discussion, the aim of this section is, therefore, to define “vulnerability” and “adaptation” in the contexts of both climate change and water quality management.

4.2 Vulnerability and Adaptive Capacity as Determinants of Adaptation

The Oxford English Dictionary defines vulnerability as “exposure to the risk of being attacked or harmed, either physically or emotionally”. Ionescu *et al*. (2009) consider vulnerability a relative property, denoting the vulnerability of “something to something”. In a more socio-ecological sense, vulnerability refers to the “degree to which a system is likely to experience harm due to exposure to a hazard” (Füssel, 2006; Ionescu *et al*., 2009). Application of this term in climate change studies has been subject to much debate and scrutiny owing to its apparent ambiguity (Ionescu *et al*., 2009). This ambiguity stems from the interdisciplinary nature of the term which has seen its application in ecology, agriculture, medicine, socio-economic development, food security and global change (Füssel, 2006; Füssel and Klein, 2006; Haines *et al*., 2006). The Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) provided the now widely-accepted definition of vulnerability in the context of climate change by stating that “vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity” (IPCC, 2001). However, as indicated in **Figure 4.2.1**, this definition is not only limited to climate change as an ‘external disturbance’, but can also include disturbances such as disease prevalence, access to human and financial capital and innate system sensitivity.

The collective insinuation of the definitions presented above is that systems which are significantly exposed to adverse external factors that may bring harm to their normal functioning, are at high risk of collapsing and are therefore highly vulnerable. In South Africa and in Africa as a whole, the general consensus regarding vulnerability is that the resilience of socio-economic, infrastructural and environmental systems to external disturbances such as climate change is very limited, making them

highly vulnerable (Paavola and Adger, 2005; Reid and Vogel, 2006; Sadoff and Muller, 2007). Access to resources, aging infrastructure, stagnant economic growth and development, widespread environmental degradation, weakening social patterns and lack of access to information are some of the factors which have been identified as components that determine vulnerability in many African nations, including South Africa (Reid and Vogel, 2006; Gbetibouo *et al*., 2010; cf. **Figure 4.2.1**). Owing to the relative nature of vulnerability (Ionescu *et al*., 2009), it is important that the vulnerabilities of various economic sectors, governmental groups and individuals be differentiated accordingly (Stuart-Hill and Schulze, 2010). This is an important consideration in the development of tailored and locally relevant adaptation strategies.

Another critical dimension to this argument also exists, which serves to accentuate two factors, *viz*. sensitivity and adaptive capacity, as important aspects that determine the vulnerability of a system. Adaptive capacity, or capacity of response, refers to "the potential or ability of a system, region or community to adapt to the effects or impacts of climate change" (IPCC, 2001; Gallopìn, 2006; Smit and Wandel, 2006). Systems which have limited response options to cope with the impacts of climate change are considered to have low adaptive capacity and are therefore considered highly vulnerable to these impacts (Reid and Vogel, 2006). **Figure 4.2.1** presents the concept of vulnerability as a concept that is limited by the adaptive capacity of a system; using, in this case, an agricultural system.

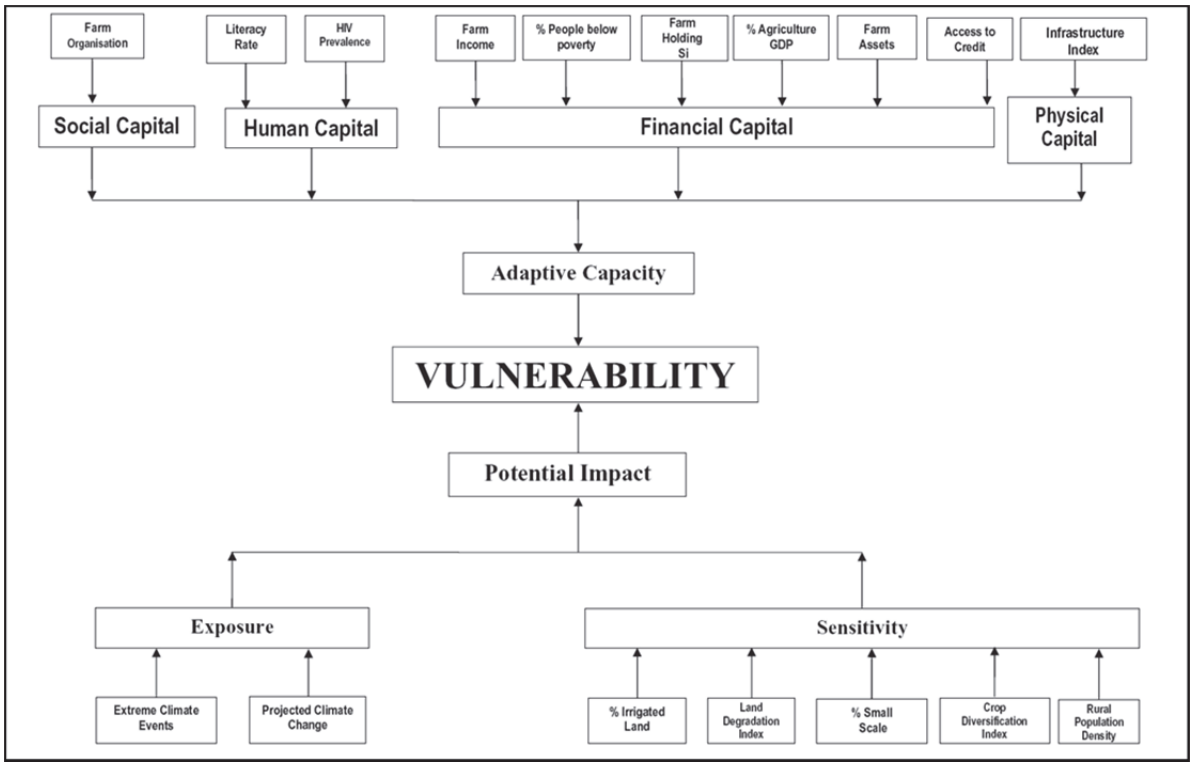


Figure 4.2.1 Conceptualization of vulnerability to climate change as a function of adaptive capacity and exposure to impacts in an agricultural production system (Gbetibouo *et al*., 2010)

As with vulnerability, adaptive capacity differs between individuals, groups, environmental systems, communities and even artificial systems. It is determined by various factors such as initial well-being (economic, physical or otherwise), livelihood resilience, social capital and societal protection (Cannon, 2000; Brooks *et al*., 2005). Adaptive capacity cannot be easily measured due to the direct connections between socio-economic development, social cohesion, political stability and the level of environmental protection (Reid and Vogel, 2006). This is because of the dynamism of socio-economic and political systems. Therefore, in order to develop appropriate adaptation strategies, it is crucial to initially assess the "state of nature" of a system with regard to the extent of its adaptive capacity and hence vulnerability, in order to locate weaknesses and address these accordingly (Gallopìn, 2006; Smit and Wandel, 2006; Sadoff and Muller, 2007).

To effectively implement adaptation strategies, the ability of society, governance structures and institutions to act collectively is paramount, since adaptation is a dynamic, interdependent initiative (Adger, 2003; Brooks *et al*., 2005). Not only will this increase the adaptive capacity of the most

vulnerable environmental and socio-economic sectors, but it might also create much more resilient governance structures that may be flexible enough to adapt to future environmental changes (Adger and Vincent, 2005; Brooks *et al*., 2005). This will have to be grounded on sound scientific principles that will provide the necessary background critical to decision-making regarding biophysical changes that ultimately affect the economy, society and infrastructure. Consequently, monitoring existing adaptation policy or developing new policies will require constant updates from scientific research to ensure that the appropriate adaptation strategies are developed and updated.

This section has extensively described the meaning of vulnerability, adaptation and adaptive capacity in the context of climate change. However, as mentioned in this discussion, these terms can be ambiguous and can lead to some confusion in their application. Since the focus of this study is on adaptive policy development, adaptive governance and adaptive water quality management, the following sections describe the differences in the application of these terms in the aforementioned focus areas.

4.3 Vulnerability and Adaptation in Policy Development and Governance of Environmental Resources

The previous section defined vulnerability as "the degree to which a system is likely to experience harm due to exposure to a hazard" (Füssel, 2006; Ionescu *et al*., 2009). Adaptive capacity was defined as "the potential or ability of a system, region or community to adapt to the effects or impacts of climate change" (IPCC, 2001; Gallopìn, 2006; Smit and Wandel, 2006). Therefore, by deduction, adaptation may be considered as a response to change which seeks to minimize vulnerability by enhancing adaptive capacity and maximising benefits (Pittock, 2009).

It is also important, at this juncture, to define governance and management in the overall context of this discussion. According to the Oxford English Dictionary, "governance" is essentially the exercise of imposing authority and asserting control and / or influence over the policies and affairs of a state. Management is the direct handling, supervision or control of a state, organization, people or resource. At first glance, the two terms appear to mean the same thing, i.e. authority and control. However, closer inspection will reveal that they are actually two different activities. Governance can be thought of as the "top line" focus, which addresses the question of what task is being attempted to be accomplished, while management can be thought of as the "bottom line" focus, addressing the question of how to accomplish a particular task. In other words, governance is doing the right things and management is doing things right. In the context of policy development and governance, these definitions will be expanded on using, as a backdrop of the discussion, developing countries.

It is a well-accepted fact that the long-term, sustainable economic development of developing countries is highly dependent on primary production systems (e.g. agriculture, forestry, fishing and mining). The maintenance and advancement of these systems requires efficient and sustainable management of their natural resource base (Barbier *et al*., 1992). The role of the environment, therefore, as a source of important resources and ecological functions which support economic activity and human welfare, needs to be duly recognised and protected. One of the most fundamental tools of environmental protection is the development and promulgation of environmental policies.

Developing countries, such as South Africa, usually have in place highly incisive environmental protection policies intended for the protection of natural resources. For example, the South African National Water Act (Act 36 of 1998), considered globally as a "progressive, forward-thinking and ambitious Act" (Muller, 2002; MacKay *et al*., 2003), has as one of its main objectives the protection, development, management and control of the nation's water resources (DWAF, 1998; RSA, 1998; DWAF, 2004; Pienaar and van der Schyff, 2007). Evidently, failure to effectively implement this Act can potentially expose South African water resources to a host of serious problems. Such failure would, in the sense of vulnerability defined above, increase the vulnerability of South African water resources to external disturbances (e.g. climate change), thus increasing the vulnerability of local production systems and ultimately, the vulnerability of the local economy.

In certain instances, where environmental policies are ineffectively implemented or are implemented without due monitoring of the implementation process, the potential deterioration or complete destruction of natural resources and ecosystems is facilitated. This essentially amounts to policy failure. Babier *et al*. (1992) state that policy failure occurs when a policy "under or over corrects for a problem", provided the exact nature of the problem is expressly known and measures are taken to

remedy the problem. Under such conditions, the State, in its capacity as the legal custodian of the nation's natural resources, may engage in corrective measures that may either be ill-advised or detrimental to the long-term sustainability of natural resources (Huang and Xia, 2001).

Therefore, in the context of policy development and governance, the ability of environmental resources, inclusive of water, to cope with adverse external disturbances will be functions of how well environmental protection policies are formulated by governance structures and how effective management structures are in implementing these policies. Essentially, the more robust, realistic and effective a policy is, the higher the adaptive capacity of the system and the greater the potential for the system to adapt and, resultantly, the less vulnerable the system is to external disturbances. The following section highlights the differences between adaptation in the context of policy development and governance and adaptation in the context of water quality management.

4.4 Contemporary Issues in Water Quality Management

Owing to increased socio-economic pressures such as population growth and economic development, the requirement for a constant freshwater supply of acceptable quality has been a subject for increased concern over the past few decades (Huang and Xia, 2001; Smeti *et al.,* 2009). In particular, challenges associated with water quality management have received an increasing amount of attention, because of the apparent close alignment of water quality related issues with sustainable development (Ouyang *et al.,* 2006; Mahjouri and Ardestani, 2011). For example, not only is access to safe drinking water considered a basic human right, but it is also recognised as one of the key Millennium Development Goals (Kundzewicz *et al.,* 2007). Global and local change issues such as population growth, economic development, urban sprawl and land use change have intensified the debate on whether or not the current global freshwater resources status will radically change over the next few decades (Falkenmark and Rockström, 2006; Kundzewicz *et al.,* 2007; UNESCO, 2009).

Further concerns also abound on whether the continued pressure being placed on water resources will lead to a change in water productivity (adequacy of water for productive use) and ultimately a change in agricultural and industrial productivity (Rockström *et al.,* 2003). It is at this interface of water resource availability and water productivity that water quality becomes an issue of concern. In order to further clarify this topic, this section presents a brief discussion on contemporary water quality management issues as a basis for adaptive water resources management. The arguments presented in this discussion are generic in both the international and local water resources management contexts.

Water quality management, aligned with principles of sustainable development, has become increasingly topical in the last few decades (Pegram and Bath, 1995; Turton, 2008; Cook *et al.,* 2009). This has been especially true in South Africa under the current conditions of economic growth and social transformation (Du Toit *et al.,* 2009). One of the reasons for the elevated concern over water quality management is the increased introduction of pollutants in surface water and groundwater through agricultural, urban and industrial activities and the consequential human health concerns (Honisch *et al.,* 2002; Ouyang *et al.,* 2006; Zhang *et al.,* 2009). As alluded to in the introductory section, increased social and economic pressures on water resources provide the sole basis for the deterioration of water quality in many local Catchments. **Figure 4.4.1** illustrates that socio-economic development and the quality of water resources and the environment are all closely related aspects. If one compartment changes then, by deduction, the other two also change. In effect, the vast majority of problems associated with water quality management are far less of a technological issue than they are social, political, economic and institutional issues (Novotny, 2003). This is especially true in South Africa, considering the capacity to generate ingenuity which this country possesses (Turton, 2008).

Local population growth and economic development have resulted in increased food, fibre, forage and energy demands, which have consequently encouraged the agricultural and commercial production sectors to use increasing amounts of toxic chemicals, soil ameliorants and nutrients to enhance production rates and meet consumer market demands (Foley *et al*., 2005; Dabrowski *et al*., 2008; Statistics South Africa, 2009). This consequently leads to the increased introduction of pollutants into the environment through non-point sources (NPS) and increased environmental and human health impact concerns (Foley *et al*., 2005; Haines *et al*., 2006; Leigh *et al*., 2010; Bryan and Kandulu, 2011). Furthermore, the reduced ability of natural ecosystems to provide goods and services such as the regulation and immobilisation of pollutants, results in increased wastewater treatment costs which

have undesirable long-term economic implications, especially for developing nations (Jewitt, 2002; Fischlin *et al*., 2007; Kundzewicz *et al*., 2007).

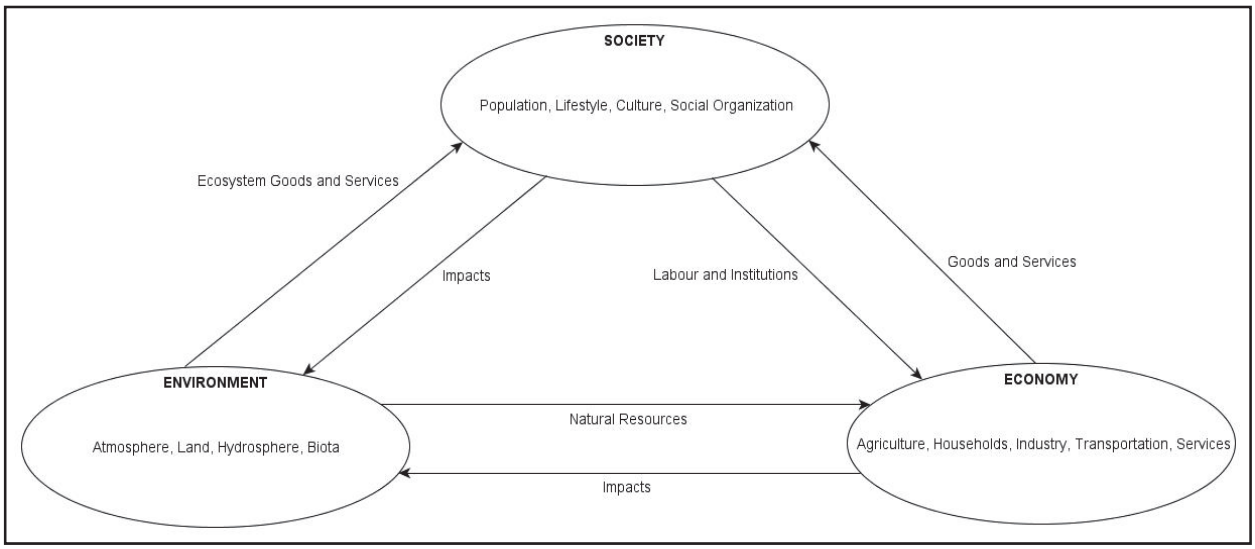


Figure 4.4.1 Causal chains highlighting socio-economic causes of environmental and water pollution (Novotny, 2003)

Considering the increased human interventions in natural ecosystems in the past century, the currently observed changes in water quality standards are not particularly surprising. Historically, humankind has a long-standing tradition of radically altering vast segments of natural environments in pursuit of economic and social security without necessarily considering the environmental impacts and/or the inevitable feedbacks (Bouma *et al*., 2002; Pittock, 2009). Nilsson and Renöfält (2008) state that compared to pristine conditions, numerous global rivers, streams and lakes have doubled their nitrogen and phosphorus content as a result of human interventions. The uMngeni Catchment, for example, located in the KwaZulu-Natal midlands of South Africa, was once a relatively pristine catchment (i.e. mid-1800s to early 1900s), with numerous undisturbed ecological regions (Water Research Commission, 2002). Increased urbanisation, agricultural land expansion, population and economic growth and development have led to the alteration and, in some cases, complete destruction of ecosystems and a rapid increase in water pollution, leading to water quality deterioration (Schulze *et al*., 2004; Turpie *et al*., 2008; Van Wilgen and Biggs, 2010). This catchment now requires highly incisive water quality management principles which ensure that freshwater resources are protected and that adequate freshwater standards are maintained (DWAF, 2003).

Providentially, water quality management in this catchment is carried out through intensive monitoring programmes applying principles from the National Water Resource Quality Monitoring Programme, Integrated Water Resources Management (IWRM) principles and water resources modelling tools (DWAF, 2003; 2004). This example shows that modern challenges associated with water quality management require not only the reinforcement of established principles, but also the extension of those principles to ensure future sustainable use of water resources (Huang and Xia, 2001; Cook *et al*., 2009). Furthermore, the importance of information generation and dissemination in water quality management cannot be over-emphasised, since decision-making is highly dependent on relevant and updated information (Chowdary *et al*., 2004).

Thus, the application of experience-based management, using historical information in conjunction with current information and management systems is an important aspect in local water quality management, since it characterizes adaptive water quality management (Kundzewicz *et al*., 2007; Bates *et al*., 2008). The aim of adaptive water quality management is to recognize the impacts of human interventions on freshwater systems and offer novel management ideas, policies and promote institutional commitment to effectively manage water quality issues (Harrison, 2007; Sadoff and Muller, 2007; Mwenge-Kahinda *et al*., 2010). Prior to considering adaptive water quality management, the main issues behind water quality management are crucial aspects to consider since they define the path towards the development of adaptation strategies. The following section is an introduction to the most critical water quality management related challenges.

4.5 Challenges in Water Quality Management

Water quality management across all different scales is primarily concerned with making decisions which seek to prevent the progression of pollution (Unami and Kawachi, 2003). However, owing to increasing pressures on water resources from climate change, population growth and economic development, global and local water quality management is far from satisfactory, particularly in developing countries (Huang and Xia, 2001; IPCC, 2007). One of the major reasons for this is that the most rapid growth, with regard to economic development and population growth, occurs primarily in low income countries (e.g. in the so-called developing national economic blocs such as BRICS) where water and wastewater infrastructure is, by global standards, generally substandard. Furthermore, water quality management in these countries is usually carried out in a conservative, non-adaptive manner and many decisions are based on historical trends rather than on current observations (World Bank, 2010). This limits the flexibility of water quality management and creates a state of policy redundancy which can, ultimately, cause policy failure (as detailed in **Section 4.3**). Bennet *et al*., (2005) and Lynam *et al*. (2009) note that water quality management has to be carried out in a holistic manner which recognises the interactions between society and the physical and biological environment. Therefore the dynamism of both society (e.g. population growth and migration) and the physical and biological environment (e.g. climate change) has to be factored into water quality management and planning, such that policy redundancy and failure is avoided.

For many developing and transitional countries such as South Africa, the rapid growth of urban centres facilitates the deterioration of water quality due to the increased generation of diffuse or non-point source (NPS) pollution (Edwards and Withers, 2008). Other sectors related to economic development in these countries including agriculture, deforestation and mining (acid mine drainage) also contribute significantly to water quality deterioration. Developing countries are subject to high levels of exposure and vulnerability (IPCC, 2007) and this consequently elevates their susceptibility to the effects of diffuse pollution (Novotny, 2003; World Bank, 2010). Novotny (2003) cites the following major reasons for the high susceptibility of developing countries to diffuse pollution and water quality deterioration:

1. Global change pressures (i.e. climate change, population growth, economic development and land use change) are largest in developing countries.
2. Many urban centres in developing countries have poorly functioning or non-existent sewer systems and wastewater infrastructure.
3. Surface water contaminated by diffuse pollution is often used as a source of potable water by households in rural communities.
4. Surface runoff is the main contributor to flow in these countries and provides the main mechanism for the transport of pollutants.
5. Intensification of the use of contaminants (fertilizer, pesticides etc.) in industrial agriculture increases nutrient inputs into surface waters and impairs the water quality of receiving waters.

For the reasons detailed above, it follows that the degradation of water quality is influenced by the interactions between society and the natural environment. It is apparent that although the environment contributes some background contamination, people are, for the most part, responsible for the undesirable changes in the quality of water resources. Therefore, the major challenges in water quality management are anthropogenic in nature and may be classified into two groups as follows (Novotny, 2003):

1. “Human alteration of the status of a water body and its habitat that downgrades its integrity and creates pollution”, and
2. “Addition of allochthonous (originating from outside the water body) pollutants to the water body”.

Group 1 essentially refers to the alteration or modification of water bodies for the benefit of society. For instance, the construction of dams and impoundments, flow diversion, construction of inter-basin transfer nodes, channel lining, wetland drainage and conversion, invasion of riparian zones by foreign species originally introduced by people and urban development which alters the hydrology of a stream. Group 2 refers to allochthonous point and non-point sources (NPS) of pollution. These include discrete or point sources of pollution such as municipal and industrial wastewater effluent, runoff from solid waste disposal sites, storm drain discharge, runoff from active mines and active construction sites. Non-point sources include return flows from agriculture, runoff from unconfined pastures, failing septic tank systems, wet and dry atmospheric deposition and other unconfined

sources of pollution (Novotny, 2003). The concept of non-point source pollution will be further expanded on later.

Successful water quality management has to recognise the role people play in the fluctuation of catchment water quality (Bennet *et al*., 2005; Lynam *et al*., 2009). It is for this reason that water quality management in developing countries has to be as adaptive as possible to ensure that adaptive capacity is increased and external impacts, such as climate change, are well prepared for. It is at this juncture that the importance of understanding the meaning of adaptive management is critical. The following section, therefore, briefly details the concept of adaptive management and its role in water quality management.

4.6 Adaptive Water Quality Management

In the introductory section it was noted that being part of the current global change mosaic, climate change could aggravate current water quality problems. Indeed, climate change is anticipated to introduce added complexities that water quality managers will have to contend with. Although decision makers make decisions under uncertainty every day, even in the absence of climate change (World Bank, 2010), a paradigm shift is required in which the compounding set of uncertainties presented by climate change are recognised and included in the decision-making process (Kundzewicz *et al*., 2007). This essentially constitutes adaptive management (Kundzewicz *et al*., 2007; Bates *et al*., 2008).

According to Bennet *et al*. (2005), adaptive management can be defined as ‘‘a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs”. **Figure 4.6.1** presents a schematic representation of an adaptive management framework developed by the Australian Coastal Cooperative Research Centre (Coastal CRC) and as shown in this diagram, adaptive management is a cyclic learning, application and review process in which the focus is on action and learning and not in preparing to learn (Lee, 1999; Bennet *et al*., 2005). In this diagram, the components are all linked through a continuous process of learning and participative action. To briefly summarise: Information collation refers to the pooling of information collected from research and from stakeholder consultation and is usually the first step in the development of an adaptive management framework, the core components of process and facilitation and evolving knowledge are essential in the planning and management cycle and comprise the establishment of healthy relationships amongst catchment stakeholders such that the entire adaptive management cycle proceeds efficiently. Systems analysis and vision focus on identifying and understanding the most important catchment systems in order to clearly define the vision and

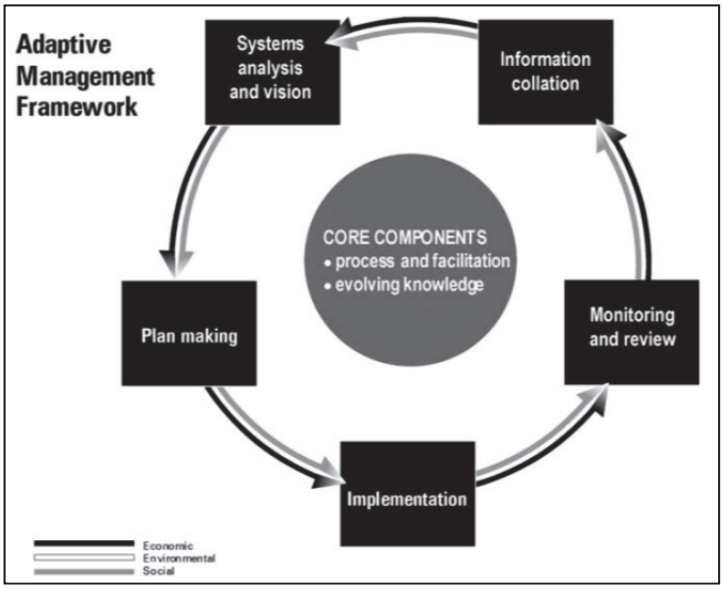


Figure 4.6.1 Schematic diagram of the Coastal CRC Adaptive Management Framework (Bennet *et al.,* 2005)

aspirations for the catchment. Plan making involves the setting of clearly defined resource management goals such that impacts on ecological and socio-economic systems are recognised and strategies are developed. Implementation involves the actual execution of the goals created in plan making and systems analysis and vision creation. Monitoring and Review follows implementation and is the assessment of the effectiveness of the goals set during the initial stages of framework development and of the effectiveness of the implementation process (Bennet *et al*., 2005).

It is apparent, therefore, that adaptive management is a process that facilitates intervention in the face of uncertainty. For instance, water quality modelling serves as an approach that water resource managers can use to abstract information about the natural environment and synthesise knowledge and make decisions based on that information. However, water quality models are often fraught with input data errors, model errors and inappropriate process knowledge by the users (Bormann, 2009).

This does not imply that these models are not appropriate to be used as decision support tools; rather it implies that water quality models should be used as tools that facilitate explicit learning from experiments in order to inform and improve future decisions.

Adaptive water quality management, therefore, requires the development of robust strategies that recognize the reality of a world of shifting baselines and intermittent disturbances (Adger and Vincent, 2005; World Bank, 2010; Firman *et al.,* 2011).

This essentially demands a rethink of traditional water quality management practices which assume a predictable future based on past experiences. The World Bank (2010) recognizes four management strategies that are essential in facilitating adaptive (resource) management under climate change. These strategies have been adapted by the author to be more specific to water quality management:

1. Priority should be given to no-regrets options: policy and investment options that maximise benefits related to water quality management even in the absence of climate change e.g. improving water and wastewater infrastructure to minimize water quality degradation in receiving waters (Novotny, 2003).
2. Increase resilience of water resource systems by buying “safety margins” in low cost long-term investments, e.g. increasing water quality awareness education and forming social resource protection schemes (Petermann, 2008).
3. Reversible and flexible options need to be favoured such that in instances of bad decisions being made, the cost of reversing the impacts of decisions is kept as minimal as possible e.g. restrictive urban planning due to uncertain flooding trends can be reversed easily and is less expensive than retreat and protection options (Heltberg *et al*., 2008).
4. Long term planning should be based on forward-thinking scenario analysis and on the assessment of strategies that consider a wide range of possible futures.

A recurring theme in this discussion has been that adaptive water quality management requires a risk-based decision-making model which favours long-term planning and robustness taking into cognisance the dynamic nature of socio-economic and environmental systems. Increasing global change pressures on water resources coupled with the compounding effects of climate change imply that risks related to water quality management cannot be ignored or omitted in the decision-making process. The aforementioned compounding set of uncertainties presented by climate change necessitates the development of robust and adaptive management strategies that will minimize the risk and thus vulnerability of environmental, social, economic and demographic systems. Having detailed the concept of adaptive water quality management and its relation to climate change, the following section provides a brief analysis of the concept of non-point source (NPS) pollution as one of the primary foci in water quality management.

4.7 Non-point Source Pollution

Non-point source (NPS), or diffuse pollution, is now widely recognized as a key agent in the deterioration of water quality, both globally and locally (Carpenter *et al.,* 1998; Hansen, 2002; DWAF, 2003; Novotny, 2003; Edwards and Withers, 2008; Jolly *et al.,* 2008; Oberholster *et al.,* 2009). Although various forms of land-based activities generate NPS pollution, agricultural activities are considered to be the leading cause of surface water quality degradation (Ma and Bartholic, 2003; Liange and Shukai, 2010; Bryan and Kandulu, 2011). Other NPS pollution sources include runoff from pastures, forestry, sewage treatment plants, abandoned mines, industrial facilities, rural livestock

feedlots and return flows from irrigated agriculture (Carpenter *et al.,* 1998; Novotny, 2003; Bates *et al.,* 2008). During high flow periods or extreme flood events, vast quantities of contaminants and pollutants may also be exported and transported from various sources such as agricultural catchment areas, landfill sites and from soil erosion (Beven, 2002; Almasri and Kaluarachchi, 2004). This, as shown in **Figure 4.7.1**, can lead to numerous water quality related problems ranging from rapid distribution of contaminants and pollutants, pH reduction (acidification), stream sedimentation and increased turbidity and in instances of post-flood standing waters, the introduction of disease carriers (Nilsson and Renöfält, 2008). The effects of NPS pollution on water quality include the introduction of above-normal loads of sediments, contamination of potable water supplies, eutrophication of freshwaters, removal of aesthetic characteristics, increased chemical toxicity and the destruction of ecosystems (Novotny, 2003; Delpla *et al.,* 2009).

Edwards and Withers (2008) suggest that the current global estimate of total nitrogen (63 Tg N yr^{-1}) introduced into water-bodies and other aquatic environments, is double that of the pre-industrial era, while that of phosphorus is estimated to be 20 Tg P yr^{-1}. Haygarth *et al.* (2005) also indicate that annual inputs of phosphorus into water-bodies derived from manure and fertilizer range between 20 and 50 20 Tg P yr^{-1}. Similarly, prior to the introduction of conservation agriculture in the Tertiary Hill of Bavaria, Germany, the total nitrogen and phosphorus fluxes into the adjacent Brook West were found to be 292 kg N yr^{-1} and 4.9 kg P yr^{-1}, respectively (Honisch *et al.,* 2002). Suspended sediment derived from soil-loss has been positively correlated with accelerated watershed land-use practices (Houlahan and Findlay, 2004).

Water quality variables	Low flows	High flows
Pollutants	Concentrations can reach toxic levels	Can be washed out from adjacent, otherwise unflooded uplands; dilution reduces but does not eliminate risk for toxicity
Drugs	PPCP:s (Pharmaceuticals and Personal Care Products) can become toxic; natural estrogens can feminize fish	
Nutrients	Can lead to eutrophication and acidification; N levels can become toxic	Removed from watercourse by downstream transport, uptake by riparian vegetation and denitrification
Salts	Can lead to acidification, mobilization of toxic metals and invasion of salt-tolerant species	
Organic matter and sediments		Considerable addition that increases turbidity, which reduces primary productivity and may increase acidity and threaten fish production Organic matter can reduce pH Sedimentation of transported inorganic matter restructures channel
High temperature	Lowers oxygen content, makes contaminants more toxic, lowers productivity	
Low temperature	Surface ice cover leads to reduced oxygen Open water and low air temperatures can foster excessive formation of frazil ice and anchor ice that damage aquatic biota Open water and temperatures rising from below to above 0°C lead to melting anchor ice that can jam up and produce local floods and upland ice that damage riparian and upland biota	If high flows occur during periods with low temperatures and surface ice, water can be forced on top of the ice, often leading to floods, or the ice cover may break up and run the risk of jamming

Figure 4.7.1 Summary of the water quality problems that may arise during extreme discharge conditions (Nilsson and Renöfält, 2008)

These estimates further highlight the importance of understanding and quantifying the effects of NPS in water quality management. Foy and O' Connor (2002) assessed the effects of agriculture on the water quality of two rivers in Northern Ireland. Specifically, this study aimed at "i) examining point source farm pollution and the associated damage to tributary or headwater streams; ii) diffuse nitrogen and phosphorus losses and associated eutrophication; and iii) the sedimentation of spawning redds of the Atlantic salmon (*Salmo salar* L.)".

The Colebrooke and Upper Bann Rivers were the subjects of farm pollution studies for a period of 8 years from 1990 through to 1998. The enrichment of these rivers with nutrients, particularly phosphorus and nitrogen, over this period was attributed to farmyard discharges of manure and silage effluent. Although the government introduced a number of initiatives aimed at reducing water pollution generated from farms, the assessment of the effectiveness of these initiatives proved to be problematic. This was owing to the fact that monitoring sites were located on larger rivers and not on tributaries, and thus water pollution data reflected a large variety of pollutant sources other than farmyards. Therefore, various chemical and biological water quality assessments were undertaken in tributaries to ascertain trends in pollution and define the causes of this pollution. Owing to the extensive use of nitrogen- and phosphorus-based fertilizers in agriculture, this sector was identified as the major contributor to water pollution in these rivers. Additionally, due to the blockage of spawning redds (i.e. breeding grounds); the supply of high loads of fine sediment was recognised as another concern that has adverse impacts on the spawning of salmon. However, the high sediment loads were not attributed to agricultural practices, but rather to human interventions. The combination of both nutrient enrichment and sedimentation resulted in a decline in available habitat for salmon spawning and, consequently, a decline in salmon populations for many parts of Northern Ireland (Foy and O'Connor, 2002). The authors concluded that agriculture was primarily responsible for the deterioration of water quality in Northern Ireland and it was difficult to minimise the generation of diffuse pollution from farming activities. Various methods for the reduction of farm-generated diffuse pollution were suggested in this study, ranging from voluntary mitigation measures encouraging farmers to apply nutrient management frameworks, to the introduction of legislative measures that increased fines for pollution. The issue of sedimentation also did not yield satisfactory solutions due to a lack of consensus as to the actual cause of the problem.

To counter increased NPS loads such as suspended solids, nitrates and phosphates, Choi (2008) and Fisenko (2004) suggested preventative management measures such as conservation tillage, soil protection and targeting areas where combinations of land management and landscape factors pose significant NPS pollution generation risks. Although this section has focused on non-point sources of pollution, point sources also exist. However, these sources tend to be continuous and vary little over time and their impacts are therefore considered to be inconsequential. Various studies in pollution sources e.g. Beven (2002), De Vries *et al.* (2002) Hatch *et al.* (2002), Tsujimura (2004), Fisenko, (2004), Deasy *et al.* (2007) and Bryan and Kandulu (2011) concur that the major pollutants associated with water quality are derived from non-point sources. The regulation and monitoring of NPS pollution has recently become central to most government water quality management policies both internationally (e.g. Hansen, 2002; Romstad, 2003) and locally (e.g. Pegram and Bath, 1995; DWAF, 2003 and 2004).

In South Africa, the rapid developments and land use changes occurring within numerous catchments are responsible for the generation of various forms of diffuse pollution, causing the water quality decline of many local rivers. However, local NPS pollution is yet to be effectively quantified and aligned to the impacts of climate change for the development of adaptation strategies. The most important pollutants in South African waterways are considered to be nitrates, phosphates, sediments, pesticides and salts; all of which are mainly generated from agricultural and urban sources (DWAF, 2004; van der Laan, 2010). An in-depth understanding of pollutant dynamics along local rivers is, therefore, critically important in water quality management. In the last few decades, however, significant advances have been made with intent to reduce impacts on water quality and promote environmental health (Arthington *et al.,* 2006; Rivers-Moore *et al.*, 2007). In spite of these advancements, the continual use of pollutants in agricultural practices implies that the issue of water quality deterioration is going to remain significant in the future (Honisch *et al.,* 2002; DWAF, 2003). Therefore, non-point source pollution and land use change form an integral part of water quality management and will become particularly important under an altered climate. The following section briefly introduces the parameters and processes most critical to South African waterways as recognised by this review.

4.8 Critical Parameters and Processes

As mentioned in the preceding sections, South African catchments are predominantly agricultural catchments and a major component of diffuse (NPS) pollution is generated within these catchments. The increased generation of nutrients such as phosphorus (P) and nitrogen (N) from these catchments due to high rates of manure and fertilizer application primarily leads to eutrophication (Foy and O'Connor, 2002; Deasy *et al.,* 2007).

Both N and P are considered as the main nutrients that drive the fluctuation of water quality in the fluvial systems of agricultural catchments (Withers and Jarvie, 2008). This statement implies that in South African catchments, more focus needs to be directed towards assessing the potential changes in both N and P generation and transport under conditions of climate change. Some of the parameters and processes considered paramount in nutrient transfer include:

1. surface erosion, entrainment, sedimentation and deposition,
2. catchment connectivity,
3. nitrogen and phosphorus cycling,
4. precipitation and soil moisture content,
5. leaching and runoff, and
6. adsorption.

Another equally important factor in nutrient delivery is sediment conveyance and catchment connectivity. N and P are either transferred in dissolved form (N and P) or attached to sediments (mainly P) (Heathwaite and Dils, 2000), and owing to the connectivity and sediment delivery dynamics characteristic of many catchments, N and P become subject to discontinuous transport and deposition (Avnimelech and McHenry, 1984). Furthermore, the connectivity of landscape compartments affects sediment conveyance processes in response to external disturbances of varying frequency and magnitude (Fryirs *et al.,* 2007). Therefore, under conditions of climate change, the source generation and distribution of sediments and nutrients is highly likely to change due to the anticipated high magnitude and intensity of rainfall events (Heathwaite and Dils, 2000). Deasy *et al.,* (2007) argue that because the "processes of sediment and nutrient transfer are not well understood over the range of scales needed for appropriate modelling and management applications" it is not yet possible to assess the likely impacts of potential changes. However, the issue of scale is somewhat mitigated by the vast amount of work that has been carried out in sediment, catchment connectivity and nutrient transfer dynamics (Haygarth *et al.,* 2005; Owens *et al.,* 2007). These issues will be expanded on in greater detail later.

4.9 Vulnerability and Adaptation in Water Quality Management

Water quality management and water-centric policy development are, in fact, closely linked focus areas that fall under the banner of water resources management. Effective water quality management requires a sound policy framework informed by well executed environmental studies and research (Brainwood *et al.,* 2004; Nangia *et al*., 2008), as well as monitoring and evaluation. However, in many instances, there is a significant disconnect between the two. This disconnect can be attributed to a number of reasons including: significant time constraints for detailed catchment scale investigations which inform policy, information is usually disconnected in time, space and function and knowledge cannot be effectively generated from environmental studies, due to the disjointed nature of the information collected (Bennet *et al*., 2005; Harrison, 2007; Nangia *et al*., 2008). The result of this is usually the development of inadequate policies, redundant management instruments, inappropriate catchment biophysical process knowledge, missing or inadequate monitoring programs, unclear institutional responsibilities and lack of financing sources (Huang and Xia, 2001; Gourbesville, 2008). This consequently creates an environment where adaptive capacity is undermined and vulnerability is increased, thus limiting the effectiveness of adaptation action.

The current mosaic of global change issues, including climate change and population growth add further complexity to the already complex relationship between policy development and water quality management. With increasing precipitation variability and increased pollutant discharge and transport, particularly under climate change, the requirement for adaptive policy and thus adaptive water quality management has been made even more imperative. It is at this juncture that the importance of catchment scale investigations of pollutant discharge is highlighted, particularly as they ultimately contribute towards informing adaptive management. One of the primary tools used to improve the

understanding of the processes controlling the release, fate and transport of pollutants across catchments is water quality modelling (Kadam and Kaluarachchi, 2006).

According to Bormann (2009), water quality models are increasingly used in decision-making despite calculations being fraught with input data errors, model errors and inadequate process knowledge. While there have been significant improvements in water quality monitoring methods, advances in regional scale water quality modelling remain a priority. Such advances would effectively imply a reduction in vulnerability owing to the implied increase in adaptive capacity and, ultimately, improved adaptive water quality management.

To ensure that adaptive water quality management is as effective as possible, it is highly critical that catchment processes are investigated in a holistic manner which recognises the interactions between people and their physical and biological environment (Bennet *et al.*, 2005; Lynam *et al.,* 2009). Such an approach is critical in linking environmental and socio-economic systems in order to create a broader understanding of sustainability and the integrative nature of water quality management and socio-economic dynamics. **Figure 4.2.1** cited social, human and financial capital as one of the key determinants of adaptive capacity (Gbetibouo *et al.,* 2010). Therefore, by linking environmental and socio-economic systems (social, human and financial capital) a framework is somewhat automatically created, in which the interactions between the two are recognised and adaptive capacity in water quality management is increased. Such a "framework" would effectively be in the form of a policy, legislature or a regulatory arrangement (Gourbesville, 2008).

The main aim of this section was to highlight the differences in the understanding and application of the terms "vulnerability" and "adaptation", in the contexts of both policy development and water quality management. In essence, vulnerability and adaptation in policy development are concerned with how well a particular policy is formulated and implemented such that it effectively protects environmental resources in order to reduce vulnerability, increase adaptive capacity and allow for effective adaptation. In the context of water quality management, however, vulnerability and adaptation are more concerned with the "end-pipe" factors. While policy development is more concerned with the conceptualization of rules and regulations which govern water quality management, water quality management is more concerned with the actual, physical execution of those rules and regulations. For instance, the monitoring of pollutant discharge from catchments is a physical activity but the requirement for monitoring would be informed by a policy aimed at ensuring that the water quality of receiving waters is protected. In essence, effective and adaptive water quality management relies on effective and adaptive policy development and, furthermore, implementation.

Having reviewed the concepts of vulnerability, adaptation and adaptive capacity and highlighted the differences in the terminology and application of these concepts, the following section presents a review of the contemporary issues central to water quality management in the context of South African water resources management. The adaptation and vulnerability concepts detailed in the preceding section will also be factored into the following discussion.

4.10 Assessing Impacts of Climate Change on Water Quality

It is now a well-accepted notion that some impacts of climate change on water resources are unavoidable (Kundzewicz *et al.,* 2007; Bates *et al.,* 2008; UNESCO, 2009). Projections generated from various General Circulation Models (GCMs) present persuasive evidence that global climate and hydrological systems are going to change despite mitigation actions (Schulze *et al.,* 2005; Bates *et al.,* 2008; UNESCO, 2009). GCM projections that herald increases in temperature and changes in rainfall variability associated with climate change, present sobering implications for, *inter alia*, environmental health and water quality (Lumsden *et al.,* 2009). Regardless of the uncertainty inherent in climate change science (Schulze, 2005; Pittock, 2009), it is important to recognize the potential effects that climate change may have on critical water resources management facets such as water quality (Nelson *et al.,* 2007). This section therefore presents the potential impacts of climate change, specifically on water quality and associated processes and constituents.

The anticipated changes in temperature, flow regimes and rainfall variability associated with climate change are expected to exacerbate water quality problems (Ducharne, 2007; Delpla *et al.,* 2009). Increased temperatures will have implications for the chemical and biological integrity of rivers and other aquatic environments. For example, Van Vliet and Zwolsman (2008) presented a case whereby a 2^{o} C increase in water temperature during a drought in 2003 resulted in a pH decline, eutrophication,

decreased dissolved oxygen and increases in metal and metalloid concentrations in the Meuse River in France. In this example, the combination of low flows and high temperatures resulted in the deterioration of the water quality of this river (Van Vliet and Zwolsman, 2008). In such instances, the consequence of this combination is an increase in the toxicity of contaminants, which increases with temperature and consequently adversely affects aquatic life (Delpla *et al.,* 2009).

Changes in rainfall variability result in changes in flow regimes (flow rates and timing), which has implications for pollutant residence times, pollutant concentrations, salinity levels in arid and semi-arid regions, pollutant transport and stream dilution capacities (Nelson *et al.,* 2007; Turton, 2008). The Meuse River case detailed in Van Vliet and Zwolsman (2008) provides an example that details how combinations of low flows and high temperatures result in high pollutant concentrations and increased pollutant residence times (eutrophication), which leads to water quality deterioration. A similar but slightly varied trend is observed during high flow periods (during floods or rainy season peaks). Although high flows can result in the dilution of pollutants and in the reduction of pollutant residence times in rivers, the transport of pollutants to other locations which can occur during these events, can result in the introduction of foreign contaminants to other aquatic environments (Beven, 2002; Turton, 2008; McCartney, 2009). For example, sedimentation, turbidity and increases in pollutant concentration can occur in rivers and dams following a high intensity rainfall event. Such events usually generate high soil losses and high runoff volumes which can cause pollutants and sediments to be transported from the upper parts of a catchment into downstream water sources (Prathumratana *et al.,* 2008; Neal *et al.,* 2008).

Climate change is not only expected to alter rainfall patterns and hence variability, but also the intensity of individual events (Schulze *et al.,* 2005; IPCC, 2007; Bates *et al,.* 2008). The high runoff generated from these events can result in the flushing out of faecal coliform bacteria, disinfectant by-products (DBPs), dissolved organic matter (DOM), pathogens, pesticides and various industrial and agricultural pollutants into surface water and groundwater (Neal *et al.,* 2008; Delpla *et al.,* 2009). Groundwater quality has an added dimension when climate change is considered. Pittock (2009) noted that the El Niño Southern Oscillation cycle, which is expected to continue with climate change, will result in extreme high sea levels which can cause salt-water intrusion into aquifers, thus impairing groundwater quality. Nelson *et al.* (2007) also indicate that the severe storms predicted to accompany global warming will result in "more polluted runoff" in a climate-altered future. **Figure 4.10.1** summarizes the potential impacts of climate change on water resources and on water quality, as outlined in this discussion. To further summarise the relationship between climate change and water quality, **Table 4.10.1** correlates changes in climatic extremes and the potential resultant effects on water quality variables.

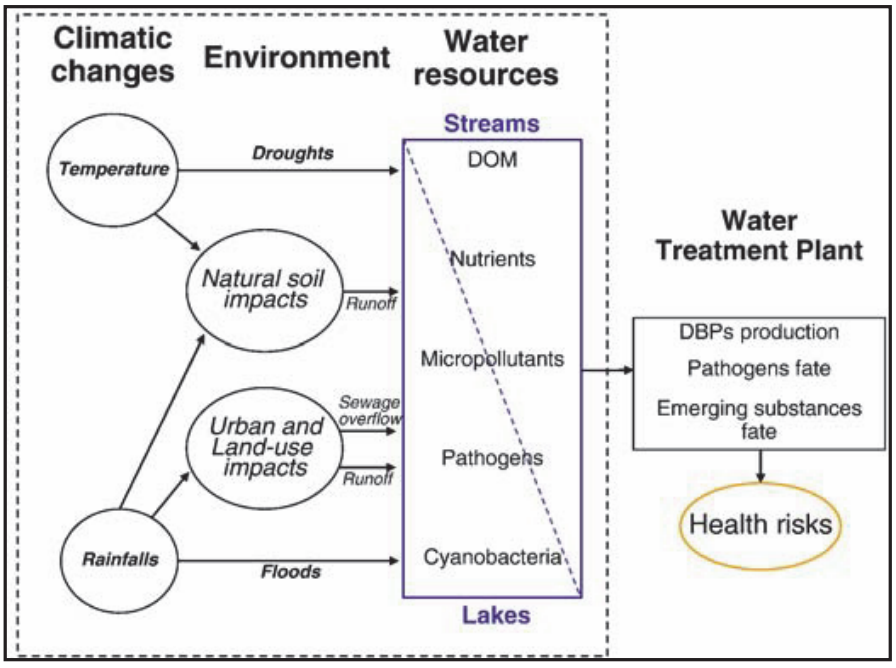


Figure 4.10.1 Potential impacts of climate change on water resources and drinking water quality (Delpla *et al.,* 2009)

Table 4.10.1 Projections of extreme climatic events and associated impacts on water quality variables (IPCC, 2007)

Changes in phenomena and direction of trend	Confidence in projected changes (during 21st century)	Impacts on water quality variables
Higher maximum temperatures and more hot days over most land areas	Virtually certain (>99% confidence)	Higher ambient and water temperatures, reduces dissolved oxygen (BOD and COD), reduces pH (increased acidity) and increases pollutant residence times, adverse impacts on aquatic ecosystems.
Higher minimum temperatures and fewer cold days over most land areas	Virtually certain	Surface ice formation can lead to reduced oxygen levels, disrupts ecological functions (e.g. spawning and migration).
Heavy precipitation events with increased frequency over most areas	Very likely (>90% confidence)	Increased flushing of toxic material, faecal coliform bacteria (e.g. *E. coli*), transport of NPS pollutants, disrupts normal flow regime pulses.
Increased areas under risk of drought	Likely (>66% confidence)	Reduced dilution capacities, increased risk of salinity level increases, increased pollutant toxicity.
Increased incidence of extreme high sea levels	Likely (>66% confidence)	Salt-water intrusion, destruction of coastal riparian ecosystems.

These changes are based on the IPCC (2007) report that details “estimates of confidence” in projected changes for the 21st century. It is apparent from this table that the most serious impacts on water quality are either virtually certain or very likely. This is a cause for real concern regarding the integrity of surface water and groundwater quality. In semi-arid countries such as South Africa, where water resources are already under severe pressure from both quality and quantity perspectives, these projections have especially significant implications. As mentioned before, many uncertainties abound in climate change science (Schulze, 2005; IPCC, 2007; Bates *et al.,* 2008; Pittock, 2009), especially because of its distinctly multi-disciplinary nature. Such projections, therefore, need to be viewed in a context that accepts the inherent uncertainty, but that does not prevent decisions being made. This is especially important in the application of multi-disciplinary concepts such as Integrated Water Resource Management (IWRM).

In view of the shift in emphasis towards environmental protection and water quality improvement under climate change, a subject that requires consideration is the water resources planning that will be increasingly critical in water quality management under future conditions of change. The previous discussion highlighted the importance of judicious decision-making under conditions of uncertainty. Water quality modelling and process-based predictive catchment studies are indispensable water resources management tools that are critical in decision-making under uncertainty (Rajar *et al.,* 2007; Argent *et al.,* 2009; Lorentz *et al.,* 2010; Schellart *et al.*, 2010). The following section presents a brief description of the principles and practices observed in water quality modelling and process-based predictive studies and the application of these concepts in climate change studies.

4.11 Managing Impacts of Climate Change on Water Quality

With the current discussion on global change, there has been an increased requirement for the development of hydrological prediction and mapping tools that support appropriate water quality management and decision-making (Kundzewicz *et al.,* 2007; Bates *et al.,* 2008; Zimmerman *et al.,* 2008). The connection between land use change, climate change and water quality degradation

necessitates the development of predictive tools that will provide support for the assessment and analysis of pollutant loads in catchments and offer possible solutions towards improving catchment water quality (Argent *et al.,* 2009; Mannina and Viviani, 2010). To fulfil that objective, a number of predictive tools such as water quality models and other predictive tools (see Leigh *et al.,* 2010 below) have been developed, tested and applied under various instances in the past few decades (Rajar *et al.*, 1997; Falconer and Lin, 1997; Huang *et al.,* 2009; Leigh *et al.,* 2010; Lorentz *et al.,* 2010). In order to effectively manage the impacts of climate change on water quality, it is important to critique the vulnerability assessment tools that will enable the development of appropriate adaptation strategies.

Leigh *et al.* (2010) undertook a study which investigated the vulnerability of reservoirs to poor water quality and cyanobacterial blooms under future conditions of change (climate and land use change), in southeast Queensland, Australia. During the summer months, this region experiences high ambient and water temperatures and high rainfall frequencies, both of which facilitate stronger stratification and increased inflow rates respectively. The result of strong stratification is the release of bio-available nutrients from anoxic sediments and high inflow rates increase the nutrient supply into reservoirs (Shanmugam *et al.,* 2008; McCartney, 2009). This results in increased incidences of toxic cyanobacterial blooms due to increases in nutrient loads in the reservoirs of this region. The ability, therefore, to assess the vulnerability of these reservoirs to bloom events was considered paramount in providing information for decision-making, hazard prevention and water resources management (Leigh *et al.,* 2010). This statement highlights a crucial step in linking biophysical processes with vulnerability and adaptation in water law and policy.

The study developed an “index of vulnerability” based on catchment characteristics and reservoir management criteria. The vulnerability index (VI) is essentially a measure of a reservoir’s vulnerability to poor water quality under future conditions i.e. the ratio of vulnerability to poor water quality for a particular reservoir (Leigh *et al.,* 2010). The vulnerability index was tested by using water quality data collected from 15 reservoirs located in and around Queensland. Water quality parameters tested for included total nitrogen and phosphorus (TN and TP), dissolved inorganic nitrogen and dissolved inorganic phosphorus. The VI of a reservoir was assessed by analysing the correlation between index scores and water quality parameters in the 15 reservoirs. For instance, a reservoir with a VI of 0.77 was considered to be the most vulnerable reservoir to poor water quality. This does not suggest that the reservoir had the highest concentration of nutrients over the duration of the study, but it implies that in the future, based on factors that influence nutrient generation and transport, water quality deterioration in this reservoir will be highly probable. A reservoir expected to experience adverse climate change-related impacts would also have a high VI. The authors concluded that although improvements can be made to the calculation of the VI, it can still serve as a valuable tool to water authorities and managers to confidently assess the vulnerability of reservoirs to poor water quality under future conditions of change (Leigh *et al.,* 2010).

The study by Leigh *et al.* (2010) highlights an important aspect regarding the vulnerability of systems: vulnerability is a relative property (Ionescu *et al.,* 2009). For example, increased pollutant discharge and extreme events under climate change can potentially lead to increases in vector-borne diseases and, consequently, an increase in human health related problems (Haines *et al.,* 2006). Leigh *et al.* (2010) also recognised that under future conditions of change, increased nutrient generation and transport in catchments can result in water quality deterioration, which can ultimately affect ecosystem functioning and human health. Therefore, the study by Leigh *et al.* (2010) was able to highlight the critical link between biophysical processes and vulnerability studies.

The use of water quality models is another equally important water resources management aspect that requires attention. The ability of water quality models to predict reaction changes and model the impacts of these changes throughout a system is not only important in enabling water suppliers to select improved operational strategies, but also ensures the delivery of safe drinking water to consumers (Munavalli and Kumar, 2004). This statement carries with it important implications for water quality modelling. Under future conditions of change, the use of models is going to be increasingly important in the management of water resources. The statement by Munavalli and Kumar (2004) indicates that the use of water quality models enables the selection of improved operational strategies such as best management practices or BMPs. This can potentially be translated to improved adaptation strategies, which will take into account the effects of climate change on water quality. Water quality modelling is, therefore, a critical tool which enables the management of existing and future pollution dynamics of receiving water bodies and/or fluvial systems. Application of water quality models in South Africa is also critically important if adaptive water quality management is

going to be effectively applied in daily water resources management. Not only does this build adaptive capacity by strengthening already existing predictive tools (e.g. design rainfall studies and the *ACRU*-NPS modelling system), but it also creates a new potential decision-making tool that will reduce uncertainty in water resources management.

4.12 Discussion and Conclusions

The above literature review of the impacts of climate change on water quality identified a number of critical parameters, variables and processes related to water quality that will become increasingly important under future conditions of change. It was identified in this review that nitrogen (N), phosphorus (P) and sediment will increasingly become variables of concern under an increasingly changing climate. Furthermore, the review recognised that the increased variability of rainfall and elevated temperatures anticipated under climate change will add further complexity to current water quality management by altering the behaviour of nutrients and sediment. This stems from the fact that the source generation and displacement of these variables is highly influenced by climatic conditions. Consequently, changes in rainfall and temperature are anticipated to result in changes in biophysical processes such as runoff (i.e. baseflow plus quickflow), evaporation, sediment and nutrient generation and displacement and finally, river flows.

This review also raised a number of contemporary water quality management issues which were considered paramount to the development of adaptation strategies for local water resources management. For example, the issue of increased human interventions in local catchments such as the uMngeni Catchment, was highlighted as being the primary cause of water quality deterioration. It was, therefore, recommended that adaptive water quality management be applied in order to enable the recognition of the impacts that human intervention has on freshwater systems, and to offer novel management ideas and policies and promote institutional commitment to effectively manage water quality issues in this country. This review also indicated some fundamental problems regarding water quality in South Africa. For instance, owing to the extensive pressure on local water resources, the majority of South African rivers are considered to have lost their ability to dilute effluent generated from point and non-point sources. Increasing concentrations of pollutants such as nitrates, phosphates and sediments are being recorded across many South African waterways and reservoirs. The implications for drinking water quality standards and the sustainability of rivers and dams in the future are, however, yet to be established.

This implies that without the establishment of the links between basic biophysical processes that influence water quality and the impacts of climate change on those processes, local water quality management is going to become increasingly complex and unsustainable. This gap in knowledge has extensive implications for adaptive water resources management in this country.

Increased concentrations of nutrients (N and P) generated from the increased use of agricultural pesticides and fertilizers, has been recognized as one of the main factors that contribute to fundamental local water quality problems such as eutrophication and bloom events. This is an inevitable outcome considering the fact that South Africa is comprised mainly of agricultural catchments and the increasing food demands prompt the agricultural sector to use increasing amounts of soil and crop ameliorants to meet these demands. An added dimension to the issue of nutrient generation and dislocation is that of sediment conveyance and catchment connectivity.

N and P are transported in dissolved states and bound to sediment particles respectively. Considering the increased magnitude and intensity of rainfall events under climate change, an increase in soil erosion and sediment transfer is expected. This implies that the movement of sediment and these nutrients (N and P) from source areas to water resource systems is likely to increase. Depending on the (dis)connectivity of landscape/catchment compartments, the movement of nutrients and sediment, N and P will vary according to how landscapes respond to external disturbances. It is therefore important to assess the relationship between climate change, sediment, N and P dynamics and landscape/catchment connectivity in local water quality management. The above discussion was considered to have significantly contributed to one of the main objectives of the review, which was to highlight the links between adaptation in water law and policy and adaptation in water quality management.

The above discussion reveals another key gap in knowledge with respect to water quality management in South Africa: although the impacts of a changing climate on local water resources

have been widely studied with a marked emphasis on water quantity, minimal effort has been directed towards assessing water quality issues under climate change. Considering the notion that water quality equally limits water quantity, this gap in knowledge requires due consideration. Even more disconcerting is the fact that such gaps in knowledge exist in a country considered to be highly vulnerable to the impacts of climate change and one that is characterised by a predominantly low adaptation capacity. In the interest of developing appropriate adaptation strategies in local water resources management, the importance of incorporating water quality into policy development and governance systems cannot be overemphasised. Ngcobo (2013) presents a detailed description of how this may be achieved.

Another equally important topic that was assessed in this review was that of water quality modelling. Although South Africa has a fair amount of experience in hydrological modelling, local water quality modelling appears to still be in its infancy. The review highlighted the necessity of developing water quality models that account for potential changes in biophysical processes under future conditions of change. The capability to develop new water quality models or, if necessary, extend existing models, exists in local water resources management. Harnessing the ability to perform the necessary modelling exercises locally is going to become increasingly important under future conditions of change, as indicated by the literature review. Consequently, the ability to model the projected impacts of climate change on sediment yield and phosphorus is going to form a critical component of the proposed study.

In conclusion, to design and implement effective adaptive water quality management strategies, the relationship between human activities and natural processes was highlighted as an important water resources management dimension in this review. The climate change projections contained in **Table 4.10.1** suggest that further investigation of this dimension is going to be increasingly crucial for the future. This is going to be especially true in South Africa, considering the perpetual pursuit of economic growth, near-exponential population growth and socio-political instability that has become a basic characteristic associated with this nation. To properly ascertain the extent of climate change impacts on water quality and the complex relationship these impacts are expected to create with socio-economic systems, it is imperative that a sound understanding and quantification of biophysical processes be established and the various links be based on that understanding. Following from the preceding assessment of the fundamental issues regarding the relationships between climate change and water quality, the following chapter provides a detailed discussion into the potential impacts of climate change on specific water quality constituents (nitrogen, phosphorus and sediment).

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CHAPTER 5: TOWARDS A FRAMEWORK FOR THE ADAPTIVE MANAGEMENT OF WATER QUALITY UNDER CLIMATE CHANGE

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5.1 Introduction

Climate change is anticipated to induce pressures on environmental and socio-economic aspects such as ecological health and integrity, food security, water security, economic stability and socio-economic development (IPCC, 2001; IPCC, 2007; Heltberg *et al.,* 2009). This implies that environmental and socio-economic systems will become increasingly vulnerable to any natural or anthropogenic disturbances introduced by the additional "layer" of impacts presented by climate change. It is widely acknowledged that the impacts of climate change will affect all water users (IPCC, 2001; IPCC, 2007; Schulze, 2005; Sadoff and Muller, 2007; Bates *et al.,* 2008), with the spectrum of affected users being determined by their individual ability to effectively respond to such changes (Paavola, 2008). In the context of adaptation and vulnerability, the developing world is considered to have limited adaptation capacity and to be highly vulnerable to the impacts of climate change (Desanker and Magadza, 2001; Paavola and Adger, 2005). This is owing to the high dependence on climate-sensitive economic sectors, geographic exposure and low-income status characteristic of the developing world (Heltberg *et al.,* 2009). Consequently, the most adverse climate change-related impacts are anticipated to occur in the developing regions of the world, of which South Africa is a part (Bates *et al.,* 2008). This serves to highlight the importance of understanding vulnerability and adaptation concepts for application in the most sensitive (*i.e.* highly exposed and least adaptive) regions of the world, including South Africa. The anticipated and potentially compounding impacts of climate change on water quality and socio-economic systems accentuate the necessity of developing robust and adaptive management strategies that will minimize the vulnerability of environmental, social and economic systems. Therefore, in the pursuit of fully representing, understanding and mitigating the impacts of climate change on the biophysical processes which influence water quality, it is important to include adaptation strategies which have the potential to be translated into policy and, ultimately, into adaptation action.

In many instances, there is a significant disconnect between adaptive water quality management and policy development. This disconnect can be attributed to a number of reasons, including significant time constraints for detailed catchment scale investigations which should inform policy. This information is usually disconnected in time, space and function and knowledge cannot be effectively generated from environmental studies owing to the disjointed nature of the information collected (Harrison, 2007; Nangia *et al.*, 2008). The result of this is usually the development of inadequate policies, redundant water resource management instruments, inappropriate or inadequate catchment biophysical process knowledge, missing or inadequate monitoring programs and unclear institutional responsibilities (Huang and Xia, 2001; Gourbesville, 2008). This creates an environment where engagement in adaptation action or adaptive management is limited and the vulnerability of socio-economic and biophysical systems to the impacts of climate change is enhanced. Such conditions underscore or facilitate the undermining of adaptive capacity. Adaptive capacity essentially refers to "the potential or ability of a system, region or community to adapt to the effects or impacts of (climate) change" (IPCC, 2001; Gallopìn, 2006; Smit and Wandel, 2006). If the proper frameworks designed to enhance adaptive capacity are not in place, it is highly unlikely that any adaptation action can be undertaken.

Effective policy development and water quality management both need to be informed by evidence obtained from well executed environmental studies and research. It is therefore critical that the biophysical or catchment processes and linkages that describe how agricultural non-point source (NPS) pollution and land use changes influence water quality, be reconciled with adaptive water resources management both in management and in policy development and governance structures. The assessment of the links between biophysical processes, climate change and adaptation is of significant importance in the pursuit of reducing vulnerabilities to climate change and building adaptive capacity. Effective WQ management requires a sound, implementable policy framework that is

informed by well executed environmental studies and research (Brainwood *et al.,* 2004; Nangia *et al.*, 2008), as well as monitoring and evaluation. Thus, the primary aim of this paper was to develop or suggest relevant adaptation strategies that can facilitate adaptive water quality (WQ) management and policy development, based on appropriate scientific investigation.

5.2 An Adaptive Water Quality Management Framework

It has been repeatedly noted in this study that as part of the current global change mosaic, climate change could aggravate current water quality problems. Indeed, climate change is anticipated to introduce added complexities that water quality managers will have to contend with. Although decision makers make decisions under uncertainty every day, even in the absence of climate change (World Bank, 2010), the extent of changes that are likely to occur under climate change means that a paradigm shift is required in which the compounding set of uncertainties presented by climate change are recognised and included in the decision-making process (Kundzewicz *et al.,* 2007) and that these decisions are reflected upon and revised as new information becomes available. This essentially constitutes adaptive management (Kundzewicz *et al.,* 2007; Bates *et al.,* 2008). Based on an analysis and synthesis of the available literature conducted in Ngcobo (2013), this study proposes an adaptive water quality management framework that, if successfully implemented, could prove beneficial in local water quality management. This framework, combined with the adaptive management framework proposed by Bennet *et al*. (2005; **Figure 5.2.1**), is intended to be used as an effective tool to assist in dealing with the potential impacts of climate and global change on water quality management in an adaptive way. This framework is, of course, not limited to climate change. It also considers natural variability and socio-economic changes as potential "hazards" in the fluctuation of catchment water quality. Adaptive management is a cyclic learning, application and review process in which the focus is on action and learning and not in preparing to learn (Lee, 1999; Bennet *et al*., 2005).

According to Bennet *et al*. (2005), adaptive management can be defined as ''a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs". In **Figure 5.2.1**, the components are all linked through a continuous process of learning and participative action. To summarise (with reference to **Figure 5.2.1**): *Information collation* refers to the pooling of information collected from research and from stakeholder consultation and is usually the first step in the development of an adaptive management framework. This step would essentially be informed by catchment process observation and monitoring conducted in operational and experimental catchments.

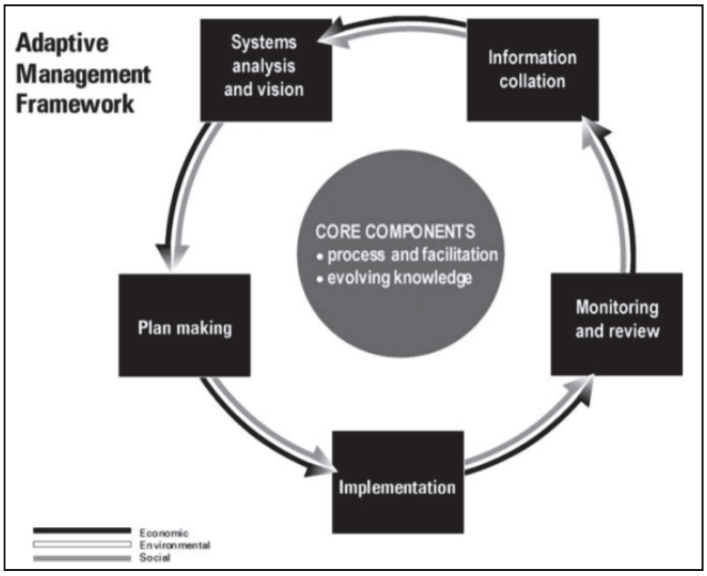


Figure 5.2.1 Schematic diagram of the Coastal CRC Adaptive Management Framework (Bennet *et al.,* 2005)

The *core components* of process and facilitation and evolving knowledge are essential in the planning and management cycle and comprise the establishment of healthy relationships amongst catchment stakeholders such that the entire adaptive management cycle proceeds efficiently. This step, as

shown in **Figure 5.2.1**, would be facilitated through the unbiased and transparent inclusion of stakeholders in decision-making and in the introduction of incentives to promote engagement in adaptation action by the relevant stakeholders. *Systems analysis and vision* focuses on identifying and understanding the most important catchment systems in order to clearly define the vision and aspirations for the catchment. This step would need to be extended to account for the long-term visions of catchment stakeholders. *Plan making* involves the setting of clearly defined resource management goals such that impacts on ecological and socio-economic systems are recognised and strategies are developed. This would, essentially, constitute the development of adaptation strategies as outlined in this study.

Implementation involves the actual execution of the goals created in plan making, systems analysis and vision creation. In essence, this step describes the actual practice of adaptive water quality management. Unfortunately, it also represents one of the biggest challenges faced in South African water resources management. However, the promotion of stakeholder participation in catchment water resources management through the introduction of incentives and the transparent inclusion of stakeholders in decision-making may ensure that implementation proceeds efficiently and with limited complications. The process of *monitoring and review* follows implementation and involves the assessment of the effectiveness of the goals set during the initial stages of framework development and of the effectiveness of the implementation process (Bennet *et al.,* 2005). It also embodies the continuous monitoring of various aspects of the framework, including biophysical processes, monitoring and gauging networks, engagement in adaptation action and the literacy of stakeholders with respect to the impacts of climate change and water quality management. Finally, it includes the re-evaluation of initial adaptation strategies and policies to ensure that the natural dynamism of environmental and socio-economic systems is accounted for and any changes are incorporated into these strategies and policies. It is apparent from **Figure 5.2.1** that adaptive (water quality) management is a process that facilitates intervention in the face of uncertainty. For instance, catchment monitoring and hydrological modelling serve as approaches that water resource managers can use to abstract information about the natural environment and synthesise knowledge and make decisions based on that information.

Water quality is influenced by various potential hazards and risks such as climate change, population and economic growth and natural variability. The framework presented in **Figure 5.2.2** recognizes these hazards and risks and suggests that a better understanding of the impacts these hazards and risks have on catchment processes, which influence water quality, should be developed through the continuous process of information collation and systems analysis and vision. Information collation and systems analysis and vision need to be followed by comprehensive and clearly defined plans or strategies designed to mitigate the impacts presented by the various hazards and risks on natural and socio-economic systems. This, as has been mentioned already, would emerge through the development of adaptation strategies.

The successful application of these strategies would rely on the participatory and explicit involvement of stakeholders (e.g. farmers, extension officers and other water users within the catchment) in catchment water quality management. This implies that any knowledge gained from modelling exercises, similar to the one presented in this study, should be communicated to the various stakeholders in a comprehensive manner. This is to ensure that the literacy of stakeholders regarding water quality management is improved. Not only is this a way of enhancing adaptive capacity (i.e. by improving access to information and knowledge, thus enhancing awareness) but it also facilitates or improves the potential for the engagement in adaptation action. This is summarised in the core components presented in **Figure 5.2.2**. Implementation, which describes the actual practice of adaptive water quality management, would be guided by well-informed policies developed through the use of knowledge gained from both modelling results and stakeholder consultations. As already mentioned, implementation needs to be followed by the monitoring and review of the effectiveness of the adaptation strategies designed during the initial stages of the framework's development. In **Figure 5.2.2**, the processes of monitoring and review (highlighted by the feedback loops), involves the continuous monitoring and updating of various aspects of the framework, including knowledge regarding changes in biophysical processes, deployment and updating of monitoring and gauging networks, re-assessing changes in hazards and risks, monitoring engagement in adaptation action by stakeholders and the re-evaluation of initial adaptation strategies and policies to ensure that the natural dynamism of environmental and socio-economic systems is accounted for and any changes are incorporated into the development of revised strategies and policies.

It has already been noted that catchment monitoring and hydrological modelling serve as useful tools that water resource managers use to understand the behaviour of the natural environment and make decisions based on the knowledge synthesised from these studies. However, as will be shown in this chapter, water quality models are often fraught with input data limitations. This does not imply that these models are not appropriate for use as decision support tools by water resource managers; rather it implies that water quality models should be used as tools that facilitate explicit learning from experiments in order to inform and improve future decisions. This is also highlighted by the feedbacks indicated in **Figure 5.2.2** which signify the importance of continually updating the knowledge related to biophysical and socio-economic changes.

Adaptive WQ management requires the development of robust strategies that recognize the reality of a world of shifting baselines, intermittent disturbances and the uncertainty of future projection of change (Adger and Vincent, 2005; World Bank, 2010; Firman *et al.,* 2011). This demands a re-think of traditional WQ management practices which assume a predictable future based on past experiences. The World Bank (2010) recognizes four management strategies that are essential in facilitating adaptive (resource) management under climate change. These strategies have been adapted by the authors to be more specific to WQ management:

1. Priority should be given to no-regrets options: policy and investment options that maximise benefits related to water quality management even in the absence of climate change e.g. improving water and wastewater infrastructure to minimize water quality degradation in receiving waters (see Novotny, 2003).
2. Increase resilience of water resource systems by buying “safety margins” in low cost long-term investments e.g. increasing water quality awareness education and forming social resource protection schemes (see Petermann, 2008).
3. Reversible and flexible options need to be favoured such that in instances of bad decisions being made, the cost of reversing the impacts of decisions is kept as minimal as possible e.g. restrictive urban planning due to uncertain flooding trends can be reversed easily and is less expensive than retreat and protection options (see Heltberg *et al.,* 2008).
4. Long term planning should be based on forward-thinking scenario analysis and on the assessment of strategies that consider a wide range of possible futures.

A recurring theme in this discussion has been that adaptive water quality management requires a risk- or hazard-based decision-making model (**Figure 5.2.1** and **5.2.2**), which favours long-term planning and robustness taking into cognisance the dynamic nature of socio-economic and environmental systems (**Figure 5.2.1** and **5.2.2**). Additionally, the uncertainties presented by the use of downscaled GCM projections also suggest that robust patters of change and natural variability need to be the primary foci in water quality management rather than absolute unverifiable predictions of change. Increasing global change pressures on water resources coupled with the potentially compounding effects of climate change imply that risks related to water quality management cannot be ignored or omitted in the decision-making process. The aforementioned compounding sets of uncertainties presented by climate change necessitates the development of robust and adaptive management strategies that will minimize the risk and, thus, vulnerability of environmental, social, economic and demographic systems as outlined in this section. These strategies have to be based on sound scientific principles. Therefore, as an extension of this discussion, the following section presents a case study where a water quality modelling exercise was undertaken in the Mkabela Catchment, a subcatchment of the Nagle Water Management Unit (WMU) of the uMngeni Catchment in South Africa. The results obtained from this exercises are then used to assess their usefulness in the framework presented and the adaptation strategies suggested in this section.

5.3 Methodology

As detailed in Ngcobo (2013), the water quality modelling work in this study was conducted in the Mkabela Catchment located approximately 1km east of the town of Wartburg, near Pietermaritzburg, South Africa (**Figure 5.3.1**). The Mkabela Catchment is a subcatchment of the Nagle Water Management Unit (WMU) which forms part of the uMngeni Tertiary Catchment in KwaZulu-Natal. Commercial irrigated agriculture is the most dominant land use activity in the Mkabela Catchment.

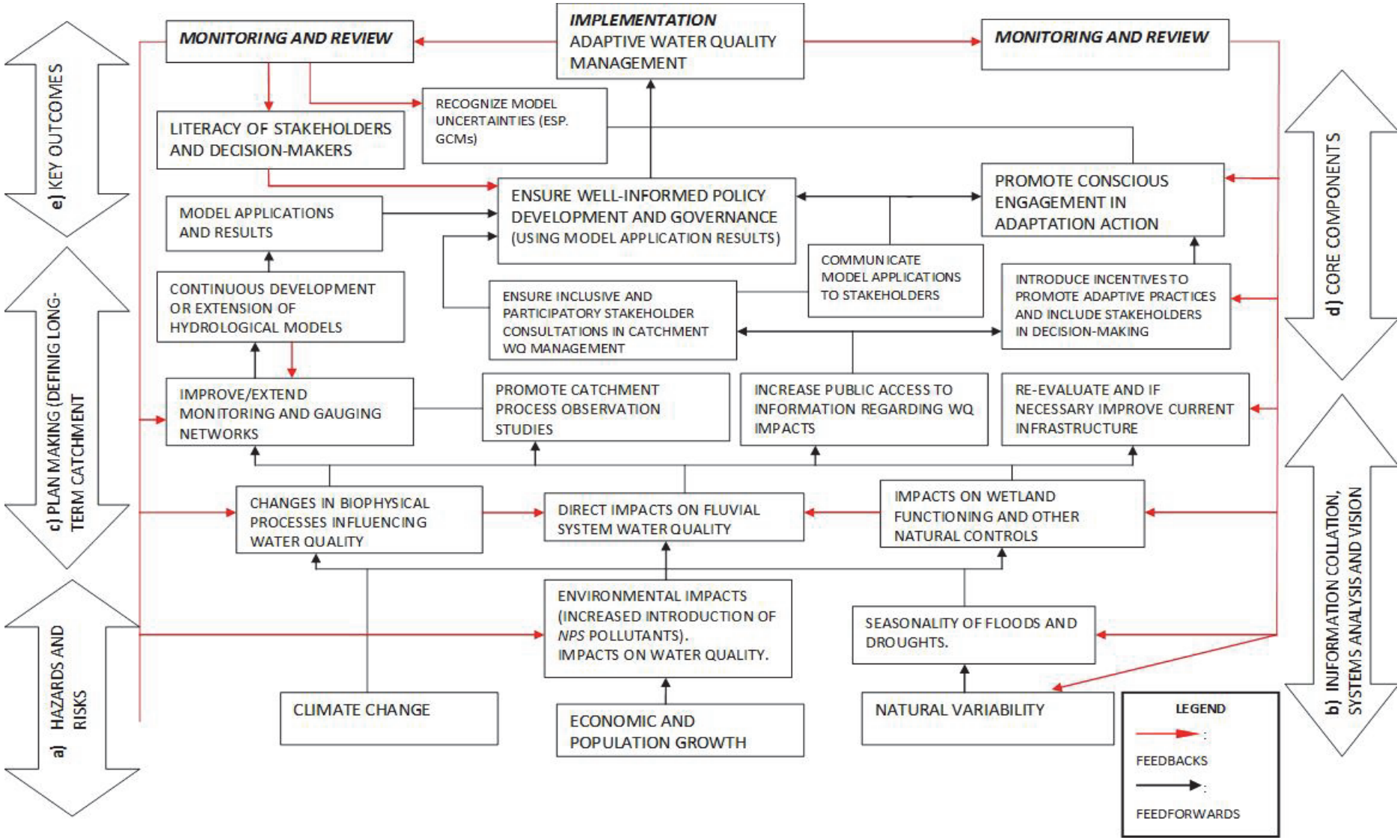


Figure 5.2.2 A proposed Adaptive Water Quality Management Framework

Various structures, which act as hydraulic controls to the movement of water and pollutants are found in the catchment, including an assortment of farm dams, wetlands and riparian buffer strips. Synthetic fertilization occurs in sugar cane, vegetable and dairy (pastures) farming systems using nitrogen (N) and phosphorus (P) based fertilizers.

The Mkabela Catchment falls within the summer rainfall region of South Africa and experiences a warm subtropical climate with distinct dry and rainy seasons interlaced with high inter-seasonal variability. The altitude in the catchment ranges from 965 m from the eastern escarpment to 755 m at the catchment outlet. The mean annual precipitation (MAP) of the catchment averages 835 mm per annum. The baseline vegetation is classified by Acocks (1988) as the Southern Tall Grassveld and the catchment relief ranges from open hills, low relief to open hills, high relief.

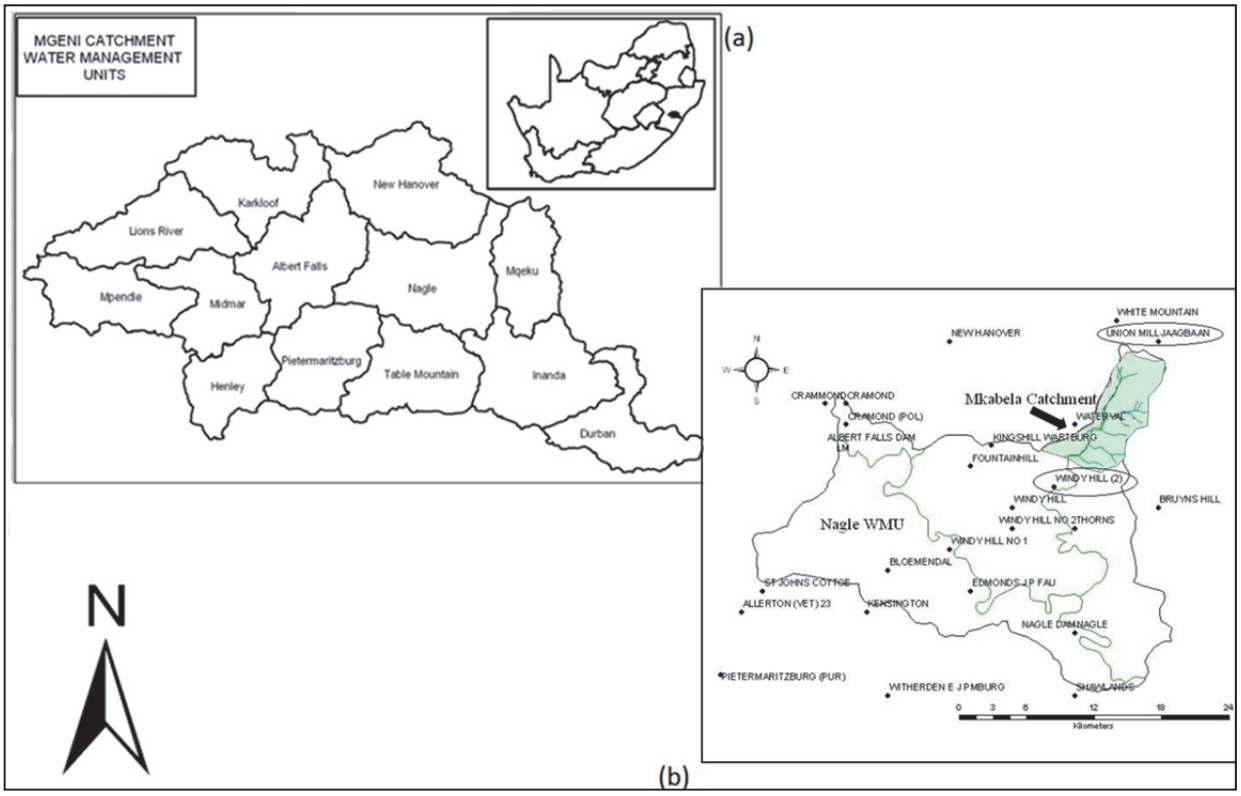


Figure 5.3.1 Location of the Nagle WMU within the uMngeni Quaternary Catchment in (a) and the Mkabela Research Catchment within the Nagle WMU in (b)

5.4 Input Data Acquisition and Processing

Since the aim of this study was to develop relevant adaptation strategies based on appropriate scientific investigation, modelling exercises were used to detail potential changes to selected WQ variables under climate change. Two types of climatic data were used as input in the *ACRU*-NPS model: i.e. observed climate data derived from the catchment monitoring network and climatic data derived from various downscaled GCMs. Daily observed climate data were acquired from two rainfall gauging stations located in and around the Mkabela Catchment. These are the Windy Hill Number 2 and Noodsberg-Jaagbaan rainfall stations. The records from these stations had rainfall data available over different periods and were combined to form a single composite record for the period 1950 to 2011.

Climate change data used in this study were derived from seven downscaled global circulation models (GCMs) employed in the Intergovernmental Panel on Climate Change (IPCC) Third (TAR) and Fourth (AR4) Assessment Reports (IPCC, 2001; IPCC, 2007). The downscaled climate change projections, derived from the downscaled GCMs, were obtained from the Council for Scientific and Industrial Research (CSIR) and from the Climate Systems Analysis Group (CSAG) based at the University of Cape Town (UCT). The downscaled climate change projections used in this study were based on the Special Report on Emission Scenarios (SRES) A2 storyline and emission scenario

(Nakićenović *et al.,* 2000), which assumes that global efforts to reduce greenhouse gas emissions are relatively ineffective.

5.5 Simulations Performed

Source-pathway-response modelling of the Mkabela Catchment with the intention of understanding the impacts of agricultural NPS pollutants on the water quality of hydraulic controls across the catchment was conducted in this study. The simulation of runoff processes (from rainfall measured within the catchment) was carried out for 3 individual Hydrological Response Units (HRUs) located in the headwaters of the Mkabela Catchment (**Figure 5.3.1**). The general characteristics of each of these HRUs are detailed in **Table 5.5.1**. The HRUs are located upstream of a perennial wetland, marked as "wetland1" in **Figure 5.5.1**. The combined runoff and streamflow from each of these HRUs form the inflow into this wetland, as indicated in **Figure 5.5.1**.

Table 5.5.1 General characteristics of the three Hydrological Response Units located in the headwaters of the Mkabela Catchment

HRU Name	Area (km^2)	Elevation (m)	Slope (%)
Sugar Cane	6.31	965	3.5
Commercial Afforestation	0.61	965	5.5
Vegetable Patch	1.06	965	1.5

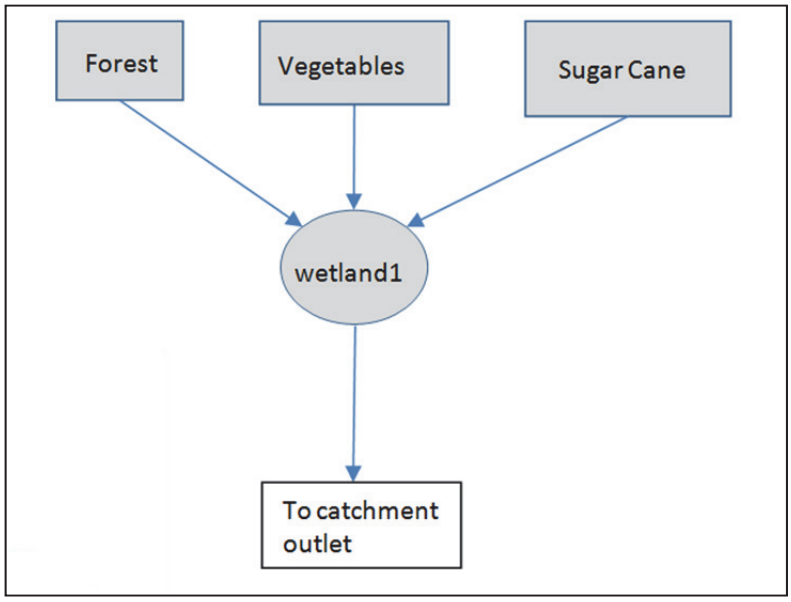


Figure 5.5.1 Location of the 3 HRUs relative to the wetland. Also indicated in this figure is the flow direction from each HRU in the Mkabela catchment headwaters into the wetland and, finally, the catchment outlet

The *ACRU*-NPS model was selected as the primary model for use in the study simulations. The description of this model and the rationale behind its selection are detailed elsewhere. It is important to differentiate between simulations performed based on observed climate data and simulations performed based on downscaled GCM climate data in the context of this study. Both modes of simulation were performed using the *ACRU*-NPS model for the individual HRUs. However, in one instance observed/historical climate data derived from *in-situ* catchment observations was used and in the other, GCM climate data derived from the downscaled GCM projections was used. For instance, the 1950 to 2011 simulations (encompassing the 1971-1990 period) in the *ACRU*-NPS model were based on observed climate data whereas the 1961-2100 simulations (encompassing the 1971 to 1990 and 2046 to 2065 periods), also in the *ACRU*-NPS model, were based on downscaled GCM-derived climate data.

5.6 Verification of the *ACRU*-NPS Model

A number of verification studies were conducted to ensure that the *ACRU*-NPS model adequately represented the observed behaviour of the Mkabela Catchment with regard to the WQ variables of concern i.e. runoff, sediment, nitrogen and phosphorus. Model simulations were verified against observed WQ variable data from the Mkabela Catchment and results from these exercises indicated that the model was representing the hydrological system satisfactorily. The results of these verification studies are detailed in Ngcobo (2013).

5.7 Impact of the Wetland on the Transfer of NPS Pollutants

Based on the simulations performed using observed input data, the influence of the wetland on runoff and on the transfer of nutrients and sediments was assessed by observing the changes between variable amounts entering the wetland (Wetland1-"variable" IN) and amounts exiting the wetland (Wetland1-"variable" OUT). These changes are indicated in **Figure 5.7.1** for runoff and in **Table 5.7.1** for all WQ variables considered. **Table 5.7.1** presents mean annual estimates of the variables entering and exiting the wetland and the percent changes between variable amounts entering the wetland and amounts exiting the wetland for the period between 1971 and 1990. The graphical representations showing the behaviour of nitrogen, phosphorus and sediment before and after the wetland are presented in Ngcobo (2013).

Table 5.7.1 Simulated mean annual estimates of water quality variables entering and exiting the wetland based on observed input for the present period

Variable	Wetland1-IN	Wetland1-OUT	%Change
Runoff (mm)	185.15	54.22	-70.72
Sediment (t)	297.75	8.69	-97.08
Nitrogen Loads (kg)	69579.00	19258.27	-72.32
Phosphorus Loads (kg)	22101.31	6602.58	-70.13

Mean annual runoff decreases by 70.72% subsequent to being routed through the wetland (**Table 5.7.1**). This simulation also highlights the high effectiveness of the wetland to mitigate floods, judging by the reduction in exit flow in the September 1987 floods by over 97% (**Figure 5.7.1**). Sediment, being sensitive to runoff, also displays a similar attenuation trend to that of runoff as indicated in **Table 5.7.1**. A linear relationship exists between runoff, streamflow and sediment generation. Following a rainfall event, the amount of sediment generated from upstream sources generally increases with an increase in runoff. The sharp decline in sediment between wetland entry and exit can be attributed to the settling effect of sediment when routed through the wetland. The factors affecting sediment transfers across water bodies were outlined in Ngcobo (2013).

Subsequent to wetland routing, a similar reduction trend observed for both runoff and sediment was also observed for nutrients. The mean annual estimates of both N and P appear to follow the runoff trend with regard to being retained in the wetland (**Table 5.7.1**). The reason for this is that nutrients have been shown (e.g. Donohue *et al*., 2005; Lorentz *et al*., 2011) to migrate easily with runoff and this was an expected trend considering the fact that crop fertilization is administered using primarily N- and P-based fertilizers in the Mkabela Catchment. Ngcobo (2013) detailed the factors affecting the behaviour of nutrients across hydraulic controls and it was shown that these nutrients have a high dependency on runoff-generating discharge mechanisms such as rainfall events and irrigation. The decline in nutrients subsequent to being routed through the wetland can be attributed to the hydropedological and biochemical characteristics of wetlands, which enable water retention for prolonged periods of time, thus promoting anaerobic conditions which facilitate the loss of both N and P through volatilisation, mass adsorption and immobilisation. Having detailed the impacts of the wetland on the transfer of WQ variables under present conditions, the following section offers a summary of the projected impacts of climate change on WQ variables.

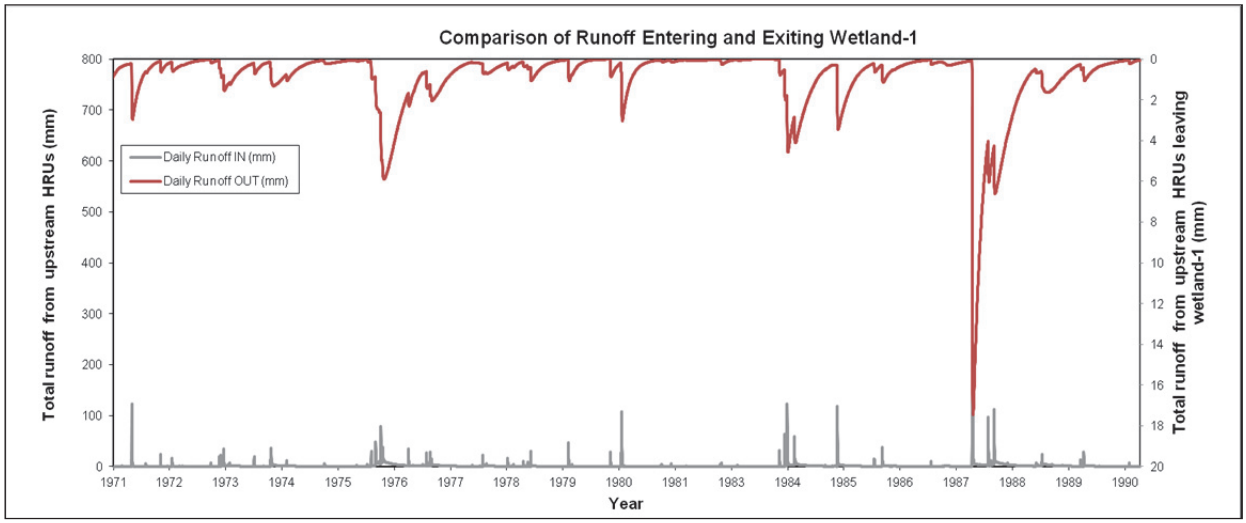


Figure 5.7.1 Simulated daily runoff entering and exiting the wetland for the period 1971 to 1990 based on observed input data

5.8 Projected Impacts of Climate Change

The changes of WQ variables between the present (1971-1990) and the future (2046-2065) were presented as ratios of change and percentage changes. Ratio values above 1 indicate an increasing trend in the simulated variable, whereas values below 1 indicate a decreasing trend in the simulated variables (**Table 5.8.1**). The ratios represent qualitative rather than quantitative changes in the simulated WQ variables. Quantitative estimates of these variables were considered to be less appropriate owing to the uncertainty presented by future GCM projections with regard to rainfall changes (see Ngcobo, 2013) and the apparent large variations in the runoff outputs generated by the *ACRU*-NPS model using GCM-derived input. Therefore, qualitative analyses were deemed more appropriate as they give a holistic representation of the potential future changes in simulated variables and highlight relative changes better than quantitative assessments which are, admittedly, only as accurate and relevant as the modelling assumptions applied.

Percentage changes, calculated by subtracting the future value of a variable from the present value of the same variable and dividing by the present value of the variable, were also included in these analyses. To summarise: a “positive” percentage change suggests an increasing trend in the variable while a “negative” percentage change suggests a declining trend in the variable. The potential impacts of climate change on mean annual runoff, nutrient loads and sediment yield are indicated as ratios of change in **Table 5.8.1** for all downscaled GCMs considered and in **Figure 5.8.1** as percentage changes for the CSIR downscaled GCMs. **Figure 5.8.1** shows the potential impacts of both climate change and the potential impacts of the wetland under climate change (i.e. under future conditions) on the generation and transfer of the WQ variables considered. In these figures, the impacts of climate change (“Impact CC”) are represented by the future versus present changes in wetland inflows. The combined impacts of climate change and the wetland (“Impact CC and Wetland) are represented as future wetland outflows versus present wetland inflows. Since the analyses of these results have been outlined in detail in Ngcobo (2013), only a summary of the main findings will be offered here.

Table 5.8.1 and **Figure 5.8.1** show that only 4 out the 7 downscaled GCMs considered project increases in runoff, nutrients and sediment going into the wetland (ratios above 1 and positive percentage changes). These were the GDFL2.1, MRI, IPSL and CSIRO GCMs. However, 3 of these GCMs, *viz*. the MIROC, ECH5 and ECHO GCMs, project decreases (albeit small decreases) in runoff, nutrients and sediment going into the wetland.

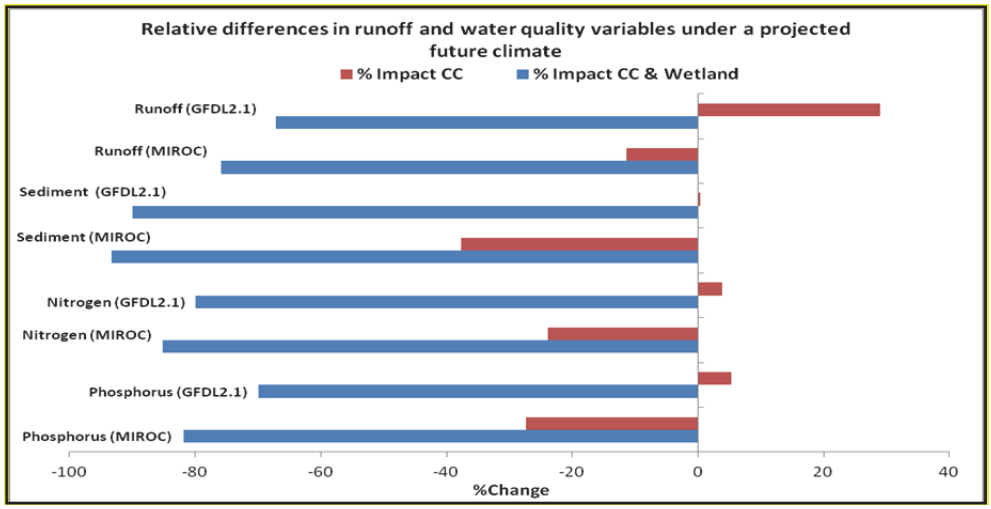


Figure .5.8.1 Impact of climate change (as a percentage difference) on mean annual wetland inflows and outflows in terms of runoff, sediment yield, nitrogen load and phosphorus load for the CSIR downscaled GCMs

For the GCMs downscaled by the CSIR, the GFDL2.1 GCM projects increased runoff going into the wetland and positive but minimal change with regard to nutrients and sediment incident to the wetland. The MIROC GCM, conversely, projects decreased runoff and decreased nutrients and sediment going into the wetland. In all instances, however, the role of the wetland is much greater than the impact of climate change and results in overall decreases in nutrients and sediments (**Figure 5.8.1**). Although the simulations project increases in runoff for most of the GCMs under climate change and also point to the potential increase in the generation of sediment and nutrients, the downstream transfer of these variables is mitigated to a high degree by the wetland.

The majority of the CSAG downscaled GCMs indicated positive changes with regard to projected runoff, nutrients and sediment under future conditions. The exceptions to these trends were the ECHO and ECH5 GCMs which indicated negligible decreases in runoff, nutrients and sediment between the future and the present. The various GCMs downscaled by CSAG indicated large variations in projected runoff, nutrients and sediment. For instance, the IPSL GCM suggested increases in runoff of up to 95%, while the MRI GCM suggested increases of only 22%. In the same sense the CSIRO GCM suggested increases of up to 71%. This, as it is evident, represents a large amount of disagreement between these GCMs. Regardless of these variations, the majority of the CSAG downscaled GCMs indicated the same direction of change, which was a generally increasing trend in the generation of runoff, nitrogen, phosphorus and sediment under climate change. GCMs are highly uncertain and they are not always expected to explicitly reproduce the exact time series variations of point scale rainfall and, consequently, that of local scale runoff. It was, therefore, considered highly critical that the focus of these analyses be on the variability and relative changes presented by the downscaled GCM projections rather than on the absolute estimates that they project.

It has been noted that there are significant variations between the CSAG downscaled GCMs regarding increases in runoff, nutrients and sediment. A closer inspection of mean annual precipitation was undertaken in an attempt to isolate and describe these trends. MAP changes indicated neutral to slight increases, yet runoff changes range from neutral to large increases (**Table 5.8.1**). Thus, downscaled GCMs projecting large runoff increases indicate a change in the distribution of rainfall (e.g. at seasonal or daily levels) which results in a lot more runoff from the same total rainfall. Some GCMs (e.g. ECHO, ECH5 and MRI) show reductions in sediment and nitrogen. These are GCMs that also project minimal change in annual runoff (save for the MRI GCM) - again this suggests changes in the distribution of the rainfall, this time in the opposite manner (less concentrated/intense rainfall). To gain a better understanding of these variations in runoff and WQ variables, it was considered important that the nature of the changes in daily rainfall (as the main "driver" of these trends) under climate change be fully detailed. The reader is referred to Ngcobo (2013) for the complete analysis of rainfall frequency changes between present and future climates.

Table 5.8.1 Ratios of future to present mean annual precipitation, runoff, nutrients and sediment for all downscaled GCMs

	RATIOS OF CHANGE*				
	MAP	**RUNOFF**	**SEDIMENT**	**NITROGEN**	**PHOSPHORUS**
DOWNSCALED GCM					
GDFL2.1	**1.05**	**1.29**	**1.00**	**1.04**	**1.05**
MIROC	**0.89**	**0.89**	**0.62**	**0.76**	**0.73**
CSIRO	**1.08**	**1.71**	**1.60**	**1.10**	**1.40**
ECHO	**1.04**	**0.95**	**0.75**	**0.91**	**1.27**
IPSL	**1.01**	**1.95**	**2.85**	**1.34**	**1.36**
ECH5	**1.00**	**0.97**	**0.92**	**0.73**	**1.00**
MRI	**1.04**	**1.22**	**1.23**	**0.99**	**1.24**
	*As ratio of future to present				

5.9 Summary of Results

To summarise, the various analyses conducted in this study to detail changes in rainfall, runoff, nutrients and sediment between the present and the future, highlighted a few critical points:

1. Global Circulation Models, like any other mathematical model, inherently contain uncertainties.
2. It is more appropriate to focus on relative changes and robust patterns of change described by the downscaled GCM projections rather than on absolute quantitative estimates which cannot be verified. This is particularly crucial in water resources planning under climate change.
3. The high degrees of variability presented by the downscaled GCM projections highlight the need to develop robust and flexible adaptation strategies that take into consideration risk, and thus have realistic safety margins.

Additionally, the uncertainties presented by the various GCM projections need to be taken into consideration particularly in the development of adaptation strategies in the highly assorted profile of South African agricultural catchments. For instance, South African catchments range from relatively simple catchments, such as those in the interior of the country, to highly complex catchments, such as those in the Western Cape and KwaZulu-Natal Midlands. Therefore, any strategies developed need to be transferrable across these catchments in order to ensure that they are robust, flexible and relevant. The following section details the development of adaptive water quality management strategies as informed by the framework suggested and by the results obtained from the water quality and climate change modelling exercises offered earlier. Also included in the following section is an assessment of the vulnerability and potential for adaptation characteristic of the Mkabela Catchment as informed by the *ACRU*-NPS simulations.

5.10 Adaptive Water Quality Management

An adaptation strategy may be thought of as a plan of action intended to minimise the anticipated impacts of change on catchment water resources. The ultimate goal of adaptation strategies is, therefore, to build adaptive capacity and reduce vulnerability. The development of these strategies is therefore important, particularly in developing countries. This section presents selected adaptation strategies considered relevant in the management of nutrients and sediment and, thus, catchment water quality as observed in the Mkabela case study and drawn from a synthesis of other relevant studies. Before these strategies are outlined, however, it was considered important that the vulnerability and potential for adaptation characteristic of the Mkabela Catchment be assessed.

5.11 Vulnerability and Potential for Adaptation as Informed by the ACRU-NPS Model Simulations

Vulnerability was defined as the “degree to which a system is likely to experience harm due to exposure to a hazard” (Füssel, 2006; Ionescu *et al*., 2009). Vulnerability is, therefore, a relative property denoting the vulnerability of something to something (Ionescu *et al*., 2009). In the context of this study, the vulnerability of the Mkabela Catchment was assessed from a perspective of the potential deterioration of catchment water quality to the increased introduction of nutrients and sediment into the Mkabela fluvial and hydraulic systems (rivers, dams, wetlands etc.), between the present and the future. That is, if an assumption is made that climate change will trigger increased runoff (as suggested by the ACRU-NPS simulation outputs) for the Mkabela Catchment, and there is an increase in the introduction of pollutants into the system for any reason (e.g. increased use of synthetic fertilizers to increase yields and meet economic demands for agricultural products), then the vulnerability of the fluvial systems and the people/farming communities who depend on them in the catchment, may also be expected to increase. It is important to note that this study considered changes in the distribution of agricultural NPS pollutants up to one specific wetland (termed “wetland1”) downstream of the pollutant contributing sites or HRUs. The relative changes in inputs into the wetland between the present and the future were used as indices that describe the vulnerability of the catchment fluvial systems or at least the headwaters of the catchment where the study was primarily focused. As noted above, all simulations based on downscaled GCM projections suggested increases in runoff and in the subsequent generation and transfer of nutrients and sediment in the future (ratios above 1, **Table 5.8.1**).

This consequently implies that there will be an increase in the loads of nutrients and sediment going into the wetland. This in turn suggests that the wetland will become increasingly vulnerable to the increased introduction of NPS pollutants, which may potentially lead to the deterioration of the water quality of the wetland. While it is true that the increased runoff volumes projected by downscaled GCMs for this catchment will potentially result in the increased washout of pollutants from agricultural lands, it is important to note that the ability and competency of wetlands to attenuate flow and limit the downstream transfer of nutrients or pollutants differs between individual wetlands. The wetland assessed in this study, as already mentioned, displayed high competency in retaining NPS pollutants and limiting their downstream transfer.

The role and importance of wetlands and other buffers was clearly indicated in the results presented. Several authors have noted that numerous factors determine how well a particular wetland prevents the downstream translocation of nutrients and sediment. Some of these factors include:

1. the size of wetland relative to the upstream contributing sources of pollutants,
2. the shape of the wetland (as a determinant of the time of concentration for runoff and thus the residence time for pollutants),
3. the permanence and seasonality of the moisture regime of a wetland (IPCC, 2007; Bates *et al.,* 2008),
4. the physicochemical properties of the wetland (e.g. C:N ratios, bacterial density or concentration, suspended sediment concentration) (Novotny, 2003),
5. the ecological conditioning of the wetland (pristine vs disturbed, flora and fauna density) (Braskerud, 2002) and,
6. anthropogenic influences or pressures on the wetland (e.g. the use of wetlands as poplar/*Populus tremula* plantations) (Braskerud, 2002).

Although the Mkabela wetland does not explicitly conform to all the factors presented above, simulation results suggested that this wetland demonstrates high competency to limit the downstream translocation of nutrients and sediment, regardless of changes in runoff and nutrient fluxes between the present and the future (**Figure 5.8.1**).

This suggests that this particular wetland has the potential of not becoming any more vulnerable to future conditions of climate change than it is to present conditions. In the context of adaptation, this highlights an important finding: the behaviour demonstrated by the wetland suggests that its preservation by the local farming community in the Mkabela Catchment would not only be an adaptation strategy in itself, but it would also potentially build the adaptive capacity and increase the resilience of this catchment to water quality deterioration instigated by the impacts of climate change. This would also prevent or limit the water quality deterioration of downstream fluvial and hydraulic systems.

It is important to note that the high competency of the wetland to limit the downstream movement of nutrients and sediment both under present and future conditions does not suggest that the appropriate and judicious management of these pollutants should not be observed. Rather, it serves to highlight the need to recognize the importance of the wetland in attenuating nutrients and sediment and the importance of having the appropriate management strategies in place to protect the water quality of downstream fluvial systems. The following section therefore provides a few of these adaptive management strategies as informed by the results of this study, as well as the literature.

5.12 Adaptive Management of Nutrients and Sediment Transport

As mentioned before, South African agricultural catchments are a kaleidoscope of relatively simple (e.g. the Maize Triangle in the Free State Province) to highly complex (e.g. mixed cropping systems in the KwaZulu-Natal Midlands) systems. It is important, therefore, that any adaptation strategies developed or suggested with the intention of minimising the anticipated impacts of climate change on water quality be transferable across these distinct catchments. Providentially, the Mkabela Catchment offers an appropriately large blend of cropping systems including vegetables, dairy, commercial afforestation, sugar cane and pastures. This provides an opportunity for the development or suggestion of adaptation strategies, takes into consideration all the various cropping systems and, arguably, allows the transferability of these strategies to other catchments, notwithstanding the limitations of the modelling exercise as detailed above.

The following strategies based, in part, on the work conducted in the Mkabela Catchment and largely on a synthesis of other studies (Ngcobo, 2013), were considered generic enough to permit their application on other "ungauged" catchments, i.e. catchments in which similar studies have not been conducted as yet:

1. Integrate catchment water quality management, applying principles from integrated water resources management (IWRM) (GWP, 2000; Schulze, 2003). Recognizing the connectivity that exists between catchment water users and uses will construct resilience and facilitate engagement in adaptation action.
2. Improve irrigation efficiency (Molden, 2007). Prevent the unnecessary increase in runoff generation which causes increased washout of nutrients and sediment.
3. Adjust fire management in forestry and sugar cane plantations. Fire is known to create hydrophobicity in soils which can enhance the susceptibility of soils to erosion, leading to increased sediment generation. Therefore only burn during low rainfall seasons.
4. Prevent waterlogging, erosion and leaching. The loss of nutrients is considered to occur to a high degree when there is an overabundance of water (as shown in Ngcobo, 2013). This is related to prudent irrigation.
5. Improve access to information. Implementing seasonal forecasting can be beneficial in improving the timing of cropping and fertilizer applications such that soil and nutrient losses are minimized. Additionally, communicating modelling results to stakeholders can also assist in promoting literacy regarding water quality management.
6. Construct discharge rate conservation structures (McCartney, 2009). This applies mainly to catchments where the release of high concentrations of nutrients and sediment is prevalent.
7. Increase public and decision-maker awareness. Cooperation between local water resource managers, farmers, local policy makers and the general public is critical in reducing anthropogenic impacts on local water quality.
8. Adopt planned rather than autonomous adaptation (Adger, 2003). In some instances, adaptation strategies are already being observed, albeit inadvertently (e.g. crop rotation and mixed cropping systems). Under future conditions of change, however, this can facilitate mal-adaptation in the sense that applying fixed management practices under altered conditions can undermine the systems integrity and potentially create new vulnerabilities and exposures.
9. "Mainstream climate change adaptation options/strategies in national development plans. Strategies and options for climate change adaptation need to be considered when preparing national development action plans" (Petermann, 2008).
10. Improve gauging and monitoring (Lorentz *et al.,* 2011). Having a dense monitoring network within a catchment not only improves daily water quality management and decision-making but it also facilitates the isolation and effective control of problem areas.

It was noted before that adaptation strategies need to be based on well-executed research and experimental work based on sound scientific principles. This study presented a case study in which the impacts of climate change on water quality constituents were assessed primarily through modelling. Admittedly, the case study offered limited scope to allow for the inclusion of catchment-wide nutrient and sediment delivery mechanisms that influence catchment water quality. This was due to a variety of limitations which included time constraints, particularly in the verification of the model, the scale at which the study was conducted and climate change input data problems.

5.13 Assessment of the Adaptive Water Quality Management Framework

The framework presented in **Figure 5.2.2** was intentionally designed to be generic in nature. The reason for this approach was to allow for the development or suggestion of an adaptive water quality management framework that can be applied in any agricultural catchment in South Africa. This was owing to the highly diverse nature of local catchments, ranging from relatively "simple" (e.g. rural) to highly complex (e.g. peri-urban to urban) catchments. This approach, it was found, has its own merits and shortcomings. The advantages of this approach were considered to be:

1. The transferability of the framework, suggesting that it is not limited to the Mkabela Catchment but can be applied in other similar agricultural catchments as well.
2. The inclusion of all aspects relating to catchment water quality management and policy development within the framework (i.e. hazards and risks, plan-making, core components and

information collation aspects, as outlined in **Figure 5.2.2**), based on a detailed review of the literature (Ngcobo, 2013).
3. Highlighting the explicit importance of communicating model applications (or any other similar research results) to catchment stakeholders and policy-makers.
4. The updating of current knowledge relating to climate change and water quality (i.e. monitoring and review) to be on par with the natural dynamism of environmental and socio-economic systems.
5. The importance of recognizing the uncertainties presented by the various GCMs used in this study is highlighted in the framework.

This approach had some shortcomings which were duly noted:

1. The framework is only applicable up to the local catchment scale (e.g. Mkabela Catchment and Nagle WMU). Regional factors (e.g. the incidence of urban areas) which would have influenced the development of the adaptive water quality management framework could not be addressed.
2. The results from the case study provided limited scope for the development of adaptive catchment water quality management strategies, but rather provide a starting point for this. This was owing to the relatively small scale at which the study was conducted and time constraints.

As mentioned before, the framework presented in **Figure 5.2.2** can be applied in agricultural catchments similar to the Mkabela Catchment. However, this framework would need to be adapted for these catchments to ensure that it maintains its primary purpose, which is to promote adaptive water quality management. To do this, the methodology presented in this study would need to be revisited and refined (see Ngcobo, 2013). For instance, this study was limited to the local catchment scale; a fact which may have potentially precluded the identification of geographically extensive biophysical mechanisms that govern the transport of nutrients and sediment.

Therefore, the extension of this and similar studies to larger catchment scales may ensure that a better understanding of these mechanisms is developed and this may, ultimately, assist in adaptive decision-making and policy development. Furthermore, the human element, or the impact of human activities on catchment water quality, could not be directly addressed in this study. That is, consultations with catchment stakeholders to understand their role in catchment water quality management could not be carried out owing to time constraints. This is an important facet of adaptive water quality management since the successful application or implementation of the framework relies on the acquiescence of catchment stakeholders to actively engage in adaptation action. Therefore, before this framework is applied in other catchments, the opinions and visions of catchment stakeholders would need to be taken into account and incorporated into the framework. This would ensure that the framework is as comprehensive as possible and includes water quality related issues most pertinent to the catchment in question.

This study also highlighted the importance of understanding uncertainty in predictive modelling. Models, such as the downscaled GCMs used in this study (Ngcobo, 2013), are uncertain. In addition, models are mathematical abstractions of reality and they are inherently limited by the boundary conditions and assumptions which they are assigned to. Therefore, the output from these models needs to be treated with a certain degree of measured scepticism. That is not to imply that the output from these models should not be used to further the understanding of natural system behaviour or to isolate and contain anthropogenic impacts on the environment, but rather to highlight the importance of recognizing the uncertainty of the output generated by these models. Decisions, particularly those pertaining to an uncertain future under climate change, need to be taken regardless of the uncertain nature of the output from these models. The framework presented in this study recognises this uncertainty and highlights the need for monitoring and review in order to ensure that these decisions remain robust and relevant under a changing biophysical and socio-economic climate. This would be applicable to all catchments where this framework may be applied. Having outlined the development of an adaptive water quality management framework and various adaptation strategies using both a review of the literature (Ngcobo, 2013) and the modelling exercises conducted using the Mkabela Catchment as a case study, the following section provides a synthesis of the results of this chapter and the implications it presents for similar studies.

5.14 Discussion and Conclusions

This paper has attempted to outline the use of the water quality model *ACRU*-NPS to suggest appropriate and adaptive water quality management strategies. Admittedly, the modelling results of this study were relatively limited for use in the development or suggestion of these adaptation strategies. The impacts of climate change on water quality could only be assessed in terms of the response of a single wetland to projected changes in the biophysical process and the consequential changes in processes governing the behaviour of nutrients and sediment across the Mkabela Catchment. This precluded the identification and assessment of geographically extensive mechanisms that control nutrient and sediment transfer dynamics. However, the local catchment-scale focus assumed in this study allowed the identification and isolation of unique catchment pulses that govern the behaviour of non-point source pollutant migration, therefore allowing the identification of the processes that may have the greatest impact on catchment water quality under climate change. This also enabled the design of management strategies and the adaptive water quality management framework and its refinement, which were considered to be both relevant and specific to the Mkabela and similar agricultural catchments (Ngcobo, 2013).

The reviews conducted in Ngcobo (2013) to outline the procedures involved in developing adaptation strategies, served as important guides in the development of the adaptive water quality management framework and adaptation strategies suggested in this paper. This study showed that adaptive water quality management requires risk- and hazard-based decision-making models (**Figures 5.2.1** and **5.2.2**) which favour long-term planning and robustness taking into account the dynamic nature of socio-economic and environmental systems. Additionally, the uncertainties presented by the use of data derived from downscaled GCM projections, also suggest that natural variability and robust patterns of change need to be the primary foci and not absolute unverifiable projections of change.

Increasing global change pressures on water resources coupled with the compounding effects of climate change imply that risks related to water quality management cannot be ignored or omitted in the decision-making process. The compounding set of uncertainties presented by climate change necessitates the development of adaptive management strategies that will minimize the vulnerability of environmental and socio-economic systems to climate change.

The strategies and frameworks outlined in this study not only have the potential to enhance the adaptive capacity of catchment water quality management but they can also serve as useful guides in the development of new adaptation strategies in other ungauged South African catchments. Limited as the results of study may have been, they still provided insight into the complexities and uncertainties involved in both water quality and climate change modelling. They showed the absolute importance of exercising caution in the application of GCM-derived data in the investigation of point-scale hydrological responses/processes. Additionally, they showed the importance of extending such investigations to larger catchment scales in order to fully represent source-pathway-response relationships that govern nutrients and sediment migration. Furthermore, the review into the probable changes in the behaviour of climate-sensitive processes under climate change served as a useful reference that allowed the explanation of the results obtained in this study.

In conclusion, this study has attempted to demonstrate the absolute importance of strategic and adaptive intervention, even under uncertainty. The framework and adaptation strategies that have been suggested take cognisance of the uncertainties surrounding the climate change discussion and note the importance of continuous monitoring and review, to ensure that any changes in environmental and socio-economic systems are factored into adaptive water quality management and policy development. Although this study was limited by scale, the adaptation strategies suggested were considered to be holistic and applicable up to local catchment scales. It was also noted that such studies need to be extended to regional catchment scales to ensure the inclusion of geographically extensive catchment biophysical processes.

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CHAPTER 6: LINKAGES BETWEEN SELECTED HYDROLOGICAL ECOSYSTEM SERVICES, LAND USE CHANGES AND CLIMATE CHANGE, AS INDICATED BY HYDROLOGICAL RESPONSES

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6.1 Introduction

The natural environment provides services to humans in the form of climate regulation, water provisioning and regulation, as well as biodiversity-related and other services. These so-called ecosystem services have economical and societal, as well as environmental value. At this point in time, decisions about changes in land use are often made without taking into account what the impacts of those changes would be on the ecosystem services which this land provides to both individuals and to society. However, increasingly significant tracts of land are being transformed from their natural state to human-influenced land uses (Foley *et al*., 2005). This can also be observed in the province of KwaZulu-Natal, South Africa (Jewitt, 2012), where the Mpushini/Mkhondeni study catchments are situated. These water-limited study catchments, which form part of the larger uMngeni Catchment, have to date experienced a degree of transformation through agricultural development and urban sprawl and there are currently various proposals for land use change, from natural and agricultural, to more concentrated urban land uses. The current and proposed land use influences on ecosystem services should be recognised and accounted for and should include feedbacks and links within the complex ecological-human system, in order to make informed land use decisions for a sustainable future.

The research reported here aims at improving the knowledge on linkages between hydrologically-related ecosystem services and the current and proposed land uses within the study area. The objectives are to model changes in hydrological responses due to land use modification and then to relate these response changes to changes in ecosystem services.

In this document, a literature review on ecosystem services, hydrologically-related ecosystem services, land use and the links amongst these, is presented in **Section 6.2**. A need for improved knowledge on the links between land use change, hydrological responses and ecosystem services is established from the literature, and this research aims to contribute towards these links. **In Section 6.3** background information is given on the water-limited study catchment, on the scenarios of baseline natural land cover, of current and proposed land uses. Methods of analysis are described in **Section 6.4**, starting with the hydrological implications of the scenarios, a description of the delineation of the study area into catchment units and further into hydrological response units, a description of the hydrological model that was used and of the relevant hydrological model inputs, as well as the outputs of hydrological responses. Key results are presented in **Section 6.5**, starting with the results of hydrological analyses from the baseline, i.e. pre-human, untransformed land cover, which is used as a reference. Thereafter, an interpretation of changes in hydrological responses between current land uses and the baseline land cover follows, as well as an interpretation of differences in hydrological responses between proposed urbanisation and current land uses. The hydrological responses are used as indicators for selected provisioning, regulating and supporting hydrological ecosystem services. The land use changes are then linked with those selected ecosystem services.

6.2 Literature Review

In this brief review of the relevant literature, the concept of ecosystem services will be explained first, followed by a description of hydrological ecosystem services. An overview of land use within an ecosystem services context will then be given, as will the links between land use and hydrological ecosystem services.

6.2.1 Ecosystem services

This section is an introduction to ecosystems, their functioning and resilience and associated ecosystem services. After this, declining ecosystem services and their consequences, as well as ecosystem services assessments for decision-making will be described, with examples of investments in ecosystem services. The section will conclude with an assessment of ecosystem services in the South African context.

Ecosystems functioning and resilience

Ecosystems may be defined as a dynamic complex of plant, animal and micro-organism communities and the non-living environment, interacting as a functional unit (MEA, 2005). Ecosystems are variable, dynamic and self-organising systems (MEA, 2005). When considering the earth as an ecosystem, the term biosphere is often used. The diversity and structure of the ecosystem are important for its functioning. There are feedbacks and links within an ecosystem, and these are generally complex adaptive systems. These feedbacks might be linear, but more often take place in increments or even lead to sudden shifts in ecosystem composition or functioning (Scheffer *et al*., 2001). Such changes may result in a permanent reduction or loss of associated ecosystem services (Jewitt, 2002) and will be explained in more detail later.

Maintaining the diversity and connectedness of ecosystems fosters resilience against disturbances. Resilience determines the scale of disturbance that can be absorbed within the structure of the system, before irreversible changes take place. Slow resistance loss sets the stage for larger changes if the ecosystem is subjected to a random event, such as a major climate fluctuation or when the ecosystem crosses a threshold (Scheffer *et al*., 2001; Carpenter *et al*., 2006). Scheffer *et al*. (2001) gives examples of ecosystem shifts, including:

1. the sudden eutrophication in a shallow lake due to increased nutrient load reaching a threshold;
2. the alternate stable states of moist vegetated and dry desert states of the Sahel region, caused by feedback between vegetation and climate; or
3. desertification through local soil-plant interactions, with reduced vegetation in certain dryland regions leading to reduced water infiltration which, in turn, renders the establishment of new plants more difficult or impossible.

Humans are an integral component of ecosystems. However, anthropogenic (man-made) influences have added increased complexity and are continually altering ecosystems, while natural habitats are declining (MEA, 2005). In 2007, the human ecological footprint, which is an indicator of the ecological capacity necessary to meet human needs, exceeded the earth's actual capacity to produce renewable resources and absorb CO_2 by 50% (WWF, 2012). Since 1966, humanity's ecological footprint has doubled (WWF, 2012) and humanity is thus living in a so-called "ecological overshoot" (Wackernagel *et al*., 2002).

Ecosystem services defined

Healthy ecosystems have the ability to provide a variety of ecosystem services which are essential to human existence, are complex and not yet fully understood. Most ecosystem services cannot be replaced by technology (Daily, 1997; MEA, 2005). Human health, the economy and security are tied to ecosystem services (MEA, 2005; Adger, 2006). They are understood to be benefits that humans obtain from ecosystems (MEA, 2005), either directly or indirectly (TEEB, 2010). Ecosystem services may be divided into provisioning services (e.g. providing food and water), regulating services (e.g. flood and drought regulation, climate regulation), cultural services (e.g. providing aesthetic, spiritual or educational services), as well as supporting services (e.g. soil formation or water purification) which are needed to maintain the other services (MEA, 2005). Further examples of ecosystem services are provided in **Figure 6.2.1**.

Often ecosystem services have been provided free of charge by nature to society and they can thus be classified as public goods or "commons" (Daily, 1997). Although ecosystem services often do not have "price tags" to them, they have value and might be expensive to replace, if this is at all possible (Turner and Daily, 2008). Valuing ecosystem services, and thereby internalising previously external costs, helps to channel behaviour "toward a future in which nature is no longer seen as a luxury we cannot afford, but as something essential for sustaining and improving human well-being everywhere" (Daily *et al*., 2009).

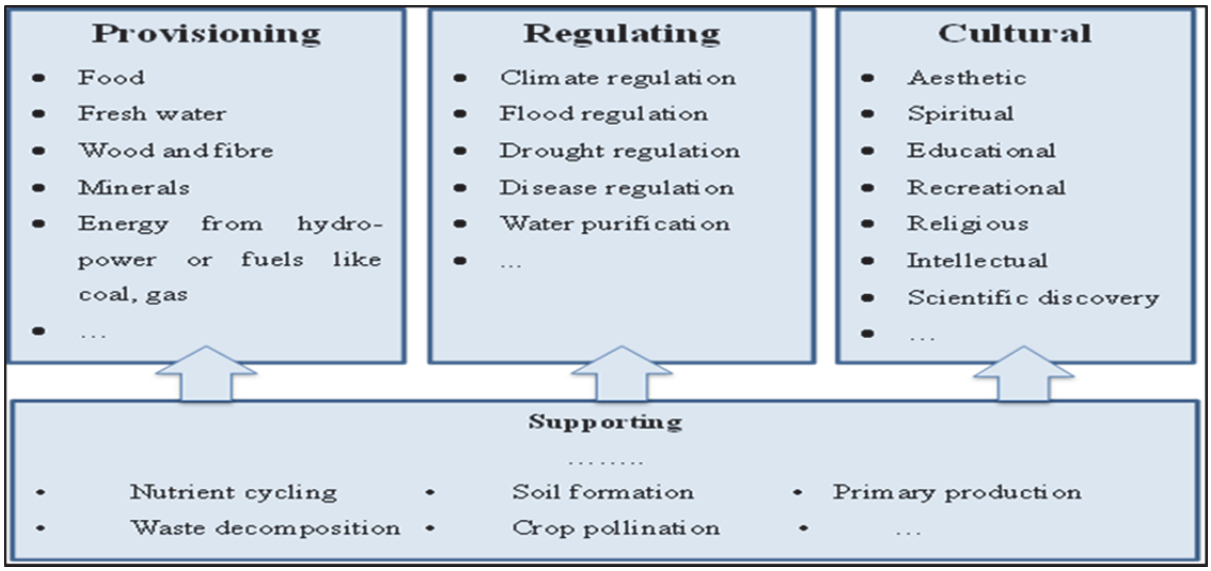


Figure 6.2.1 Components of ecosystem services (adapted from Millennium Ecosystem Assessment, 2005)

An ecosystem management approach should allow society to harness ecosystem services sustainably. Ecologists emphasise the importance of conserving natural areas for their ecological processes and functions within a landscape which, next to preserving biodiversity, also gives rise to other ecosystem services and, therefore, ensures sustainability (Daily, 1997). However, not only natural areas, but to a certain extent also landscapes with multi-functional uses, give rise to various ecosystem services.

The emerging science of ecosystem services is interdisciplinary, attempting to bring together knowledge from ecology, economics, engineering, earth sciences, landscape architecture and land use planning, for an improved and integrated understanding for decision-making that includes the maintenance of ecosystem services. To translate the benefits of ecosystem services into an economist's language, the term "natural capital" is sometimes used. Natural capital provides benefits, *inter alia*, from soil, climate, topography, flora and fauna and their interaction in a thermodynamically closed system, powered almost exclusively by solar energy (Daly and Farley, 2003). In economists' terms, natural capital is the stock of natural ecosystems that yield a flow of valuable ecosystems goods or services into the future, comparable to the interest of financial capital (Wackernagel and Rees, 1997; Daly and Farley, 2003). It has a relationship with the economic and social capital and is supported by good governance, as shown in **Figure 6.2.2**. Natural capital has been identified as increasingly becoming the limiting factor in economic growth, development and well-being (Daly and Farley, 2003; Aronson *et al*., 2006). Farley and Daly (2006) explicitly distinguish between economic growth, which they understand as the physical increase in the rate at which the economy transforms natural resources into economic output and waste, and economic development, which is an increase in human welfare for a given level of resource use.

Severe and irreversible declines in ecosystem services and human well-being may occur if not enough emphasis is placed on enhancing natural capital at the same time as human, social and manufactured capital (Carpenter *et al*., 2006). There are strong arguments for a re-investment into natural capital, either *via* payment for ecosystem services provision, or *via* other means (Jewitt, 2002; FAO, 2007; Turner and Daily, 2008). The ecosystem, as a whole, provides multiple associated services. Therefore, there might be multiple benefits to investing in natural capital (de Groot, 2006).

The stock of natural capital has decreased from the pre-industrial era to the present human-dominated era (Aronson *et al*., 2006), with an associated reduction in overall ecosystem services. At the same time, the stock of manufactured capital has increased. The human use of energy, matter and waste material has grown, while the size of the biosphere has stayed the same (**Figure 6.2.3**). There were also trade-offs between ecosystem services, e.g. a worldwide increase of food production, but a decrease of other services.

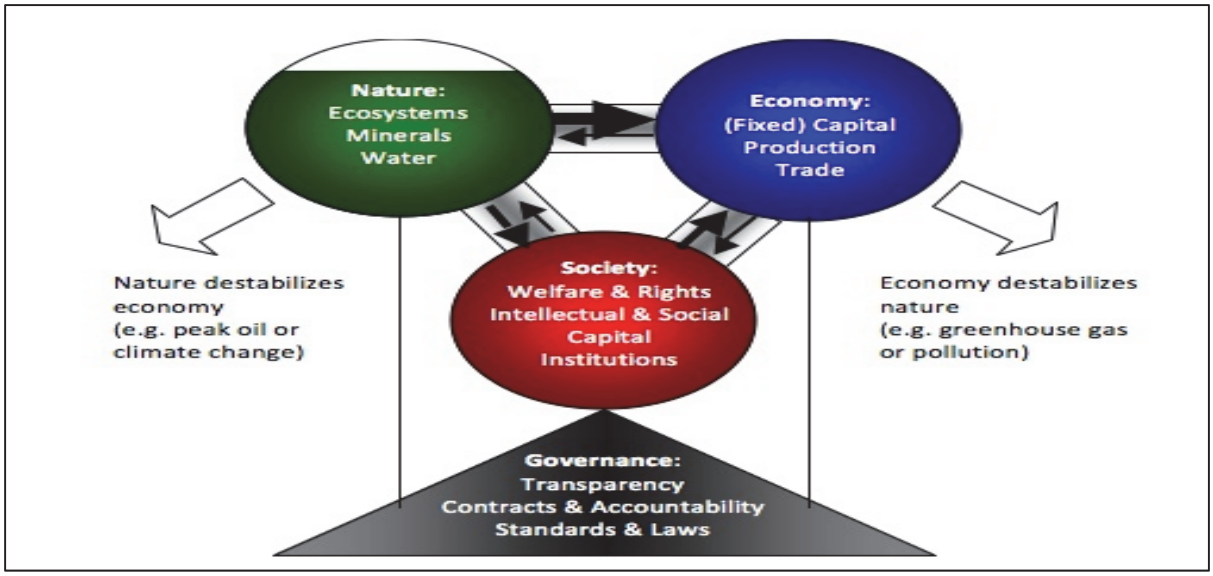


Figure 6.2.2 Natural capital in context with the economy and social capital (Du Plooy, 2012)

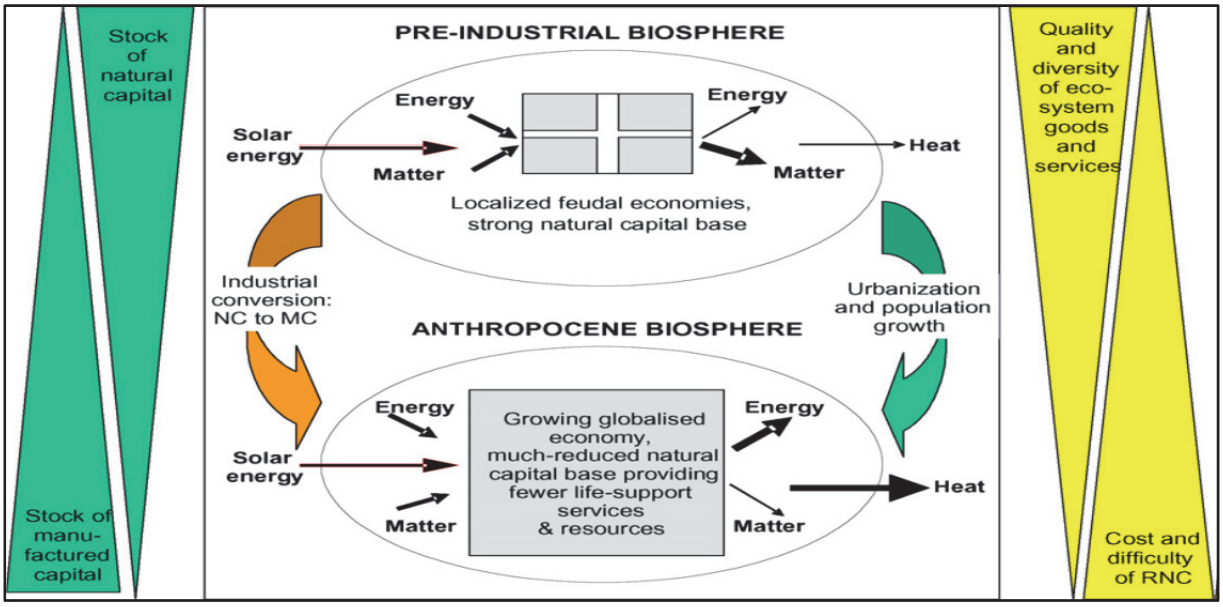


Figure 6.2.3 A pre-industrial and anthropogenic biosphere diagram (Aronson *et al*., 2006), in which NC is natural capital, MC is manufactured capital and RNC is restoring natural capital

Owing to the loss of natural capital from past development and the associated deterioration of ecosystem services, there is now a need for any further development to be sustainable. The aim of sustainable development is to meet current needs, while not compromising future generations' ability to meet their own needs (Brundtland, 1987). Therefore, the development of a resource should be such that the resource's resilience, integrity and characteristics are sustained (Jewitt, 2002). Social and economic development requires the use of natural resources and is thereby impacting on the natural system. A trade-off is likely between certain benefits gained and certain benefits lost, as human influence impacts negatively on some ecosystem services which benefit society (Foley *et al*., 2005; Brauman *et al*., 2007). The ideal would be an optimised mix of different ecosystem services and overall maximum benefits from natural and human (artificial) derived services (**Figure 6.2.4**). However, there are also views that development cannot be sustainable, if that involves the transformation of natural land (Balmford *et al*., 2002; Lovelock, 2009). Adopting a sustainability paradigm means rethinking the meaning of development and questioning the adequacy of impact mitigation (Crane and Swilling, 2007).

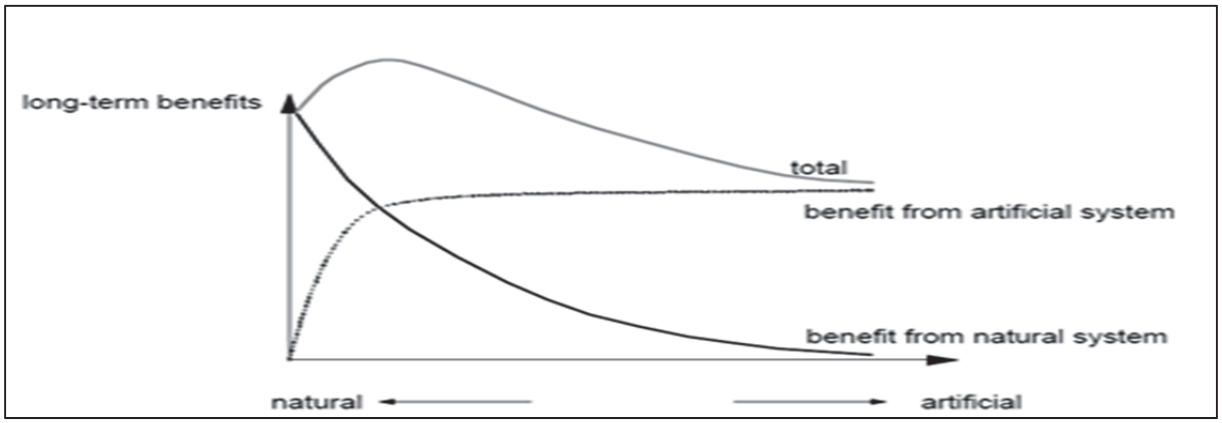


Figure 6.2.4 Maximising of the provisioning of natural and human-made services (after McCartney *et al*., 2000)

Declining ecosystem services

In the Millennium Ecosystem Assessment (MEA, 2005), compiled from inputs of over 1300 scientists from 95 countries, 15 of the 24 global ecosystem services were found to be declining. When ecosystems are over-utilised, their ability to provide services reduces (Jewitt, 2002). The societal responses to declining ecosystem services may be passive and include falling ill from polluted drinking water or food, famine due to land fertility degradation, disputes due to controversies over water and land use, or active responses, for example, when individuals migrate or reduce fallows during crop rotation (Falkenmark *et al*., 1999). A worst-case scenario of reducing ecosystem services would be that after reaching a threshold the services might be irreversibly lost. Depending on the services lost or reduced, the quality of life for society would then decline, first affecting the poor and resulting in a lowering of average living standards (MEA, 2005). A large-scale reduction in essential ecosystem services would reduce the carrying capacity of a habitat, i.e. the population that can be sustained by that habitat, in this case the earth, leading to increased species extinctions and human mortality (Pimentel *et al*., 1999). To reduce the chances of this happening, a number of planetary boundaries for a safe operating space for humanity have been suggested (Rockström *et al*., 2009) for the total amount of land system change, as well as biodiversity loss, climate change, ocean acidification, stratospheric ozone depletion, the nitrogen cycle, the phosphorus cycle, global freshwater use, atmospheric aerosol loading and chemical pollution (**Figure 6.2.5**). These planetary boundaries create an environmental ceiling for human well-being, while a social foundation is required on the inside, thus figuratively creating a “doughnut” of a safe and just place for humanity to thrive (Raworth, 2012).

The question arises why humans nevertheless allow ecosystem and the associated services to decline, especially as it is usually cheaper to avoid degradation than it is to pay for ecological restoration (TEEB, 2010). Explanations for this can be found in the literature and include the following:

1. Intrinsic value alone does not signify the dependence of humans on natural capital (Wackernagel and Rees, 1997);
2. scientific information about ecosystem services and changes to these are not available (Turner and Daily, 2008);
3. decision-makers (governments or individuals) continue to discount inappropriately when deciding between ecosystem conservation and conversion (Pearce, 2007);
4. markets often reward short-term exploitation values of natural capital and greed, to the detriment of sustainable ecological health and associated human welfare (Ostrom, 1990; Balmford *et al*., 2002; Turner and Daily, 2008);
5. beneficiaries and producers might not be linked (van Jaarsveld *et al*., 2005);
6. multiple services across a range of competing land uses are not evaluated, so decision-makers do not have all the facts (Balmford *et al*., 2002);
7. the decision horizon is not long enough (Turner and Daily 2008);
8. the future is discounted for the present (Wackernagel and Rees, 1997);

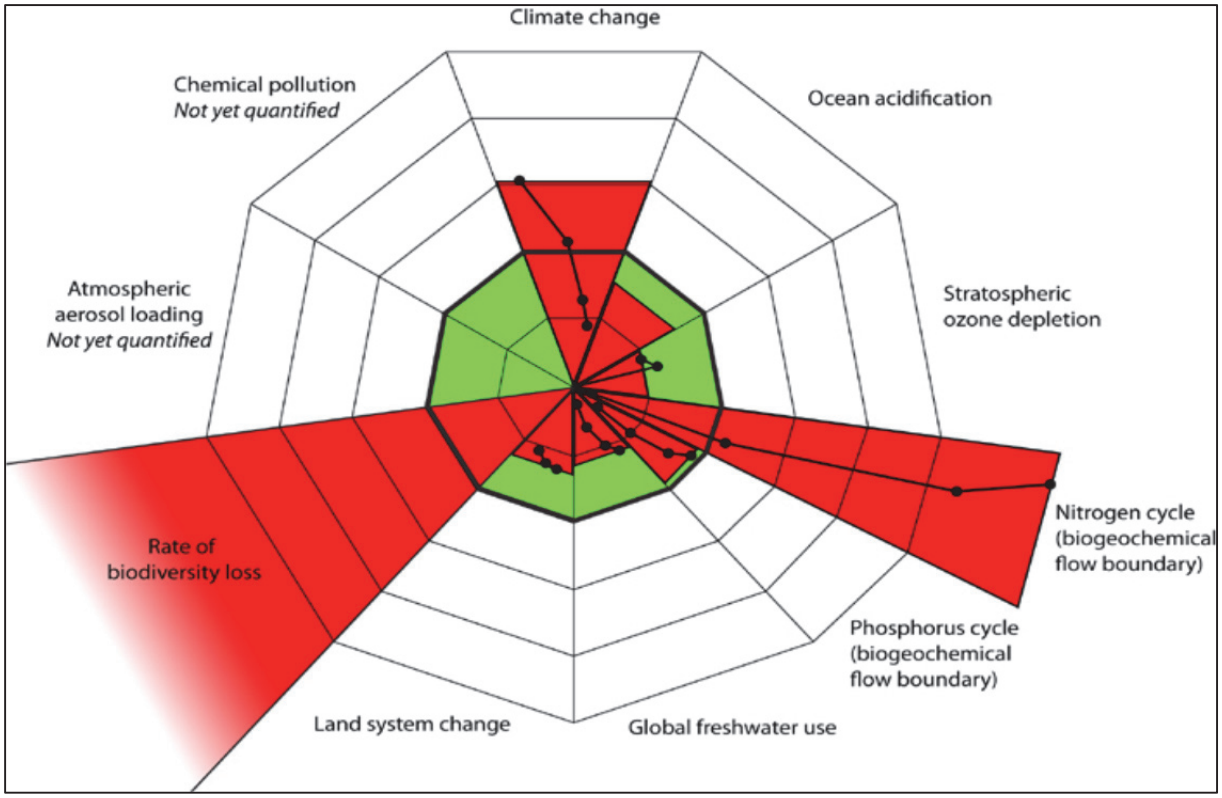


Figure 6.2.5 Planetary boundaries (after Rockström *et al*., 2009). The inner (green) shaded area represents the safe operating space, with proposed boundary levels at its outer contour, where the extent of the wedges for each boundary shows the estimate of current position of the control variable and points show the estimated recent time trajectory (1950 - present) of each control variable

9. there might be a blocking effect to change through strong stakeholder's interest (Falkenmark et al., 1999);

10. where environmental legislation is in place, there might be a lack of enforcement mechanisms or a fragmented administration or bureaucracy (Falkenmark *et al*., 1999);
11. there might be a "global deficit of care" (Pearce, 2007);
12. various psychological barriers exist to environmental action (Wackernagel and Rees, 1997; Giffort, 2011);
13. a consumer-driven, human-controlled world seems to be the goalpost for many humans (Daly, 1991); and/or
14. the perceptions of environmental baselines keep shifting from generation to generation, thus masking change (Sáenz-Arroyo *et al*., 2005).

Ecosystem services assessments for decision-making

An ecosystem approach is about a new way of thinking and working, by shifting the focus away from looking at natural environmental policies separately e.g. air, water, soil and biodiversity, towards a more integrated approach based on whole ecosystems (DEFRA, 2007). However, measuring and valuing services does not directly lead to an increased use of this knowledge. To see knowledge about multiple ecosystem services generated from a landscape implemented into planning and development tools, communication across ecosystem and sector boundaries is required, including the identification of a range of services as well as cross- comparison and trade-off analysis (Primmer and Furman, 2012).

Any management approaches to ecosystems require dealing with uncertainty because, as already stated, ecosystems are complex adaptive systems (Jewitt, 2002). Various studies have been undertaken where ecologists and economists have valued the social benefits and costs of conserving biodiversity and ecosystem services (e.g. Balmford *et al*., 2002; Chan *et al*., 2006). Most conclusions were that conserved ecosystems generally generate net benefits. For the purpose of decision-making,

it might not be so important to know the total value of specific ecosystem services. Of greater importance, when a certain area is transformed, is often the change or margin to the flow of ecological services. Therefore, a change assessment (also called a marginal assessment) can be used, comparing the changes in ecosystem services before and after a scenario (Daily, 1997). An example is the recent TEEB project, which is a study commissioned by the United Nations to assess the global economic costs of ecosystem degradation and biodiversity loss. The TEEB project concentrates on assessing the consequences of changes resulting from alternative ecosystem management options, including best practice examples from around the world, rather than attempting to estimate the total value of ecosystems (TEEB, 2010).

It is recognised, however, that ecosystems often do not follow linear feedbacks. There might also be sudden consequences e.g. when a critical threshold has been exceeded, as was explained above. A change analysis can be made, as long as the threshold is not exceeded, which means that the lowest functioning point of the specific ecosystem function is not reached. It is acknowledged, however, that this information is often not available and that it is then safer to err on the side of caution.

If only one ecosystem service is taken into the equation of deciding on ecosystem degradation, conservation or restoration, then the benefits might be different to when various ecosystem services are considered simultaneously. There might also be a trade-off between different ecosystem services and their respective value might, in turn, be perceived differently by the various beneficiaries (Louwe *et al*., 2009). The over-exploitation of provisioning ecosystem services usually leads to a reduction in regulating ecosystem services. This might reduce future yields of provisioning services and it may increase the vulnerability of people to environmental variability (Carpenter *et al*., 2006).

If in doubt, a complete ecological assessment should be undertaken before ecosystem transformation is allowed. The science of ecosystem services is still evolving, including an integrative framework. Important components for capturing the benefits of ecosystem services are, inter alia, property rights (Carpenter *et al*., 2006), as well as stakeholder perceptions and institutional arrangements (Turner and Daily, 2008). Turner and Daily (2008) suggested an 'Ecosystem Services Framework', i.e. an environmental change process which starts with identifying the ecosystem services and the relevant spatial and time scales. Thereafter, suitable models and mapping approaches need to be identified (Turner and Daily, 2008), followed by an environmental change scenario analysis for the relevant different resource uses, policies or choices; an ecosystem services 'benefit capture' *via* payments; capacity building and monitoring; and last, a post-policy appraisal and possible re-evaluation (Turner and Daily, 2008). There is a need for further research to improve the implementation of the ecosystem services concept into decision-making, for example, in landscape planning (Herman *et al*., 2011).

Various approaches and means of implementing the ecosystem concept have been used, as well as different classifications regarding ecosystem services, values, benefits, functions, processes and indicators (Herman *et al*., 2011). A widely accepted definition of ecosystem processes is the complex interaction among biotic and abiotic elements of ecosystems (Herman *et al*., 2011). Most authors agree that goods and services are generated by ecological functions (Herman *et al*., 2011) and that ecosystem processes, functions and services are interlinked (de Groot, 2006). Louwe *et al*. (2009) emphasise the importance of modelling trade-offs for different scenarios, while Herman *et al*. (2011) recommend local scale, model-based research activities as significant tools in aiding decision-making. Cowling *et al*. (2008) see the biophysical quantification of ecosystem services as an essential step towards successful implementation actions in order to safeguard them and Egoh *et al*. (2012a) call for a robust biophysical quantification of ecosystem services.

Ecosystem services assessments are, however, not without challenges, including the fact that the assessment of the full range of ecosystem services seems to be impossible (Herman *et al*., 2011; Primmer and Furman, 2012). Further challenges include the fact that it is still an evolving concept, without universal standards on what to measure and how, and these are important requirements to be able to compare studies (Herman *et al*, 2011). Various investigations have found that human-induced change to ecosystems might benefit the landowner and individuals, while disadvantaging the community locally and globally. Multi-functionality and sustainability might often not be in the individual owner/manager's interest (Hubacek *et al*., 2009). Therefore, the total benefit to society needs to be considered in ecosystem services assessments. Furthermore, different scenarios might yield trade-offs between different ecosystem services. Payment for ecosystem services is a possible

way of transferring benefits from users to producers and thereby attaining sustainability (Turner and Daily, 2008). The time-frame considered in an assessment might also give different results (a five-year view vs a 50-year view), as will the aim. For example, if the aim is the "highest possible quality of life compatible with the conservation of resilient, healthy ecosystems" (Farley, 2012) or an increase in total sustainable social welfare or happiness per capita, compared to the current approach of increase in Gross Domestic Product (GDP), the outcomes would be different (Heinberg, 2011). When an ordinary economic approach is used, discount rates to the present are applied, which assumes the possibility of unlimited growth, which is an enigma (Heinberg, 2011). The current economic approach seems to fail to protect ecosystem services and to internalise previous external costs (Daly, 1991; Wackernagel and Rees, 1997; Heinberg, 2011).

Examples of benefits from investments into ecosystem services

Examples of successful investments into ecosystem services abound (e.g. Daily *et al*., 1997; Balmford *et al*., 2002; Foley *et al*., 2005; Turner and Daily, 2008). Some are mentioned below.

1. In the 1990s, New York City officials invested in restoring the natural asset, *viz*. the watershed, rather than building a water filtration plant and saved over $6 billion (National Research Council, 2000; Turner and Daily, 2008).
2. Decision-makers in Napa, California invested in a "living river", which included the restoration of floodplains, rather than building physical concrete barriers. The restoration of wildlife, fish and scenic beauty led to a revitalisation of the town and major private capital investment followed (Turner and Daily, 2008).
3. Costa Rica launched a payment scheme for the provision of a suite of ecosystem services, including water quality and quantity, carbon sequestration, biodiversity and scenic beauty, funded by a diversity of sources, thereby giving farmers an additional income (Turner and Daily, 2008).
4. South Africa has invested in the "Working for Water" programme, the aim of which is to increase water availability by clearing water-thirsty alien invasive plants and, at the same time, create employment (Mander *et al*., 2011).

Ecosystem services in the South African context

South Africa is a developing country, with a population of over 50 million (Statistics SA, 2011). The emphasis of the post-apartheid government is on economic growth and the upliftment of previously disadvantaged communities. There is a drive for economic development, including mining of natural resources and industrialization. The population trends are moving towards an urbanized population. "In South Africa, we see a desperate bid to generate economic growth and deliver incomes, jobs and basic services to poor people - the country's majority - and politically that means development at all costs" (Mander *et al*., 2011). Biodiversity conservation and environmental protection is perceived as a threat to welfare improvement and an obstacle to development. This simple jobs-versus-the-environment paradigm needs to be changed (Mander *et al*., 2011). The South African development assumptions largely fail to consider the limits of key ecological resources. When it comes to local government, the development drive is caught between two mutually exclusive paradigms: the municipal integrated local area development frameworks (IDPs) and the environmental impact assessments (EIAs), a 'development-plus-impact-assessment' (Crane and Swilling, 2007).

Enabling laws are in place in South Africa, for the beneficial use of environmental resources, in order to serve the public interest and to protect the environment as the people's common heritage (NEMA, 1998; Stuart-Hill and Schulze, 2010). However, the link between natural capital and poverty reduction has yet to be made by many with decision-making power (Shackleton *et al*., 2011).

Ecosystem services are vital for environmental performance. The environmental performance index and South African ecosystem vitality, in recent studies (Yale Center, 2012; Standard Chartered, 2013) was extremely poor in absolute terms, amongst the poorest performing countries out of the assessed countries, and with a declining trend. The ecosystem effect on water resources showed a very strong decline over the last decade (Yale Center for Environmental Law and Policy, 2012).

From a point of studies about ecosystem services provision, however, South Africa is leading the way in Africa (Egoh *et al*., 2012b). Water, tourism and grazing are found to be important ecosystem services in Africa and have been included in assessments. The role that water flow regulation, as well as water filtration to provide clean water, is found to be important in poverty alleviation in South Africa

(Egoh *et al*., 2012b). A big attraction to tourists in South Africa is the landscape, high biodiversity, flowers and scenery, and Africa remains one of the most pristine continents.

Rouget *et al*. (2010) conducted a partial sectorial analysis for ecological goods and services in South Africa, specialising in carbon sequestration, surface water supply, water flow retention and soil retention. The study found that it is possible to find economic benefit in restoring or conserving natural capital. The potential market was found to be considerable. The challenge, however, is to create the appropriate institutions to develop such markets (Blignaut and Moolman, 2006; Rouget *et al*., 2010).

6.2.2 Hydrological ecosystem services

Water and associated hydrological ecosystem services are fundamental to life. Constraints in providing sufficient, fresh, good quality water are a limiting factor to development in many parts of the world. This is projected to get worse (FAO, 2000), due to rising demand, as freshwater comprises only 0.26% of global water. In the 20th century the freshwater extraction has increased seven-fold. The major drivers have been population growth, the rising standards of living, the expansion of irrigated agriculture (Gleick, 1998), as well as increased meat consumption (Hoekstra and Chapagain, 2007). Resources are limited, and if more resources are needed to cure past and present ills, then less will be available to prevent future degradation (Falkenmark *et al*., 1999). Most relevant for this study are freshwater ecosystems.

Freshwater ecosystems

Freshwater ecosystems are often understood to consist mainly of rivers and riverine areas. A more inclusive view, which is taken here, and is in line with those of McCartney *et al*. (2000) and Jewitt (2002), is that freshwater ecosystems can be understood as landscape elements that link and affect the passage of water from the land to the sea, and water as evapotranspiration from the land to the atmosphere. This definition includes the whole terrestrial catchment area. When examining freshwater ecosystems, the entire hydrological cycle needs to be examined, starting from rainfall over the catchment and not only the water in a river or in other water bodies (NWA, 1998; McCartney *et al*., 2000; Jewitt, 2002; FAO, 2007). The hydrological cycle, therefore, will be examined next.

The hydrological cycle with the partitioning of precipitation into blue, green and white water flows

The total amount of water on earth is unchangeable and finite. This unchangeable amount of water moves within the hydrological cycle, albeit differently in different parts of the world and differently from season to season (L'vovitch, 1979). In the hydrological cycle, precipitation is partitioned into runoff flows, through ground and water bodies, and into water vapour that flows back into the atmosphere, through evaporation and transpiration processes. This partitioning of precipitation into the evapotranspiration output (also called total transpiration), is often termed "green water", while "blue water" represents the water flows through ground and water bodies (Falkenmark *et al*., 1999; Falkenmark, 2000; FAO, 2000; Jewitt, 2002; 2006). There is a dynamic interrelationship between evapotranspiration and ''blue'' water (Falkenmark *et al*., 1999; FAO, 2000; Jewitt, 2002). Savaniije (2004) and Newman *et al*. (2006) request a further separation of evapotranspiration into evaporation and transpiration, which Schulze and Maharaj (2008) outlined as white and green water flows. For the purpose of this study, the approach of Schulze and Maharaj (2008) is followed, where green water is understood to be the soil water taken up by plants to create biomass and transpired by the vegetation into the atmosphere, excluding evaporation. White water is the portion that is evaporated into the atmosphere from intercepted rainfall by plants or buildings, as well as directly from the soil. Blue water is understood to be water flows through ground and water bodies, in this case streams, rivers, groundwater, wetlands, as well as abstracted water. In other words, it is the runoff coming from the partitioning of precipitation at the land surface, which forms streamflow, and the partitioning of soil water, which forms baseflow and the recharge of groundwater.

The hydrological cycle, showing landscape - hydrological ecosystem - atmosphere interactions, is illustrated in **Figure 6.2.6**.

Humans have influenced the hydrological processes and transformed the landscape to provide freshwater for irrigation, industrial and domestic use. This, in turn, has influenced the hydrological cycle (Foley *et al*., 2003).

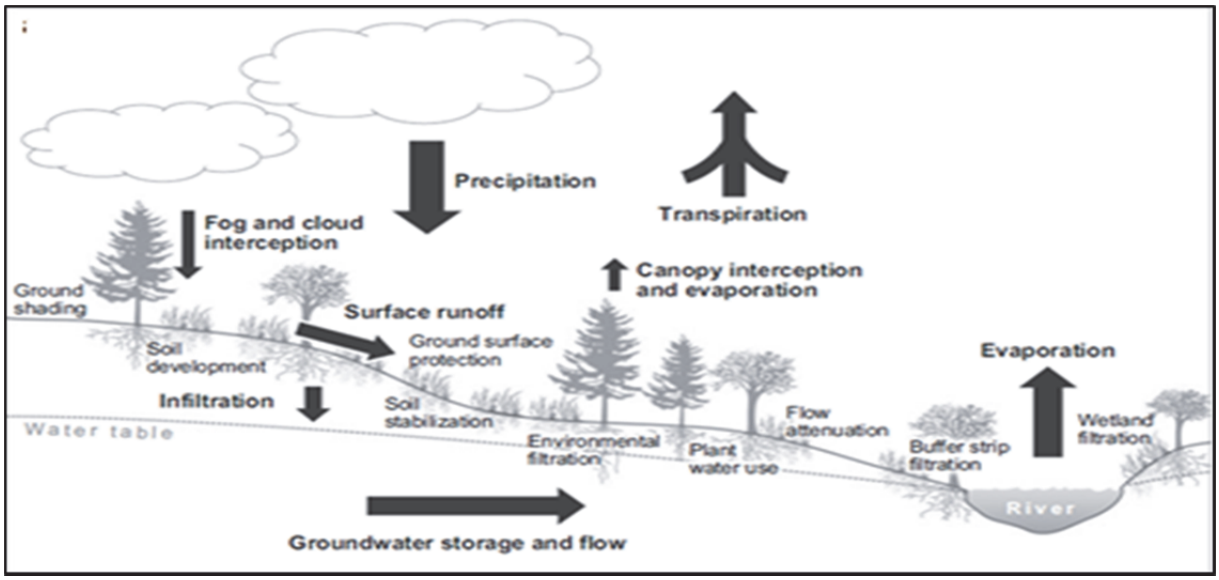


Figure 6.2.6 The hydrological cycle, showing landscape - hydrological ecosystem - atmosphere interactions (after Brauman *et al*., 2007)

Hydrological terminology, processes and responses

Flows through landscape and water stores generally transform high frequency precipitation variability into low frequency modes of hydrological variations (Bounoua *et al*., 2002). These hydrological processes are influenced by climate and land characteristics. The climate influences on hydrological processes are, for example, precipitation and temperature parameters, in as much as they influence evaporative processes and plant growth rates, as well as changes in CO_2 concentrations regarding transpiration feedbacks. Hydrological processes are further influenced by land characteristics such as soil properties, soil water saturation rates, slope, land use, land cover and land management characteristics, which influence soil water evaporation, the infiltration of rainwater and soil erodibility, as well as changes in soil surface properties. While the whole landscape has a role to play in influencing hydrological processes, wetlands and floodplains are often singled out in the literature (e.g. Aylward *et al*., 2005). They act as natural sponges; expanding by absorbing excess water in times of heavy rain and contracting as they release water slowly throughout the dry season to maintain streamflow (Aylward *et al*., 2005).

Environmental processes on approximately half of the global land mass are limited by water availability. These so-called water-limited environments include arid, semi-arid and sub-humid regions, and may be understood as areas where the annual precipitation is less than the potential evapotranspiration, with often extreme temporal variability resulting from extended periods with little or no precipitation (Newman *et al*., 2006). Low flows may be understood as flows of water in a stream during prolonged dry weather and are usually a seasonal phenomenon, while drought is a natural occurrence resulting from less than normal precipitation for an extended period of time (Smakhtin, 2000). The hydrological processes over the catchment control the ability to absorb and store water during precipitation events for later release as low flows, while the processes in the river channel zone are the most relevant for the discharge of stored water into the channel (Smakhtin, 2000). The spatial and temporal components of low flow hydrology are related to physiographic factors, as well as to various man-induced effects (Smakhtin, 2000).

Human demand for water in certain areas might be met by the transfer of water from other catchments and within catchments (NWRS, 2004). However, apart from such transfers being expensive, they may also lead to consequences within the receiving, as well as the donating, catchment (WWF, 2009).

Hydrological processes which are relevant for water quantity and pathways through the landscape (Falkenmark, 2000) thus give rise to various hydrological responses e.g. to streamflows, to runoff and its components of stormflow and baseflow, as well as to transpiration, evaporation and sediment yield. The terminology used in this dissertation to describe these hydrological responses is explained next.

1. Streamflows have magnitudes, are variable and are spatially distributed. They are made up of runoff accumulated from the entire catchment upstream of a point of interest (Schulze and Maharaj, 2008).
2. Runoff is defined here as having been generated from a specific sub-catchment and it may be divided into its components of stormflow and baseflow (Schulze and Maharaj, 2008).
3. Stormflows are generated from a specific rainfall event and have unique attributes of magnitudes, rates and carrying capacity of soil particles. They are the main runoff contributors during times of floods (Schulze and Maharaj, 2008).
4. Baseflows also derive from groundwater storage or other delayed sources and also have unique attributes of magnitudes and rates of release into a stream (Brauman *et al*., 2007; Schulze and Maharaj, 2008) and are typically the biggest contributor to streamflow during dry season low flow conditions (Smakhtin, 2000).
5. Transpiration is understood to be the soil water taken up by plants and transpired by the vegetation to the atmosphere, and in the process they create biomass (Schulze and Maharaj, 2008).
6. Sediment yields consists of the soil detached from a landscape after a rainfall runoff event, which reaches the stream and results from the interaction of slope, vegetation cover and management characteristics, with the peak discharge of an event as the detaching agent and stormflow as the sediment transporting agent. Sediment yields reduce storage capacity in water bodies and slow down streamflows (Schulze, 1995).

Cilliers *et al*. (2013) call for an understanding of land-water interactions based on processes and links between different components, an understanding of their function and structure, as well as the temporal and spatial scales at which they are dominant or dormant. Hydrological processes give rise to hydrological ecosystem services which will be examined next.

Hydrological ecosystem services and their importance, with examples and categorisations

Precipitation is the ultimate source of water on earth (Mirza and Patwardhan, 2005). The understanding is that a certain amount of water can be utilised before the ecosystem loses resilience. However, a level of ecological functioning and integrity is required for maintaining resilience (MacKay, 2000; 2001). It needs to be understood that both ecosystems and the hydrological cycle require adequate multi-level functioning. Failure on one system level will ultimately result in the failure of the entire system. To sustain ecosystem functions, as well as to maintain sustainable water supplies, the amount of water that can be abstracted is limited (FAO, 2000; Jewitt, 2002).

Hydrological ecosystem services contain more than just freshwater provisioning services. The hydrological cycle plays many roles in the earth's systems of climate, chemistry and biology and it is difficult to define distinct supporting, regulating, cultural or provisioning service categories (Mirza and Patwardhan, 2005). An attempt to divide hydrological ecosystem services into such provisioning, supporting, cultural and regulating services was compiled by Aylward *et al*. (2005), where provisioning services include sustained quantities and an acceptable quality of water from inland water ecosystems, the variability and seasonality of flows and whether flows are perennial or ephemeral. They make this water available for consumptive uses, e.g. for drinking, domestic, agricultural (dry land and irrigation) and industrial purposes, as well as for non-consumptive uses such as power generation and transportation/navigation. Supporting services include soil water essential for primary production, nutrient cycling and the resilience of the natural hydrological system to extreme events. Cultural services contribute to human well-being through, for example, recreational activities, tourism and scenic values and existence values, such as the satisfaction gained from free-flowing rivers (Aylward *et al*., 2005). Regulating services include the maintenance of water quality through natural filtration and natural water treatment, the buffering of flood flows and erosion control by floodplains and wetlands. (Aylward *et al*., 2005; Le Maitre *et al*., 2014).

Different approaches in classifying hydrological ecosystem services, or trying to link them with functions, processes and attributes, were found in the literature (e.g. Aylward *et al*., 2005; de Groot, 2006; Brauman *et al*., 2007). These various approaches regarding hydrological ecosystem services, with an emphasis on provisioning, regulating and supporting services relevant for this study, have been combined and are shown in **Table 6.2.1**. This table is not meant to be an exhaustive list of hydrological ecosystem services and the processes that give rise to them, but serves to derive an approach suitable for this dissertation.

Table 6.2.1 A summary of relevant ecosystem functions, processes, hydrological attributes and services found in the literature (Aylward *et al*., 2005; de Groot, 2006; Brauman *et al*., 2007)

Ecosystem Functions	Ecosystem processes and components	Hydrological attribute	Example of services	Author
Provisioning			Water (quality and quantity) for consumptive use (for drinking, domestic, agricultural or industrial uses)	Aylward *et al*. (2005)
			Water for non-consumptive use (for generating power and transport/navigation)	
			Aquatic organisms for food and medicines	
Regulation function: Disturbance prevention	Influence of ecosystem structure on dampening environmental disturbances		Flood prevention	De Groot (2006)
Regulation function: Water regulation	Role of land cover in regulating runoff and river discharge		Drainage and natural irrigation	De Groot (2006)
Regulation function: Water supply	Filtering, retention and storage of fresh water		Provisioning of water for consumptive use (e.g. drinking, irrigation, industrial uses)	De Groot (2006)
Regulation	Natural filtration and water treatment		Maintenance of water quality	Aylward *et al*. (2005)
	Water / land interactions and flood control infrastructures		Buffering of flood flows and erosion control	
Regulation function: Soil retention	Role of vegetation root matrix and soil biota in soil retention		• Maintenance of arable land • Prevention of damage from erosion/siltation	De Groot (2006)
Supporting			• Role in nutrient cycling (role in maintenance of floodplain fertility), primary production • Predator/prey relationships and ecosystem resilience	Aylward *et al*. 2005)
Habitat functions: Refugium and nursery function	Providing suitable living and reproduction habitat		• Maintenance of biological and genetic diversity (basis of most other functions) • Maintenance of commercially harvested species	De Groot (2006)
Production functions: Food,	Provision of natural resources, Conversion of solar energy into edible plants and animals		• Hunting of fish or game • Small-scale subsistence farming • Aquaculture	De Groot (2006)
Production functions: e.g. Raw materials	Provision of natural resources, Conversion of		• Building and Manufacturing • Fuel and energy • Fodder and fertilizer	De Groot (2006)

Ecosystem Functions	Ecosystem processes and components	Hydrological attribute	Example of services	Author
	solar energy into biomass for human construction and other uses			
Functions supporting cultural services			Cultural services: • Recreation (river rafting, kayaking, hiking, fishing as a sport) • Tourism (river viewing) Existing values (personal satisfaction from free-flowing rivers)	Aylward *et al*. (2005)
• Local climate interactions • Water use by plants		Quantity (surface and ground water storage and flow)	• Diverted water supply: • Water for municipal, agricultural, commercial, industrial, thermoelectric power generation uses • *In situ* water supply: • Water for hydropower, recreation, transportation, supply of fish and other freshwater products • Water damage mitigation:	Brauman *et al*. (2007)
• Environmental filtration • Soil stabilization • Chemical and biological additions or subtractions		Quality (pathogens, nutrients, salinity, sediment)		
• Soil development • Ground surface modification • Surface flow path alteration • River bank development		Location (ground/surfaces, up/downstream, in/out of channel		
• Control of flow speed • Short and long-term water storage • Seasonality of water use		Timing (peak flows, base flows, velocity)		

To be able to monitor changes to hydrological ecosystem services, suitable indicators are often required. This will be examined next.

Relevant indicators

Changes to hydrological ecosystem services often cannot be measured directly. This is especially so for case studies with different scenarios, and for some provisioning and many regulating, supporting and cultural services. Frequently, indicators or proxy information are used in practice to measure ecosystem services (Egoh *et al*., 2012a). Those indicators are a measure of an attribute that can provide the required information. The quantity and quality of water integrates many processes occurring within the catchment. Some of these processes can be measured directly or indirectly by measuring an attribute that can provide information on those processes (Jewitt, 2002).

Streamflow, as well as runoff and its components, are often considered useful indicators of the health of the hydrological ecosystem services (Brauman *et al*., 2007; Schulze *et al*., 2010). Blue water indicators are, however, a delayed response to events within the ecosystem (Jewitt, 2002). Furthermore, the magnitude and duration of low flows and high flows, rather than mean flows, might be more important to ecosystem services in water-limited environments (Nilsson *et al*., 2003; Jewitt, 2006; Schulze and Horan, 2007). Sediment yield, conversely, is an indicator of water quality, along with *E. coli* bacteria counts and nutrient concentrations, e.g. of nitrates, phosphates, heavy metal.

Owing to the complex processes related to the biophysical sciences behind regulating services, e.g. the regulation of water flows, or erosion prevention and/or the moderation of extreme events, single indicators are often not adequate and process-based modelling often becomes the best option (Egoh *et al*., 2012a). In their review of 67 scientific papers concerned with practical ecosystem services quantification, Egoh *et al*. (2012a) found that runoff was frequently used as a proxy for surface water availability, followed by land cover (**Figure 6.2.7**.). For mapping water regulating services, the main indicators used were nutrient retention, land use and soil characteristics (**Figure 6.2.8**), with their definition being that water provisioning services relate to the water that is already available, while regulating services relate to a process through which clean water becomes available. For the ecosystem service of the control of soil erosion, the main indicators used were the type of vegetation cover and the soil erosion potential.

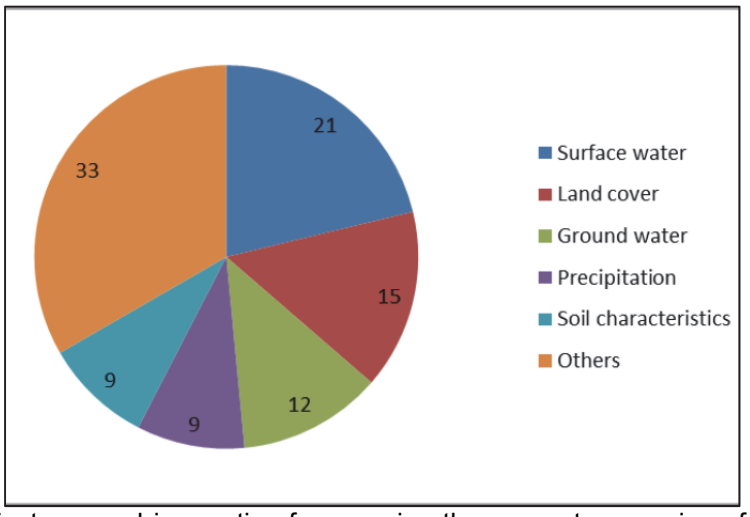


Figure 6.2.7 Indicators used in practice for mapping the ecosystem service of water provisioning (after Egoh *et al*., 2012a)

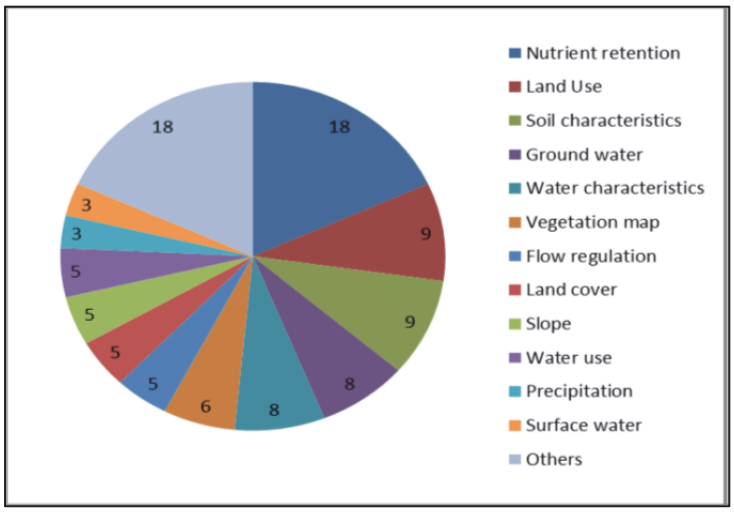


Figure 6.2.8 Indicators used in practice for mapping the ecosystem service of water regulation (after Egoh *et al*., 2012a)

For the purpose of this study a hydrological process model is used with measured biophysical data as input and hydrological responses, e.g. runoff and its components of stormflow and baseflow, accumulated streamflow, extreme runoff events, sediment yield and transpiration, as modelled outputs. These hydrological responses are seen as proxy information, or indicators, for the ecosystem services of water provision, water regulation (e.g. flood attenuation and erosion control) as well as supporting services (e.g. the supply of green water for primary production).

Hydrological ecosystem services in a South African context

Overall, South Africa faces shortages in water and these affect hydrological ecosystem services. South Africa is generally a water-limited country, with major spatial and temporal variations in rainfall and hence runoff. Within semi-arid environments, the green (and white) water flows dominate over blue water flows (Jewitt, 2006).

Its natural hydrology creates a high-risk natural environment (Schulze, 2003). A low mean annual precipitation, as well as a low rainfall-to-runoff rate of conversion is exacerbated by high inter-annual rainfall variability. This inter-annual variability is amplified in the responses of the hydrological system (Schulze, 2003). Over much of South Africa, terrestrial and freshwater ecosystems are not in pristine condition, but rather in a modified and often damaged state, usually through unsustainable human exploitation and often linked with the failure to enforce policy together with a lack of structured and effective governance (Maloti Drakensberg Transfrontier Project, 2007; Lankford *et al*., 2011).

Many catchments in South Africa are water stressed. Total water availability, including requirements for food production, is expected to decline to below 1700 m3/person/year, which makes the country vulnerable to serious water shortages by 2030 (Scholes and Biggs, 2004). New big dam infrastructures, inter-basin transfer schemes, high levels of assurance of supply to key sectors of the economy, as well as widespread local reticulation networks, requiring extensive pumping and associated energy use, are expensive and the cost of water provisioning is set to rise (The Government of South Africa, 2010a). Just a 10% decline in runoff is estimated to double the cost of new water schemes (The Government of South Africa, 2010a). Like most of the rest of the world South Africa has, historically, focused its water resource management approach on controlling part of the hydrological cycle, mainly through building water infrastructures, including dams, to provide sustained water supplies and to reduce threats of water shortages and to thus produce less variable flows. Inevitably, this natural resources management approach resulted in a reduction in the natural diversity of ecosystem functions, associated ecosystem services, as well as ecosystem resilience. In the decision-making process, ecological functioning may have often been ignored, owing to a lack of scientific understanding as well as the difficulties faced by planners and policy-makers to feature the uncertainties within the ecosystem functions and dynamics (Jewitt, 2002).

South African water legislation related to hydrological ecosystem services

Progressive new water laws came into effect at the end of the 1990s (Water Services Act (WSA), 1997; National Water Act (NWA), 1998). Healthy aquatic ecosystems are considered to be the cornerstone of water resources and are required for equitable access to water as well as for development. The water resource can, therefore, be seen as an ecosystem which includes water, aquatic habitats, as well as the ecological, physical and chemical processes linking habitats, water and all organisms in the given area (MacKay, 2000). Legislation stipulates that a “reserve” will be determined on all river systems. This reserve is defined as the assurance of the quantity and quality of water required to meet basic human needs, as well as to protect aquatic ecosystems, in order to secure sustainable utilisation and development (NWA, 1998).

However, the implementation of laws and policies has been difficult and slow (Schreiner, 2013). At the time of writing this in 2013, 15 years after the NWA came into effect, only few ecological reserves have been determined and implemented (King and Friedman, 2008). A number of misunderstandings and gaps exist concerning the intention of the law and its implementation (Jewitt, 2002; van Wyk *et al*., 2006). There are warnings that the land-water link has been neglected and that ill-considered responses to rising freshwater demands could sever ecological connections within the hydrological cycle (Jewitt, 2002; Gifford, 2011). Van Wyk *et al*. (2006) state that South Africa’s water law acknowledges not only water, but the entire ecosystem, as a life support system. This realisation is not widely appreciated because no common understanding exists in South Africa of the reserve being an ecological means to achieving socio-economic ends.

This may be seen in a recent South African policy document (DWAF, 2009) in which it is unclear on the link between water and ecosystem services, yet acknowledging that natural resource management is essential for ensuring water supply for growth and development. The public works natural resource management programmes, e.g. Working for Water, for Wetlands, on Fire, for Woodlands and Working for Energy, are seen as very important to the management of South African water quantity and quality and essential to growth and development (DWAF, 2009). Resource management is understood to yield the best returns on investment for water management, but with the added benefits of other ecosystem services, as well as job creation. On the other hand, the same policy document states, for example, that "developed rivers, such as the uMngeni, are today no more than 'workhorse rivers' and should be managed as such", with no clear indication of what that implies (DWAF, 2009).

Based on the above, the implementations of the water laws have been slow and not without problems and misunderstandings, which, amongst other things, lead to reducing hydrological ecosystem services in South Africa. While investigating hydrological ecosystem services in the section above, land use in an ecosystem services context will be examined next.

6.2.3 Land use within an ecosystem services context

In this section, land as a physical resource, including the roles of land function, land cover and land uses, will be explored, followed by a general perspective on the links of land use changes and ecosystem services. Finally, land use in a South African context will be examined.

Land, land cover and land use

Land may be viewed as a physical resource. Land cover describes the biophysical state of the earth's surface and immediate subsurface in broad classifications, such as grasslands, natural forest, cropland, water bodies or mining (Turner *et al*., 1995). Land use frequently involves the conversion or modification of natural land cover due to human actions, for the primary purpose of agricultural production and settlement (Turner *et al*., 1995). The term land use can be further broken down into land utilisation, land treatment and land management, which include the specific crops, conservation structures (contours, terraces), grazing control, crop rotation or the intensification of production, different modes of tillage practices, burning regimes, as well as the application of fertilizers and herbicides (Schulze, 2004).

Although land has many uses, it is often zoned, based on a single purpose in planning frameworks (Hubacek *et al*., 2009). The multi-functionality of land provides several potential ecosystem services (Hubacek *et al*., 2009). There are many studies illustrating the economic, ecological and socio-culturally benefits of multi-functional landscapes, compared to landscapes that only provide few ecosystem services (e.g. Balmford *et al*., 2002; Turner *et al*., 2003; Naidoo and Adamowicz, 2005, Hermann, *et al*., 2011).

Many forms of land uses alter or degrade ecosystems. Ecosystem services thus respond to land use and the changes thereof (Foley *et al*., 2005).

Land use and ecosystem services

Land use, in an ecosystem services context, is all about coordinating the long-term and the short-term, the small-scale and the large-scale, the public interest and the private interest, the economy and the environment (Louw *et al*., 2009).

Ecosystem services provided by a landscape, e.g. the availability of water, will often determine the land use and, thereby, influence land use change. For example, agriculture and forestry require a certain level of water availability. Conversely, land uses influence ecosystem services, with property rights often being unclear on the rights or duties of the land user in respect of the ecosystem services that this land provides (Carpenter *et al*., 2006; Louw *et al*., 2009).

The effects of land use on ecosystem services are complex and interdependent. Land use change from natural land cover often leads to ecosystem degradation, which may be slow or abrupt (Carpenter *et al*., 2006). Impacts might not be observable on a larger spatial scale, because of the self-cancelling effects and therefore no action may be taken. Land use impacts depend on the type of

use, their intensity and spatial extent (Hobbs, 2000; Schulze, 2004). Land use changes may lead to utilised, replaced or completely removed ecosystems vs conserved ecosystems (Hobbs, 2000).

Human activities, including various uses of land, are driven by several factors, generally placing increasing demands on resources. These factors include a growing population and their basic life support needs, including wants above the level of mere life support needs and economic growth aspirations, which include both the needs and wants of people (Falkenmark *et al*., 1999). Winter and Lobley (2009) perceive a strong link between the importance of land and the survival of the human species.

Land use is often changed to satisfy immediate human needs and usually leads to a reduction in ecosystem functions and, therefore, to trade-offs (Foley *et al*., 2005). When taking trade-offs into account, a scenario of big gains for immediate human needs, but small losses for ecosystem functions, should be aimed at (Foley *et al*., 2005). Large-scale development schemes that require major changes in land use often turn out to be less profitable than improving the sustainable management of the unaltered ecosystem (de Groot, 2006). Furthermore, modern agricultural land uses may be trading short-term increases in food production for long-term ecosystem services losses, including those that are important for agriculture (Foley *et al*., 2005). In addition, whilst there is a current worldwide trend towards urbanisation, the resulting land use change is likely to lead to a reduction in the potential local supply of ecosystem services, while the amount available per capita is further decreased through a locally increasing human population (Eigenbrod *et al*., 2011).

Whilst most environmental problems surface on a regional or global scale, the solutions are at the local and individual levels (Mouratiadou and Moran, 2007; Cowling *et al*., 2008). Local conservation, land management and stewardship determine local ecosystem responses that make up regional, national and, eventually, global ecosystem responses. Land use planning provides an opportunity for mainstreaming ecosystem services. Land use decisions should be made on the basis of ecological validation studies and the persistence of ecosystem services, including scenarios of alternative futures, with the goal of achieving social and ecological resilience in an uncertain world (Cowling *et al*., 2008).

Land use and land use change in the South African context

Land use in South Africa is highly varied. In 2010 almost 20% of the land area had been transformed, with the main land uses being crop cultivation (12.1%), forestry (1.5%), urban built up (1.1%) and land degradation (5%) (DEA, 2010) and only 6% of land being under formal protection in 1999 (Barnard and Newby, 1999). The recent tendency has been an increased rate of transformation from natural land cover to various land uses (Gbetibouo and Ringler, 2009). Projections in some provinces are that if the current trends are followed, there will be no natural land cover left by 2050 outside of protected areas (Jewitt, 2012). Another development is that South Africa's population is urbanising. Despite many policy statements favouring compact cities, the trend seems to be towards low density urban sprawl along road transportation routes (Crane and Swilling, 2007). To try to reduce the amount of natural land cover lost, the South African conservation authorities have initiated a stewardship programme with landowners to help them manage their land in a sustainable way and thereby also maintain ecosystem services that this land provides. Private landowners can voluntarily be part of stewardship programmes (Egoh *et al*., 2012b).

From a legislative perspective, recent South African land use classifications aim at unifying land uses and give a broad list of scheduled land use purposes (The Government of South Africa, 2011). The term land use management is further defined to include the regulation of land use changes. Land use changes include the rezoning of a property from residential to commercial use, the regulation of the development of previously undeveloped land, termed 'green fields', as well as the regulation of the consolidation and subdivision of land parcels (The Government of South Africa, 2001). Furthermore, legislation stipulates that every municipality requires a land use management system, with certain minimum requirements having to be met. While land use is varied globally and in South Africa, it is linked to hydrological ecosystem services and vice versa. This link will be presented next.

6.2.4 The link between land use and hydrological ecosystem services

Ecosystem services, which include hydrological ecosystem services, as well as land use and climate, form a complex and interdependent system with feedbacks and linkages (Turner *et al*., 1995. They

are further influenced by human population pressures (**Figure 6.2.9**.). Land uses, being water-related, are often dependent on hydrological ecosystem services, while they might, at the same time, impact them (Brauman *et al*., 2007). This relationship is thus interdependent and, therefore, complex (Falkenmark *et al*., 1999). Forecasting the effects of land use change on stream ecosystems is a challenge, with interdisciplinary approaches being important for future ecosystem management (Nilsson *et al*., 2003). Especially in water-limited environments, Newman *et al*. (2006) postulate that an interdisciplinary, collaborative approach of ecohydrology is required for the effective management of environmental problems in the critical zone of those environments. It is widely acknowledged that land uses influence hydrological responses, and these influences are discussed next.

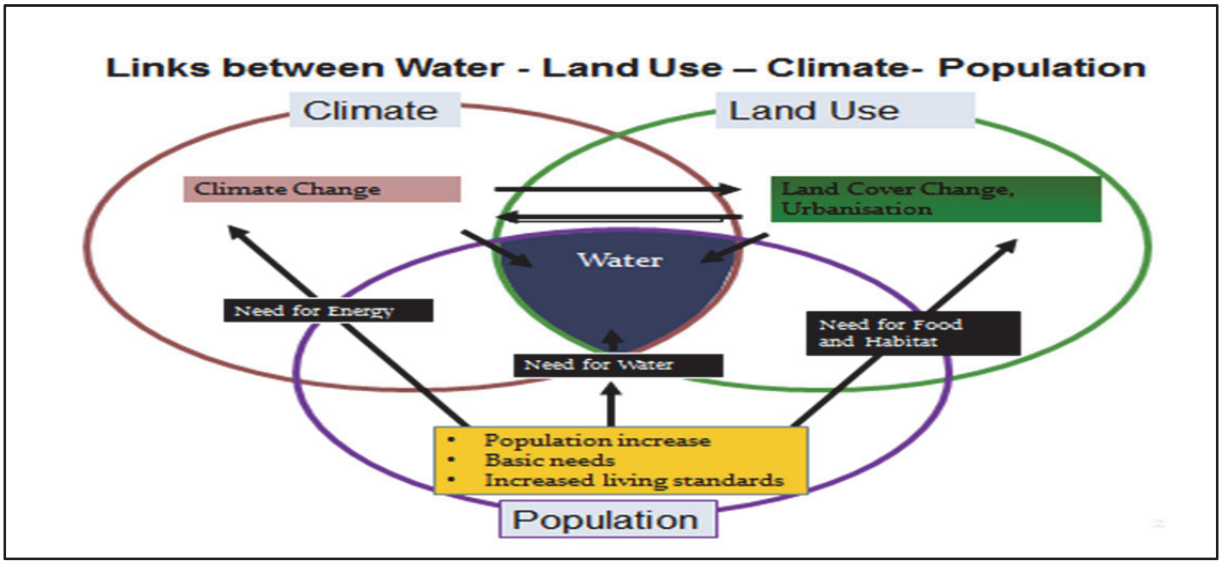


Figure 6.2.9 A schematic of the climate - land use - population - water interactions (adapted from Schulze, 2007)

Land use influences on hydrological responses

Land uses influence hydrological responses of a catchment by influencing the partitioning of rainfall between returns to the atmosphere, as evaporation or transpiration, and flows to rivers and aquifers (Falkenmark *et al*., 2000; Hope *et al*., 2004, Foley *et al*., 2005). Multiple processes control the quantity, quality and water flow regime. This poses a significant challenge to both management and scientific understanding. The pattern and extent of cities, transport routes, agricultural and natural areas within a catchment influences runoff patterns, infiltration properties and evapotranspiration rates. This, in turn, affects water quantity and quality (Vörösmarty *et al*., 2005). The impact of land use change on hydrological responses is further complicated by changing climates, as well as the changing dominance of different factors at different spatial and temporal scales.

Several effects of relevant land use types on hydrological responses have been identified by various authors and are described next. More examples may be found, for example, in Falkenmark *et al*. (1999). Most rivers today are altered (Ricciardi and Rasmussen, 1999) and so are the low flow regimes and the origin of water in a stream during low flow conditions (Smakhtin (2001). Anthropogenic impacts on low flow generating processes include groundwater abstraction within the sub-surface drainage area, the artificial drainage of valley bottom soils, changes in the vegetation regime, afforestation and deforestation (Smakhtin 2001). Commercial plantation afforestation leads to a reduction of stormflows (up to a point), as well as to reduced groundwater recharge (Gush *et al*., 2002). Agricultural practices such as ploughing and tillage alter the partitioning of rainfall into stormflow and baseflow components, depending on whether conventional or conservation practices are followed (Lumsden *et al*., 2003). Smakhtin (2001) hypothesises that conservation strategies, including contouring, terracing and mulching, are expected to reduce runoff volumes. Grazing, depending on conditions and management, might increase or decrease stormflows, soil losses and groundwater recharge (Schulze and Horan, 2007). Land use changes resulting in degradation often increase flow variability (Schulze, 2003; Maloti Drakensberg Transfrontier Project, 2007), and are thought to reduce soil water retention, water infiltration and as a result groundwater recharge and increase overland flow, while invasive vegetation, which replaces indigenous vegetation, might increase water use (Le Maitre *et al*., 2007). Land infested by alien invasive plants that spread, often

due to poor land management, especially in riparian zones, is often associated with reductions in streamflows (Jewitt *et al*., 2003). Intensive agriculture often increases erosion and hence the sediment load, thereby degrading water quality (Foley *et al*., 2005). Dams can cause changes in natural flooding regimes, which impact on the various provisioning, regulating, supplying and cultural hydrological services to downstream communities (Lankford *et al*., 2011) and directly influence low flows (Smakhtin, 2001). Irrigation water use reduces freshwater supplies downstream of the abstraction point and is globally the biggest water user (Gleick, 1998; Foley, *et al*., 2005). Urbanisation substantially degrades water quality (Foley *et al*., 2005). Urbanisation also leads to a reduction of the ecosystem service of flood mitigation, because reduced permeable areas lead to larger floods and more frequent small floods, while more people are being affected by these floods, because of denser settlements and/or settlements on floodplains (Eigenbrod *et al*., 2011). Human settlements, with high proportions of impervious areas, are predicted to lead to higher stormflows, higher peak discharges, lower baseflows and frequently to a deterioration of water quality (Schulze, 2004). Nilson *et al*. (2003) postulate that the impervious urban surfaces limit infiltration and should therefore lead to reduced groundwater levels and low flows; however, leaking urban water supply networks and the irrigation of gardens might lead to greater complexity in the system. Falkenmark *et al*. (1999) found increased streamflows as a result of urban growth and an increase of ground water levels, thought to be from leaking water and sewerage pipes, septic tanks and excessive garden irrigation. Smakthin (2001) found that low flows in urban areas usually decrease due to the effects of impervious areas on runoff, infiltration and evapotranspiration, while direct effluent flowing into river channels can significantly reduce the water quality and therefore limit its availability for downstream users. The relative quantitative impacts of anthropogenic influences vary substantially in different river catchments (Smakhtin, 2001).

While the above examples mostly refer to the hydrological responses pertaining to the blue water portion of the hydrological cycle, the evaporation or transpiration portion is also of importance. For urban areas, reduced vegetation cover, impervious surface areas and the morphology of buildings contribute to lower cooling through reduced evapotranspiration, compared to surrounding rural areas, which leads to storage of heat and the warming of the surface air, thereby creating urban “heat islands” (Arnfield, 2003; Foley *et al*., 2005). Furthermore, the conversion of vegetation cover is an important contributor to climate change, which is a major driver of hydrological responses, not only on a global scale due to release of carbon from the soil, but also regionally (Foley, *et al*., 2005) as changes in vegetation type, reduction in density and increase in albedo can cause changes in the active regulation of water and energy fluxes and might even result in lower local rainfall in certain places (Hutjes *et al*., 1998). Land cover changes (from forest to agriculture) in the tropics have been found to affect local climate through water balance changes, while boreal vegetation changes have been found to have a big effect on local climate through changes in surface radiation balance (Bounoua *et al*., 2002; Foley, *et al*., 2005). The effects of land cover conversion on climate can be seen on a regional scale, rather than on a global scale (Bounoua *et al*., 2002). The author could not find studies on the influence of land use change on microclimate within the sub-tropics or semi-arid environments, which seems to be a knowledge gap.

The following is a summary of the key influences of various land uses on hydrological responses and effects, as found in the literature:

1. Runoff generally increases when natural vegetation is cleared (Foley *et al*., 2005).
2. Land use change upstream might lead to negative external impacts downstream (Hope *et al*., 2004).
3. The influence of land use change on hydrological ecosystem services can vary from being negligible to being severe, with possible major hydrological changes in respect of total streamflows, the seasonality and responses of flows, e.g. higher peaks and shorter peak lag times, as well as the partitioning of flows into baseflow and/or stormflow (Brauman *et al*., 2007; Schulze and Horan, 2007).
4. The impact of land use often depends on its intensity and may result in a considerable hydrological lag time. Depending on the land use change, a change in annual runoff may be severe and either increase or decrease, with the land use change also influencing total evaporation and water quality (Schulze, 2003; Warburton *et al*., 2012).
5. The evidence of land use change on a small scale is often diminished on a larger scale (Schulze *et al*., 1998).

6. Urban areas were generally found to increase stormflows; however, some authors found increases and others decreases of low flows or baseflows.

In general, the land use in the catchment is critical for hydrological responses and associated ecosystem services (Jewitt, 2002; Schulze, 2003). The impact of land use within a water-limited South Africa is most significant during periods of low flow, when natural land use is often dormant, and it thus has the highest relative impact on streamflow. This is also the time when people and natural systems most require water (Jewitt, 2006). Low flows are, therefore, a better indicator of impacts of land use than mean annual flows (Jewitt, 2006).

The integration of land use planning and management with water resources planning and management is crucial (Falkenmark *et al*., 1999; Jewitt, 2006; Warburton *et al*., 2010). Water pathways, flows and quality are determinants of land use practices (Falkenmark et al., 1999). The manner and extent to which freshwater ecosystems and their catchments are either well-managed or misused by humans, largely determines the attributes of the water resource over an area. To maintain the water supply in a stressed system, considerations about land use and management, therefore, become critical. Innovative smaller-scale, locally-managed, water-conserving land management methods are often more cost-effective and less disruptive to local communities than major new water infrastructure projects, as has been found internationally (Gleick, 2000) and in South Africa (Maloti Drakensberg Transfrontier Project, 2007). It is critical to encourage and develop water-sensitive, resilient land use planning, including urbanisation, because of the impact of urban areas on their wider hinterland, as well as considering the vulnerability of poor urban communities to land use change. Urban areas should be considered as 'problem sheds' within catchments (Colvin *et al*., 2011). Human-transformed systems need to be seen as part of ecosystems and be managed to contribute to ecosystem services (FAO, 2007).

The link between land use and hydrological ecosystem services

Case studies in South Africa, using scenario modelling, found that upstream land use change, e.g. the conversion of natural vegetation to commercial afforestation and/or irrigated agriculture, has the potential for increased production and employment, but the apportionment of the catchment water has negative impacts for downstream communities. The rural poor are the most vulnerable because their livelihood is more dependent on local natural resource use, which is a frequently undervalued ecosystem service that might occur in addition to benefits from dryland rangeland agriculture (Hope *et al*., 2004).

Regarding links between land use and ecosystem services related to freshwater habitat functions, various findings exist in the literature. Human activity has been a primary factor in the modification of the eco-hydrological system (Newman *et al*., 2006), with flow modification, water pollution and habitat degradation being amongst the main drivers of freshwater biodiversity reduction (Dudgeon *et al*., 2006). Land use change is associated with altered flood regimes and increased sediment channel input, affecting particle size, particle distribution, bed mobility and suspended sediment loads (Nilsson *et al*., 2006). Increased river sediment loads can lead to habitat alterations, such as the clogging of river bottoms, shoreline erosion, the smothering of shoreline habitats or floodplain degradation (Dudgeon *et al*., 2006). For example, in some places freshwater fauna extinction was found to be four times as high as terrestrial fauna extinction. The increased extinction rate is linked to extensive habitat deterioration, resulting from sediment loading, pollution and flow regulation as an effect of land use activities (Ricciardi and Rasmussen, 1999). River flow is a major determinant of physical habitat in streams, also determining biotic composition (Bunn and Arthingtom, 2002; Nilsson *et al*., 2006). Aquatic species have evolved primarily adapted to the local natural flow regime. Catchment land use change and associated water resource development inevitably lead to changes in the flow regime, e.g. to the increased stability of baseflow and reduction of flow variability, erratic patterns in flow below dams and the conversion of flowing stream habitat to standing lake habitat. These influence the habitat function, resulting in an alteration of the biology, a decline in aquatic biodiversity, while there is an increased invasion of alien invasive species (Bunn and Arthington, 2002). Newman *et al*. (2006) call for the potential rapid advance in understanding environmental processes by linking the more reductionist approaches of hydrology with the more complex approaches of ecology into 'ecohydrology', especially in water-limited environments.

Trade-offs within and between ecosystem services causes by land use change

To be able to support an increased number of people with an accessible, reliable water supply, substantial stabilisation of flows and increased withdrawals over all regions of the world have occurred (Vörösmarty *et al*., 2005). This has led to trade-offs between human and natural system requirements for services from freshwater. These trade-offs are made both explicitly and inadvertently. The challenge now is to manage fresh water so that the needs of both people and ecosystems are balanced and that ecosystems can continue to provide other services which are essential for human well-being (Mirzab and Patwardhan, 2005; Vörösmarty *et al*., 2005).

Some examples of trade-offs caused by humans include natural flow regime alterations in rivers and waterways, the loss and fragmentation of aquatic habitat, extinction of species, pollution of water, groundwater aquifer depletions, as well as aquatic systems deprived of oxygen (so-called 'dead zones') found in many inland and coastal waters (Mirza and Patwardhan, 2005; Vörösmarty *et al*., 2005; **Table 6.2.2**). Human drivers and their links with ecosystem services (Aylward *et al*., 2005) are presented in **Table 6.2.3**.

Table 6.2.2 Direct drivers as appearing in the Millennium Assessment (Aylward *et al*., 2005, after Postel and Richter, 2003)

Human Activity (Direct Driver)	Impact on Ecosystems	Services at Risk
Dam construction	alters timing and quantity of river flows. Water temperature, nutrient and sediment transport, delta replenishment, blocks fish migrations	provision of habitat for native species, recreational and commercial fisheries, maintenance of deltas and their economies, productivity of estuarine fisheries
Dike and levee construction	destroys hydrologic connection between river and floodplain habitat	habitat, sport and commercial fisheries, natural floodplain fertility, natural flood control
Diversions	depletes stream flow	habitat, sport and commercial fisheries, recreation, pollution dilution, hydropower, transportation
Draining of wetlands	eliminates key component of aquatic ecosystem	natural flood control, habitat for fish and waterfowl, recreation, natural water purification
Deforestation/land use	alters runoff patterns, inhibits natural recharge, fills water bodies with silt	water supply quality and quantity, fish and wildlife habitat, transportation, flood control
Release of polluted water effluents	diminishes water quality	water supply, habitat, commercial fisheries, recreation
Overharvesting	depletes species populations	sport and commercial fisheries, waterfowl, other biotic populations
Introduction of exotic species	eliminates native species, alters production and nutrient cycling	sport and commercial fisheries, waterfowl, water quality, fish and wildlife habitat, transportation
Release of metals and acid forming pollutants into the atmosphere	alters chemistry of rivers and lakes	habitat, fisheries, recreation, water quality
Emission of climate altering air pollutants	potential for changes in runoff patterns from increase in temperature and changes in rainfall	water supply, hydropower, transportation, fish and wildlife habitat, pollution dilution, recreation, fisheries, flood control

Table 6.2.3 The type of land use change and its consequences on freshwater provisioning service (Vörösmarty *et al*., 2005)

Type of Land Use Change	Consequences on Freshwater Provisioning Service	Confidence Level
Natural forest to managed forest	slight decrease in available freshwater flow and a decrease in temporal reliability (lower long-term groundwater recharge)	likely in most temperate and warm humid climates, but highly dependent on dominant tree species adequate management practices may reduce impacts to a minimum
Forest to pasture/agriculture	strong increase in amount of superficial runoff with associated increase in sediment and nutrient flux decrease in temporal reliability (floods, lower long-term groundwater recharge)	very likely at the global level; impact will depend on percentage of catchment area covered consequences are less severe if conversion is to pasture instead of agriculture most critical for areas with high precipitation during concentrated periods of time (e.g., monsoons)
Forest to urban	very strong increase in runoff with the associated increase in pollution loads strong decrease in temporal reliability (floods, lower long-term groundwater recharge)	very likely at the global level with impact dependent on percent of catchment area converted stronger effects when lower part of catchment is transformed most critical for areas with recurrent strong precipitation events
Invasion by species with higher evapotranspiration rates	strong decrease in runoff strong decrease in temporal reliability (low long-term groundwater recharge)	very likely, although highly dependent on the characteristics of dominant tree species scarcely documented except for South Africa, Australia, and the Colorado River in the United States

In South Africa and elsewhere, it is important to invest in water, which is a resource that can limit development. An efficient and relatively cheap method of investing in water security is to protect it through prudent land management. In a South African case study, the value accruing from ecosystem services, as a result of the restoration and maintenance of natural capital, was found to be sufficient

to be converted into incentives to induce land use management change for the better, for land users and buyers of ecosystem services e.g. water and carbon (Maloti Drakensberg Transfrontier Project, 2007; Mander *et al*., 2010). Therefore, payment for ecosystem services is seen as a cost savings option for consumers in future water supply augmentation. Payment for water related ecosystem services, especially if it includes other services such as carbon sequestration, was found to be ecologically, hydrologically, economically and institutionally feasible (Maloti Drakensberg Transfrontier Project, 2007; Mander *et al*., 2010).

The above section has showcased several trade-offs in ecosystem services, resulting from actual or proposed land uses. Modelling trade-offs are an important tool and cannot be emphasised enough (Hubacek et al., 2009)

Determining changes in hydrological ecosystem services as result of land use change, using hydrological models

Some ecosystem services, e.g. water provisioning, may be measured directly by utilising a weir in a river, or dam levels. However, often indicators need to be used, especially when comparing scenarios. Hydrological models may be used to determine hydrological responses due to land use change. Models represent a simplified understanding of a system and are especially suitable for what-if analysis. A model is a tool for transferring knowledge from a research plot or catchment to other areas (Schulze, 1995). Process simulation models are suitable for representing complex systems, with interaction between the system's components, and for establishing patterns and trends. Models, however, are limited, as they cannot predict everything and they also introduce uncertainties. The results thus need to be critically evaluated, to evolve the complex system thinking behind the assumptions and processes within a model (Cilliers *et al*., 2013).

Hydrological models suitable for the simulation of the interactions between land use and hydrological responses should model the hydrological cycle within the atmosphere-soil-plant-water continuum on the landscape, as well as modelling river flow and its components (Schulze, 2012). The model ideally needs to distinguish between stormflow events, baseflows and sediment yields, generated on an event-by-event basis. Nilsson *et al*. (2003) stress the importance of estimating the magnitude, duration and future changes in flows, including low flows, based on an understanding of the components and processes of the hydrological system, in order to be able to make forecasts of running water ecosystems. Smakhtin (2001) mentions that to model low flow conditions, the model would require regional information for model parameter values which, especially in the case of a daily time step model, is a very difficult task. A model further needs to distinguish explicitly how different land use scenarios are accounted for in their hydrological response (Warburton *et al*., 2010). The model needs to simulate at appropriately fine time and spatial scales. A daily time step, physical-conceptual hydrological process model such as the *ACRU* model could be considered as suitable for the above (Schulze, 2010). The *ACRU* hydrological model has been verified in South Africa and abroad, and has been used to account for land use change influence on hydrological responses (e.g. Schulze, 1995; Jewitt and Schulze, 1999; Hope *et al*., 2004; Warburton *et al*., 2010).

While modelling appears to be a viable option to assess the linkages between hydrological ecosystem services and land use, various uncertainties revolving around land use-related (and other) process representations will be introduced if a modelling approach is used. Further uncertainties include unknown future land use scenarios. However, land use change decisions are continually being made. Therefore, simulations of hydrological responses to plausible scenarios of land use are required (Nilsson *et al*., 2003). Associated uncertainties should be recognised and, where possible, be constrained (Beven, 2006), rather than used as a reason for not proceeding with studies of projected future changes (Schulze, 2003; Warburton *et al*., 2010).

6.2.5 Synthesis and discussion of literature including knowledge gaps

Natural capital and the associated ecosystem services are essential for human existence and need to be sustained and invested in, in order to ensure sustainable development (Daily, 1997; MEA, 2005; Adger, 2006). Because of rapid population growth and higher living standards, resulting in higher resource use, humanity is now at a threshold where future losses may not be able to be compensated for. However, social and economic development, while providing crucial benefits (Foley *et al*., 2005), results in a trade-off between additional benefits gained from ecosystem services and potential services lost to society (Jewitt, 2002). Trade-offs will always exist and have to be dealt with (Foley *et*

al., 2005). This calls for an in-depth understanding of the value of ecosystem services, their potential benefits and losses, feedbacks and linkages, as well as communication of results to decision-makers. A paradigm shift is required by decision-makers, from considering the environment to be an unlimited resource supplier, to valuing and conserving natural capital for sustainable development. The value of the gross domestic product (GDP) as a measure of development must be looked at critically and discount rates to the present need to be assessed, in order to halt a decline in the services that healthy ecosystems provide. Alternative assessments, such as the ecosystem services approach, need to be considered for decision-making.

Hydrological ecosystem services form part of services provided by ecosystems. Hydrological ecosystem services were found to be much more than simply freshwater abstraction (Aylward *et al*., 2005; de Groot, 2006; Brauman *et al*., 2007). The exact categorisation and naming of hydrological ecosystem services, functions, processes and values varies in the literature. In this study, however, irrelevant of the exact categorization, of prime importance is that a link between land use change, hydrological responses and a beneficial ecosystem service is made, irrelevant of whether it is a direct or indirect ecosystem service to benefit humans.

Changes to hydrological ecosystem services often cannot be measured directly. This is especially valid for case studies with different scenarios as well as for some provisioning and many regulating, supporting and cultural services. Frequently, indicators i.e. proxy information, are used in practice to quantify ecosystem services, with selected hydrological responses e.g. runoff, used in practice as indicators for some hydrological ecosystem services (Egoh *et al*., 2012a). Owing to the complex hydrological processes, modelling often becomes the most adequate option (Egoh *et al*., 2012a).

Land cover and land use can have a major influence on hydrological responses (e.g. Falkenmark *et al*., 1999; Brauman *et al*., 2007). Land cover affects interception, infiltration, overland flow, groundwater recharge and evapotranspiration, all of which affect streamflow. Examples of the land use influencing hydrological flows abound (e.g. Falkenmark *et al*., 1999; Smakhtin, 2001; Gush *et al*., 2002; Lumsden *et al*., 2003; Nilsson *et al*., 2003; Schulze, 2004; Foley *et al*., 2005; Vörösmarty *et al*., 2005; Eigenbrod *et al*., 2011, Le Maitre *et al*., 2014).

In the South African context, many environmentally sound laws and policies are in place. However, their implementation and enforcement is often slow (King *et al*., 2008; Stuart-Hill and Schulze, 2010; Schreiner, 2013). South Africa is experiencing significant land use changes (Gbetibouo and Ringler, 2009; Jewitt, 2012). Environmental considerations seem to be frequently overridden by a drive towards mining and industrial development, based partially on the assumption that this would create jobs and result in the upliftment of the poor. However, a focus on poverty reduction that erodes the supply of ecosystem services can make poverty reduction increasingly difficult (Carpenter *et al*., 2006). Ecosystem services are vital for environmental performance. In recent studies (Yale Center for Environmental Law and Policy, 2012; Standard Chartered, 2013), the environmental performance index and South African ecosystem vitality were extremely poor in absolute terms, amongst the poorest performing countries out of the countries assessed, and with a declining trend. Unsustainable development will result in expenditure for compensation to lost ecosystem services and it will endanger sustainable development. This may result in an increase of poverty now, as well as for future generations.

Payment for ecosystem services may provide many opportunities in South Africa, given that a large part of the land is currently still in a natural state and/or can be rehabilitated. Conservation, as well as adaptation to adverse conditions, including water stress, needs to be undertaken at a local level.

If land use changes are considered, an assessment should show potential ecosystem services trade-offs, and these should be compared to land use that conserves and rehabilitates natural capital. An individual environmental impact assessment (EIA), often required for an application for land use change, will not take accumulative impacts of other proposed land use changes into account, nor does it consider all ecosystems services. A need for improved knowledge on the links between land use change, hydrological responses and ecosystem services is established from the literature, and this research aims to contribute towards these links.

On the basis of the above literature review and discussion, the aims, objectives and methodology of the proposed case study are outlined in the next section.

6.3 Background Information on the Mpushini / Mkhondeni Study Area

Following the literature review, background information on the Mpushini/Mkhondeni study catchment is given, which included a biophysical outline that places the study area in a water-limited environment with strong seasonal variances. Next, different land use scenarios, used for subsequent work within the study are identified. These scenarios are the baseline land cover scenario, which represents the pre-human influenced natural land cover, the current (2008) land use scenario with a mix of land uses, including various agricultural and urban land uses, degraded areas and a large portion of remaining natural land cover. Thirdly, a possible future land use scenario is examined, consisting of submitted proposed land use change applications, which would considerably increase urban areas.

6.4 Methodology

The methodology is based on using the daily-time step *ACRU* hydrological process simulation model. To set up the model to be able to undertake simulations, the relevant land use related hydrological inputs are established first, followed by the catchment delineation into 10 linked smaller catchment units (CUs), based on river networks, topography, location of dams and major current and proposed land uses. The delineation of these CUs remains constant for all three scenarios of baseline land cover, current land uses and proposed land uses, while the various land uses of the three scenarios are identified by using GIS analyses of land cover and land use maps. Every catchment unit is then further subdivided into a basic configuration of five linked, land use determined hydrological response units (HRUs), to facilitate the isolation of local effects of the particular land use in question, where land uses with expected similar hydrological responses being aggregated into relatively homogeneous hydrological units. These aggregated land uses are, for HRU 1, the natural vegetation cover (KwaZulu-Natal Hinterland Thornveld or Eastern Valley Bushveld), which is the dominant land cover, as well as urban land uses (because the effects of urbanisation can be isolated within the *ACRU* model together with another land use or land cover). The land use of HRU 2 consists of a dryland agricultural cluster which, in the case of this study area, is represented by improved pasture (the dominant dryland agricultural land use). HRU 3 designates so-called “special case land uses”, in this study area, either sugarcane or tree plantations, whichever is dominant in a given CU. HRU 4 accounts for a second set of special case land uses, in this instance the degraded land use cluster. Finally, hydrological effects of natural watercourses, dams and irrigated areas are simulated in HRU 5. In the event that the HRU 2 - HRU 5 do not exist within a catchment unit, they take on the attributes of the natural vegetation, but require a minimum area to be simulated with the *ACRU* model. Note that HRUs are not of equal area, but together make up the total area of the CU. This approach allows for each HRU to be modelled individually, thereby isolating the local particular land use influence on hydrological responses.

Various hydrological model inputs were obtained from research previously undertaken in the School of Agriculture, Earth and Environmental Sciences at the University of KwaZulu-Natal. These inputs included the study area’s climate data (e.g. daily rainfall, maximum and minimum temperature and potential evaporation), physiographic data (e.g. altitude and slope), as well as soil information (e.g. thickness of soil horizons, soil water retention constants, drainage rates and soil erodibility). These climate and physiographic data and most of the soil information inputs remained constant for all three land use scenarios. The hydrological model inputs related to the respective land use determined HRUs are outlined next. These inputs are either taken from previous research on similar land cover, based on expert advice, or are calculated where appropriate. This included vegetation related inputs e.g. biomass indices, root distribution and colonisation, vegetation cover factor, dam and irrigation related, impervious urban areas calculations, urban return flow calculations, as well as inputs related to the schematic catchment configuration.

Following the various land use related model inputs, the *ACRU* model’s selected relevant outputs of hydrological responses are described. These modelled outputs include stormflow, i.e. the water which is generated from a specific rainfall event, either at or near the surface, to contribute to flows in the channel of the HRU; baseflows, i.e. the delayed water from rainfall that has percolated through the soil horizons into the intermediate and groundwater zones and then contributes as a delayed slow flow to the streams within a HRU; runoff, i.e. the water yield from an individual HRU, consisting of stormflow plus baseflow; and streamflow, i.e. the runoff from the HRU plus the runoff contribution from all upstream HRUs. Further relevant outputs are sediment yield, which consists of the soil detached

from a landscape after a rainfall runoff event, which then reaches the stream; extreme (design) one-day runoff, which is the statistically expected daily runoff from an annual maximum series for the 2, 5, 10, 20 and 50 year return periods. Also important is the modelled output of total transpiration, which is water that is modelled to have flowed from the soil via a plant into the atmosphere, but excludes direct evaporation from intercepted rainfall or from the soil surfaces. The output variables of modelled hydrological responses described above are presented in numerous monthly and annual statistics. These statistics included arithmetic mean values, median values (e.g. of flows, sediment yields, rainfall, etc.), the 1:10 year high value implying that statistically only in 1 year in 10 that value will be exceeded, the 1:10 low value signifying that the value would be exceeded in 90% of years.

6.5 A Summary of the Main Results and Discussion

Selected hydrological responses under baseline land cover were modelled and assessed first. Thereafter, selected hydrological responses from current land use conditions were modelled and compared to those from baseline land cover conditions. Following this, selected hydrological responses under proposed urbanisation were modelled and compared to those under current land uses.

6.5.1 Results of hydrological responses assuming baseline land cover

In assessing various influences under baseline land cover, with no current land use influences included yet, the following findings were made for the various hydrological responses within the study area:

1. The annual, as well as monthly runoff is highly variable between years, with monthly and annual dry season runoff often extremely low.
2. Annually, stormflow contributes more to runoff than baseflow and the contribution of stormflows to total runoff displays major differences between years of high, median and low flows.
3. Differences in baseline land cover can have a significant influence on runoff, although these differences are relatively small within this particular study area.
4. Blue water flows make up proportionally the lowest fraction of the study area's water budget, when compared to green and white water flows.
5. Differences in green water flows i.e. transpiration, vary from month to month and from year to year in this study area, depending on available soil water.
6. Sediment yields are increased markedly during years with high flows.
7. Hydrological responses such as sediment yields, stormflows and especially baseflows, amplify any changes in the rainfall regime.

Changes to hydrological responses from the various current land uses, compared to those from baseline land cover, are summarised below:

1. Certain land uses, in this case sugarcane and wattle plantations, reduce runoff, compared to that from baseline land cover conditions.
2. Irrigation from dams leads to a significant local decrease in streamflow, which is especially significant in years with low flows. It also leads to a lag in streamflows when these increase again at the start of the wet season, because a depleted dam first has to be filled before overflows commence. The decrease in streamflow is more pronounced immediately below an individual dam.
3. Land degradation is modelled to result in increases in runoff and sediment yield, but in reductions in baseflows when results are compared to those from baseline land cover conditions. The effects of degradation could be largely reversed through rehabilitation, and if all degraded areas within the catchment were to be rehabilitated, this would reduce the sediment yield in years with median flows by 57 Mt/year and in years with 1:10 high flows by 130 Mt/year.
4. Urban areas in this study area have their return flows generated from externally-sourced water. Based on assumptions made on modelling urban return flows, these contribute to a consistent increase in flows, irrespective of the month of the year or whether years are wet or dry. Return flows of water from external sources increase the overall streamflow, and they are relatively more significant in dry periods.
5. In addition to the above effects from return flows, impervious urban areas were found to increase the runoff and thus blue water flows. The increases are made up of increased stormflows as well

as increased baseflows. The magnitudes of one day design runoff for selected return periods also increased when compared to those from baseline land cover conditions.

6. Where there is a spill-over from impervious to pervious urban areas, the biomass production (as measured by transpiration) from the pervious areas increases. However, the overall biomass production decreases, because the pervious areas have been reduced through urbanisation.
7. The combined effects of the current land use mosaic on annual streamflows for the entire study area at this catchment's outlet partially cancel out the effects of individual land uses. For this study area, during average and dry years, the current land uses result in a small reduction in flows. In wet years, the combined influences of current land uses result in essentially the same streamflow at the catchment outlet as under baseline land cover conditions.
8. In contrast to the above, however, the combined effects of the current land uses show a marked increase in sediment yields, which is especially significant, in absolute terms, during years with high flows, while the relative increase is bigger during years with low flows. This is likely due to an overall increased stormflow component of runoff, especially for high flow events.

The proposed land uses, consisting mainly of industrial and residential uses, would urbanise and thereby transform the presently mainly rural study area. This proposed urbanisation, with markedly increased impervious urban areas, was found to lead to significantly increased runoff, in absolute terms made up of mainly increases in stormflows, while the often fairly low baseflows would also increase markedly, in relative terms. The increases in baseflows are more significant, in absolute terms, during the rainy season but they increase less (in absolute terms) when there is little rain during the dry season. The relative contribution of stormflows to total runoff increases, while that of baseflows decreases. The increased runoff is modelled to significantly increase streamflows. In addition, urban return flows from water sourced externally to this catchment lead to drastically increased, but less variable, streamflows. Overall, the effect of the proposed urban land uses would be the dominant one on annual streamflow, which at the catchment outlets was modelled to increase by 176% in years with 1:10 low flows, by 78% in years with median flows and by 33% in years with 1:10 high flows, compared with flows from current land uses.

6.5.2 Linking hydrological functions and responses to hydrological ecosystem services

Next, changes in hydrological responses were proposed as being suitable indicators for changes in selected ecosystem services. The ecosystem service of water provisioning was, for this study, defined as arising from blue or green water flows. Changes to water provisioning through blue water flows were indicated by changes in the hydrological responses of accumulated streamflow or by changes in runoff and its components of stormflow and baseflows, from an individual HRU. Changes to the ecosystem service of water provisioning through green water flows in this study were indicated by changes in the hydrological response of transpiration. Changes to regulating services relating to flow regulation were discussed next. In regard to regulation of high flows, these can be indicated by changes to stormflow responses, as well as by changes to the relative contribution of stormflows to runoff, as well as changes to extreme one-day design runoff magnitudes for varying return periods. In contrast, changes in low flow regulation can be indicated by changes to baseflows. Changes in physical water quality can be indicated by sediment yield. Selected supporting ecosystem services were also found to be affected by changes in the above described hydrological responses. The ecology in streams has evolved to local conditions and both biodiversity and genetic diversity are negatively affected through streamflow regime changes, physical water quality deterioration and habitat alteration through increased sediment yields. Therefore, a reduction in the ecosystem service of biodiversity and genetic diversity can be indicated (together with other biotic and chemical indicators) through alterations in streamflow, and these could be either increases or decreases or changes in the timing of streamflows, as well as low flows, the runoff components of baseflow and stormflow, or increases in extreme one-day runoff events and changes in sediment yield. The above described changes to flows and sediment yield might, however, also imply that some aquatic species benefit from the altered landscape conditions.

6.5.3 The link between land use change and ecosystem services, as indicated by hydrological responses

The modelled land use changes in the study area were linked with changes in ecosystem services by using the modelled hydrological responses as indicators. The type of land use was found to have a highly significant influence on hydrological responses and associated ecosystem services.

Land uses that conserve land, as well as land uses that maintain near natural vegetation e.g. extensive cattle or game farming, if managed correctly, maintain the ecosystem services that natural vegetation provides. Such activities should therefore be encouraged and even incentivised through rebates or payments for ecosystem services, because they add benefit without altering ecosystem services.

High biomass crops such as sugarcane and wattle plantations were found by modelling to reduce streamflows. The benefits of sugarcane plantations, for example to food security, job creation, foreign exchange earnings and economic benefits, therefore need to be weighed up against the reduced ecosystem services to downstream users. In this catchment the wattle plantations do not consist of managed production plantations, but rather of unmanaged areas invaded by alien wattles (*Acacia mearnsii*). Therefore, the small economic benefit of these alien wattles is likely to be superseded by the reduction in the water provisioning service they cause. It would therefore be beneficial to eradicate this alien vegetation to the benefit of downstream water users.

The greatest relative impact of a reduction in downstream blue water provisioning was modelled as a result of irrigation. Irrigation should, therefore, be applied as efficiently as possible and the benefits of agricultural production be weighed against the needs of downstream water users.

Degraded lands were found to increase stormflows, decrease low flows and increase sediment yields. This implies that the physical water quality is reduced and the water during low flow periods, when most needed, is reduced. On the other hand, degraded areas hold potential to be rehabilitated so that increased flow regulation and water provisioning during low flow periods could occur. The rehabilitation of degraded land within the study area, therefore, holds potential to increase ecosystem services, and should be incentivised.

Urban land uses were modelled to significantly increase runoff, thereby increasing the quantity of total blue water provisioning, while reducing physical quality and likely also other types of water quality (e.g. through wash off of oil or pathogens). The stormflow component of runoff in urbanised areas was found to be most markedly increased, leading to spiked runoff responses and, therefore, a reduced regulation of high flows. It was modelled that not only stormflows, but also baseflows increased, the latter through a spill-over of water from impervious to pervious areas with the result that variability of baseflows decreased. This implies that for baseflows there is an increase in flow regulation. The increased blue water flows, however, reduce green and white water flows. The conversion of pervious vegetated areas into impervious areas shifts most of the water portion that would have transpired *via* the vegetation, as well as part of the portion of water that would have evaporated, towards the blue water flows, which is the water that runs off. In addition, the urban return flows generated from water which is imported into the study area, were modelled to increase the blue water flows, and by steadying the flows also increasing low flow regulation. Potential leaking water pipes and outlets from septic tanks were not taken into account in this study, but might increase this effect. While an increase in low flows from urban areas has positive effects in terms of increased water provisioning during low flow periods, it needs to be borne in mind that this water is likely to be of lower water quality and, therefore, an overall negative water provisioning service is likely.

Nevertheless, the increased flows from urban impervious areas and urban return flows create opportunities which include:

1. rainwater harvesting from roofs,
2. water collection from stormwater drains into dams and artificial wetlands,
3. use of treated water from waste water treatment works,
4. use of grey water from households,
5. spill-over from impervious areas to pervious ones, and thereby slowing flows, resulting in additional infiltration and, hence,
6. production of more biomass in the remaining pervious areas.

If utilised, these positive factors partially mitigate the negative impacts of urban areas by

1. augmenting the urban water requirements and, therefore, reducing the amount of water brought into the catchment,

2. increasing biomass production in urban areas and thereby creating green area with possible benefits for recreation, relaxation, biodiversity and food production, and by
3. reducing the downstream ecosystem impacts of upstream urbanisation.

Having evaluated impacts of individual land uses above, it needs to be emphasised that from a biodiversity and genetic diversity perspective in and adjoining streams, the ecology has evolved according to natural local conditions. The resulting streamflow alterations, reduced water quality and altered habitat functions are, therefore, likely to reduce the biodiversity in and adjoining streams.

6.6 Climate Change Projections for the Mpushini / Mkhondeni Catchments

The climate inputs used for the above study consisted of historical records of a 50 year span (1950-1999). We are, however, living in a world of changing climates, which are projected to have major influences on hydrological responses and associated ecosystem services in the future. This is in addition to the land use influences. In this section, therefore, the additional projected effects of climate change will be examined. Climate output from downscaled Global Circulation Models (GCMs) which project climate change are used to examine how this could change the hydrological responses and associated ecosystem services in this study area.

The climate scenarios used in this study

The climate change scenarios developed by Climate Systems Analysis Group (CSAG) at the University of Cape Town (CSAG, 2008) and applied in this project were derived from global scenarios produced by four GCMs, all of which were applied in the IPCC's (2007) Fourth Assessment Report (AR4). Details of the four GCMs used in this study are provided in **Table 6.6.1**. All of the future global climate scenarios were based on the A2 "business as usual" emissions scenario defined by the IPCC SRES (Nakićenović *et al*., 2000).

Table 6.6.1 Information on GCMs, the global climate change scenarios of which were empirically downscaled by CSAG to point scale for application in this project (CSAG, 2008; Schulze *et al*., 2010)

Institute	GCM
Canadian Center for Climate Modelling and Analysis (CCCma), Canada	**Name:** CGCM3.1(T47) **First published:** 2005 **Website:** http://www.cccma.bc.ec.gc.ca/models/cgcm3.shtml
Meteo-France / Centre National de Recherches Meteorologiques (CNRM), France	**Name:** CNRM-CM3 **First published:** 2004 **Website:** http://www.cnrm.meteo.fr/scenario2004/indexenglish.html
Max Planck Institute for Meteorology (MPI-M), Germany	**Name:** ECHAM5/MPI-OM **First published:** 2005 **Website:** http://www.mpimet.mpg.de/en/wissenschaft/modelle.html
Institut Pierre Simon Laplace (IPSL), France	**Name:** IPSL-CM4 **First published:** 2005 **Website:** http://mc2.ipsl.jussieu.fr/simules.html

Daily climate values from the climate change scenarios were downscaled to the Quinary Catchments spatial resolution using techniques described in Schulze (2012). Using the daily climate values of minimum and maximum temperatures and precipitation of the four GCMs, various hydrological responses were simulated with the *ACRU* hydrological process simulation model. For each GCM two time periods were compared in order to be able to establish trends. These time periods are 2046-2065, which will from now on be termed the intermediate future time period, and the time period 1971-1990, which from now on will be called the present time period.

First, in the case of temperature, the absolute differences in monthly and annual means of daily maximum and minimum temperature were calculated. Secondly, the precipitation ratios between the intermediate future and present were determined for the monthly and annual means. Thirdly, the following monthly and annual means of hydrological responses were modelled: daily total streamflow from the study area into the Msunduzi River, the runoff components of baseflows and stormflows, total evaporation, transpiration by itself and, in each case, the ratio between the intermediate future and the present scenarios were determined. Fourthly, one day design runoffs for selected return periods were modelled and the ratios determined. Results were generated assuming selected current land

uses and in one case proposed urbanisation. In each case results are expressed as the mean of the difference or ratios of the 4 GCMs, and presented in **Table 6.6.2**.

In addition, a confidence index (CI) was calculated. A measure of confidence in the projected changes in, for example, MAP by the various GCMs used is expressed through the Confidence Index (CI) which, for each hydrological response unit (HRU), is a measure of the differences or dispersion between the changes (e.g. of MAP between the intermediate future and present climates) generated by the individual GCMs. This Index is computed as the Confidence Index (%) of the ratio changes of the individual GCMs by

$$CI\ (\%) = \frac{100 * \text{Standard Deviation (of ratio change of GCM1, GCM2, GCM3, GCM4)}}{\text{Mean (of ratio changes of GCM1, GCM2, GCM3, GCM4)}}$$

The lower the value of the CV in a given Quinary, the higher the confidence that there is consistency among the outputs of GCMs used in an analysis. The CIs are presented in **Table 6.6.2**.

Results and discussion
For the Mpushini / Mkhondeni study area, the projected relevant resulting changes for the time period of 2046-2065, compared to the time period of 1971-1990, are presented. The confidence levels will be presented thereafter.

Temperature
The annual means of daily maximum temperature are projected to increase by 1.09° C into the intermediate future and the annual means of daily minimum temperature are projected to increase by 1.18° C. The projected increases are thus slightly higher in winter than in summer.

Precipitation
The mean annual precipitation is projected to increase by 26%.

Total evaporation
The mean annual total evaporation within HRU 1 of CU 3 is projected to increase by 22%. Total evaporation is made up of plant transpiration and evaporation from intercepted water as well as from soil water and other surfaces. It needs to be remembered that the evaporation component of total evaporation is non-recoverable water.

Transpiration
The mean annual transpiration within HRU 1 of CU 1 is projected to increase by 25%. This should lead to an increased biomass production which, in turn, should lead to a higher crop harvest per hectare, but also to increases in growth of unwanted plants such as alien invasive land- or water weeds.

Table 6.6.2 Summary of results of monthly and annual means of daily minimum and maximum temperature, precipitation, total evaporation, transpiration, total streamflow, baseflows, stormflows, sediment yield and design runoffs for selected return periods, using the means of the differences or ratios from multiple GCMs for the intermediate time period (2046-2065) compared to the reference time period (1971-1990), and the Confidence Index, for selected current and proposed land uses and areas within the Mpushini/Mkhondeni study area

Land use scenario	Loca-tion	Output	Sta-tistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Not applicable	U20J2	Tmax	Mean differ-ence	1.19	1.07	1.08	1.12	1.11	1.08	1.08	1.08	1.09	1.10	1.08	1.09	1.09
Not applicable	U20J2	Tmax	CI	1.23	0.42	0.89	1.42	0.35	1.49	1.48	0.59	0.84	1.23	1.45	1.06	0.36
Not applicable	U20J2	Tmin	Mean differ-ence	1.14	1.13	1.13	1.22	1.28	1.22	1.25	1.23	1.22	1.21	1.16	1.15	1.18
Not applicable	U20J2	Tmin	CI	0.43	1.27	1.46	2.03	3.46	22.5	23.4	7.47	3.39	1.75	1.08	0.67	0.83

Not applicable	U20J2	Precipitation	IOP	1.18	1.26	1.16	1.35	1.80	1.39	1.87	1.26	1.37	1.26	1.31	1.19	1.26
Not applicable	U20J2	Precipitation	CI	3.21	6.97	9.44	6.28	33.20	32.1	35.5	21.5	3.64	8.35	11.0	7.46	4.78
CLU, nat. vegetation, low urbansiation	HRU 1 of CU 3	Mean of total evaporation	IOP	1.16	1.20	1.15	1.20	1.25	1.39	1.42	1.42	1.28	1.41	1.22	1.15	1.22
CLU, nat. vegetation, low urbansiation	HRU 1 of CU 3	Mean of total evaporation	CI	5.02	4.95	2.89	7.33	8.68	10.8	16.6	12.2	11.2	10.9	3.12	7.42	3.20
CLU, nat. vegetation, low urbansiation	HRU 1 of CU 1	Mean of transpiration	IOP	1.22	1.27	1.18	1.25	1.34	1.33	MC	MC	1.32	1.49	1.26	1.20	1.25
CLU, nat. vegetation, low urbansiation	HRU 1 of CU 1	Mean of transpiration	CI	6.76	6.74	5.50	9.44	12.98	MC	MC	MC	16.2	12.8	4.60	10.5	4.57
CLU	Entire study area	Total streamflow	IOP	1.34	1.40	1.47	1.38	1.90	1.56	1.65	1.56	1.25	1.57	1.69	1.38	1.45
CLU	Entire study area	Total streamflow	CI	11.74	23.16	22.16	16.10	46.99	35.2	19.2	17.8	19.9	25.4	21.1	17.9	13.3
PLU, urbanisation	Entire study area	Total streamflow	IOP	1.25	1.31	1.34	1.30	1.49	1.25	1.26	1.19	1.15	1.30	1.41	1.28	1.30
PLU, urbanisation	Entire study area	Total streamflow	CI	7.20	15.47	15.88	11.82	19.11	12.6	4.02	4.79	6.54	13.3	11.1	11.0	7.77
CLU, nat. vegetation, low urbansiation	HRU 1 of CU 1	Mean of baseflows	IOP	1.29	1.33	1.43	1.39	1.79	1.66	1.74	1.74	1.50	1.41	1.51	1.30	1.42
CLU, nat. vegetation, low urbansiation	HRU 1 of CU 1	Mean of baseflows	CI	9.38	19.28	19.41	13.50	38.48	30.1	24.0	29.4	23.6	23.1	16.4	12.6	12.1
CLU, nat. vegetation, low urbansiation	HRU 1 of CU 1	Mean of stormflows	IOP	1.27	1.30	1.42	1.31	2.38	1.11	1.75	1.67	1.23	1.34	1.45	1.23	1.33
CLU, nat. vegetation, low urbansiation	HRU 1 of CU 1	Mean of stormflows	CI	9.03	16.71	19.14	23.08	82.24	117.	91.5	MC	41.3	27.1	19.6	12.7	8.37
CLU, degraded area	HRU 4 of CU 7	Sediment yield	IOP	1.29	1.33	1.31	1.33	2.13	1.22	2.09	1.11	1.65	1.34	1.40	1.19	1.32
CLU, degraded area	HRU 4 of CU 7	Sediment yield	CI	4.67	18.00	8.49	24.29	66.75	MC	MC	MC	30.7	19.9	23.5	18.1	8.59
		Return period		**2 year**	**5 year**	**10 year**	**20 year**	**50 year**								
CLU, nat. vegetation, low urbansiation	HRU 1 of CU 1	Design runoff	IOP	1.15	1.17	1.19	1.22	1.26								
CLU, nat. vegetation, low urbansiation	HRU 1 of CU 1	Design runoff	CI	9.55	6.13	8.82	12.49	17.16								

CLU= current land use; IOP = ratio of intermediate future to present; CI= Confidence Index; MC= meaningless computation, because numerator is zero

Total streamflow

The mean annual streamflow from the study catchments into the Msunduzi River for the current land use scenario is projected to increase by 45%. This is a large increase in streamflow and emphasises the amplification of streamflow responses to changes in rainfall, given that projected changes in MAP

are 26%. For the proposed urbanisation, the total streamflow for the whole study area is projected to increase by 30%. This relative increase is somewhat smaller for the scenario of proposed urbanisation, which already had a large increase of 78% in years with median flow conditions, compared to the current low urbanisation, and, therefore, a larger reference streamflow, both modelled for the historical climate (1950-1999).

The components of runoff: baseflows and stormflows
The mean annual baseflows within HRU 1 of CU 1 are projected to increase by 42%. The mean annual stormflows are projected to increase by 33%. However, it must be borne in mind that the baseflows in these catchments are considerably lower than the stormflows, therefore in absolute values of water volume, the increase in stormflows remains larger than that of baseflows.

One day design runoff of selected return periods
The design runoffs for a 2 year return period are projected to increase by 15% and for a 50 year return period by 26%.

Sediment yield
The mean annual sediment yield is projected to increase by a factor of 1.32. Stormflow is the determinant with the greatest variable influence on sediment yield under climate change conditions. The factor change is therefore similar to that of stormflow.

On the confidence level of the results
The confidence index (CI) of daily maximum temperature is 0.36%, and of daily minimum temperature is 0.83%. These low CIs are indicative that the changes among the GCMs are highly consistent. Temperature is a primary output of the GCMs, with a higher consistency of change among GCMs.

The CI of mean annual precipitation is 4.78%, with the CI of the mean annual total evaporation within HRU 1 of CU 3 being 3.20% and that of mean annual transpiration within HRU 1 of CU 1 4.57%. The CI of total annual streamflow from the study area into Msunduzi River for the current land use scenario is, however, a considerably higher 13.32% and under proposed urbanisation 7.77%. The CI of annual baseflow within HRU 1 of CU 1 is 12.13% and that of stormflows 8.37%. The CIs of one day design runoffs for a 2 year return period is 9.55% increasing for a 50 year return period to 17.16%. The CI of the mean annual sediment yield is 8.59%.

The uncertainty thus increases from the primary GCM output of temperature, to the secondary output of precipitation and then even more so in the conversion to simulated hydrological responses of runoff, baseflows, stormflows, total streamflow, design runoff and sediment yield. This is because any variances stemming from the GCM's are amplified. In addition, the results show that the uncertainty in the wetter summer season is generally lower than the drieer winter season. The general trend for the confidence for design runoff for selected return periods is that the higher the return period, the lower the confidence.

Significance of the Results
Climate change is projected to play an added role, in addition to that of land use change, to further change hydrological responses. Maximum temperatures are projected to increase by 1.09 °C which, *inter alia*, might result in an increase in days with human discomfort, as well as animal and plant stress. A projected increase in minimum temperature might reduce a killing off in winter of pests and disease bearing organisms, as well as possible chill units required for some fruit bearing plants, but might also increase the growth rate of some species. Increases in maximum and minimum temperatures might cause a shift of the ecosystem composition and, more than before, connectivity of ecosystems are required in order to allow species to migrate. A projected increase in precipitation might lead to more rain days and more heavy storms. A projected increase in evaporation implies more water is lost without being put to direct use. A projected increase in transpiration implies more water is used for plant growth, with an expected positive increase in yield, for example for sugar cane, but also the negative consequences of enhanced growth of alien invasive weeds, both terrestrial and aquatic. A projected increase in total streamflow potentially implies an increase in consumable water, which is positive for human downstream users. A projected increase in baseflows implies the streams are flowing at a more consistent rate, with an increase in low flows. A projected increase in stormflows potentially means more flooding and an associated higher sediment yield. The increases in streamflow and flow modifications are likely to shift the river ecology, which has evolved to the flow

conditions over many centuries. This, in addition to the changes caused by land use, is likely to lead to additional shifts in ecosystem composition and a further reduction in biodiversity.

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CHAPTER 7: UNDERSTANDING THE LINKS BETWEEN WATER, LIVELIHOODS AND KEY HYDROLOGICAL DRIVERS IN THE COMMUNITIRS OF BERGVILLE, FRANCE AND SCOTTSVILLE: A CASE STUDY

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This Chapter was taken in part from Ngubane, T.F. 2013. Understanding the links between water, livelihoods and key hydrological drivers in the communities of Bergville, France and Scottsville: A case study. Unpublished Hydrology Honours Study, University of KwaZulu-Natal, Pietermaritzburg

7.1 Livelihood Backgrounds of Different Communities

It is important to outline the background of human settlements that demonstrates the capabilities, assets and activities reflected in each settlement. This is done in order to understand the implications that different livelihood activities have on water and its resources. Some of these activities can reduce the quality or quantity of water, thereby affecting the environment and reducing the livelihood capacities of those that rely on the resource. Water management needs to first identify the problem domain and study the causes for different water issues in order to develop planning and management strategies to deal with the issues.

7.1.1 Rural indigenous communities, typified by the Bergville area in KwaZulu-Natal

Rural indigenous communities mainly rely on primary sector activities such as agriculture, stock farming and stock piling of produce to sustain their livelihoods. In addition to these activities, social grants, pensions and remittances play a key role in the way rural people make a living. Rural communities usually lack productive assets due to low levels of income which result in restricted capabilities and poverty thereof. Their labour market is limited to house construction, repairs, fencing, toilet building, some carpentry, domestic work and labour for ploughing and weeding of arable fields and gardens for others (Hebinck and Lent, 2007). The village economy does not offer sufficient local employment opportunities to villagers, hence the reason that they are mostly inhabited by old people and their grandchildren (Hebinck and Lent, 2007). This occurs as a result of young people persuing employment in cities such as Gauteng, Cape Town or nearby industrial zones (Hebinck and Lent, 2007)

In such rural areas making a living is mainly through subsistence farming. Small scale farming protects people from poverty and enhances food security (Oumer *et al*., 2013). They usually plant crops such as maize, spinach and cabbage in their small gardens or agricultural land and these crops often provide a major source of food security (Angelsen *et al*., 2011). Small scale farming requires land and water for irrigation, which are two dominant livelihood assets in villages. Rural dwellers also use other natural resources such as forest products to enhance their livelihood strategies (Angelsen *et al*., 2011). Most areas around villages in South Africa are currently experiencing a decline in agriculture resulting from water scarcity caused by droughts as well as overgrazing of rangelands by livestock, causing increased soil erosion and contributing to sediment deposition which, in turn, is a contributing factor to the reduction in water resources (de Satge, 2002). The poor strategies within the rural indigenous communities such as the use of fertilizers and also inadequate management of irrigation systems lead to further degradation of water resources,

Water supply and sewage disposal in such rural areas

In some villages water is accessible through communal taps, with some areas including water troughs for cattle. The communal taps are located at central points where most people can access them easily, but some of them still have to travel long distances to get to the taps (Hebinck and Lent, 2007). Communal water is available at no cost to rural households and is provided by the municipality. These water systems are usually not monitored and are misused in many cases (Homewood, 2005). In some rural communities people draw water from rivers and other natural water sources, which may cause conflict amongst the users as this can be an additional demand on the village where the resource is

situated (Bruns and Meinzen-Dick, 2000). Some houses are built near a water source because of easy access to water. This causes problems because the areas along the river banks in water scarce regions become highly populated, and result in an increase in water pollution (Homewood, 2005). People dump garbage in rivers and they wash their clothes, leaving chemicals that reduce water quality. Pollution is also caused by the leaking of underground pits and septic tanks due to improper sanitation systems, which then contaminate groundwater (Mallick, 2013). Some rural home owners cannot afford to install septic tank systems, so they channel their sewage directly into the local streams (Mpenyana-Monyatsi *et al*., 2012). Reduction in water quality poses threats to local livelihoods and is a great challenge for water resources management (Mallick, 2013).

7.1.2 Peri-urban communities, typified by the township of France near Pietermaritzburg

Peri-urban areas, formally known as township areas, are generally underdeveloped urban areas that are dominated by black people. Townships are usually established on the peripheries of cities and towns and are often associated with large informal settlements (Watkins, 2009). Some parts of the township areas have improved from informal settlements to now include wealthy and middle income areas whilst the others still have people living in poor conditions. As a result of the poor conditions often occurring in informal settlements, the National Housing Act was promulgated and aims to assist low income households to gain access to adequate housing with basic services such as potable water and sanitation on an equitable basis (Mallick, 2013). Much of this has been achieved through Reconstruction and Development Programme. The Municipality receives funding and subsequently undertakes all planning and project activities (Homewood, 2005). However, the development does not change the behaviour of the individual, hence the reason for a need for social learning (Grimshaw and Kala, 2011).

Water supply and sewage systems in peri-urban areas

Highly populated areas such as townships present a higher range of challenges that limit peoples' capabilities as well as posing threats to water resources (Angelsen *et al*., 2011). One issue is that of pressure pumps which determine the availability of water where its supply is reduced due to the high volumes of water being used at the same time. In cases where the pressure is low, there is only a trickle of water instead of full flow, therefore sparse amounts become accessible to households (Chambers and Conway, 1991). There is usually one pump per section for every township community, hence the challenges which arise with water supply (Mallick, 2013). However, improvements can be made in order to increase water supply in peri-urban areas. An example would be adding more pumps coming from different water systems which will allow more water in each area without dealing with lower pressure (Grimshaw and Kala, 2011).

Most townships are poorly developed with inadequate sewerage systems (Grimshaw and Kala, 2011). Population growth exerts additional pressure on the existing systems as they were not built to accommodate a growing population. This causes an overload on the system which leads to a spill. Spills occur as a result of frequent blockages and surcharges, and cause the roads to flood and water resources to be polluted (Gao *et al*., 2011). Township areas often have a limited number of public toilets which are over-used, causing health hazards for the community. In addition, there is poor maintenance of sewerage systems because some people cannot afford plumbers. There are areas that still do not have access to facilities because they are not connected to formal sewerage systems (Tyler, 2005).

7.1.3 Urban communities, typified by the suburb of Scottsville in Pietermaritzburg

Urban communities are generally characterized by formally planned human settlements. This type of settlement highlights the importance of clean, healthy, accessible and affordable water required for their more sophisticated livelihoods (Redwood, 2009). Urban livelihoods are market related, which is why water usage revolves around service (sanitation), irrigation, public space use (recreational gardens), household domestic use, industries and other uses. These are important for job creation which generates income (financial assets) to improve social, human and physical assets. Financial assets are essential to make a living in urban areas (Moser and Dani, 2008).

There can, furthermore, be intense industrialization, with factories and office parks in urban settlements creating a platform for job creation and attracting immigrants into the area. Migrant labour, particularly in South Africa, has a very long history with a great deal of literature around its

socio-economic importance. It is regarded as a major feature in South Africa's social background, and has been so for the past century.

Although rural to urban migration in South Africa has always been primarily an African experience, it has undergone some changes over the years. At the beginning of the 20th century it was often undertaken for relatively short periods (usually by males) and was linked to investment in peasant agriculture (Bonner, 1995). The opportunities started diminishing when Africans became more confined to the local reserves. It does not seem that migrant labour will end anytime soon. More Africans are migrating permanently to urban areas. Up to 5.5 million people moved to urban areas in South Africa between 1996 and 2001, that is a rate of more than a million a year.

7.2 Socio-Economic Implications on Water Resources

7.2.1 Background

Various activities that are performed for survival nowadays exert pressure on water resources and consequently leave many livelihoods under pressure (Mallick, 2013). The impacts of poverty are compounded by the fact that South Africa is faced with other challenges such as HIV/Aids, food shortages, water scarcity and lack of employment (Watkins, 2009). This section will examine the different factors that exert pressure on our water resources. The factors that arise from different livelihood activities will be taken into consideration. In addition, implications of water depletion and degradation will be evaluated and reasons will be put forward on how they lead to water scarcity, accessibility and vulnerability issues in communities, which then limit and constrain livelihoods.

7.2.2 General water related challenges

This section will only address water related challenges that exist within societies, and will focus on the themes that only relate to the case study presented here. Some of the problems related to water and its resources are related to infrastructure, inefficient use of water, climate and planning as well as management (Mallick, 2013). Where dependence is on groundwater, during drought seasons there is not enough water available due to boreholes having very low yields. Also, after long periods of drought, rivers and springs can dry up more rapidly than usual and this is common in rural areas (Homewood, 2005). In areas where there is infrastructure, pumps and pipes may break down and cause waterlogged conditions in soils, and leaks from taps and reservoirs increase the amount of waste water which may then lead to disasters, and dams can silt up. Another issue is the ineffective use of water by people in different communities (Redwood, 2009). Water can be used inappropriately such as being wasted in inefficient irrigation schemes. Some people put in their own connections (illegally) and water their gardens while others do not have drinking water (Tyler, 2006).

Poor planning processes can lead to problems with water supply. For example, too few standpipes can be installed in a village or the wrong size pump can be supplied to the borehole. The water resource, water infrastructure and water use all require management. Good management requires skills and effective institutions, and problems can lie in both areas. Inadequate understanding and skills in maintaining infrastructure can lead to breakdowns, that is, many institutions have a role to play in water provision and management. The lack of coordination and communication can also lead to poor planning and undefined roles and thus delays in responding to problems (Watkins, 2009). These problems are often related to each other, thus poor coordination can lead to poor planning and inappropriate infrastructure (Tyler, 2006). The linkages between these problems are important to understand in order to identify what the underlying problems are, and so to deal with causes and not only symptoms of problems (Redwood, 2009). To understand the uses of water in peoples' livelihoods, it is important to focus on peoples' needs around water services in order to perform their specific livelihood activities and possible new activities. In addition, it is also important to identify issues other than water that contribute to the success of peoples' water related activities (Tyler, 2006).

Poor planning for water infrastructure and ineffective management of water resources can cause diseases as a result of pollution and poor sanitation and sewage systems. Sewage carries excessive nutrients such as nitrogen and phosphorus to stream water (Sayer and Campbell, 2004). The excessive nutrients can lead to decreased levels of dissolved oxygen as a result of the process of eutrophication. Sewage also contributes to increased total solids, including fecal coliforms, as well as increased water temperature. In addition, the dumping of garbage and washing in rivers can leave a

large number of harmful substances in the river causing a reduction in water quality (Mpenyana-Monyatsi *et al*., 2012). Other substances that contribute to water pollution may come from agricultural activities resulting from poor irrigation practices. This can raise soil salinity and evaporation rates, while also enhancing soil erosion (International Institute for Environmental and Development. 1999).

Water pollution does not only contribute to a reduction in the availability of potable water, but it also gives rise to many water related diseases (Mpenyana-Monyatsi, *et al*., 2012). Water-related diseases include waterborne, watershed, water-based and water-related insect vector diseases. Waterborne diseases are diseases caused by drinking contaminated water which consists of pathogenic micro-organisms (Mpenyana-Monyatsi *et al*., 2012). There are many cases of human health issues that are related to water and which have become increasingly dominant in rural communities (Mpenyana-Monyatsi *et al*., 2012). Humans are placing even greater pressure on existing sparse water resources, with this posing threats not only to humans, but to the aquatic ecosystems as well (Ellis, 2000).

Urban areas have an impact on the hydrological processes, with urbanization causing a shift in natural processes (Redwood, 2009). Water storage within the catchment is influenced by the effects of infiltration, land cover wetting, and interception as well as depression storage. Urbanization has a great impact on these natural hydrological processes through the changes introduced to the parameters governing the processes (Cook *et al*., 2009). With the removal of vegetation in the catchment, interception of precipitation is reduced allowing higher volumes of precipitation to reach the ground (Martius and Nuppenau, 2009). Changes in land use by the construction of buildings, roads, parking areas and other facilities in the process of urbanization, increases the impervious proportion in the land area. With urbanization, vegetation cover is drastically reduced (Redwood, 2009). Water drainage system is improved by introducing lined canals, buried sewers to efficiently drain water out from the urbanized area to avoid inconvenience to the public. Changes in hydraulic efficiency of storm water collection systems with artificial channels and storm sewers increase the velocity of flow. In an efficient manner, stormwater from roofs is conveyed to storm drains through gutters and downpipes. Curbs and gutters are designed to convey storm water away from the road surface to storm drains. Thus drainage systems quickly convey the runoff directly into receiving waters compared to pre-urbanized setting (International Institute for Environmental and Development, 1999).

Immigration in urban areas leads to population growth which results in an increase in consumption of vegetal material and increases in commercial activities (Miller and Spoolman, 2008). With that there is an increase in the generation of municipal and industrial wastewater, and even solid waste in the catchment. The sources of stormwater pollutants are diffuse and highly variable. Large cities and urban areas in particular can affect local climate and local hydrology. Urbanization is accompanied by accelerated drainage of water through road drains and city sewer systems, especially in suburbia and the CBD, and this increases the magnitude of urban flood events (Moser and Dani, 2008). Urbanization alters the rates of infiltration, evaporation and transpiration that would normally occur in a natural system. Less replenishing of groundwater aquifers occurs. Together, these various effects determine the amount of water in the system and can result in highly negative consequences for catchments and for the environment as a whole. Therefore, it is vital to learn about and protect our water resources (Grimshaw and Kala, 2011). Urban areas attract both seasonal and permanent migrants, and the livelihood sources in urban areas are clearly more diverse and much less dependent on natural resources than in rural areas. Furthermore, general education levels are also better in urban areas than in rural areas.

7.3 Conclusions

In conclusion, the rural community of Bergville, the township of France and the suburb of Scottsville exhibit distinct and vital characteristics which encompass water availability which is largely historically, infrastructurally and income determined. Their spatial location and socio-economic backgrounds influence livelihood setups. A comprehensive study of the link between water and livelihoods is required to understand the activities that link people with water resources. In addition, negative and positive impacts imposed by human activities can be drawn from this study and can inform decisions about the community. As a result of different characteristics reflected in the three study areas, specific strategies are required to minimise water issues for the Bergville, France and Scottsville communities.

Having identified water related issues in the three communities, I believe that South Africa should prioritise in water planning and managing strategies that will promote sustainability. People should learn that water is an important resource that might not be available for the future generation as a result of the things we do. This can be done through education and awareness in local communities. If this is not done we might suffer the consequences of misusing existing resources. Effective management comes with fixing and maintaining water infrastructure, because that has tremendous impacts on water resources. Poor water infrastructure and lack of services such as a lack in stormwater drainage and garbage disposal systems can lead to reduced water quality. Bergville and France suffer adverse consequences because of poor infrastructure. More funding should be invested for maintenance projects rather than only supply projects. Livelihoods rely intensely on water for survival. We also need to learn from countries that are already water scarce and adopt some of their models and strategies to plan for existing and possible vulnerabilities. An integrated approach is required for effective management in community development. Integrated Water Resources Management (IWRM) in conjunction with community livelihoods needs to be studied to improve the lives of people and water security.

Financial assets are mostly required to enhance infrastructural assets that are required for effective water management. Bergville, France and Scottsville communities displayed links between the livelihoods as a result of their dependence on water for various livelihood activities. Most importantly the social environment, the behaviour of the inhabitants and consequences thereof showed the impacts that communities had on hydrological processes and water. Future studies should look at the critical livelihood assets required to mitigate the drivers of global change in local communities. In addition, studies focusing on industrial water use and management strategies that can reduce water pollution by industries are necessary. Lastly, poor infrastructure is common in most RDP communities and municipalities need to rectify this. The more RDP homes that are built with improper planning will lead to many water resources becoming degraded. The impact of livelihoods on water as well as the limitations that humans endure as a result of water scarcity demonstrates that livelihoods and water are indeed inseparable counterparts of the system.

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CHAPTER 8: CLIMATE CHANGE AND FOOD SECURITY: PERCEPTIONS OF RURAL COMMUNITIES IN KWAZULU-NATAL AND IMPLICATIONS FOR FOOD SECURITY POLICIES

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This chapter is a summary derived from three sources:

- Shisanya, S. Climate Change and Food Security: Perceptions of rural communities in KwaZulu-Natal and implications for food security policies. PhD study, University of KwaZulu-Natal, Pietermaritzburg (Forthcoming, as of February 2014).
- Shisanya, S. and Bogale. A. Assessing household perceptions and vulnerability to climate change: The case of rural small-scale farming communities in Tugela river basin of South Africa (paper in preparation as of February 2014)
- Shisanya, S. and Bogale, A. Farmers' adaptation to climate risk and the impacts on household food security: A case of rural small-scale farming communities in Tugela River Basin, KwaZulu-Natal, South Africa (paper in preparation as of February 2014)

8.1 Introduction

The challenge of attaining sustainable household food security in rural communities remains daunting given the prevalence of poverty and deprivation, with even greater difficulty by two looming challenges: a growing world population and perceived increasingly negative productivity effects from climate change. Food security is multi-dimensional and cannot be understood in isolation from other developmental elements such as social protection, sources of income, rural and urban development, changing household structures, health, access to land, water and inputs, retail markets, education, nutritional knowledge, government policies, conflict, globalisation as well as environmental issues.

Climate change is expected to have serious environmental, economic, and social impacts on South Africa, particularly for rural farmers whose livelihoods depend on the use of natural resources, especially water, agricultural land, climate-sensitive activities such as arable farming and livestock husbandry, and natural resources such as fuel-wood and wild herbs. Vulnerability to climate change is expected to be high among rural communities owing to social, economic and environmental conditions that amplify susceptibility to negative impacts and contribute to low capacity to cope with, and adapt to, climate hazards. There is a need to understand the threats from climate change, formulate policies that will lessen the risks and to take action at household level to enhance household food security.

This study focused on evaluating in specific terms the interaction between household food security and rural communities' perception of climate change in KwaZulu-Natal and to use the findings to enhance policy, dialogue and advocacy in respect of food insecurity. The key research questions for the study were:

1. What are the rainfall and temperature patterns in KwaZulu-Natal over time as determined by recorded meteorological stations' data?
2. What are the perceptions of households on climate change and to what extent are they vulnerable?
3. What is an effective community-based model for adapting to climate change and impacts on household food security?

The results of this study were obtained through a survey of 200 households living in the Maphephetheni area of uMzinyathi District, KwaZulu-Natal, South Africa. This was accompanied by community conversations that were meant to obtain a deeper understanding of the subject matter. Information was collected on household assets including human, financial, natural, social and physical assets. The collected data were then fed into the SPSS statistical analysis programme and a Vulnerability Index for each household was generated. Further to this, household food security levels

were determined using the Household Food Insecurity Access Scale (HFIAS). Relationships between household vulnerability, household food security and their characteristics were then analysed. The findings confirm that community members were well aware of the changes that were occurring in the climate of their area and that households were responding to these changes in the context in which they were living. Households were found to be vulnerable to climate change and subsequently this had negative impacts on household food security. Despite households having the desire to explore more options with the changing climate, they lacked resources that would enable them to overcome any negative impacts of climate change.

8.2 Assessing Household Perceptions and Vulnerability to Climate Change

Climate variability is projected to increase with more frequent extreme weather events affecting all aspects of the hydrological cycle, altering the balance between food demand and supply, with regions such as South Asia and Africa expected to be particularly vulnerable due to their large population, predominance of agriculture and limited resource base (Aggarwal and Singh 2010). Indeed, heavy precipitation and related floods, landslides, storm surges, and relatively higher temperatures have had devastating consequences in several parts of the world in recent years. Such global climatic changes will affect agriculture through their direct and indirect effects on crops, soil, livestock and pests (IPCC 2007).

Agriculture constitutes the backbone of most developing world economies, being the largest contributor to GDP, the biggest source of foreign exchange, accounting for about 40% of Africa's foreign currency earnings, and the main generator of savings and tax revenues, with about two-thirds of the continent's manufacturing value-added tax based on agricultural raw materials (NEPAD 2002; Wiggins 2006). Agriculture remains crucial for pro-poor economic growth in most African countries, as rural areas support 70 – 80% of the total population. More than in any other sector, improvements in agricultural performance have the potential to increase rural incomes and purchasing power for large numbers of people to lift them out of poverty and food insecurity (Ludi, 2009).

Water plays a fundamental role in food security and also plays a critical role in the health and nutrition systems, as an input into industrial production, and maintaining balance in the environmental and ecosystem services. Water availability impacts directly on the four food security pillars (availability, access, utilization and stability). More than one billion people of the world's poor rural communities are without sufficient drinking water and appropriate sanitation (Polak *et al*., 2002). By 2050, water availability levels are expected to decline by 50% on average, under normal climate conditions, as a result of population growth alone. It is estimated that 15% of the world's population live with relative water abundance with the majority experiencing moderate to severe water stress, most of whom are in the rural areas (Vorosmarty *et al*., 2005). For Africa it is estimated that 25% of the population (approximately 200 million people) currently experience water stress, with more countries expected to face high risks in the future which may lead to increased food and water insecurity for at-risk populations, undermining growth (Ludi, 2009). Global food demand has increased markedly over the past 50 years due to the large increase in human population and additional quantities of food will have to be produced from the same or even shrinking land resources due to increasing competition for land from the non-agricultural sector (Aggarwal and Singh, 2010).

Irrigated agriculture has played a major role in boosting agricultural yields and outputs in order to feed the world's growing population and was a major component of the green revolution package, contributing to price stability through greater control over production and increased scope for crop diversification (Ringler *et al*., 2010). Irrigation accounted for 38% of the cereal harvested in developing countries, equivalent to 59% of cereal production in the mid-1990s while only 18% irrigated cereal area contributed 23% of total cereal production in the developed countries (Rosegrant *et al*., 2002). This implies that most of the agricultural production still comes from predominantly rain fed lands. Irrigation has contributed to water scarcity, water pollution, and ecosystem degradation to the extent that without some form of water control across the world's river basins, freshwater lakes and associated aquifers, local, regional and global food security will not be possible (FAO, 2008). Although there has been rapid agricultural and economic growth up to 2007, food security has remained out of reach for more than 800 million people (Ringler *et al*., 2010).

Water security is defined as 'availability of, and access to, water in sufficient quantity and quality to meet livelihood needs of all households throughout the year, without prejudicing the needs of other

users (Calow *et al*., n/a). At any one time around the globe, there are reports of the devastating impacts of either too much or too little or too polluted water among poor rural communities with direct effects on household food security. Many factors underly household food insecurity among rural communities, but an inadequate and unreliable supply of water is the most important single factor (Merrey *et al*., 2003). Smallholder and subsistence farmers are likely to suffer complex, localized impacts of climate change, having limited adaptive capacity with a likelihood of experiencing any negative effects of climate change on yields of tropical crops with high vulnerability to extreme events (Aggarwal and Singh, 2010). Oversimplified perspectives on agricultural water use in the context of water management can lead to serious negative impacts on household food security and well-being of rural farming communities. Ngigi (2003) demonstrated that basic low-cost strategies to capture rainfall concentrate and store it, and the re-use of grey water at household level can contribute hugely to improved diets, nutrition and cash incomes.

Practically all soil processes important for agriculture are directly affected in one way or another by climate, where precipitation patterns and amount, and temperature can influence soil water content, runoff, erosion, salinization, biodiversity as well as organic carbon and nitrogen content (Aggarwal and Singh, 2010). Food and water security is largely determined by activities undertaken at the local or national scale and global factors, such as the global trade and finance systems, climate change and climate policy, energy policy, demographic changes, including migration and foreign policies also affect local food and water security (Ringler *el al*., 2010). It is anticipated that the developing countries will be affected significantly and in highly uncertain ways by food and water security, largely because poverty levels are high and developing country capacity to adapt to global change is weak. To ensure future water and food security, greater attention is now needed on adaptations to climatic change, which calls for increased diversification, improved land use and natural resource management policies, increased use of biofuels, improved risk management through early warning systems and crop insurance, and wastewater recycling in agriculture (Aggarwal and Singh, 2010).

Climate change will superimpose itself on socio-economic and environmental drivers that inform water and food security policies by modifying and increasing future risk and vulnerability of crop production related to water supply and water availability (FAO, 2008). In order to adapt to climate change, farmers must first perceive that changes are taking place. Hansen *et al*. (2004) observed that farmers' memory of past climatic variability may be distorted in systematic ways, reflecting wishful thinking by distortions consistent with decision goals as well as being shaped by personality characteristics and pre-existing beliefs. Easterling *et al*. (2007) indicated that adaptation strategies need to take a number of factors into consideration, including globalization, and population and income growth, and the resulting changes in food preferences and demand, as well as the socio-economic and environmental consequences of alternative adaptation options.

With regard to agricultural production and water, climate change adaptation may include (Bates *et al*., 2008):

1. Adoption of varieties and species of crops with increased resistance to heat stress, shock and drought;
2. Modification of irrigation techniques;
3. Adoption of water-efficient technologies to 'harvest' water, conserve soil moisture (e.g. crop residue retention, zero-tillage), and reduce siltation and saltwater intrusion;
4. Improved water management to prevent waterlogging, erosion and nutrient leaching;
5. Modification of crop calendars, i.e. timing or location of cropping activities;
6. Integration of the crop, livestock, forestry and fishery sectors at farm and catchment levels;
7. Implementation of seasonal climate forecasting; and / or
8. Land use changes that take advantage of modified agroclimatic conditions.

There is vast literature on food security in terms of definitions, dimensions, causes and impacts but there is still limited analysis of the relationship between water and food security as observed through the rural communities' lens. A study of Canadian farmers showed that farmers' responses vary when faced with the same climate stimuli, even within the same geographic area, given different agricultural systems and market systems in which farmers operate as well as different individual characteristics and contexts such as personal managerial style and entrepreneurial capacity and family circumstances (Maddison, 2007; Nhemachena and Hassan, 2007).

Aggarwal and Singh (2010) observed that adaptations should occur at multiple scales, including the individual, society, farm, village, watershed, and national level which may include the following:

1. Development of resource-conserving technologies;
2. Augmenting production and its sustainability;
3. Increasing income from agricultural enterprises;
4. Improved land use and natural resource management policies and institution;
5. Improved risk management through early warning systems and crop insurance; and
6. Recycling wastewater and solid wastes in agriculture.

This study will look at a systems perspective to food and water security by investigating the following key areas:

1. What are the emerging climate risks affecting food security of the rural farming households in Tugela river basin?
2. What are the levels of household food security in Tugela river basin?
3. What is being done at household level to cope with climate risks to reduce impacts on household food security?
4. What policies and investments can be put in place to improve household food security among the rural farming communities?

8.3 Materials and Methods

The conceptual framework employed in the study is shown in **Figure 8.3.1**. Agricultural climate risks are embedded in a series of changes in agricultural climate environment, including a combination of forces in social dimension referred to here as “farmers’ exposure-sensitivity”. Farmers’ agricultural outputs become changeable and reflect farmers’ food in/security. Farmers’ adaptation is also affected by other off-farm activities including human, social, environmental and economic which may present new risky opportunities.

The Tugela River Basin community under study is found in the uMzinyathi District Municipality (DM) (District Code: DC 24), one of the eleven District municipalities of the province of KwaZulu-Natal, South Africa. 2011 population estimates indicated that the South African population was at 50 million people with 21.3% of them living in KwaZulu-Natal. The total population of uMzinyathi was estimated at 514 840 according to the Stats SA (Mid-year 2011). Some 13% accounted for children less than five years of age, 7% accounted for sixty years of age and above and 55% of the population are females, 45% are males. It is estimated that 72% of the population is under 35 years of age. Approximately 82% of the population is located within the rural areas. A community survey of 2007 estimated that 93 770 (4.4%) households were found in uMzinyathi DM compared to a total of 2 117 274 households in KwaZulu-Natal (Stats SA 2012).

uMzinyathi (**Figure 8.3.2**) is in a deep rural area and has a mountainous topography with poor basic infrastructure. The poverty index of the district is at 93% (Stats SA). The District was identified in 2001 as one of the Presidential nodes due to its status as one of the municipalities with the highest poverty rate sitting at 68%. In 1996, 9% of the population lived below $1 per day and 26.2% lived below $2 per day. This figure improved to 1.6% living below $1 per day and 11.7% below $2 per day by 2009.

There is a weak social base, with the district having the highest levels of unemployment and illiteracy in KwaZulu-Natal. Only 26.4% of the adult population has completed primary school education. The unemployment challenge in the Umzinyathi DM is significant, with an estimated unemployment rate of around 46% in 2007.

In uMzinyathi District Municipality, the HIV/AIDS infection rate for 2005 was 23% which is lower than the national average of 27.9% and significantly lower than the 37.5% average for the province of KwaZulu-Natal, the province has the highest HIV prevalence rate in South Africa (uMzinyathi District Municipality, 2009).

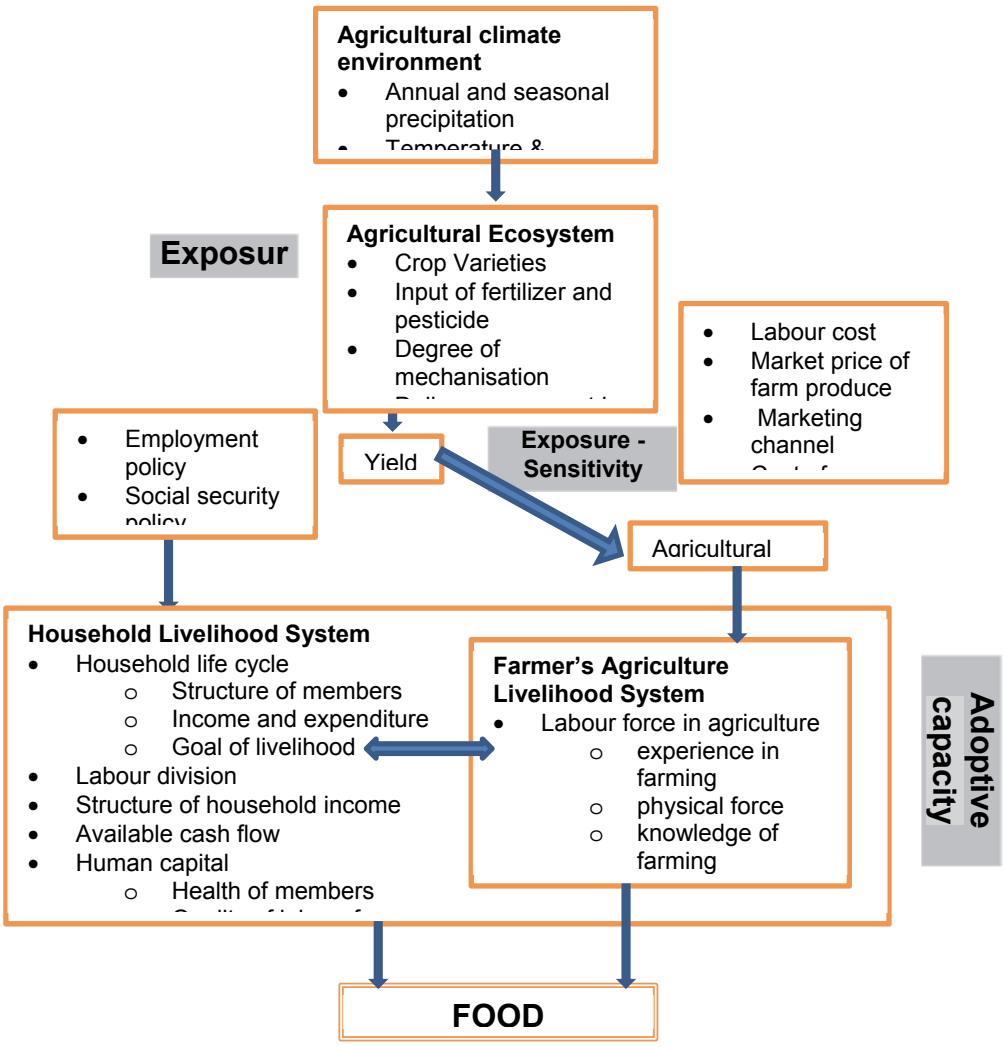


Figure 8.3.1 Conceptual framework of farmers' adaptation to climate risk with resulting impacts on household food security (Adopted from Chen *et al.*, 2010)

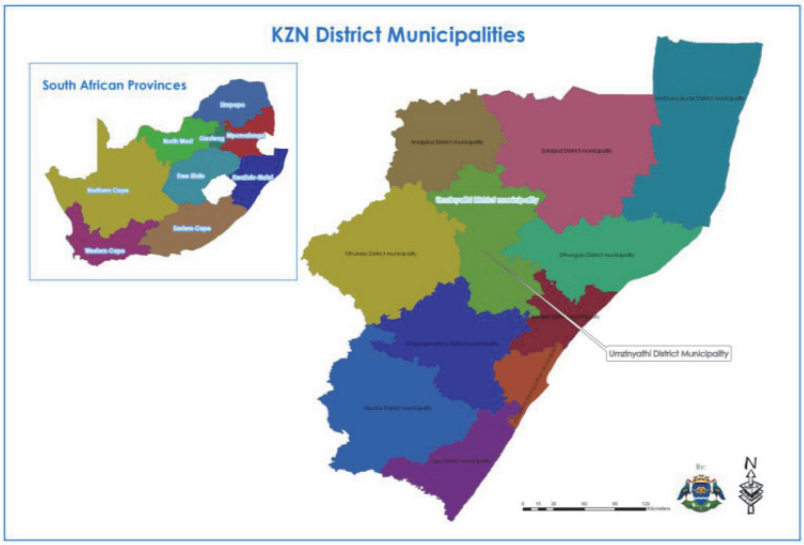


Figure 8.3.2 Location of the study area - Umzinyathi District municipality of KwaZulu-Natal

Key informant interviews and household semi-structured questionnaires were used to identify individual farmer's specific attributes of livelihood and household food insecurity. Key informants helped to give a general picture of the community and a reflection on past climate risks. Data were collected on demographic characteristics and socio-economic conditions of families / households which included a review on yields and incomes of households from both agricultural farming systems and non-farm activities. Information was gathered on agricultural inputs and lastly open ended questions were asked about perceptions on agricultural resources, e.g. precipitation and temperature, impact of government policies, markets, availability of financial credits and levels of technological innovations. Questions were also asked on farmers' adaptation to counter perceived agricultural risks. Food security data were collected using the Household Food Insecurity Access Scale (HFIAS) tool (**Table 8.3.1**; Coates *et al*., 2007). Data were then analysed using SPSS.

The Household Food Insecurity Access Scale (HFIAS) was developed by the Food and Nutrition Technical Assistance (FANTA) project of US-AID. The HFIAS was preferred over other scales for this study because of its extensive use in many other studies such as those of Webb *et al*. (2006), Melgar-Quinonez *et al*. (2006), Frongillo and Nanama (2006), Swindale and Bilinsky (2006), Ballantine *et al*. (2008), Oketch *et al*. (2011), Kirkland *et al*. (2011) and Shisanya and Hendricks (2010). The HFIAS tool consists of nine yes / no questions (**Table 8.3.1**) to which a respondent is to respond to and represents universal domains of insecure access to food (Coates *et al*., 2007). The questions represent a generally increasing severity of food insecurity. The questions probe a household's experience of insufficient access to food in the past four weeks. Each question is followed by a frequency of occurrence question, recorded as Rarely (=1), Sometimes (=2), and Often (=3). Three domains are reflected in the HFIAS which include; domain A - Anxiety about household food supply (Question 1), domain B - insufficient quality of food consumed (Questions 2, 3 and 4 and domain C - insufficient quantity of food consumed (Questions 5, 6, 7, 8 and 9). Based on the responses, the HFIAS score is computed and it measures the degree of food (access) insecurity. The HFIAS scores range from 0 to 27; the higher the score, the greater the food (access) insecurity of the household.

Household Food Insecurity Access Prevalence (HFIAP) can also be computed, and this categorizes households into four levels of household food insecurity: food secure, mildly food secure, moderately food secure and severely food insecure (Coates *et al*., 2007). The categorization scheme is designed to ensure that a household's set of responses will place it into a single, unique category. A food secure household experiences none of the food insecurity (access) conditions, or experiences only worry, but then rarely so. A mildly food insecure (access) household worries about not having enough food sometimes or often, and / or rarely eat a monotonous diet or less preferred food. The household does not cut back on quantity nor experiences any of the three most severe conditions (going a whole day without eating, going to bed hungry or running out of food). A moderately food insecure household sacrificed quality more frequently by eating a monotonous diet or less preferred food sometimes or often, and / or has had to start to cut back on quantity by reducing size of meals or number of meals rarely or sometimes. A severely food insecure household has deteriorated to cutting back meal size or number of meals often, and / or experiences any of the three most severe conditions (going a whole day without eating, going to bed hungry or running out of food), even as frequently as rarely. Any household that experiences one of these three conditions even once in the past 30 days is considered as severely food insecure.

Table 8.3.1 Household Food Insecurity Access Scale (HFIAS) generic questions

No.	Occurrence Questions
	Domain A: Anxiety and uncertainty about the household food supply
Q1	In the past four weeks, did you worry that your household would not have enough food?
	Domain B: Inadequate Quality (includes variety and preferences of type of food)
Q2	In the past four weeks, were you or any household member not able to eat the kind of food you preferred because of a lack of resources?
Q3	In the past four weeks, did you or any household member have to eat a limited variety of food due to a lack of resources?

Q4	In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?
	Domain C: Less Quantity or Insufficient Food Intake
Q5	In the past four weeks, did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food?
Q6	In the past four weeks, did you or any household member have to eat fewer meals in a day because there was not enough food?
Q7	In the past four weeks, was there ever no food to eat of any kind in your household because of lack of resources to obtain food?
Q8	In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food?
Q9	In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?

8.4 Vulnerability Assessment, Livelihoods Analysis and Policy Implications

This study analyzed the vulnerability of households of rural farming communities in Tugela River Basin to climate change by creating vulnerability indices and comparing these indices across households. An index of household vulnerability to climate change was constructed and presented for 200 households. The vulnerability analysis followed the IPCC (2001) definition of vulnerability, which explains it as a function of adaptive capacity, sensitivity, and exposure. Thus, the integrated vulnerability assessment approaches were adopted to combine biophysical and socio-economic indicators. Positive values were attached to adaptive capacity and negative values to sensitivity and exposure. Results are shown in **Figure 8.4.1**.

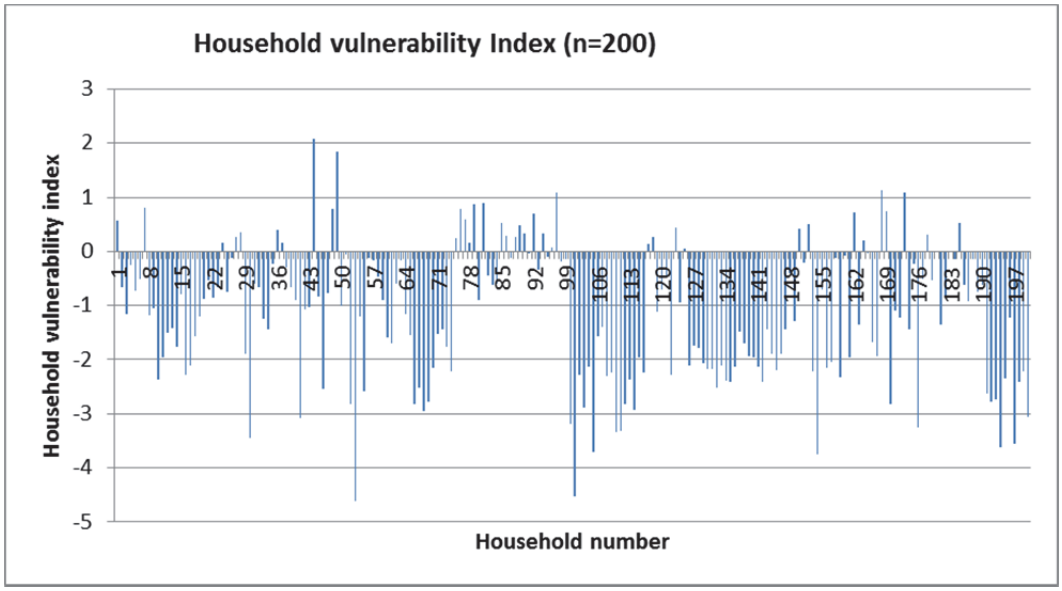


Figure 8.4.1 Individual household vulnerability index

The statistical analysis of rainfall data from 1981 to 2009 in the Tugela River Basin showed a trend of generally decreasing levels of precipitation. Over the 17 years for which temperature records were examined, temperature showed a generally increasing trend. Farmers' perceptions of climatic variability were in line with climatic data records. Indeed, farmers in the Tugela River Basin of South Africa were able to recognize that temperatures have increased and there has been a reduction in the levels of rainfall. Measures need to be put in place to mitigate the observed changes in order to reduce future negative impacts. Although farmers were well aware of climatic changes and the different crop management practices to adapt to the changing climate, famers remained very vulnerable to climate change in future. The main adaptation strategies of farmers in the Tugela River Basin included growing of different crop varieties, planting different fields at different times, use of organic fertilizers, leaving some fields fallow, practising minimum tillage, planting trees alongside

slopes, cropping in valley bottoms and carrying out mixed cropping. It is, however, one thing for farmers knowing about the different mitigating practices, but another to effectively practise them. Further research is required to investigate to what extent farmers are effectively undertaking the different mitigating practices.

The changing climate conditions may have a profound effect on the constitution and impacts of pests and diseases. Selection of varieties and crops that are resistant to the new pests and diseases may be necessary. Support to the farming communities through appropriate and effective extension services will be necessary to deal with the new crop growing conditions arising among the agricultural community. The possibility of utilizing the Tugela River for irrigation of crops needs to be investigated in order to compensate for the generally decreasing levels of rainfall in the region.

The results showed how roles of various development agents, especially the government, are important in rural farming communities' adaptation now and in the future. The analysis revealed a rural community that is vulnerable at different levels to climate fluctuations now and in the future. The results indicated that vulnerability to climate change is highly masked by the fact that the community relies heavily on government grants for their livelihoods and that agricultural activities are generally shrinking and becoming unimportant to the communities (**Figure 8.4.2**). This situation makes poor households vulnerable to national policy choices and politics. It is essential that creative and meaningful solutions be found to enable the rural community in the Tugela river basin to become self-reliant and look beyond government grants that can be abolished by a simple change in government policy. These results do not inform policy makers how to design adaptation. The results do suggest, though, that activities other than agriculture might usefully form part of overall adaptation strategies including engaging in alternative income generating activities to compensate for the delicate agricultural activities that are totally reliant on the decreasing levels of rainfall.

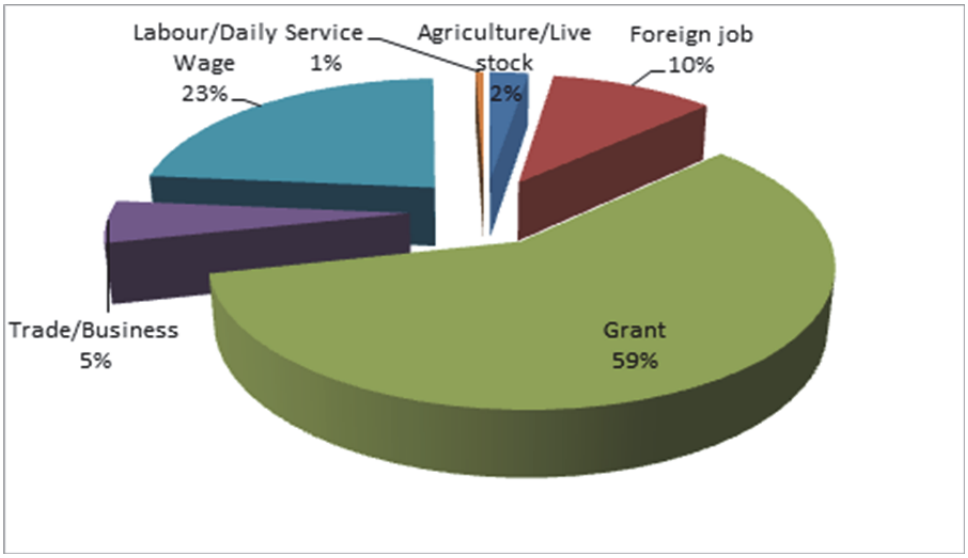


Figure 8.4.2 Percentage of household livelihoods (N=200)

The results also showed that improving crop production contributed to reduction in household vulnerability. Thus, policy interventions should focus on strengthening household crop production through mitigating and coping practices aimed at reducing the damages from climate change. This should include encouraging the crop management practices that were seen to reduce vulnerability of households to climate change. Policies that support coping strategies at the household level should encourage ownership of income generation and asset holding that will enable households to cope in the event that government changes its policy on giving grants. Other mitigation strategies might include water harvesting, resource conservation and especially management of land, irrigation systems, provision of household and agro-ecological extension packages, supporting social networks already existing in the areas in the form of Self Help Groups and a system of drought early warning systems.

8.5 More Details on Household Food Security, its Relationship to the Agricultural Climate Environment, Agricultural Ecosystems, Water Management, and Farmers' Agricultural and Household Livelihood Systems

This study set out to evaluate farmers' adaptation to climate risk and the impacts on household food security among the rural small-scale farming communities in Tugela River Basin, KwaZulu-Natal, South Africa. The study assessed the responses of household representatives (N = 200) to questions that gave information on agricultural climate environment, farmers' exposure-sensitivity, famers' agricultural outputs and farmers' food in/security. More information was generated by farmers response to issues related to off-farm activities including human, social, environmental and economic. Focus group discussions were held to get clarity and deeper understanding on some of the issues raised in the questionnaire.

Household food security

Household food security was assessed using the HFIAS procedure described by Coates *et al*. (2007). Household food insecurity access related to domains is shown in **Table 8.5.1**. All households analysed were anxious and uncertain about food supply. Most households did experience the other two food insecurity domains (poor quality food and inadequate quantity of food consumption).

Table 8.5.1 Household responses to Household Food Insecurity Access-related domains, Tugela rural farming households (N = 200)

Household Food Insecurity Access-related Domains	Percentage
1. Anxiety and uncertainty	100.00
2. Households with insufficient food quality	89.00
3. Insufficient food intake and its physical consequences	84.00

Table 8.5.2 Household Food Insecurity Access-related conditions among Tugela rural farming households (N = 200)

Food insecurity Conditions	Frequency of Experience of Food Insecurity Condition in Past 4 weeks (%)			
	Once or twice	Three to ten times	More than 10 times	Total
Anxiety and uncertainty about food supply	12.00	36.00	52.00	100.00
Poor quality food consumption coping strategies				
Un-preferred kinds of food	14.50	25.50	60.00	100.00
Limited variety of food	16.50	26.50	57.00	100.00
Un-preferred food	15.00	23.50	61.50	100.00
Inadequate quantity of food coping strategies				
Ate a smaller meal than they needed	16.50	22.50	61.00	100.00
Ate fewer meals in a day	22.5	15.50	62.00	100.00
Experienced total lack of food due to lack of resources	15.50	59.00	25.50	100.00
Went to sleep at night hungry due to lack of food	18.00	67.00	15.00	100.00
Going whole day and night without eating anything due to lack of food	37.00	48.00	13.00	100.00

Further disaggregation of food insecurity is presented as Household Food Insecurity - Access related to conditions (**Table 8.5.2**). The frequency of households experiencing anxiety and uncertainty about household food supply was high. Households consumed poor quality food by eating un-preferred kinds of food; they ate a limited variety of food and also ate un-preferred food at higher frequencies. Similarly households consumed an inadequate quantity of food. Most households experienced the mild coping strategies more frequently such as eating a smaller meal. As the quantity of food coping strategies progressed in severity, the frequencies experienced among households reduced with fewer households going a whole day and night without eating anything (most severe) less frequently.

Further household food security assessment was shown by calculating the Household Food Insecurity Access Scale Score (HFIAS Score; **Figure 8.5.1**). Most households have a high score of food insecurity, indicating the high prevalence of food insecurity among households in Tugela River Basin.

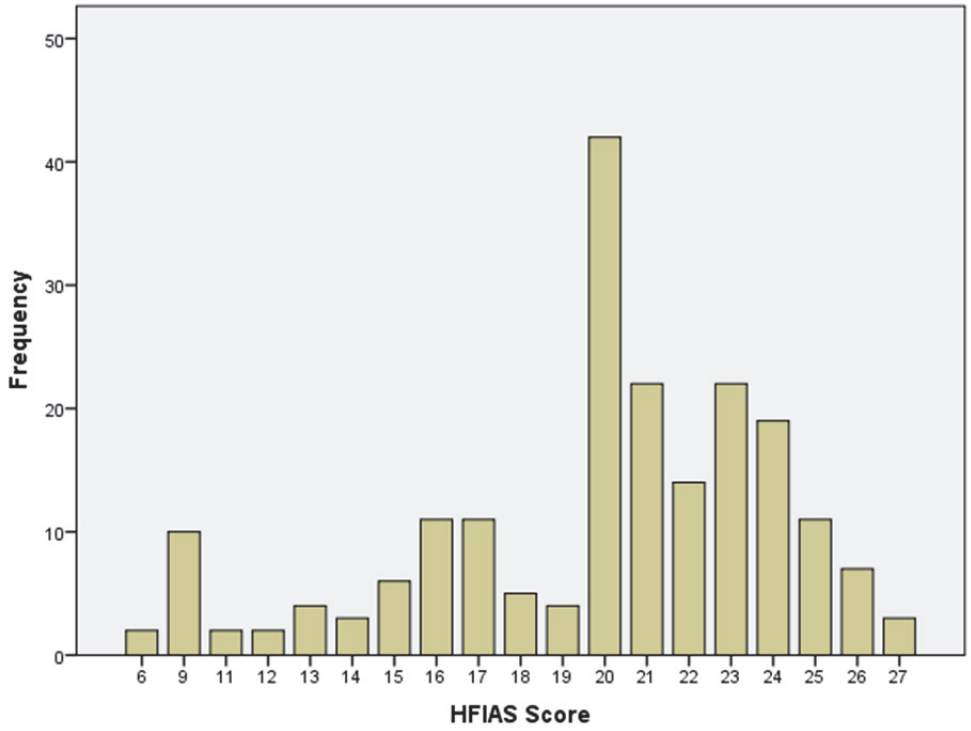


Figure 8.5.1 Bar chart of frequency of Household Food Insecurity Access Scale (HFIAS) Scores among Tugela rural farming households (N = 200)

A final presentation of the level of food insecurity was placing individual households into specific food security categories as they responded to the nine HFIA scale questions (**Table 8.5.3**). Most households in the Tugela River basin were found to be severely food insecure.

Table 8.5.3 Proportion of household in each food security category, Tugela rural farming households (N = 200)

	Household Food Security Categories (Coates *et al*., 2007)			
	Food secure	**Mildly food insecure**	**Moderately food insecure**	**Severely food insecure**
Number of household in each category	10	34	42	114
Proportion of households in each category (%)	5.00	17.00	21.00	57.00

Through group discussions, a number of explanations were given for the high prevalence of food insecurity among surveyed households. Respondents explained that they relied on purchases for their food supply. Household incomes were mainly from remittances which were limited and unreliable. Similar results were realised from a study among households participating in community gardens in the region (Shisanya and Hendricks, 2010). Food from agricultural activities was also unreliable due to the erratic nature of weather experienced in the area. Generally the area is agriculturally marginal confirming the Wiebe *et al*. (2001) observation that the imbalance distribution of land by the apartheid system resulted in many black African communities occupying marginal land.

Agricultural climate environment

Analysis of the relationships between the agricultural climate environment and household food security is shown in **Table 8.5.4**.

Table 8.5.4 Pearson's correlation coefficient between household agricultural environment and measures of food security among Tugela rural farming households (N = 200)

	Measures of Household Food Security			
Agricultural Climate Environment	**Overall HFIAS Score**	**Quality of food**	**Quantity of food**	**Anxiety over food supply**
Perceived changes in the mean temperature	0.203**	0.139*	0.246**	0.025
	(0.004)	(0.049)	(0.000)	(0.724)
Worried that household will face recurrent drought	0.219**	0.232**	0.170*	0.184**
	(0.002)	(0.001)	(0.016)	(0.009)
Worried that household will face recurrent floods	0.170*	0.187**	0.136	0.110
	(0.016)	(0.008)	(0.055)	(0.121)
Worried that household will face late onset of rain	0.072	0.072	0.051	0.093
	(0.314)	(0.314)	(0.475)	(0.190)
Worried that household will face shorter rain season	-0.047	-0.027	-0.076	0.058
	(0.510)	(0.705)	(0.284)	(0.417)
Household vulnerability to climate change	-0.920**	-0.807**	-0.898**	-0.513**
	(0.000)	(0.000)	(0.000)	(0.000)
Household copes or adapts to climate variability by praying for rainfall	-0.246**	-0.195**	-0.295**	0.031
	(0.000)	(0.006)	(0.000)	(0.666)

Household concern over the agricultural climate environment was recorded as their worry over climatic occurrences. Households which perceived an increase in temperature had corresponding increased household food insecurity, affecting both quality and quantity of food consumption. Similarly, households which were concerned about recurring droughts, recurring floods and a late onset of rains, exhibited high levels of food insecurity. Households that prayed for rainfall did show corresponding high levels of food insecurity. Overall, households that were vulnerable to climate change were shown to have high levels of food insecurity.

Agricultural ecosystems / practices

An analysis of household agricultural ecosystems is presented in **Table 8.5.5**. Households which frequently received information on agricultural practices displayed lower levels of food insecurity.

An analysis was carried out on some of the agricultural practices farmers were advised to follow considering the three measures of food security (food quality, food quantity and anxiety over food supply). A low level of food insecurity was observed among households which practiced across-slope conservation cultivation methods and utilised valley bottoms for crop production. These practices contributed to households having more area for crop production, directly contributing to food availability to households. Households which used organic manure in their fields also registered a lower level of food insecurity resulting from subsequent expected high yields. Households which

intentionally practised crop diversification also showed decreased levels of food insecurity. Households which diversified from farming to non-farming activities did show a lower level of food security as the proceeds from the non-farming activities were used to purchase food.

A further assessment was undertaken on the relationship between household water management and levels of food security (**Table 8.5.6**). Households that had received training on water and soil management showed lower levels of food insecurity resulting from increased quantity of food consumed in households.

Table 8.5.5 Pearson's correlation coefficient between household agricultural ecosystems and measures of food security among Tugela rural farming households (N = 200)

Agricultural Ecosystem	Measures of Household Food Security			
	Overall HFIAS Score	**Quality of food**	**Quantity of food**	**Anxiety over food supply**
Household received advice / information on agricultural practices	-0.192** (0.007)	-0.173* (0.014)	-0.156* (0.028)	-0.221** (0.002)
Worried that household will face crop disease	-0.025 (0.724)	-0.010 (0.886)	-0.050 (0.481)	0.057 (0.423)
Worried that household will face price decline of farm products	0.245** (0.000)	0.190** (0.007)	0.265** (0.000)	0.105 (0.140)
Worried that household will face price increase of inputs	0.262** (0.000)	0.212** (0.003)	0.281** (0.000)	0.096 (0.178)

****** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
Note: Numbers in brackets refer to *P* values

Table 8.5.6 Pearson's correlation coefficient between farmers' household water management and measures of food security among Tugela rural farming households (N= 200)

Household Water Management	Measures of Food Security			
	Overall HFIAS Score	**Quality of food**	**Quantity of food**	**Anxiety over food supply**
Time taken to get water from nearest water source (minutes)	0.042 0.554	0.013 0.855	0.041 0.565	0.072 0.309
Money spent to bring water to household	0.048 0.496	0.052 0.461	0.039 0.579	0.009 0.903
household received information on water management	0.057 0.424	-0.014 0.848	0.084 0.237	0.021 0.773
Received training on water and soil management	-0.157* 0.026	-0.090 0.204	-0.200** 0.004	0.025 0.724
Rain water harvesting for irrigation	-0.056 0.435	0.004 0.950	-0.112 0.113	.114 0.108

****** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
Note: Numbers in brackets refer to P values

Farmers' agriculture livelihood system

Components of farmers' agricultural livelihood systems were compared to the measures of household food security (**Table 8.5.7**). Households which received training in water and soil management showed a lower level of food security, impacting more on the quantity of food available to households. Households which intentionally practised crop diversification showed a lower level of food insecurity, more specifically to quality and quantity of food available to households.

Households which diversified from farming to non-farming activities had decreased levels of food insecurity in all the categories of food insecurity measures. Differential planting time of different fields contributed to lower levels of household food insecurity. The use of organic manure in crop production significantly contributed to decreasing the level of household food insecurity.

Table 8.5.7 Pearson's correlation coefficient between farmers' agriculture livelihood system and measures of food security among Tugela rural farming households (N = 200)

	Measures of Food Security			
Farmers' Agriculture Livelihood System	**Overall HFIAS Score**	**Quality of food**	**Quantity of food**	**Anxiety over food supply**
Received training on water and soil management	-0.149*	-0.090	-0.200**	0.025
	(0.035)	(0.204)	(0.004)	(0.724)
Households practice crop diversification	-0.234**	-0.193**	-0.260**	-0.040
	(0.001)	(0.006)	(0.000)	(0.578)
Households diversify from farming to non-farming activities	-0.460**	-0.478**	-0.379**	-0.332**
	(0.000)	(0.000)	(0.000)	(0.000)
Households plants different fields at different times	-0.156*	-0.141*	-0.176*	0.022
	(0.027)	(0.047)	(0.013)	(0.762)
Households uses organic manure in crop production	-0.368**	-0.366**	-0.312**	-0.279**
	(0.000)	(0.000)	(0.000)	(0.000)
Households prays for rainfall	-0.246**	-0.195**	-0.295**	0.031
	(0.000)	(0.006)	(0.000)	(0.666)
Households utilises moist valley bottoms for crop production	-0.276**	-0.289**	-0.211**	-0.259**
	(0.000)	(0.000)	(0.003)	(0.000)
Total income from sale of crops	-.156*	-.150*	-.173*	.034
	(.027)	(.034)	(.014)	(.637)

**Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
Note: Numbers in brackets refer to *P* values

Households which prayed for rain also showed significant decrease in levels of household food insecurity. Utilizing moist valley bottoms for crop production had significant impact on decreasing food insecurity in all measures of food insecurity. Sale of crop produce did contribute to lowering the levels of household food security.

Farmers' household livelihood system

A relationship between farmers' household livelihood system was assessed (**Table 8.5.8**). Incomes from remittances significantly contributed to the quantity of food consumed in households. On the other hand there was a significant relationship between incomes from disabilities and the quality of food consumed. Incomes from pensions significantly reduced anxiety over household food supply.

Table 8.5.8 Pearson's correlation coefficient between farmers' household livelihood system and measures of food security among Tugela rural farming households (N= 200)

Farmer's Household Livelihood System	Measures of Food Security			
	Overall HFIAS Score	**Quality of food**	**Quantity of food**	**Anxiety over food supply**
Number of children living in household	0.002	-0.002	0.001	0.019
	(0.975)	(0.975)	(0.990)	(0.791)
Number of adult female living in household	-0.108	-0.081	-0.098	-0.131
	(0.127)	(0.253)	(0.167)	(0.065)
Number of adult male living in household	-0.026	-0.084	0.032	-0.071
	(0.720)	(0.237)	(0.650)	(0.318)
Sex of household head	-0.061	-0.074	-0.048	-0.023
	(0.389)	(0.295)	(0.499)	(0.751)
Age of household head	-0.040	-0.109	0.038	-0.125
	(0.575)	(0.125)	(0.591)	(0.077)
Income per month from pension	-0.039	0.022	-0.040	-0.172*
	(.587)	(.762)	(.573)	(.015)
Income per month from remittances	-0.113	-0.048	-0.142*	-0.078
	(0.111)	(0.495)	(0.045)	(0.274)
Income per month from child grant	-0.070	-0.028	-0.104	0.011
	(0.326)	(0.694)	(0.143)	(0.873)
Income per month from disability grant	-0.129	-0.189**	-0.101	0.045
	(.069)	(.007)	(.155)	(.524)
Total Household income per month	-0.005	-0.005	0.009	-0.063
	(0.939)	(0.947)	(0.897)	(0.379)

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
Note: Numbers in brackets refer to *P* values

8.6 Conclusions from the Findings and Recommendations

In this Chapter an attempt has been made to analyse farmers' adaptation to climate risk and the impacts on household food security among 200 rural small-scale farming communities in Tugela River Basin, KwaZulu-Natal, South Africa. The study found that only 5% of surveyed households were food secure with the remainder having varied levels of food insecurity. Climate risk was analysed by looking at household experience of the agricultural climate environment; household exposure to climate risk, denoted by agricultural ecosystem; and household adoptive capacity, studied by considering the interaction between household and agricultural livelihood systems.

The results showed that households were concerned about their agricultural climate environment, overall represented by household vulnerability to climate change and this had direct impacts on household food security. Providing farmers with information on good agricultural practice, including water and soil management, had the direct impact on reducing the level of household food insecurity. Such information included coping mechanisms with regard to adverse climatic conditions, hence the need for farmers' access to appropriate extension services. Farmers' preparedness for adverse climate outcomes was necessary, given that out of their experience they knew of some of these outcomes including outbreak of crop and animal diseases. Farmers did not have enough resources and needed external support to be able to prepare for these climate challenges.

Boosting household incomes played an important role in reducing the impacts of climate risk to household food security. Diversifying from farming to non-farming activities was important for the households that needed incomes. Households that received government grants showed higher resilience to climate risk impacts on household food security. Mechanisms to protect farmers from higher input prices and lower farm product prices need to be put in place to increase farmers' flexibility in dealing with the challenges of climate risk.

8.7 Some Concluding Thoughts on the Research Experience

Like most rural communities in the rural areas, rural famers of Maphephetheni who participated in the study relied on agricultural production which was significantly influenced by changing climatic conditions. The reported climatic changes included: increasing temperatures, reduced rainfall amounts, erratic rainfall, frequency of extreme events such as droughts and floods. Lack of capacity to overcome the impacts of changing weather patterns rendered households highly vulnerable to climate change which had serious implications to household food security. Households did undertake to varying degrees activities to adapt to the changing climatic condition. The most common practices included water conservation through terracing, cover-cropping to conserve moisture in the soils, differential planting times to overcome the consequences of erratic rains, cultivation across slopes for both soil and water conservation, water harvesting from the roofs for irrigation and when the situation grew out of hand, many resorted to praying.

It can be concluded that although there is the willpower from households to respond to the changing climatic condition, the depth of response is dismal towards countering the effects of the changing climate. A lot has to do with the lack of household capacity to effectively undertake adaption practices in response to climate change. Households lacked the human capacity to undertake the adaption practices that require high levels of manpower. Most of the farmwork was carried out by women who already have been burdened with household chores, leaving them with limited time to undertake these adaption practices. The practices were also undertaken without an understanding of how they would effectively be delivered, due to limited knowledge of the practices. Many of the household members interviewed had never received any training on how to undertake the practices. Lack of finance was cited as a major limitation to counter the effects of a changing climate, where purchase of suitable seeds, fertilizers and pesticides was not possible. Hiring an extra hand to help in the gardening activities was also limited. Poor infrastructure contributed to households' inability to effectively adapt to a changing climate. Lack of good roads contributed to high cost of transporting agricultural inputs including seeds, fertilizers and pesticides. This made acquisition of these materials remain a pipedream to many households. The study area is characterised by a very rugged terrain. Most houses are situated on top of the hills while the agricultural gardens are beside their houses. Streams are found flowing at the valley bottom. Utilizing these streams for irrigation is not possible due to the slopes and distance. Household members indicated that they wished they were able to cultivate the fertile and moist valley bottoms, especially during dry periods. This was not possible due to thefts and destruction of crops by animals.

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LESSONS LEARNED AND RECOMMENDATIONS FROM SECTION B

Water Quality Management

The following strategies are based, in part, on the work conducted in the Mkabela Catchment and largely on a synthesis of other studies. They were considered generic enough to permit their application on other "ungauged" catchments, i.e. catchments in which similar studies have not been conducted as yet.

1. *Integrate catchment water quality management, applying principles from integrated water resources management* (IWRM; GWP, 2000; Schulze, 2003): Recognizing the connectivity that exists between catchment water users and uses will construct resilience and facilitate engagement in adaptation action.
2. *Improve irrigation efficiency* (Molden, 2007): Prevent the unnecessary increase in runoff generation which causes increased washout of nutrients and sediment.
3. *Adjust fire management in forestry and sugar cane plantations*: Fire is known to create hydrophobicity in soils which can enhance the susceptibility of soils to erosion, leading to increased sediment generation. Therefore burn only during low rainfall seasons.
4. *Prevent waterlogging, erosion and leaching*: The loss of nutrients is considered to increase when there is an overabundance of water. This is related to prudent irrigation.
5. *Improve access to information*: Implementing seasonal forecasting can be beneficial in improving the timing of cropping and fertilizer applications such that soil and nutrient losses are minimized. Additionally, communicating modelling results to stakeholders can also assist in promoting literacy regarding water quality management.
6. *Construct discharge rate conservation structures* (McCartney, 2009): This applies mainly to catchments where the release of high concentrations of nutrients and sediment is prevalent.
7. *Increase public and decision-maker awareness*: Cooperation between local water resource managers, farmers, local policy makers and the general public is critical in reducing anthropogenic impacts on local water quality.
8. *Adopt planned rather than autonomous adaptation* (Adger, 2003): In some instances, adaptation strategies are already being observed, albeit inadvertently (e.g. crop rotation and mixed cropping systems). Under future conditions of change, however, this can facilitate mal-adaptation in the sense that applying fixed management practices under altered conditions can undermine the systems integrity and potentially create new vulnerabilities and exposures.
9. *Mainstream climate change adaptation options / strategies in national development plans:* Strategies and options for climate change adaptation need to be considered when preparing national development action plans (Petermann, 2008).
10. *Improve gauging and monitoring* (Lorentz *et al*., 2011): Having a dense monitoring network within a catchment not only improves daily water quality management and decision-making but it also facilitates the isolation and effective control of problem areas.

Management of Natural Capital

1. Environmental Impact Assessments of individual land use change applications do not take into account accumulated effects of large scale land use change within a catchment.
2. Land use changes lead to changes in ecosystem services that an area provides, which need to be taken into account.
3. Various land uses were found to have strong implications on hydrological responses and associated hydrological ecosystem services relating to flows through the landscape.
4. The impact of these land uses on certain hydrological responses can be modelled.
5. Hydrological responses obtained from modelling using this approach, e.g. runoff, baseflows, stormflows, low flows and / or sediment yield can be used as indicators / surrogates for hydrological ecosystem services.
6 Hydrological responses, such as sediment yields, stormflows and especially baseflows amplify any changes in the rainfall regime.

Combined effects of mixed land uses on annual streamflows for an area might partially cancel each other out. In contrast to the above, however, the combined effects of the current land uses show a marked increase in sediment yields, due to an overall increased stormflow component of runoff and high flow events.

Land uses that conserve land, as well as land uses that maintain near natural vegetation, e.g. extensive cattle or game farming, if managed correctly, maintain the ecosystem services that natural vegetation provides. Such activities should therefore be encouraged and even incentivized through rebates or payments for ecosystem services, because they add benefit without altering ecosystem services.

High biomass crops such as sugarcane and wattle plantations were found by modelling to reduce streamflows. The benefits of sugarcane plantations, for example, to food security as well as job creation, foreign exchange earnings and economic benefits, therefore need to be weighed up against the reduced ecosystem services to downstream users. In this catchment the wattle plantations do not consist of managed production plantations, but rather of unmanaged areas invaded by alien wattles (*Acacia mearnsii*). Therefore, the small economic benefit of these alien wattles is likely to be superseded by the reduction in the water provisioning service they cause. It would therefore be beneficial to eradicate this alien vegetation to the benefit of downstream water users.

The greatest relative impact of a reduction in downstream blue water provisioning was modelled as a result *of irrigation*. Irrigation should, therefore, be applied as efficiently as possible and the benefits of agricultural production be weighed up against the needs of downstream water users.

Degraded lands were found to increase stormflows, decrease low flows and increase sediment yields. This implies that the physical water quality is reduced and the water during low flow periods, when most needed, is reduced. On the other hand, degraded areas hold potential to be rehabilitated so that increased flow regulation and water provisioning during low flow periods could occur. The rehabilitation of degraded land within the study area, therefore, holds potential to increase ecosystem services, and should be incentivized.

Urban land uses were modelled to significantly increase runoff, thereby increasing the quantity of total blue water provisioning, while reducing physical quality and likely also other types of water quality (e.g. through wash off of oil or pathogens). The stormflow component of runoff in urbanised areas was found to be most markedly increased, leading to flashier runoff responses and, therefore a reduced regulation of high flows. It was modelled that not only stormflows, but also baseflows increased, the latter through a spill-over of water from impervious onto pervious areas with the result that variability of baseflows decreased. This implies that for baseflows there is an increase in flow regulation. The increased blue water flows, however, reduce green and white water flows. The conversion of pervious vegetated areas into impervious areas shifts most of the water portion that would have transpired *via* the vegetation, as well as part of the portion of water that would have evaporated, towards the blue water flows, which is the water that runs off. In addition, the *urban return flows* generated from water which is imported into the study area, were modelled to increase the blue water flows, and by steadying the flows also increasing low flow regulation. Potential leaking water pipes and outlets from septic tanks were not taken into account in this study, but might increase this effect. While an increase in low flows from urban areas has positive effects in terms of increased water provisioning during low flow periods, it needs to be borne in mind that this water is likely to be of lower water quality and, therefore, an overall negative water provisioning service is likely.

Nevertheless, the increased flows from urban impervious areas and urban return flows create opportunities, which include:

1. rainwater harvesting from roofs,
2. water collection from stormwater drains into dams and artificial wetlands,
3. use of treated water from waste water treatment works,
4. use of grey water from households,
5. spill-over from impervious areas onto pervious ones, and thereby slowing flows, resulting in additional infiltration and, hence,
6. production of more biomass on the remaining pervious areas.

If utilised, these positive factors partially mitigate the negative impacts of urban areas, by

1. augmenting the urban water requirements and therefore reducing the amount of water brought into the catchment,

2. increasing biomass production in urban areas and thereby creating green area with possible benefits for recreation, relaxation, biodiversity and food production, and by
3. reducing the downstream ecosystem impacts of upstream urbanisation.

Having evaluated impacts of individual land uses above, it needs to be emphasised that from a biodiversity and genetic diversity perspective in and adjoining streams, the ecology has evolved according to natural local conditions. The resulting streamflow alterations and reduced water quality and altered habitat functions are, therefore, likely to reduce the biodiversity in and adjoining streams.

Achieving Food Security under Climate Change

General: In order to design appropriate management interventions a better understanding of vulnerability of rural communities involved in agriculture to climate change and the resulting impact on household food security is needed.

Policy Implication: Comprehensive policies targeting rural communities on climate change, its impacts and possible adaptive processes are lacking. At different levels, rural households have a role to play in averting negative consequences of climate change on household food security.

Micro-level: Investment in agriculture alone will not able to significantly contribute to the reduction of the impacts of climate change on household food security. Households need to be encouraged to undertake practices besides agriculture that will enhance their resilience to food insecurity that is exacerbated by climate change. This may include sustainable use of natural resource within reach of households to increase incomes which will in turn increase their ability to access food. Policies are required that will allow communities to access natural resources in their surroundings and that infrastructure should be in place to allow the effective use of these resources. Households seemed to work independently in dealing with issues related to climate change. Policies need to be put in place that will encourage household to take advantage of social security programmes at community level communities that will lessen the impacts of climate change on household food security. The programmes may be economic, social or cultural. The study area has a rugged terrain and is bare of trees due to deforestation. It is necessary that policies are put in place to ensure that land that is not arable is covered with trees, if trees were present in the natural vegetation. This will contribute to increasing the carbon sink and hence mitigating on the impacts of climate change. Products from afforested areas can provide incomes that may contribute to household food security.

Market response: Markets in the study area were dysfunctional. The government should consider putting in place market infrastructure that will allow households to purchase farming inputs including seeds, fertilizers and also a place where famers will be able to sell their produce. This set-up will motivate rural farming households to invest more in climate change adaptation processes.

Institutional: Community members indicated that they had not been visited by government official in a long time. Responding to the impacts of climate change will not be achieved by a single government department. The government will be required to put in place a system that will ensure government departments are playing complementary roles in the rural farming communities to ensure that the impacts of climate change on household food security is minimised. In responding to agricultural production, the government extension system needs to be capacitated enough to be able to provide rural communities with information and methodologies on how they can effectively respond to a changing climate. This will include investing in training extension staff on climate change and food security and ensuring that the number of extension staff will adequately cover the rural communities in South Africa.

Technological: The use of improved methods in agricultural production among rural farming communities need to be encouraged. For example growing of crop varieties that are responsive to the changing climate will be appropriate. This will ensure increased yield per unit cropped area. Appropriate and improved methods of crop and animal husbandry need to be encouraged among households. This may include for example the use of animal drawn plough. This will allow for timeliness in land preparation to take advantage of early rains which would otherwise not be possible when using a hoe for cultivation. This will require government to put in place policies that will ensure that rural communities can access improved and appropriate technologies. The use of media will be critical in ensuring that those vulnerable to climate change have information. Process need to be put

in place to ensure that messages on climate change, possible impacts and what can be done at all levels to avert the negative impacts should reach the rural agricultural communities.

Classifying Livelihoods and Managing Resulting Vulnerabilities

Identifying water scarce regions in regards to quantity and quality would be the first step in planning for water resources because prior to planning for the future, with reference to the National Water Act (1998), water has to meet all basic human needs, therefore all humans need to receive adequate water.

SECTION C:
GOVERNANCE AND MAINSTREAMING IN CLIMATE CHANGE ADAPTATION

Introduction of Section C

This section on governance and mainstreaming in climate change adaptation addresses points 5 and 6 (a and b) in **Figure C1**.

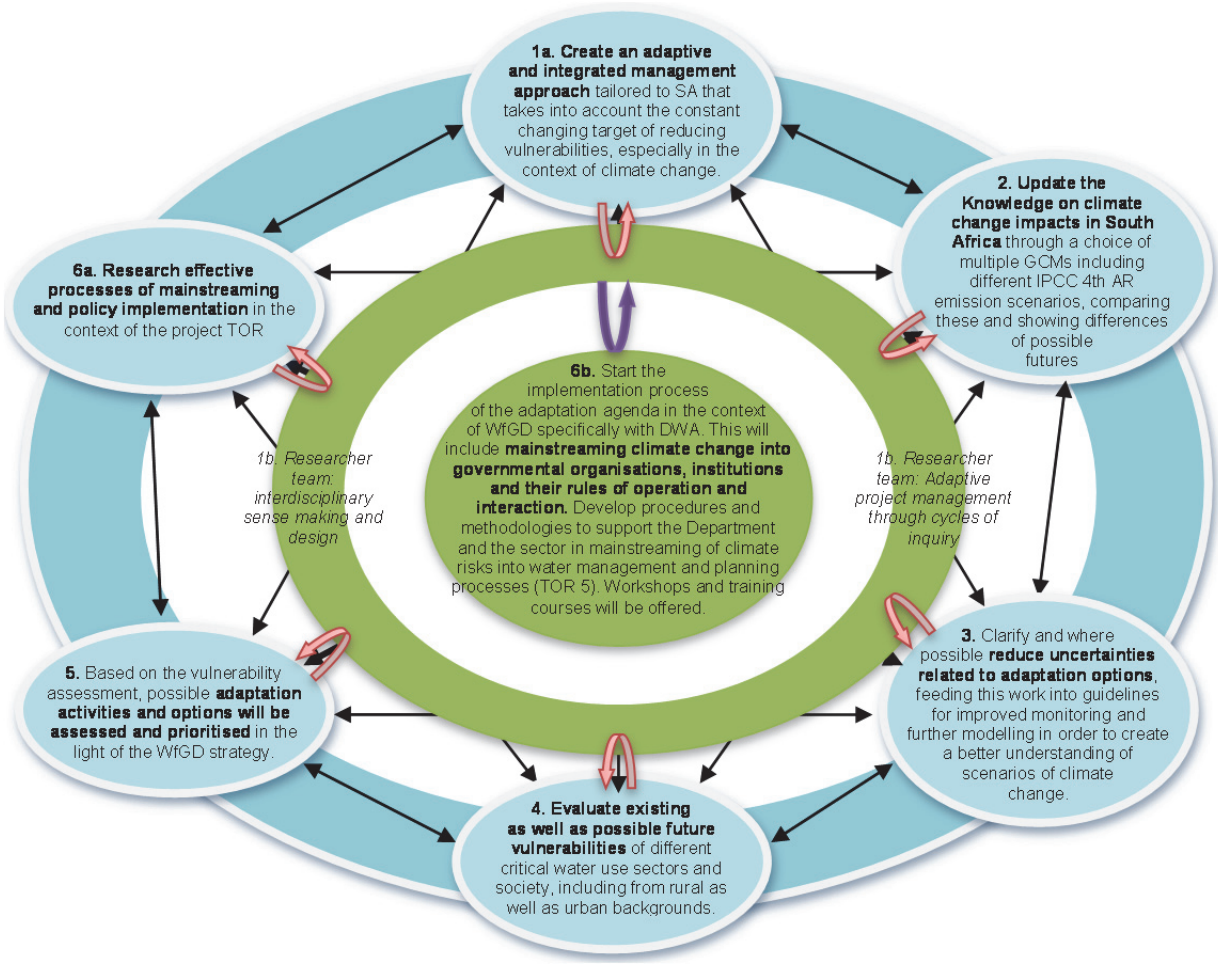


Figure C1 The six project work packages and their inter-relationships, illustrating how the research team intermediates, with the inter-relationships between the six work packages shown in the outer (blue) circle, and the work package focusing on knowledge co-production with stakeholders inner (green) circle, through a process of interdisciplinary sense-making and adaptive project management in the middle (green) circle

People are only able to perform their daily livelihood activities and explore a wide range of opportunities if adequate water resources are available (Oumer *et al*., 2013). Inadequate water supply can result in a degradation of natural resources, which not only affects water users downstream, but often creates other water related hazards, which can lead to a threat to human livelihoods and economic growth at local levels (Mallick, 2013). Thus, water management needs to aim at the reliable availability of water at an acceptable quantity and quality of water for livelihoods and health so as to meet the society's (and the economy's) needs. This is the definition of "water security", a theme that

has been increasingly debated in recent years. **Section C** is related closely to this aim. Also, as studying water security enables us to understand the vulnerability of livelihoods and how they are affected by water availability, quality and water related hazards, it also highlights areas that have limited access to water, thereby reducing social benefits, affecting crop yields and undermining livelihoods (Percival and Homer-Dixton, 2009).

In developing countries such as South Africa, water is still not equitably distributed across human settlements. Regardless of the many dams that exist, South Africa still has water impoverished regions that often rely solely on local natural water resources such as groundwater and rivers. Water insecurity in these regions occurs as a result of unconstructive interactions that occur between humans and water resources. These unconstructive interactions are largely a consequence of pollution, ineffective water use, poor management and planning as well as an uneven landscape of knowledge (Muller *et al*., 2009). In addition, many regions are water insecure because of poor governance and an unequal supply and distribution of water In order to build water secure societies, water managers need to collaborate with different expertise involved in community development in order to address water related issues that will benefit livelihoods and local markets (Sayer and Campbell, 2004). Moreover, socio-economic growth and development are not necessarily determined by water scarcity, but rather by the management and planning strategies that are put into place. Societies need to develop local, catchment and national strategies that recognise their water source confinements and use the existing resources wisely in order to enhance economic growth and livelihood capacity. Identifying water scarce regions and understanding vulnerabilities would be a first step in planning and managing South Africa's water resources. Furthermore, subsequent to knowing whether water is available and reliable for human life, it is crucial to have knowledge on how water is used and perceived in different societies to ensure long term availability (Martius and Nuppenau, 2009).

Understanding vulnerabilities, both those existing as well as those emerging, is a key issue for adapting to climate change. This implies the necessity for vast amounts of information and knowledge on the complex consequences of climate change on our resources as well as direct and indirect impacts on livelihoods, society and economic activities. Such knowledge would need to be mainstreamed adequately into decision-making, which places a strong emphasis on actual management and its intervention design as well as implementation when tailoring to more local settings. In the course of design to implementation, prioritisation will be needed as the limitation of capacities, finances and 'one-size-fits-all' solutions will lead to trade-offs between benefits for users and / or the environment.

The aim of this section is thus to design a mainstreaming approach that deals with the manner in which climate change actually translates into vulnerability of the individual and the biosphere, as well as what the emerging threats to society and the economy are, in order to inform water management processes and resulting interventions. In order to design and implement appropriate interventions three key aspects have to be dealt with, *viz*. incorporating and adapting to new information, promoting vertical and horizontal integration as well as undertaking advanced monitoring. In South Africa climate change has often been mainstreamed into important policy and planning documents, but the research has shown that this is a 'minimum requirement'. What seems to be needed on a very personal level is the respect for other perspectives, values and priorities as well as the ability to reflect, question, evaluate and learn from what has been implemented. However, so far it is unclear what leverage points for more complex mainstreaming are available. Additionally, this also needs to be seen in the context of a lesser skilled human environment as well as with more fragile organisational structures, such as exist in lesser developed or developing countries. The diverse workshops and initiatives held and followed in the course of this research project, have given us some ideas in regard to leverage points, certainly at the level of key individuals and groups, but it is still unclear how complex issues such as climate change adaptation can be successfully initiated and mainstreamed on a systemic level.

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CHAPTER 9: MAINSTREAMING CLIMATE CHANGE ADAPTATION BY PREPARING FOR DECISION MAKING IN THE WATER SECTOR

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The contents of this chapter is an edited version of a paper currently (February 2014) under in review as a paper in the International Journal of Climate Change Strategies and Management.

9.1 The Context

Climate change has been on the research agenda of many academics and donors since the early 1980s. Since the publications of the status reports of the Intergovernmental Panel on Climate Change (IPCC), impacts of climate change in general and on water resources in particular have started to become a focal point of governments and politics. As a result, the complexities in water management and water governance have increasingly been recognised over the past decades. Furthermore, our world, societies and economies are rapidly changing, thereby creating uncertainties far beyond climate change. Especially in Africa, the focus has progressively shifted towards the local context. This is the level where impacts and vulnerabilities become visible and hence adequate adaptation needs to be designed. Thus, the core question of this chapter is: What kind of framework for water governance and management is needed to address complexities and uncertainties and deal effectively with future impacts of climate change, i.e. avoiding maladaptation, and yielding potential benefits, with the latter being crucial for African poverty eradication? To address complexities, the global academic and latterly the development aid communities have homed in and refined the notion of Integrated Water Resources Management (IWRM). This integrated and holistic approach focuses, besides on infrastructural and other "hard" measures, on participatory and so-called "soft" activities, thereby offering a framework within which a range of choices for adaptation can be evaluated. As one answer to the uncertainties associated with climate change, the discussion and development of Adaptive Management (AM) has matured and gained momentum in the past decade. Adaptive Management thinking offers ways to deal with slow as well as fast changes. In this chapter it is argued that if these two approaches are combined and focused on existing as well as emerging vulnerabilities, activities for adaptation can be framed, negotiated as well as prioritized adequately and can support sustainable development. Additionally, a governance system will emerge that offers spaces for learning as well as mainstreaming of adaptation to climate change. In brief, climate change is one of the global change issues as to ***why*** we should be doing things, vulnerabilities advise as to ***what*** we should be doing, while IWRM and AM point towards ***how*** we should be doing them.

9.2 Introduction

One of the most significant current discussions on adapting to climate change has been fuelled by the IPPC Reports of 2007 and 2013. They show that the impacts of climate change will, with a high probability, exacerbate problems around livelihoods and health, especially in the developing world (IPCC, 2007). Agreement amongst experts also exists that the impacts of climate change and its vulnerabilities are mainly felt through our water resources. This is why this chapter focuses on the water sector specifically, using water as a catalyst to create awareness and urgency to act as well as using climate change as a catalyst to deal with change and long-term sustainable development.

As impacts of climate change on our water resources manifest themselves as vulnerabilities mostly on the local scale, adaptation often has to be site-specific (e.g. Adger, 2006, Stuart-Hill and Schulze, 2010). Of late greater emphasis than before has been placed by research on regional and local adaptation strategies (e.g. Ostrom, 2010). Overall, this calls for a thorough understanding of vulnerabilities resulting from climate change (as defined as by IPCC, 2007) in order to enable the crucial prioritisation and implementation of adaptation actions. This is not only true for the developing world, but also for the developed world. In both cases an appropriate governance and efficient

management system[14] is indispensable. However, current literature identifies a lack in research on how to design adaptation options based on the interplay of climate, socio-economic characteristics and values (Storch, 2009; Barnett, 2010; Miller *et al.*, 2010; Hinkel, 2011; Hjerpe and Glaas, 2012). Even more so, research seems to be lacking on how to include vulnerabilities of climate change into decision making of water management and potentially mainstreaming such an approach, *viz.* moving from conceptualising governance issues to prioritising management interventions, taking decisions and implementing these. Therefore, this chapter focuses on how to frame and prepare decisions on climate change adaptation, thereby hoping to ensure their successful implementation. The core question of this chapter is, what kind of framework is needed to assure sustainability within water sector management under projected future impacts of climate change, in terms of governance and in terms of management at all levels (national to local) as well as at all spatial, temporal and administrative scales? Such a framework would need to create a decision-making environment where the design of adaptation activities is well informed, negotiations are transparent and thus maladaptation becomes highly unlikely. Furthermore, adaptation must not be understood as a task solely of the governmental sector.

Climate change impacts and, even more so, resulting vulnerabilities are highly dynamic over space and time (Birkmann, 2005; Hjerpe and Glaas, 2012) and uncertain in many ways. Expected impacts of climate change such as increased variability of seasonal and inter-annual climates and an increased frequency of individual extreme events translate into increasing uncertainty about climate conditions and water availability, thus exacerbating current vulnerabilities as well as heralding the emergence of 'new' vulnerabilities. At the same time the complexities of water resource management and governance are increasing (Medema and Jeffrey, 2005). In order to address these dynamics of vulnerability and complexity, adaptation needs to be framed in an integrated manner, *viz.* not only from a biophysical / environmental perspective, but taking especially its societal and economic dimensions into consideration (TEC GWP, 2004; Reid and Vogel, 2006; Koch *et al.*, 2007). Therefore, the authors are of the opinion that a vulnerability lens, guiding the design and negotiations around adaptation activities as well as their prioritisation for implementation into water management, will ensure equity and efficiency - especially in developing countries.

Furthermore, in order to address uncertainties, adaptation calls for developing adaptive capacity[15] (Folke *et al.*, 2002), as information and knowledge will need to be updated continuously and fed into the governance system. As a consequence, an integrated and adaptive framework will be needed to understand vulnerabilities, design adaptation activities and also evaluate them, *viz.* judging them based on their success (Barnett, 2010).

The design work of this chapter is based on the premise of looking at vulnerabilities in order to guide the preparation of decision-making as well as its implementation. This will be discussed in further detail later. The aim of developing an integrative and adaptive framework calls for appropriate management approaches taking scales into account for framing the approach of adaptation to climate change. Furthermore, core features needed to perform in such a management environment are identified which, as a consequence, call for crucial characteristics to successfully learn and also mainstream adaptation activities into the overall governance system. The discussion at the end of the chapter will allude specifically to the two latter aspects.

9.3 Conceptual Background

Long term sustainable and conscious adaptation planning (and implementation) cannot be achieved by an individual or by chance. There is the need for a tailored way to include knowledge creation within and beyond organisations and the water sector, with as little bureaucratic intermingling as

[14] The terms of governance, management and systems are understood here as defined by Pahl-Wostl *et al.* (2012, 25): "A governance system […] encompasses structural features and transient processes at both rule making and operational levels. […] Management refers to activities of analyzing and monitoring, developing and implementing measures to keep the state of a water resource within desirable bounds. The notion of governance takes into account the different actors and networks that help formulate and implement water policy."

[15] Adaptive capacity is here understood as defined by the IPCC (2007, 727). "Adaptive capacity is the ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behaviour and in resources and technologies."

possible. Such planning must be based on existing water law and rooted in current policies, but needs to take into account obvious gaps and challenges in the overall governance system (Stuart-Hill and Schulze, 2010).

Therefore, the framework's aim is to support the creation of an enabling environment for the framing and preparation of decisions on climate change adaptation for the water sector. This needs to be done in a feasible way that assures the successful implementation through management of the designed adaptation options. In the context of water management, this is crucial, especially as the traditional stationarity approach of planning and design is no longer appropriate under climate change (Milly *et al.*, 2008). Consequently, the framework needs to be applicable on any spatial scale - although the catchment scale is recommended (see later) as the cornerstone for adaptation design, prioritisation and implementation. Furthermore, the framework needs to allow being re-visited as often as is deemed necessary by water managers and stakeholders, owing to the dynamics and uncertainties surrounding climate change, as alluded to earlier. Nevertheless, participatory processes organised on a particular scale or level need to consciously inform other levels and sectors, although these do not need to be actively included in the design process itself (Pahl-Wostl, 2007; Vogel *et al.*, 2007).

With integration and adaptation being core elements of the framework, a focus on understanding vulnerabilities, creating knowledge, dealing with change and uncertainty on an organisational as well as individual level is inevitable. This implies that the framework needs a strong adaptive element. The Resilience Theory (Folke 2006; 2010) and specifically adaptive cycles (Gunderson and Holling, 2002; Berkes *et al.*, 2003) offer repetition of actions (here understood as incorporating new information, creating new knowledge and implementing / evaluating action), as well as phases of repose, i.e. avoiding change or the creation of new knowledge, in order to consolidate. The latter is especially important so as to gain predictability and reliability of governance and government (Termeer, 2009) in times of change as well as in periods after change (Herrfahrdt-Pähle and Pahl-Wostl, 2012). However, in order to develop a holistic and implementable framework, the concept not only has to take the overall system within which decisions are taken into account, but also has to take up an actor's perspective. Here we argue not so much an organisational viewpoint, but far more the individual actor and decision maker respectively in his or her context (Grothmann and Patt, 2005) is relevant. Only then is attention paid to governance in its totality. Furthermore, the interplay between elements of governance, i.e. legislative framework, policies, implementation, stakeholders, etc., is vital for an enabling environment (Stuart-Hill and Schulze, 2010).

In our argumentation special attention needs to be given to "change". This refers to change within organisations as well as change in respect of individuals of that organisation. As suggested by the authors, since climate change is in itself a field of on-going new knowledge creation, so much more are the existing as well as emerging vulnerabilities because they relate strongly to socio-economic issues of society. For government and governance it means that not only the knowledge base is constantly changing, but also feasible approaches to reducing vulnerabilities and other impacts of climate change. At the same time it is central for government to assure an element of predictability, as that is essential for continuity and consistency in planning (cf. Herrfahrdt-Pähle and Pahl-Wostl, 2012).

Another crucial aspect for the framework is that of "fit" between social and ecological systems (Young 2002). Young (2002) identifies the concept of fit as a means to increase the effectiveness of natural resource management by assuring closeness of the ecological system and social system properties, the latter referring especially to governing institutions, in order to deal with undesirable environmental change. "Fit" can be categorised in various ways, depending on the properties of both the resource and the institutional arrangements chosen for the analysis, for example, in a spatial or functional sense (Cash *et al.,* 2006; Cumming *et al.,* 2006; Folke *et al.,* 2007). ***Spatial fit*** refers to the matching of resource boundaries and the institutional regimes which govern them (Young 2002). A lack of spatial fit, e.g. a mismatch between jurisdictional and hydrological boundaries, is associated with poor results in resource management since institutions which cover only part of the resource may ignore, or even affect negatively, external effects (Moss, 2007), e.g. overuse and pollution of water resources resulting in loss of a social system's adaptive capacity and / or of the ecological system's resilience. ***Functional fit*** relates to the congruence of resource use mechanisms or institutional attributes on the one hand, and on the other ecosystem functionality, i.e. the ecosystem properties or functions addressed through them (Cumming *et al.,* 2006; Ekstrom and Young, 2009). A functional mismatch

may thus occur if water pricing mechanisms are so designed that they lead to a rate of groundwater use in excess of the rate of aquifer recharge. The requirements of the various dimensions of fit may be consistent with each other if, for example, the institutional arrangement provides for the monitoring of water availability in a catchment (spatial fit) and allows for water use rights to be adjusted on the same scale, i.e. in the catchment, according to seasonal availability (functional fit). However, the requirements associated with the dimensions of fit often differ and sometimes contradict each other as scales of negotiations, regulations and decisions do not necessarily fit and therefore discrepancies exist (Herrfahrdt-Pähle, 2010; Herrfahrdt-Pähle, in review). Scales of fit most probably will differ depending on the issue that needs to be dealt with. In such cases the appropriate properties or dimensions for which fit should be achieved are often difficult to determine and trade-offs are inevitable. Therefore, the "most appropriate adaptation responses will often be multi-level responses" due to the diversity of impacts of climate change (Adger, 2001, 924). However, most often water governance and management seem to give preference to spatial fit and thus promote the catchment as the backbone of integrated water management (Moss, 2007). To finally negotiate and take decisions on adaptation and management interventions, the catchment does seem to be the most appropriate space as this is where the visions of policy meets local needs and potential limitations for implementation.

The latter is a space that lends itself strongly to create and benefit from social learning processes. New partners and networks will develop new knowledge and will have to "integrate different, but equally valid, approaches to knowledge rather than to start with a one-sided perspective and to add insights from the other perspective at the margin." (Young, 2006). This offers the possibility of a variety of social learning processes (Mostert *et al*., 2007; Pahl-Wostl *et al*., 2011; Hjerpe and Glaas, 2012; Huntjens *et al*., 2012). Additionally, in this learning space, science will play an important role in assisting with knowledge creation and guiding sense-making (Roux *et al*., 2006).

9.4 IWRM and Adaptive Management: Combining Water Management and Governance Approaches for Adaptation

The complexities in water management and water governance have increased significantly over the past decades (Gleick 2003; Pahl-Wostl, 2009; Pahl-Wostl *et al*., 2010). This has also led to a greater emphasis on water governance because the technological control paradigm is experiencing its limits (Milly *et al*., 2008). Furthermore, recent discussion on global water governance and management shows the challenge of decision makers dealing with impacts of a global scale that translate into a local context and finally impact on the local level (Barnett, 2010), individual livelihood and living standards, e.g. water services (Schulze, 2008). With Integrated Water Resources Management, IWRM (e.g. GWP, 2000 and updates), both the academic community globally and subsequently the development cooperation / assistance community, have conceptualised an integrated and holistic approach that focuses on participatory and "soft", in addition to infrastructural and "hard", issues (Gleick, 2003). As alluded to earlier, existing and emerging vulnerabilities should guide decision making, and therefore these need to be known when designing adaptation activities / strategies, especially when prioritising these for implementation. To finally design feasible and successful management interventions, vulnerabilities furthermore need to be understood in context (i.e. historically as well as current, biophysical as well as socio-economic), including any feedbacks and feed-forwards. This is where IWRM as a management approach offers an understanding of the complexities between society, the environment and economic activities (Colvin *et al*., 2008; Grigg, 2010; Schulze, 2011). Hence, within IWRM a range of choices for management interventions can be evaluated jointly, based on the long-term vision of sustainable water management. However, the latter might prove to be a weakness in times of change and uncertainty where short- to mid-term interventions, their evaluations and more iterative and partially explorative management approaches are needed.

The world, its societies as well as its economies, are changing rapidly, creating uncertainties (Ostrom, 2010) far beyond those attributable solely to climate change. However, climate change does provide an opportunity to learn proactively on how to adapt to slow ("push") and fast ("pulse") changes, to mitigate negative impacts and to simultaneously harvest the benefits from such change (Adger, 2006; Gallopin, 2006). This is why adaptive water management, AM (e.g. Pahl-Wostl, 2007 and 2008; Roux *et al*., 2006; Adger, 2001 and 2009), has increasingly been discussed, developed and explored in diverse cases around the world. Adaptive management is an attempt to deal with these uncertainties and enable (water) managers to act despite incomplete information, and in so doing opening the

opportunity to “accelerate the rate at which environmental decision makers learn from experience” (McLain and Lee, 1996). One definition of AM is connected to seeing policy as a set of experiments. Hence it requires open and flexible institutions and a multi-level governance system because the process of learning takes place while these experiments are undertaken. It allows for learning and thus increases adaptive capacity without, at the same time, foreclosing future development options (Folke *et al*., 2002). Thus, AM does justice to the dynamics not only of the climate itself, but especially also to socio-economic changes and feedback loops between the two. However, AM also displays a potential weakness in that the main strategic vision which needs a long-term foresight and commitment, similar to a common ground for negotiations, might be lost in an experimental, and therefore a more short- or mid-term sighted, approach.

IWRM combined with a stronger focus on AM could mitigate the weaknesses of the individual approaches and complement their strengths. Both would emphasise the holistic approach and responsiveness of the system needed (Muller, 2007), thus promising a governance system that can deal better with change and uncertainty, as well as on-going learning and negotiations within and beyond the water sector. Furthermore, this combination opens the opportunity to make use of the flexibility offered by most water regulations, and also facilitating the opportunity to overcome challenges of implementation, as they often exist in the developing world (Schulze, 2007). This could mark the entry into a progressive water management era whereby the framework and its adaptive practices would allow to frame, design and negotiate adaptation activities adequately and therefore could create momentum to pro-actively face negative impacts of climate change and benefit from others, thereby reducing vulnerability specifically in the poverty-stricken communities of our global society.

However, in order to implement integrative understanding and negotiate the prioritisation of adaptation activities / strategies and adaptive implementation and management thereof, certain performance characteristics need to exist within government as well as governance.

9.5 Characteristics Needed to Perform under IWRM and AM

The application of a framework for IWRM and AM will require certain characteristics in order to perform in an environment of sequential change and periods of consolidation and evaluation (*viz*. feedbacks and adaptation). These are coordination and cooperation in order to deal with complexities within and beyond the water sector, and flexibility and responsiveness in order to deal with uncertainties and change.

First, existing but especially emerging complexities under climate change have to be understood in an integrated, i.e. holistic manner in order to design appropriate adaptation options. The dynamics that are displayed through the interplay of biophysical and socio-economic features of the spatial unit under scrutiny (e.g. the nation, catchment, sub-catchment or municipality) can only be understood sufficiently when a diversity of knowledge and views is expressed and brought together (e.g. Koch *et al*., 2007). Additionally, designing adaptation options beyond just communicating risk is imperative (Grothmann and Patt, 2005). Essential mechanisms are, therefore, not only communication, but going beyond that and achieving coordination and cooperation (Rogers *et al*., 2000; MacKay *et al*., 2003; TEC GWP, 2004, Folke *et al*., 2005; Olsson *et al*., 2006; Vogel *et al*., 2007). Cooperation here is understood as connecting across levels and scales resulting in collective action towards a common goal or even contractual arrangements on finance management, joint management strategies, joint monitoring, mediation and dispute resolution (UN, 2013). Cooperation results in connections that should be “linking different networks and creating opportunities for new interactions [as these] are important when dealing with uncertainty and change” (Olsson *et al*., 2006, 13). The transparency and organisation of those connections as well as their outcomes (i.e. designed adaptation options, evaluations, implementing interventions) need to be well coordinated. Thus, for a holistic approach that can even deal with trade-offs when prioritising adaptation options and implementing these, coordination and cooperation within the water sector as well as beyond it, is crucial.

Secondly, uncertainties, which are increasingly emerging in the context of climate change, require revisiting governance structures regarding their flexibility and responsiveness. Flexibility is needed to enable continuous adaptation as social, ecological or economic parameters change over time (Olsson *et al*., 2006). Adaptive water governance requires flexible institutions (in terms of rules and norms), which offer mechanisms that provide for the adjustment of management procedures and governance

structures (Pahl-Wostl, 2007). Institutions should simultaneously provide planning security and leeway for adapting to unforeseen events. For example, several provisions of the South African National Water Act include time-bound regulations. The National Water Resource Strategy is subject to reviews every five years. Likewise, water licences are reviewed every five years and may not be granted for longer than 40 years. This allows for the reallocation of water resources should this become necessary.

In comparison to flexibility, responsiveness to contextual changes goes one step further since it involves the direction of change (Pollard and du Toit, 2011). Responsiveness (both of the system and of individual actors) is thus not only about recognising changes in the water system (e.g. decreasing water availability or increasing water pollution), but also about reacting to them with timely, adequate measures (Herrfahrdt-Pähle and Stuart-Hill, 2010). Past experience as well as current and future changes in the social-ecological system (such as increasingly frequent droughts and floods as well as increasing vulnerabilities) need to be monitored and taken into account in the decision making process. In addition, the long-term effects of present interventions need to be anticipated (e.g. by climate proofing) and monitored during implementation in order to be able to adjust measures that have unintended negative effects. Summing up, in an environment of uncertainty and change, flexibility and responsiveness are needed to deal with new information and to create appropriate knowledge to inform 'better' decision making and adjusting management interventions as well as governance approaches.

Based on the points discussed above, the framework presents itself as in **Figure 9.5.1**.

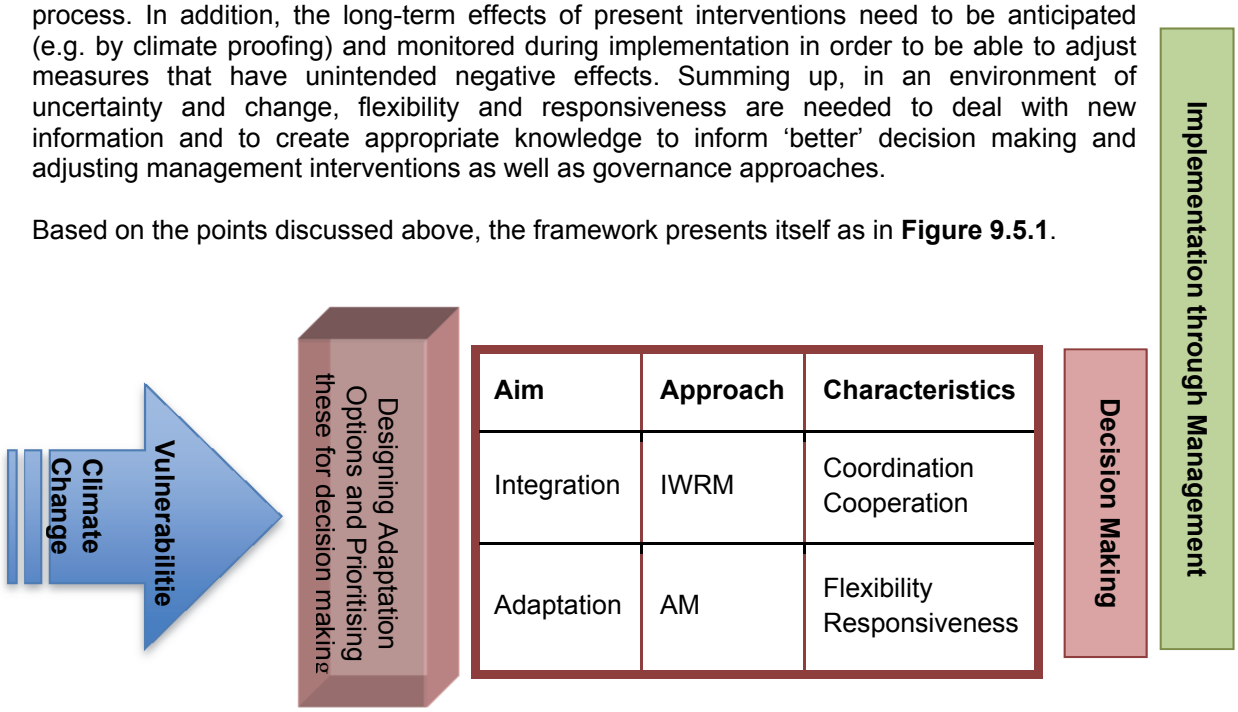


Figure 9.5.1 Conceptualising water governance and management interventions for adapting to climate change

9.6 Maintaining Success

Both IWRM and AM have been criticised for neglecting the governance perspective and the political dimension of natural resource management. However, numerous studies underline the relevance of factors such as power structures, incentives etc. for the successful implementation of policies (Young, 2006; Wallis and Ison, 2011). Experience shows that a conceptual framework as the one above could even be supported by existing legislation, but implementation as well as according performance do not unfold (e.g. Stuart-Hill and Schulze, 2010). Therefore, "applying" those characteristics identified will require certain catalysts on an individual as well as an organisational level.

As indicated earlier, the climate change arena and its emerging vulnerabilities play out very diversely, even when in close local proximities. ***Bringing knowledge together*** from different spheres in order to design and prioritise adaptation through coordination and cooperation is the first and preparatory step of the decision making process. In order to evaluate and optimise management interventions, ***reflection*** is needed (second step). Only when individuals reflect on their values, frames and knowledge on their own as well as while negotiating management interventions, will adaptation take place on a broader basis than just incrementally improving established management practice (Pahl-Wostl, 2009). Only then can flexibility and responsiveness be directed towards adapting on different

scales and effectively avoiding maladaptation while simultaneously consciously dealing with trade-offs of certain decisions and / or interventions.

Additionally, adaptation to climate change is not a once-off activity, but is on-going which has to deal with new information, has to create new knowledge, and adjust decisions taken if evaluation indicates so, in order to prevent maladaption. For individuals who finally take decisions, this means operating in an environment of severe, and often necessary, change. Such change might only be the improvement of routines, but might go as far as questioning policies and law (i.e. transforming, see Pahl-Wostl, 2009). The latter, especially, will pose a threat to people as change is often experienced as being painful. Resistance may be built up as water managers, i.e. governmental officials in their day-to-day working environment, could feel insecure despite understanding the need for change and adjustments (TEC GWP, 2004). Hence, guidance and ***leadership*** are needed to create a sense of stability and certainty by which stress can be avoided (Kotter, 2005; Muller, 2007; Taylor, 2010). Leadership differs from pure management by including facilitating processes, engaging with individuals and creating motivation for long-term impacts within the leaders' organisation as well as outside of it in the water sector (Termeer, 2009). Leaders see business challenges as opportunities for growth and learning on the part of both individuals and the organisation (Rooke and Torbert, 2005). Furthermore, leadership may be displayed by individuals as well as by teams (Taylor *et al.*, 2011). Thus, leadership will be a requisite to deal, not only with change, but also when negotiating adaptation options and implementing these.

Resultantly, ***reflection*** and *leadership* are needed by individuals for the actual management intervention as well as by organisations to achieve feasible and successful adaptation in the long-term. With this we conclude the framework design and can display the issues discussed above as in **Table 9.6.1**.

Table 9.6.1 Moving from the preparation of decision making to preparing management interventions

Aim	Approach	Characteristic	Requisite
Integration	IWRM	Coordination Cooperation	Leadership
Adaptation	AM	Flexibility Responsiveness	Reflection

9.7 Deriving a Framework for Adapting to Climate Change

Our point of departure for this chapter has been the impacts of climate change that translate into a very diverse set of vulnerabilities in a local context. These may be as drastic as threatening lives and livelihoods of people, creating economic crisis or collapses of governance systems. Understanding these vulnerabilities in an integrated manner and designing appropriate adaptation options is therefore imperative. However, we must be aware of the uncertainties and constant improvements in our understanding of climate change as well as socio-economic features of communities.

We can summarise:

- Global change, including climate change, is ***why*** we should do things;
- Vulnerabilities as ***what*** we should be doing or prioritising; and
- IWRM and AM as to ***how*** we should approach the design of adaptation options.

Additionally, characteristics had been derived, based on IWRM and AM, in order to perform in an environment of sequential change and periods of consolidation as well as evaluation which include:

- Dealing with uncertainty in order to increase resilience, with this being expressed through ***flexibility***;
- Enabling change and adjustment, which is expressed through ***responsiveness***;

- Establishing a discourse amongst governmental departments as well as beyond the water sector, which is expressed through ***coordination***; and
- Connecting across levels and scales, which is expressed through ***cooperation***.

Furthermore, two core characteristics of the framework have been derived in order to move towards decision making:

- While designing and prioritising adaptation options needs to include all stakeholders, ***leadership*** is needed in order to take the decision on the final management intervention - this answers the question of who should be implementing the catchment as a potential space, and where the discourse should take place (including other spatial scales is advisable!)
- ***Reflection*** of individuals and organisations is indispensable to evaluate and therefore optimise and revise decisions taken - how we should take decisions and perform management.

9.8 Conclusions

It has been shown that not only is preparing adaptation options a complex process, but even moving from design to decision making and final implementation are not easy tasks and actually call for certain preconditions (here called characteristics and requisites). Consequently, just because stakeholders or government know of climate change impacts, it cannot be expected that management interventions will automatically be implemented. However, the suggested framework offers two additional benefits that emerge as interesting spaces, these being mainstreaming climate change (see next chapter) and social learning processes.

The authors understanding of mainstreaming climate change needs to be differentiated into two aspects: that of governance and that of management. In the context of governance it means creating preconditions and offering the required options to access choices for action and adaptation respectively. In the context of actual management, and therefore decision making, mainstreaming is rather a process which aims at designing, prioritising and implementing management interventions.

Basically mainstreaming climate change calls for exceeding existing planning processes and breaking through the usual pattern of thinking. Such a space opens when leadership and flexibility / responsiveness meet. However, this needs further investigation as this would call for a highly adaptive and potentially even iterative process that constantly creates and mainstreams new knowledge.

Another space that is emerging is when cooperation / coordination meets reflection - especially when this happens “out the box” (*viz*. with new partners and networks). Any spatial scale or level of interaction offers this unique and very valuable space in which a more integrated framing of the impacts of climate change and resulting vulnerabilities can take place. However, to design and implement real management interventions, further investigations will be needed on aspects of the science-policy interface as well as the science-society interface.

9.9 Acknowledgements

The authors wish to thank the National Research Foundation of South Africa for their financial support in this research, through assistance in discussing and developing the drafted framework with colleagues of the German Development Institute in Bonn, Germany. We additionally acknowledge the financial support of the Water Research Commission of South Africa in this research.

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CHAPTER 10: MAINSTREAMING ADAPTATION TO CLIMATE CHANGE BY TAKING ORGANISATIONAL ISSUES INTO ACCOUNT FOR SUCCESSFUL MANAGEMENT INTERVENTIONS

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Taken chapter is taken in parts from a paper in preparation (February 2014).

10.1 Introduction

Decision making is a core issue in management; and when adaptation activities are designed and implemented, they are understood in the context of this chapter as management interventions. However, decision-making is not a once off activity of adaptation, but a process over time that aims to "improve policy performance" (Mickwitz *et al*., 2009a). It needs to be noted here that this chapter uses the perspective of water and climate change in its argumentation. However, many issues discussed and concluded could be more generic.

According to Pahl-Wostl *et al*. (2012, 25), "Management refers to activities of analyzing and monitoring, developing and implementing measures to keep the state of a water resource within desirable bounds." The actual implementation of management interventions should then lead to successful adaptation which should then be reflecting sustainable development (Chuku, 2010), reduction of vulnerabilities and ensuring the well-being of society under a future of climate change. Policies and legal documents create an enabling - and sometimes a disabling - environment for designing and implementing such management interventions (Stuart-Hill and Schulze, 2010), depending on how issues of fit, interplay and scales are reflected in laws, regulations and organisational design (Young, 2006; Herrfahrdt-Pähle, in review). This is a crucial aspect for decision-making and needs to be given appropriate attention when adaptation activities are framed and designed (Stuart-Hill *et al*., in review).

Even so, understanding or being aware of climate change and its impacts does not automatically lead to adaptation activities by decision makers (Grothmann and Patt, 2005). In particular, water managers at all governmental levels will have to mainstream the resultant impacts, as well as adaptation to these, into their day-to-day work. Here a broader approach than focussing on risks and direct, visible impacts on water resource management, such as floods and droughts, has to be taken. Mickwitz *et al*. (2009a) identify "adaptation issues related to agriculture, forestry impacts on ecosystems and natural habitats" as just some of the key issues that should be included for mainstreaming. Overall the focus of understanding impacts of climate change, and furthermore designing adaptation, should be holistic. This would also contribute to ensuring sustainable development (Chuku, 2010). In the context of climate change this calls for adaptation[16] which avoids lock-in situations, *viz*. panaceas or non-reversible interventions, and inflexibility towards stresses and shocks in the future.

10.2 Setting the Scene

As any impacts of climate change on the environment will translate into lesser or enhanced levels of vulnerability of individuals, communities and organisations, and these will need to be understood in context and be incorporated in decision making. Additionally, vulnerabilities may play out very differently even in close local proximity (Stuart-Hill and Schulze, 2010) and hence, not only have to be understood in their current, but also their potential future, state (Stuart-Hill *et al*., in review). The variety of vulnerabilities emerging will be competing with current ones as well as with other needs (Kabat, 2013) and thus a process is needed where prioritisation of activities have to be negotiated.

[16] "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPPC, 2007, 869).

The aim of prioritisation is key, especially in developing countries where capacities and finances will be limited, but also in situations where trade-offs between benefits for users and / or the environment will have to be dealt with. Such trade-offs might not be obvious, but rather hidden and therefore need to be made explicit by open discussion (which has to include the public) in order to "identify winners and losers [and] to ensure that adequate buffering systems can be put in place during transformation" (Eakin *et al*., 2009). Hence, a transparent and continual negotiation process is needed where decisions can be taken which include change of knowledge on all matters influencing the play-out of vulnerabilities in time and space. It needs to be noted here that vulnerability is understood more holistically than the descriptions given by Miller *et al*. (2010) and O'Brien *et al*. (2004). Vulnerability is understood as an existing characteristic of society that varies due to any change that is taking place. This implies that it will always be part of the start as well as the end point of an adaptation process, but differing in intensity.

Based on the above, mainstreaming needs to be purposeful (Grothmann and Patt, 2005) on the one hand, while on the other hand the preparation of a decision should lead to a management intervention aimed at integrative and adaptive understanding and management (Stuart-Hill *et al*., in review). This calls for the ability of responsiveness as well as a continual uptake of new information into decision-making processes, also in order to evaluate any negative effects and potential benefits of climate change (Muller, 2007). Therefore the integration of climate change into decision making cannot "take place in a vacuum - it happens within functioning policy systems at global, national, local and state levels" (Ahmad, 2009). This also applies to a flexible management approach as alluded to earlier that reveals change and disparities over time and space, and adapts / adjusts to these accordingly. This reflects strongly the idea of mainstreaming. As Klein *et al*. (2005) define mainstreaming, it is the integration of policies AND measures into planning AND decision-making, aiming at sustainable development by reducing vulnerabilities to today's as well as future climate change. As measures of planning and resultant decision-making are framed by national politics and policies, mainstreaming in its relation to policy implementation and planning has to reflect a strong alignment with governmental set-ups. This echoes a bias towards top-down approaches as well as sectoralism, while the dimensions of measures and decision making for interventions reflect regional and local governmental structures. Thus, it simultaneously echoes a bias on local and resultantly bottom-up issues within a governance system.

Furthermore, decision-making requires knowledge creation, especially when aiming at understanding climate change impacts, reducing vulnerabilities and ensuring overall sustainable development. Science should play a major role in contributing to knowledge creation of water managers that guides adaptation design. Therefore, water management has to move towards a culture of processing "reliable knowledge", i.e. scientific outcomes, into "socially robust knowledge" (Ison *et al*., 2011), i.e. co-production with an emphasis on processes that are "shaped by multiple relations and reservoirs of knowledge, and a host of intermediaries and policy-brokers" (Vogel *et al*., 2007). This includes continuously moving back and forth, up and down, and even across scales and levels of governance and management

The aim of this chapter is to design a mainstreaming approach that deals with the manner in which climate change actually translates into vulnerability of the individual and the biosphere, as well as what the emerging threats to society and the economy may be, in order to inform water management processes and resulting interventions. In sections which follow the main characteristics of the mainstreaming process are first examined. As mentioned earlier, an appropriate negotiation process is needed that prioritises management interventions over a defined timeline. Such interventions and their prioritisation will be based mainly on cultural and political contexts, which are reflected by domestic and international norms, as these "channel and regularise behaviour" (Finnemore and Sikkink, 1998), by values and world views, which not only change over time, but vary between societal groups and decision-makers (O'Brien, 2009), as well as by other institutional and organisational factors, such as routines, cognitive views and knowledge management (Inderberg and Eikeland, 2009). Thus, context and culture may limit or constrain actions (Finnemore and Sikkink, 1998), while they definitely shape the options chosen and interventions designed. This also calls for the ability of decision makers to handle general conflicts over ideology and values (Mickwitz *et al*., 2009a). Additionally, if the aim is more universal adaptation which goes beyond climate change, then issues of current water scarcity, population growth, decrease in natural capital (Pielke *et al*., 2007) as well as organisational and governance weaknesses (Pahl-Wostl and Kranz, 2010) need to be included in the mainstreaming process. This results in a focus on integration across many scales and levels as well

as including adaptive capacity of management interventions themselves (see later section). The process that is required to finally implement a management intervention presents itself in **Figure 10.2.1**.

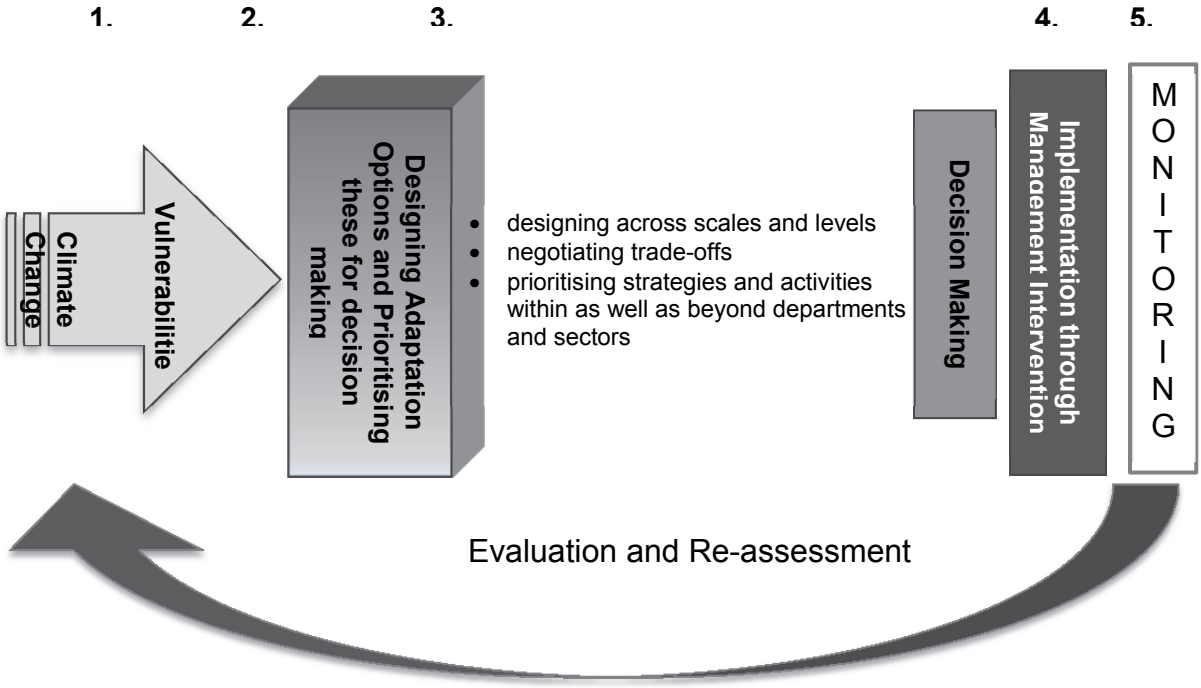


Figure 10.2.1 Conceptualising water management interventions for adapting to climate change

10.3 Conceptual Background

All of the issues described above can lead to turbulence in the relevant organisations, lead to change and increase already existing complexities in the work of decision makers. This can only be dealt with when "new organisational cultures, management strategies and individual competencies" (Woodhill, 2010) accompany the process as suggested in the next section of this chapter. Furthermore, it calls for dynamic organisations that are well informed and offer leadership that can create effective strategies when adjusting to changing circumstances (Muller, 2007).

But beyond these more theoretical and abstract issues, it is essential that policy and strategies lead to actual management interventions that are implemented - and are adjusted over time. Otherwise, mainstreaming might be successful on a systemic, conceptual and even legislative level, but does not lead to adaptation and change in livelihoods of people, in a robust economy, and in resilience of ecosystems. Hence, the management cycle in regard to the process presents itself in six essential steps, as in **Figure 10.2.1**, *viz*.

1. Knowing impacts of change;
2. Understanding the vulnerabilities (and also risks) which are critical at a certain time and in a certain place;
3. Making sense, which results in design and prioritisation of options for adaptation;
4. Implementing management interventions for adaptation;
5. Management, monitoring and evaluation thereof; and
6. Re-assessing and adapting based on new knowledge or understanding.

Thus, integrating new information and creating new knowledge on impacts of climate change and resulting vulnerabilities are important aspects of the mainstreaming process. Another is the horizontal and vertical integration in order to negotiate potential trade-offs and prioritise activities. Finally, an inevitable aspect of the management cycle, especially for adaptive management, will be the monitoring of the implemented adaptation options as well as management itself in order to ensure

sustainable development and therefore success, *viz*. learning from outcomes (Pahl-Wostl, 2006; 2009) and optimising management and performance respectively (Mickwitz *et al*., 2009a). **Box 10.3.1** provides further details on these concepts.

Another dimension that will not be touched upon in this section is that of politics. Although important for reflexive governance approach (Voss and Bornemann, 2011), it lies beyond the scope of this chapter. Nevertheless, politics will have to be reflected upon and cannot be bypassed in the real world of management and decision-making.

Box 10.3.1 Conceptual details for mainstreaming climate change adaptation

Incorporating and adapting to new information

Two main streams of new information in the context of adapting to and mainstreaming climate change have been identified:

1. New and updated information from climate change science in regard to projected impacts, and
2. New and updated information on existing and emerging vulnerabilities.

The latter is strongly determined by social entitlements and assets and hence a prerequisite is detailed information on individuals, communities and their livelihoods. Only then can one gain any knowledge on their direct and indirect dependencies on water and, resultantly, their current as well as future emerging vulnerabilities under climate change. Therefore, the uptake of new information must happen internally (across sectors and government levels) as well as externally (by the stakeholders who use and impact water directly and indirectly). However, science informs rather than guides the process (Methmann, 2010).

Vertical and horizontal integration

In the part of the management cycle described above, knowledge is being created as a starting point, based on which adaptation activities and management interventions will then be designed. In the course of this design process, conflict will be highly probable (Mickwitz *et al*., 2009a; Ogallo, 2010) especially when trade-offs arise, more so when the design process includes cross-sectoral and integrated activities beyond the water sector. Negotiations will have to take place, which again (just as in the case of knowledge creation and understanding of vulnerabilities) will need to span scales within and outside the water sector. Resultantly, vertical and horizontal integration, i.e. interplay and coordination between levels and sectors of management, are key issues in the quest to gain a holistic approach. **Figure 10.3.1** shows the organisational and policy canvas, based on which management interventions are designed and implemented. This shows how highly influential the national set-up with all its organisational and policy rules can be. In this context, policy coherence is crucial in order to avoid conflicting incentives and signals (Mickwitz *et al*., 2009a) towards water managers when designing interventions. It also needs to be noted that both modes of integration may, and often do, exist independently of each other. Management often reflects the pathways of policy making, which often follows the hierarchical form of governments (Koch *et al*., 2007), both within departments as well as from national to local level. Vertical integration is mostly based on the "formal structure of a strategic plan" (Lafferty and Hovden, 2003) and therefore currently limits intervention design to the originating sector, e.g. the water sector. This might result in an easier flow of information and decisions in the arena of vertical integration (especially when higher levels of decision-makers dominate lower levels) than in regard to horizontal integration. Top-down approaches will probably also dominate because of the financial dependence of local or provincial governments on national transfer payments and hence their preferences (Young, 2006). But it is the bottom-up processes that are important to include as they are seen to potentially reduce the uneven landscape of decision makers and stakeholders in regard to knowledge, power, the ability to form social relations (Eriksen and Lind, 2009), or issues of equity and access to governance institutions (Adger, 2006).

Monitoring

Whatever interventions are designed and implemented on whatever scale, their outcomes and actual consequences will need to be assessed. This is why Lafferty and Hovden (2003) stress the fact that mainstreaming needs to go beyond the thinking of the first generation, i.e. policy (goal) integration, but needs to presume consequences and evaluation thereof. Such monitoring is challenging as, in the context of understanding vulnerabilities and climate change adaptation, incomplete knowledge and sometimes a scarcity of usable data is inherent (Dasgupta and Baschieri, 2010). Here it can be helpful to widen the conversations of the management cycle to activities such as "cognitive biases", "risk experience appraisal", "social discourse" and "adaptation incentives" (Grothmann and Patt, 2005).

Choosing properties that need to be monitored and developing relevant indices in this regard can be quite difficult (Moser, 2009; Woodhill, 2010). Furthermore, such properties might increase or decrease in importance or influence over time. As a result detailed monitoring combined with an adaptive approach based on learning from outcomes will be crucial. In the end, decision makers will need to deal with the fact that in complex systems such as water resources management, some issues may have to be left out, knowingly or unknowingly to all partakers (Stirzaker *et al*., 2010). Also, the causes of vulnerability are not always direct, but might be hidden, as highlighted in a case study of Adger's (2006). Therefore, monitoring of mainstreaming will need to include other, less obvious, variables than we are used to. Detailed investigations of local and regional environmental, societal and economic dependencies will assist in identifying these.

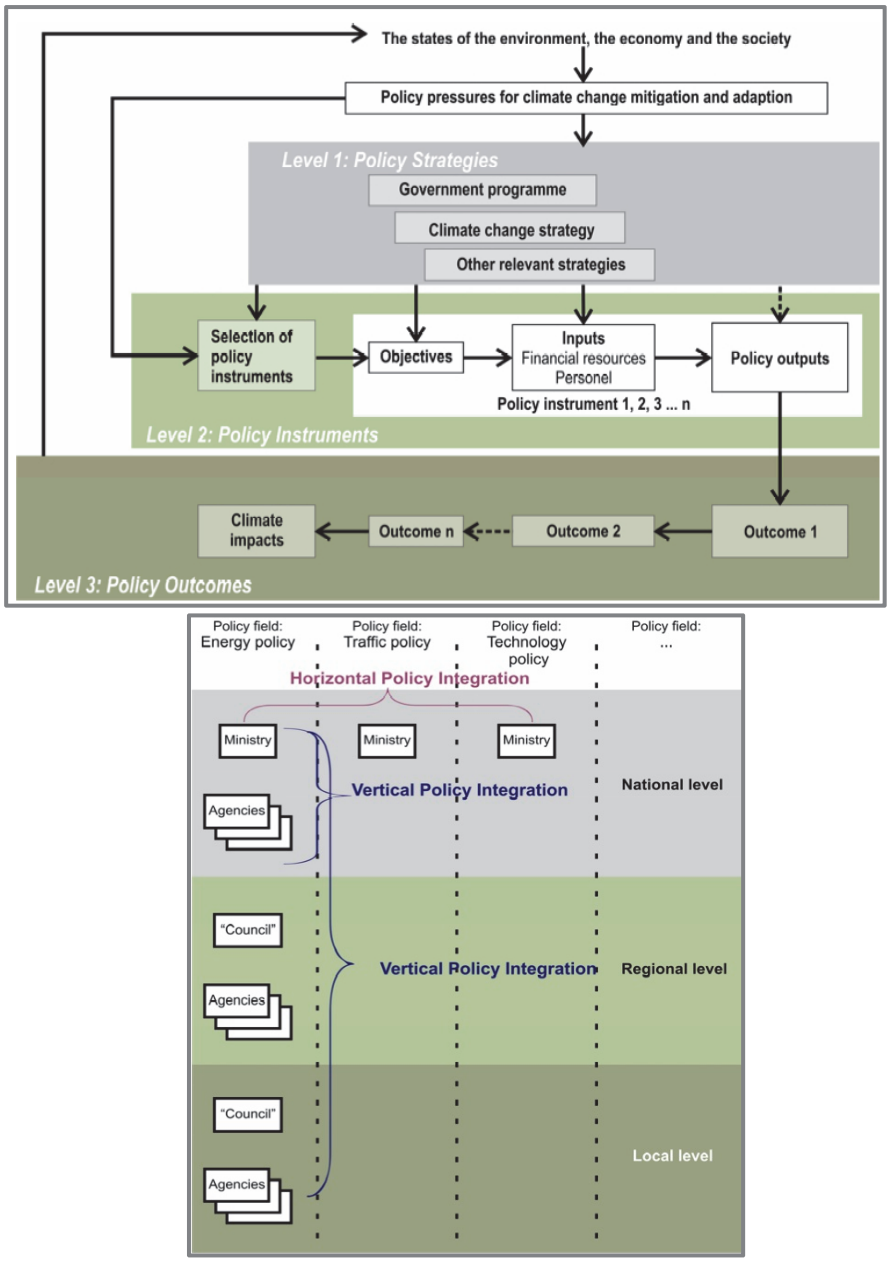


Figure 10.3.1 Levels of vertical (top) and horizontal (bottom) climate policy integration (Mickwitz *et al.*, 2009b)

Therefore, spanning levels and scales as desirable for mainstreaming will have to reflect a systemic, institutional and organisational dimension (Lafferty and Hovden, 2003), *viz*. "integration of policy-making as a feature of governmental steering according to differentiated sectoral responsibility" (Lafferty and Hovden, 2003).

10.4 The Process of Mainstreaming for Management

As mentioned earlier, mainstreaming is a dynamic process with many uncertainties (Klein *et al*., 2005; UNDP, 2009). It is not a means to an end, but rather needs to be partially iterative and on-going, operating in a changing environment where information and knowledge are of importance in the management process. As Lyytimäki (2010) concludes, mainstreaming needs to look at an overarching climate agenda, not only at environmental implications. It is also essential to have a broad-based debate between a "wide array of actors" (Lyytimäki, 2010). This points to the crucial dimensions of moving beyond sectors as well as beyond governmental officials in order to design adaptation

interventions. Kok and Conninck (2007) underline this by pointing at the potential to cross-fertilise when mainstreaming takes place across policy domains and interlinks different sectors and actors. Therefore, mainstreaming into planning is a bare minimum. Including knowledge and decision makers outside of the water sector will probably lead, respectively, to a more integrated and successful approach and development. Additionally, coherence can be increased and trade-offs can be dealt with. However, to accommodate different capacities of regimes or governance systems, the authors suggest multiple levels of intensity of mainstreaming.

The diversity of issues that are needed for successful mainstreaming are vast and interlinked. Depending on how far the conversations are widened, based on the stakeholders involved (Kok and Conninck, 2007) in the negotiations and the level of participation in the actual decision making process, the intensity of mainstreaming can vary. That is why, in order to design practical and useful steps, we suggest four levels of intensity of mainstreaming. This is reflected by the minimal to maximal approach in **Box 10.4.1**.

Box 10.4.1 Levels of intensity of mainstreaming climate change adaptation into management

1. Understand and include climate change into the planning of the water sector (*minimum*)
2. Integrate issues from outside the water sector (*low optimum*)
3. Understand and include climate change impacts on a relevant scale into decision making and the design of regulations within the water sector (*high optimum*)
4. Understand and include climate change into any daily decision making and design of regulations, while simultaneously also integrating issues from all other sectors (*maximum*).

The more intense or wider the conversation of mainstreaming is, the more the approach has the potential to design integrative, innovative solutions as well as assuring the legitimacy of interventions taken towards the broader public in a democratic state.

Halsnaes and Traerup (2009) also note that there is a large potential for integrating climate adaptation measures into already existing and on-going projects and planning efforts. But this will only be possible when moving at least beyond level 1 and most probably can be assured when mainstreaming on a level 4. Halsnaes and Traerup (2009) also suggest assessing the relationship between climate and development by defining climate variables and development indicators, linking these and then developing adaptation options.

To keep such a diverse process transparent and understandable to the participants, a detailed communication strategy and capacity modules have to be included (Pahl-Wostl, 2007). This should increase the chance that needs and viewpoints of the different participants are understood and, in the end, sum up to a holistic and implementable strategy.

Increasing the level of intensity and integration (as in **Box 10.4.1** from 1 to 4) increases the complexity of mainstreaming significantly. This is where ensuring transparency and communicating responsibilities are crucial. Decisions need to be taken by those implementing them and being held accountable for monitoring and optimising the outcomes. At the same time this will require institutional change and most probably different capacities to what is known (Snowden and Boone, 2007; Woodhill, 2010). Furthermore, the amount of data, knowledge and commitment needed for a successful process increases at the same time (Olhoff and Schaer, 2010).

The listed levels 1 and 2 in **Box 10.4.1** only focus on planning. This is a bare minimum. There will most probably not be many trade-offs to discuss. But when the need for trade-offs arises, power relations will become highly influential. Within government they will at the highest level become obvious in cabinet discussions, but with a high probability of influencing the policy and systemic decision-making processes before that already.

Moving higher to levels 3 and 4, the conversation widens significantly and more decision makers and stakeholders will need to be involved. This will lead to several challenges: trade-offs will become significantly more relevant, knowledge and hence known vulnerabilities will increase, and more requirements / demands will have to be satisfied. Power relations will come into play strongly as well.

Overall, the challenge at hand is to integrate different, but equally valid, approaches to knowledge rather than to start with a one-sided perspective and to add insights from the other perspective at the margin (Young, 2006).

Especially when increasing complexity and also aiming at management interventions, there is a "need [for] scientific knowledge to be translated into robust guidelines, and identifying a requisite simplicity may provide this" (Stirzaker *et al*., 2010). In the context of water management and adaptation design, this could be done by identifying key hydrological drivers that are representing most issues in a specific area on a spatial and/or temporal scale. A known example for this is using modelled system yield in water management as the only parameter in order to plan infrastructure, or streamflow for water availability. Using these in isolation is not advisable as they ignore many aspects of the wider catchment and societal context. However, these limitations can be dealt with when taking transdisciplinary aspects into consideration (Jones, 2011).

10.5 Skills Needed for Successful Mainstreaming

What specific skills by management and decision makers are needed to mainstream certain issues such as climate change adaptation into planning, design and implementation of management interventions? Three main challenges regarding the required skills arise from the defined levels of intensity for mainstreaming:

There is a need for ***connection*** in the sense of cooperation and coordination of organisations and individuals, beyond their day-to-day work which is normally focused on colleagues and activities within one department on one governmental level. This connective communication skill is needed to ensure the inclusion of new information, the creation of new knowledge and understanding vulnerabilities. The increasing complexity implies dealing with more diverse knowledge and also negotiating trade-offs between different players and sectors in order to prioritise and implement management interventions. This skill of managing complexities has two dimensions, *viz*. the individual and his / her organisation. On the one hand it calls for the ability of the individual to appreciate different views and to be able to change working and thinking approaches according to the problem at hand. At the same time the individual has to be practical in designing interventions and have the courage and technical skill to simplify context down to appropriate key variables, including a specific hydrological response (e.g. baseflow), an economic indicator (e.g. industrial production) or societal capacity (e.g. livelihood assets). On the other hand, organisational culture needs to offer and build trust towards and around those individuals, especially by top management and politicians. Finding ways of innovation in a rather rigid organisational set-up, as Olsson *et al*. (2006) have demonstrated regarding the utilisation of windows of opportunity, may play a crucial role. This relates to a creative and visionary entrepreneurial skill that would need to include creative thinking and solution seeking. Most probably an existing visionary outlook of the individual, *viz*. knowing how the single decision fits into the long-term development of water resources, would be helpful here.

Overcoming these challenges and the change and transformation they imply, calls for appropriate, i.e. situation dependent, leadership and learning capacities within and beyond organisations, as many authors have identified (e.g. Coninck, 2007; Inderberg and Eikeland, 2009; Ison *et al*., 2011; Pahl-Wostl *et al*., 2011). Olsson *et al*. (2006) go as far as stating that management *per se* is needed to a far lesser extent, but rather that a process is needed to govern negotiations and learning. However, both capacities will need critical reflection that lies outside the scope of this chapter. However, individuals can have very non-altruistic reasons that may undermine or counteract the shared vision of moving forward and finding solutions. Especially in times of "crises, rapid change and turbulence" we are "susceptible to toxic leaders" as Lipman-Blumen (2005) argues. Her suggestions could be translated in the context of this chapter by defining do-able goals on a practical time line, dealing openly with any emotions arising in the process (e.g. anxiety and angst) and accepting that uncertainty was and always will be part of the process.

In the process of mainstreaming, individuals who are able to transcend scales within the originating sector and beyond have to be identified and they have to be able to move /think /act both horizontally and vertically. Such individuals may demonstrate the leadership skills already identified (Olsson *et al*., 2006), especially when collaborating in governance networks by providing "key functions for adaptive governance, such as building trust, making sense, managing conflict, linking actors, initiating partnership among actor groups, compiling and generating knowledge, and mobilizing broad support

for change" (Folke *et al*., 2005). However, depending solely on these individuals during the process of solution finding and decision-making would be inconsiderate. The transparency and openness, i.e. the facility for individuals to enter and leave the process of the conversations taking place, is vital to the success of mainstreaming.

The learning dimension in the context of this chapter is basically an optimisation process: as we move forward we learn, based on our experiences, but we also incorporate new knowledge built by reflecting on decisions taken, which facilitates one's own learning as well as that of groups and organisations. It will also enable decision makers to share a large interface with sustainable development (Klein *et al*., 2005) which, especially in the developing world, is critical. Learning in this context will also need to engage politically and be self-reflective (Woodhill, 2010). With only few individuals displaying such a wide set of characteristics, this leads us again to the significance of certain skills: leaders and other decision-makers who are capable of arguing, of reflecting on their own perspectives and values as well as those of others, and of utilising certain organisational and individual relationships.

10.6 Concluding Thoughts

Although an enabling environment for the mainstreaming of climate change at the present point in time should at least be achieved on a systemic level in order to provide an enabling environment, this by itself is not nearly enough. Real and successful management interventions for climate change adaptation call for a better and more holistic understanding of impacts of climate change and existing as well as emerging vulnerabilities. The latter, especially, will need to be dealt with by aiming at more local discussion and solution finding processes, in addition to making final management interventions more relevant and implementable. Organisational and individual levels beside the systemic level are even more critical, as this chapter has demonstrated.

Generally mainstreaming of climate change is a highly complex task when taken seriously and simultaneously aiming at sustainable development in the long-term. It includes a variety of actors within and outside of government, who communicate and negotiate across levels and scales. This will only be possible when actors meet on a playing field where power differences are minimised, and more or less everyone is trusted and respected by their counterparts, based on their expertise and knowledge. Leadership plays a key role here, but anyone in the process should have certain skills, such as the relevant technical expertise, the ability to process new information and for systems thinking, experience in their profession as well as some organisational / institutional memory. What also seems to be needed on a very personal level is the respect for other perspectives, values and priorities as well as the ability to reflect, question, evaluate and learn from what has been implemented.

The suggestions on the mainstreaming process and the capacity and skills needed by the actors will take time to implement and build. They demand new partnerships, potentially new organisational arrangements and a strong focus on gathering a variety of socio-economic information that is included in robust and continuous monitoring processes. Such a management style needs financial commitment and political will. However, it no doubt should be possible to identify windows of opportunity for policy as well as management to start implementing certain aspects of the suggested process. Such innovations or best practices could be the nuclei for up- and out-scaling and they should motivate for learning and building new conversations in other departments, communities and networks.

The latter would need to be further researched. It would also be valuable to investigate the relevance of knowledge brokers or boundary organisations as leverage points for more complex mainstreaming. In the context of the developing world where the issues are most pressing and current levels of vulnerability are already high, it would be important to discuss the above concepts for a lesser skilled environment as well as for generally more fragile organisational structures.

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CHAPTER 11: A SNAPSHOT OF SOUTH AFRICA'S WATER RESOURCE MANAGEMENT STATUS - WHAT DOES THIS INDICATE FOR OVERALL WATER GOVERNANCE?

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Parts of this chapter have been extracted from the PhD thesis of Sabine Stuart-Hill

11.1 Introduction

Much has been written in the previous chapters on water management and governance concepts, as well as on organisational set-ups and institutional issues. But the realities of actual decision-making, intervention design and their respective implementation have to be seen in context (Berkoff, 2013; Eriksen and Lind, 2009) and have seldom been interrogated. Integrated Water Resources Management is such a case in point, where successful implementation is linked to three pillars, *viz*. an enabling legislative environment, an appropriate institutional framework and a tailored set of management instruments (Agarwall *et al*., 2000). However, as Medema *et al*. (2008) conclude, they "are not sufficiently detailed or prescriptive to fully specify how to realise the claims of the framework". Even those detailed 'To-Do Lists' by some authors (e.g. Grigg, 2008) might not be applicable to the realities of decision-making and intervention design and its implementation. Furthermore, the aim of water management should be to optimise and improve its performance over time (Mickwitz *et al*., 2009). This will need to be reflected in decision-making beyond the design of policies, regulations and instruments, and will need to reflect in the overall sustainable development of our water resources (Someshwar, 2008). Thus, decision-making and implementation are at the centre of this chapter.

Management and governance unfold based on legislative frameworks, policies and regulations (e.g. Ebbesson, 2009). Especially when laws, regulations and policies are rewritten and include a major shift in thinking and decision making, the realities of managers and users are often lagging behind (Schreiner, 2013; Ténière-Buchot, 2013) or are facing unintended and never thought-of challenges (Foerster, 2011). Additionally, institutional constraints may hamper or limit adaptation, not only in a single organisation, but within the entire system (Inderberg and Eikeland, 2009); in this case the water sector. This is where learning and knowledge management as well as every day routine-based activities play a crucial role (Roux *et al*., 2008; Inderberg and Eikeland, 2009) if integrative, adaptive and sustainable water management were to be achieved. All of this must be seen in context (Berkhoff, 2013), relating not only to national policies, but also to local water management and the resulting interventions that will unfold with all their complexities on a more local scale (Urwin and Jordan, 2008; Barnett, 2010). Hence, the realities of decision making must be understood, as must be the manner in which these influence the wider environment of water governance[17] and the specific sector within which water management is embedded. The key research question, therefore, is "How are water management decisions actually taken nowadays and how do they relate back to the overall state of water management and governance?"

Based on the challenges facing water management to deal with rapid and complex change patterns, the following needs of water management have been identified by Stuart-Hill and Schulze (2010):

- understanding vulnerabilities, both current and emerging,
- integrating all aspects of the hydrological responses as well as those of the stakeholders involved,
- displaying flexibility and preparedness of the uptake of new information into decision making, and

[17] Governance is understood here as defined by Pahl-Wostl *et al*. (2012, 25): "The notion of governance takes into account the different actors and networks that help formulate and implement water policy. Governance sets the rules under which management operates."

- including the participation of effective institutions in their knowledge building and decision making.

Overall, this calls for adaptive organisations, individuals and decision making (Stuart-Hill *et al*., in review). This chapter, therefore, will undertake investigations in a specific case to understand the decision making environment of water managers and stakeholders and how strongly, if at all, the needs identified by Stuart-Hill and Schulze (2010) actually reflect in the different phases of decision making in the water sector.

11.2 The Case of South Africa

As commented on earlier, an institutional and legislative potential is only the formal canvas on which water management and governance takes place. Even when an enabling environment exists, but law enforcement and overall policy implementation are lacking or are incomplete, the degradation of the resource base is highly probable. This currently appears to be the case in South Africa, which displays a promising water legislation to tackle challenges of societal transformation, growth and development, as well as taking account of future uncertainties (Seetal and Quibell, 2005; Swatuk, 2010; Schreiner, 2013), but at the same time is experiencing marked degradation in its water resources (CSIR, 2011). This implies that South Africa's capacity to implement effective water arrangements is poor (Iza and Stein, 2009), especially when taking into consideration the needs to implement IWRM as the main management approach, as set out in the National Water Act (RSA, 1998).

When exploring the legislative components of South Africa's water regulatory framework in the context of its ability to perform in an integrated and adaptive manner, it offers a unique and flexible set-up to understand existing as well as emerging vulnerabilities in order to proactively adapt to climate change (Stuart-Hill and Schulze, 2010). It even offers the flexibility to tailor regulations and water management to each catchment area.

Hence, a reality check needs to be undertaken, which this chapter aims at, as shown in **Figure 11.2.1**. The research should show whether an integrated and adaptive management approach is implemented and if interventions designed are relevant to tackle the challenges lying ahead.

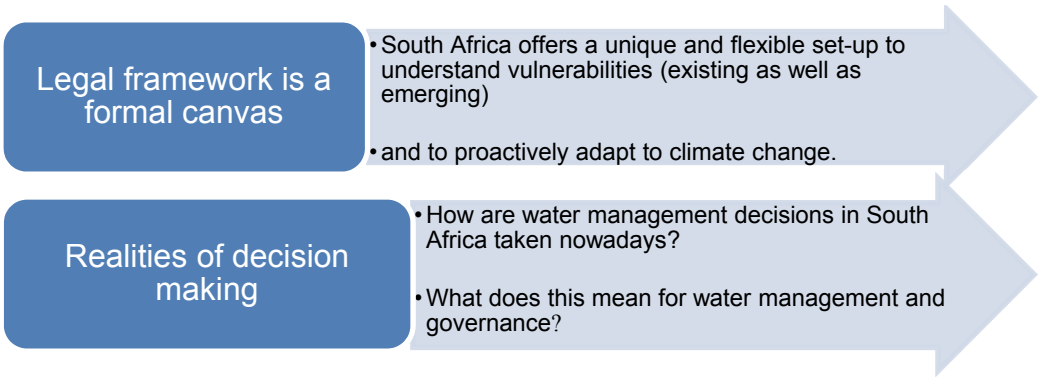


Figure 11.2.1 Derivation of the research question(s) for this chapter

The aim of the research undertaken is to explore whether the governmental set-up as well as interactions with society and other sectors are functioning according to their intent, whether existing and emerging vulnerabilities are understood, whether leadership for learning and collaboration exists and whether participatory activities are spaces of dialogue that ensure the success of the aforementioned steps and issues. This was done by undertaking a series of semi-structured interviews, via a questionnaire, with relevant players in the South African water sector.

11.3 Methodological Approach

This section will be split into four sub-sections. The first is on what needs to be analysed, *viz*. the policy-management cycle in regard to its potential for integration, learning, feedback and adaptation. The second is on who was interviewed in order to accordingly gain insights. Thirdly, a discussion

ensues on how the questionnaire was designed and used, and fourthly, how the analysis was carried out.

11.3.1 The Policy-Management Cycle

As discussed above, the adaptive capacity and the integrative potential of decision making needs to be investigated. Decision making takes place in regard to policies as well as day-to-day management. Furthermore, it is not only the approach, but also its overall level of actual implementation that is of interest here. Thus, based on a diversity of research designs and results in regard to governance (Deason *et al*., 2010; Loorbach, 2010; Woodhill, 2010), policy design (Benvie, 2005; Pahl-Wostl *et al*., 2007b; Plummer and Slaymaker, 2007; Pahl-Wostl, 2009) and adaptive management (Holling, 2001; Pahl-Wostl, 2006; Kingsford *et al*., 2011), the so-called Policy-Management Cycle was designed as laid out in **Figure 11.3.1**. The main characteristics that make up the cycle are integrative understanding and decision design and, following on from there, learning, feedback and resultant adaptation. Only when the Policy-Management Cycle is closed, i.e. when all phases are reflected strongly in the relevant decision making processes around water, can one speak of an implemented adaptive management approach that takes into consideration vulnerabilities, new information and participatory sense-making. This leads to the current status of the cycle, represented by n, to move to the next phase, n+1, and so forth into the future, ensuring the optimisation of management performance as discussed previously, and the overall mainstreaming into the water sector. When this is embodied in water management, then the potential is high that management interventions will deal with change and specifically with adaptation, for example in the context of climate change and its vulnerabilities (Stuart-Hill and Schulze, 2010), and resultantly will mainstream adaptation into the water sector (Stuart-Hill *et al*., in review).

The Policy-Management Cycle applied in the context of the research undertaken by the authors consists of four phases:

- Phase I = How far is the holistic and integrated approach of water management implemented?
- Phase II or L = Is learning of individuals in the governance system as well as in their decision-making environment possible?
- Phase III or F = Are there opportunities to feed what has been learnt back into the governance system?
- Phase IV or A = How far is this resulting in adaptation and a change in decisions taken thus far? Or, put differently, how does this result in an overall adaptive management approach?

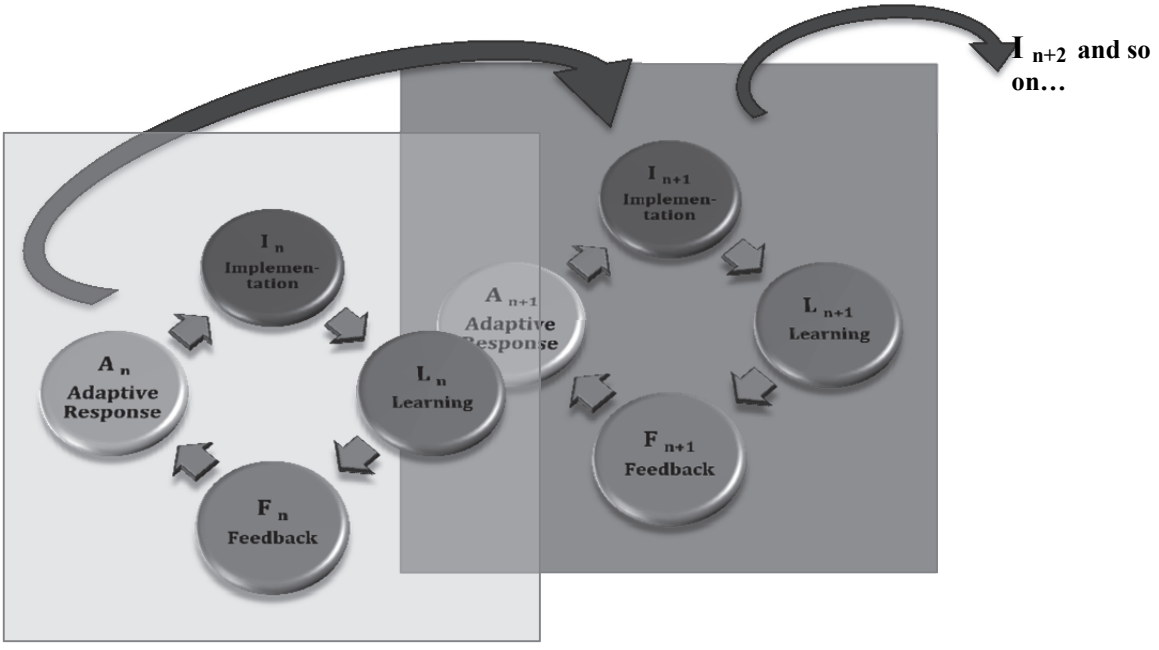


Figure 11.3.1 The Policy-Management Cycle

11.3.2 Interviewees

In order to gain insights into the day-to-day decision-making realities of South Africa's water managers, 34 semi-structured interviews were conducted in 2009 and 2010. They aimed at describing a *status quo* of decision-making in the water sector (Flick *et al*., 2003). The interviewees came from the governmental, consulting, academic and industrial sectors. In South Africa, decision-making and its corresponding accountability rests mainly with government. However, government and its decision-making is being heavily advised by consultants (Schreiner, 2013) and, therefore, these two groups are strongly represented, with 13 and 10 interviewees, respectively. Furthermore, certain academic leaders have been, and still are, involved in informing policy design and decision-making, e.g. through membership in the South African COP delegations and the National Water Advisory Committee of the Minister of Water Affairs. Thus, 8 influential academics were interviewed. Additionally, 3 interviewees originate from the industrial / private sector. It needs to be noted here that in numerous cases interviewees had moved between the named sectors. Here the assumption has been made that once the individual has spent more than three years in the latest sector, he / she was assigned as 'belonging' to that sector. If not, then it was assumed that the knowledge base and framing of their answers to the questionnaire were influenced by their former work, which in all cases represented the majority of the individuals' work life experience. Only two such re-assignments had to be made: two current consultants having been formerly, i.e. less than 3 years ago, with national government and academia, respectively.

All interviewees who were approached were known to have been in the water sector for many years and some had even been part of development and formulation of the South African National Water Act of 1998. Furthermore, the individuals interviewed reflect either leading managerial positions in government, or strong involvement with and close relationships to decision makers from the consulting sector, or are influential thinkers from the academic and industrial sectors closely linked to the other two sectors.

11.3.3 Questionnaires

The questionnaire (**Annexure 1**) which was developed consists of four sections, the first two with global questions investigating the integrative and adaptive potential, the second two tailored specifically to the South African case.

Section A evaluates the enabling environment in regard to policies, the legislative framework as well as financing and incentive structures. The aim of this section is to assess the *status quo* in regard to implementation of the acts and policies as well as the principles of IWRM.

Section B evaluates institutional roles and management instruments. The first part is to again assess the *status quo* in regard to implementation of the acts and policies as well as the principles of IWRM, but also to evaluate effectiveness of overall water governance.

Section C performs a reality check for South Africa in regard to implementation of key policies, transformation and cooperation between sectors.

Section D deals with issues of change, leadership, participatory management and adaptation. The aim here is to assess barriers and drivers of change as well as cooperation and beyond the water sector and integrating interests of users and decision-makers from all levels.

The questions of **Sections A**, **B** and question 7 of **Section C** were founded on two Technical Briefs of the Global Water Partnership, *viz*. 1 and 3 (Carriger, 2006a; Carriger, 2006b), as well as the corresponding TEC Background Papers 3, 4 and 7 (Solanes and Gonzalez-Villarreal, 1999; Agarwall *et al*., 2000; Rogers and Hall, 2003). The others were tailored inquiries in regard to the implementation status and decision-making around South Africa's existing policies and regulations.

The **Sections A**, **B** and **C** of the interview always queried the level of alignment between 'what is on paper' (what should be) and 'how reality is presenting itself' (what is). Comments and elaboration on other issues were allowed in order to gain a better contextual and (partially) historical understanding.

11.3.4 Analysis

The interviewer took notes as well as recording the interviews in order to enable a re-visit, if needs be, for clarification on certain issues. As the interviews varied between a little more than one and three

hours, the interviewer decided not to transcribe these. All questionnaires were made anonymous before analysing any answers.

For this chapter and its aims, a specific set of questions was chosen representing core issues in fulfilling the four phases of the Policy-Management Cycle. These were for the Integration Phase (I) from **Section A** with questions 2, 3, 7, and 11; questions 1, 2, 3, and 12 from **Section B**; and questions 1 and 2 from **Section C**. These looked at the level of integration of policies and frameworks, alignment of policies and organisations, cooperation between players and sectors, implementation levels of core policy tools (*viz*. the reserve, licensing, poverty measures) and the overall representation of IWRM in decision making. For the Learning Phase (II) the questions were taken from numbers 6, 7, 8 and 20 of **Section B**, which reflect on issues of capacity building, improvement of practices, collection and analysis of relevant data as well as the sharing of information. For the Feedback Phase (III) questions 9, 10 and 21 of **Section B** were selected as these relate to feeding back results into decision making and planning, the communication of results and the availability of decision-support tools. For the Adaptation Phase (VI) question 18 from **Section B** was used (effective cooperation). All other questions originated from **Section D** and they reflect on the initiation, implementation and evaluation of adaptive activities, the availability of leadership vs skills, as well as participatory knowledge management and decision making. Please refer to **Annexure 1** of this chapter for the wording of these questions.

In only one section of Phase I were the interviewees asked to rate implementation of laws and policies as well as the reflection of IWRM in their daily work between 1 (not at all) and 5 (fully implemented). The interviewer rated all other answers, as it must be assumed that the interviewees would not have rated their daily performance and success objectively enough to gain useful insights into the daily water management processes. Nowhere were more than 10% in total of the questions left unanswered. This indicates a professionalism and honesty of the interviewees not to judge on issues of limited knowledge. Only in the section on the capacity narrative was the unanswered percentage higher at 16%, although in two cases this was also caused by lack of time in finalising the interview. Overall, the majority of unanswered questions originated from consultants, and this is probably linked to their limited insights into certain issues of governmental performance. Only a few from the governmental sector indicated no answer for their questions, with 8 unanswered questions in total.

In the course of the analysis the well-known narrative from many personal conversations of “a lack of capacity on all levels of South Africa’s water managers, especially those making decisions” came up on frequently. Hence, the interviewer included a section to investigate this capacity narrative. The analysis was based on three different parts: a general capacity question that was asked in the early stages of the interview (**Section B**, question 5), the analysis of the strongest barriers that the interviewees listed in the later stages of the interview (**Section D**, question 5) and a more detailed section on human capacity (**Section D**, question 7, i-iv), which broke the matter down into four components of capacity, *viz*. political, professional, implementation and compliance capacity.

The overall aim of the interview process was to gain insights into the executive and decision-making part of the water sector; its functioning within the governmental set-up as well as its interactions with stakeholders and civil society. Three main areas of concern were targeted for the analysis presented in this chapter, *viz*. (i) how far is the holistic and integrated approach of water management implemented? (i.e. Phase I of the Policy-Management Cycle), (ii) is learning of individuals as well as feedbacks into the governance system possible? (i.e. Phase II and III of the Policy-Management Cycle), and (iii) how far is this resulting in adaptation and an adaptive management approach? (i.e. Phase VI of the Policy-Management Cycle). In combination with other topics such as leadership and especially clarifying the capacity narrative, the decision making environment of the individual within the water sector was studied.

The results obtained should allow an understanding of the *status quo* of the implementation of water policy developed post-1994 and how new challenges such as climate change are dealt with. Results were to reveal how water resources issues are framed and understood, if learning and feedbacks are possible in the framing as well as decision-making process, and if this would result in adaptation of any scale in regard to knowledge creation or decision-making. Furthermore, overall levels and types of fragmentation were hypothesised to become visible when assessing the strengths and weaknesses of the policy-management cycle, as well as whether the cycle was actually closed or not.

11.4 Results

All interviewees engaged well with the questions and gave detailed insights into South Africa's water governance and management system. All 34 interviewees had significant years of experience in the water sector, with a minimum of 5 years (in two instances), and the maximum of 39 years. On average the experience reflected in the answers was based on more than 20 years of involvement, understanding and know-how of South Africa's water sector.

It needs to be noted here that no correlation or patterns could be found between questions or phases and the individual interviewee's sector representation, e.g. governmental players did not rate their performance higher than that of the others and / or academia did not rate capacity issues significantly low compared to other sectors.

11.4.1 Results from the Policy-Management Cycle

The results are presented for each phase that makes up the cycle.

Phase I - Integration

As elaborated upon earlier, Phase I looks at the integrative creation of knowledge and the integrative design of solutions. In Phase I the independent rating shows that 36% of the interviewees rated the requirements of a holistic and integrated approach as having been fulfilled (**Figure 11.4.1**). However, a similar number of interviewees, i.e. 37%, rated the approach as having been fulfilled, but with many limitations. The remaining 27% rated holism and integration as not being existent in the water sector.

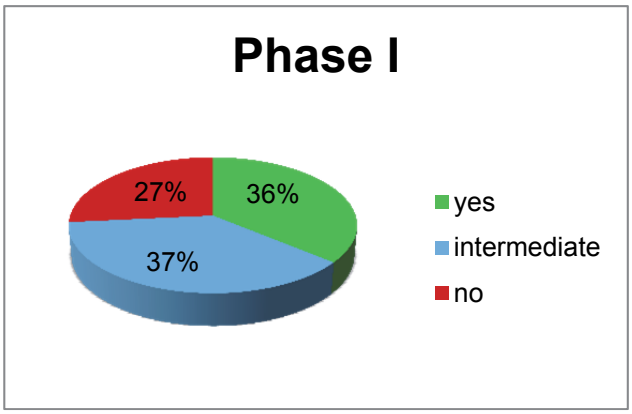


Figure 11.4.1 Independent rating in regard to the reflection of a holistic and integrated approach of water management in decision-making and implementation

Re-occurring (i.e. mentioned by > 5 interviewees) themes in the comments made in this phase were as follows:

- A lack of capacity and skills exists in the decision-making environment.
- Different levels of implementation exist in different parts of the country.
- Formally South Africa's set-up is very good, but is very challenging and hence, only slow progress can be seen in implementation.
- The lowest governmental levels, *viz.* local and municipalities, are the most problematic.
- Many of the acts are not aligned and lead to controversies or confusion.
- A high staff turn-over in the governmental departments on all levels has been identified as problematic .
- Not as often as the issues above, but mentioned a number of times, were examples of political pressures overriding management as well as lack of political will in certain areas.

The highest level of agreement on fulfilment existed in regard to question 12 in **Section B**, *viz*. that investments were too low in empowering and involving excluded social groups such as women and the poor. The highest level of disagreement on fulfilment existed in regard to question 2 in **Section A**, viz. that economic and social policies take into account water resource implications.

In regard to the direct ratings from 1 to 5, as done directly by the interviewees, the results reflect that the implementation of the National Water Act (NWA) was rated with an average of a weak 2.6, which is almost 1 point lower than the question on the implementation of the Water Services Act (WSA), which was given a relatively good rating of 3.4. The reasoning was often that the WSA is clearer in its definitions of roles and responsibilities. The incorporation of the principles of IWRM in regulations was rated with a very high 4. However, as regulations are only as good as their implementation, the actual relevant rating is the one for incorporating IWRM in actual decision-making, which came in far lower at just under 3, *viz*. at 2.8. This is slightly higher than the rating of the implementation of the NWA.

It seems that the individual decision makers in the water sector have started to incorporate the principles of IWRM into their value judgements and hence into their interventions. Yet, the organisational environment seems to be lagging behind when it comes to implementation. Overall, the perceptions reflected reality with the overall performance of the water sector in regard to implementation of IWRM, which is rather weak in both cases, i.e. with an independent rating is 37% and a direct rating 2.8 out of 5.

Phase II - Learning

As elaborated upon earlier, Phase II assesses whether, and how, learning is possible within the existing water management organisations. This entire section rested on the independent rating by the interviewer. Again elements (via 4 questions) identified as crucial for the phase were rated according to their fulfilment with yes, no, or intermediate / limited. This phase links closely to the next phase as it is a prerequisite for creating feedback. In Phase II the independent rating shows that only 28% of the interviewees who answered perceived that learning was possible and on-going in the water sector (**Figure 11.4.2**). An only slightly lower percentage at 25% rated this as not taking place at all. Almost half of all interviewees said that some type of learning was taking place, but only with significant limitations.

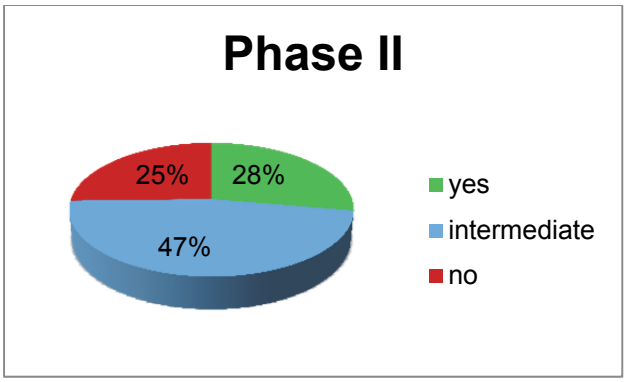


Figure 11.4.2 Independent rating in regard to the learning environment within the water sector

Re-occurring (i.e. mentioned by > 5 interviewees) themes in the comments made in this phase were as follows:

- A high staff turn-over in the governmental departments on all levels was identified as problematic (same as in Phase I).
- Socio-economic data are very limited and have been derived mainly from the national population census.
- Catchment Management Agencies[18] (CMAs) were often mentioned as the example of a learning platform.

[18] ***"Catchment management agencies (CMAs) represent the second tier of the water resource management framework. A CMA will be established in each of the […] water management areas. Each CMA is responsible for the progressive development and broad implementation of a catchment management strategy." (de la Harpe et al., undated,[8]) "Catchment management agencies must ensure that all interested and affected stakeholders including poor communities that have been disadvantaged and marginalised are able to participate in the consultation processes and decisions of the CMA." (De la Harpe and Ramsden, 1998, 37)***

- Capacity building plans were often been noted as being in place, but not working or achieving their aims.

The highest level of agreement on fulfilment existed in regard to question 20 in **Section B** on user-friendly platforms for sharing information among water-related, governmental and non-governmental organizations and with the general public. The highest level of disagreement on fulfilment existed in regard to question 7 in **Section B** which related to individuals and institutions (public and private) provided with incentives to improve their practices and approaches.
From the responses it seems, and correctly so, that learning is a very personal experience. Many different viewpoints and reflections came to light in this section and individuals often referred solemnly to 'their part or organisation' of the water sector when answering these questions, i.e. their direct personal working environment. The topic of learning did not appear as something that should be part of the working environment, and less so part of a decision-making process. The topic of learning was nothing obvious to reflect upon and many of the interviewees took quite some time to formulate their answers. Furthermore, interviewees reflected very differently on what the appropriate platforms for learning were and could be, varying form simple websites of organisations to the complex negotiating environment of Catchment Management Agencies.

Phase III - Feedback
As elaborated upon earlier, Phase III evaluates whether new knowledge and learning outcomes are actually fed back into the management cycle. This links closely to the next phase as feeding back is a prerequisite for adaptation. As was the case in Phase II, this whole section rested on the independent rating by the interviewer. Three questions were identified being key for this phase and were rated accordingly. Phase III showed some surprising results: significantly higher numbers, *viz.* 37%, of the interviewees who answered saw feedbacks into the system actually taking place (**Figure 11.4.3**). Only 19% rated this with 'not at all' and 44% said that only few feedbacks were actually taking place.

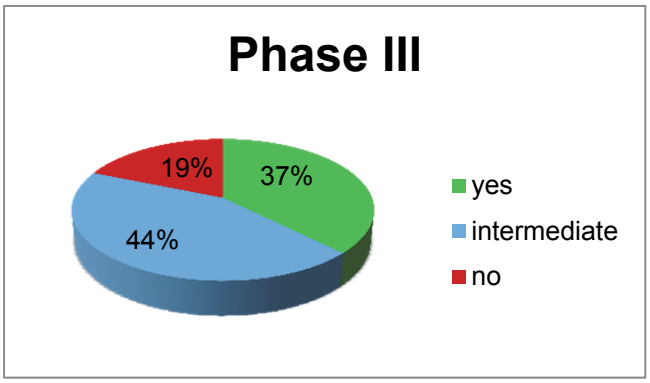


Figure 11.4.3 Independent rating in regard to the ability to feed back new knowledge and learning outcomes into the decision-making processes of the water sector

Re-occurring (i.e. mentioned by > 5 interviewees) themes in the comments made in this phase were that communication with stakeholders was, by and large, described as 'one way', *viz.* governmental departments informing stakeholders and others. Considerable decision-making that was done was said to be based on computer models. At the same time the interviewees felt unclear about the proper use of these models and if they, in the end, actually do lead to any type of action or intervention. The feedbacks elaborated upon showed no consistency: they derived either from specific consultancies, or the outcomes of a research project, or sometimes from a specific organisational set-up.

When trying to identify the strongest and weakest element in this phase, both were reflected by the same question, i.e. 10 in **Section B** on whether assessment results communicated to stakeholders were available in accessible form. Therefore, the authors see this as the most ambiguous issue amongst the interviewees and hence in water management. Overall, it was observed that there was only limited elaboration on the answers in this phase. The feedbacks that were elaborated upon were very selected / specific cases that did not represent a systemic way of dealing with learning outcomes. Also, they never showed an integrated or holistic view of framing and dealing with the issue on hand. Some feedback opportunities existed within departmental structures, but these were perceived not to feed back towards society and / or other sectors.

Phase IV - Adaptation

As elaborated upon earlier, Phase IV assesses the adaptive mode of water management in South Africa, i.e. whether there are actions of adaptation taking place based on anything that had been learned and that was being fed back into the management cycle. This is the crucial phase in order to have an effective management approach in place, which understands on-going changes (environmental, societal, economic) as well as their consequences, which learns from outcomes, includes new knowledge and as a result optimises management performance. Phase IV shows an extremely low agreement of only 13% on adaptation activities taking place in water management (**Figure 11.4.4**). The majority of interviewees, *viz.* 54%, did not see any adaptation happening while a third (33%) could see some type of adaptive interventions taking place.

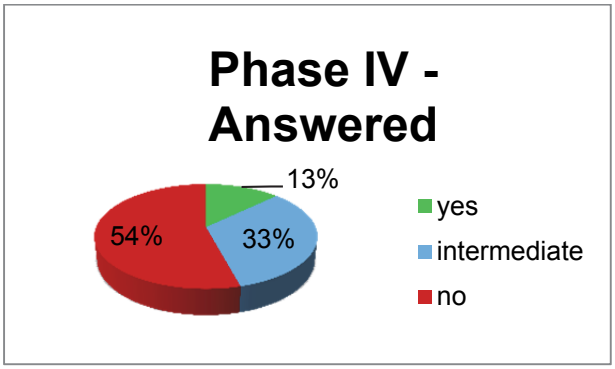


Figure 11.4.4 Independent rating in regard to the adaptation taking place in the overall water management approach across the water sector

Re-occurring (i.e. mentioned by > 5 interviewees) themes in the comments made in this phase were the following:

- The picture around participation and stakeholders, especially outside of governmental structures, is very messy. Comments varied from "the layman is not useful, we [water managers] as professionals know best", to several comments around "stakeholders do not participate, they are not interested", "these are intransparent processes" and "processes are often politically hijacked".
- Those interviewees who did not see adaptation taking place suggested a more or less hierarchal process to be developed that initiated activities on a higher level (even the Presidency was mentioned once), with implementation and evaluation on a lower level (regional or local).
- One of the key questions in this section, *viz*. on effective co-operation on regulatory decisions between land use planners and water managers, was often seen as not taking place (11 times) or only in a limited way (13 times). Many of the interviewees pointed to the CMAs as the only possible place for such cooperation. On the other hand, several interviewees mentioned that the CMAs are under strong political influence.
- Other, or alternative, places for participatory learning and decision making were seen in the Water User Associations19 (WUAs).

As the strongest aspect fulfilled in this phase was the involvement of organisations, also beyond the CMAs, in participation. The weakest element was, not surprisingly, the actual initiation of adaptation or adaptive management interventions.

11.4.2 The capacity narrative

As alluded to in many sections of this chapter, the lack of capacity and skills was often the reasoning of the interviewees for limited implementation of any of the phases described above. When evaluating **Section D**, question 5, *viz*. please list the 5 strongest barriers to change in RSA[20], lack of capacity - in the sense of a lack in expertise, education, experience, knowledge, understanding, technical skills,

[19] Water User Associations (WUAs) "are associations of individual water users that undertake water-related activities for their mutual benefit." (de la Harpe *et al.*, undated, [8]) "It is a grouping of water users who wish to work together because of a common interest. The water users 'co-operate' in undertaking water-related activities at the local level for their mutual benefit." (De la Harpe and Ramsden, 1998, 39)

[20] Republic of South Africa

institutional memory - was listed mainly in the first or second place by 19 out of 33 interviewees. The most mentioned other barriers were “decision makers stay in their comfort zone” (7 out of 33) and “too much change has and is taking place” (5 out of 33). Only 10 of the interviewees did not touch on either of these barriers.

Furthermore, relatively early in the interview, i.e. **Section B** question 5, a general question was asked as to whether capacity was in place to fulfil the diverse mandates of water management. An overwhelming 70% of the interviewees answered ‘no’, with only one interviewee answering ‘yes’. However, in the comments, the majority related the ‘no’ to Human Resources, while funding and equipment was mostly seen as not being problematic.

When interrogating the limited amount of capacity available within the water sector towards the end of the interview (ca. 45 minutes to 1 hour later), the picture that emerged was slightly skewed compared to the more general assessments beforehand: In particular the professional capacity in the country and in the water sector were seen as fulfilled by almost half the interviewees, *viz*. 48%. The weakest dimension of capacity was seen as the compliance capacity, with 53% of the interviewees seeing this as not fulfilled at all.

Overall, the capacity narrative could not be confirmed with confidence.

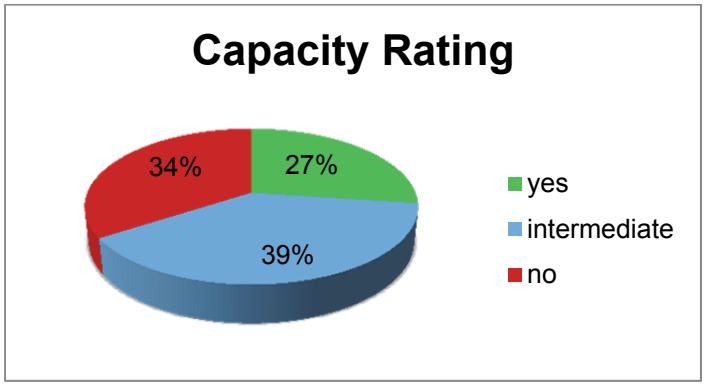


Figure 11.4.5 The rating of overall capacity based on the four dimensions of political, professional, implementation and compliance capacity

An additional conversation that emerged was around skills and leadership. These were seen as being closely linked to the capacity challenge, with 12 of the interviewees viewing skills as more important, while 13 interviewees rating skills and leadership equally as important.

11.5 Discussion and Conclusion

The above analysis shows that the four phases are all distinctively mediocre to weak with fulfilment levels at below 40%. It needs to be noted here that even the first phase (Phase I looking at integration), which should reflect well after 15 years of the ‘new’ Act, and which reflects IWRM as the management approach to be followed, and the many water policies having now been in place for over 10 years, still shows high levels of fragmentation and limited integration. Holistic thinking and decision making approaches are only reflected in a few cases. In evaluating the phases of the cycle, the learning phase (Phase II) is significantly weaker than the integration phase (Phase I). Although the feedback phase (Phase III) might be surprisingly high with a 37% fulfilment, it has to be relativized due to the fact that the learning outcomes are very limited, and even those are incomplete and partial as they only link certain issues or projects. Overall, learning and feedbacks are not systemic to the management approach and cycle. The final phase of the cycle, which relates to taking adaptive action, is almost non-existent.

Based on these outcomes, the *status quo* of implementation in regard to an integrative and adaptive management approach in South Africa must be regarded as weak overall. It must be assumed that the Policy-Management Cycle within government is not well established and weakens as the issues at hand (integrated learning, reflection, processing new knowledge, participatory activities and feeding back into the system in order to enhance performance and capacity) become more demanding and

complex. However, a few individual cases seem to exist, and these might be the pockets of innovation from which the country needs to learn.

Additionally, different dimensions of capacity were discussed. The well-known narrative of a skills and capacity crisis could not be confirmed meaningfully. However, the interviewees confirmed that Human Resources are the area of great capacity deficiency. At least the financial situation and the availability of equipment were seen as remarkably good. What this inquiry has shown is that issues need to be differentiated and broken down into more specific questions, otherwise a proper understanding of the challenges at hand is not possible and any solutions designed will probably not be effective or sustainable.

On the one hand a major challenge is the uneven landscape in regard to many of the issues discussed, *viz*. integrative and holistic thinking, law enforcement, capacity issues of different types and / or ineffective communication with stakeholders. On the other hand political pressures and interference seems to exist in several cases, but is not systemic to the governance system. Also positive is that all phases and almost all elements seen as crucial for an effective policy-management cycle exist at least in their basic structures. This indicates that a paradigm shift from the old technological control paradigm (Stuart-Hill and Schulze, 2010) is starting to take place - at least in parts of the water management system. However, the process is extremely slow and fragmented. It is questionable if it will, at all, mature further in the future.

Overall, South Africa's water management system and sector shows a diverse set of emerging issues which need to be dealt with urgently. The Policy-Management Cycle is fragmented and not closed. Therefore, change in general and climate change specifically cannot be dealt with effectively as yet. This also applies to current and emerging vulnerabilities and the further degradation of the water resources. The South African narrative of 'lack of capacity and skills' needs to be differentiated into its dimensions. Each level will require a tailored approach with certain tools, and only then can a sustainable solution to this be found. Communication with stakeholders etc. (governance dimension) exists in a systemic way, but is not effective, with real cooperation[21] lacking. Last but not least, fatigue is embedded in many parts of the system because of constant change taking place - new policies, changes in leadership and re-organisation. It seems that a time of consolidation is urgently needed.

Overall, opportunities and pockets of success have been highlighted by the interviewees, besides their often negative ratings and evaluations. It seems that South Africa's water managers have not given up the hope of implementing their innovative and challenging water laws and policies.

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[21] Cooperation and coordination of organisations and individuals beyond their day-to-day work, i.e. normally focused on colleagues and activities within one department on one governmental level. (UN, 2013)

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Annexure 1: Questionnaire

Setting the scene

The way we are dealing with our water resources today does not seem to be sustainable. Availability and quality problems occur throughout the country, more or less independent of rainfall distribution and impacts of climate change. For the future we must find more effective, long lasting solutions to our water problems, based on the principles of efficiency, equity and environmental sustainability. In that way today's situation - which has the potential to develop into a crisis - can provide a window of opportunity that we can use to ensure a response to challenge rather than reinforcing the *status quo*. We need to put ourselves in a position to judge which management tools can treat the disease rather than the symptoms and therefore, how to deal with constant change and constant adaptation respectively.

Date: _____

Name: _____

Q: How long have you been working in the water sector and in what position? *(Aim: pin-point Expertise)*

_____

Section A: Enabling Environment

1-3 Policies; 4-7 Legislative Framework; 8-11 Financing and Incentive Structures

(Aim: define status quo in regards to implementation of the act and principles of Dublin/IWRM)

1 Water policies accord with overall national economic policy and related sectoral policies.
2 Economic and social policies take into account water resource implications.
3 Water policies support economic efficiency, social equity and environmental sustainability in water development, management, and use.
4 Water policies establish secure and transferable water rights.
5 They protect public interests - including the interests of future generations, for example, by ensuring water to meet environmental needs.
6 They clearly define the responsibilities and authority of water / environmental management agencies and water and sanitation service providers.
7 Water laws are operational / enforceable.
8 The water funding strategy estimates overall investment requirements and identifies funding sources; is regularly reviewed and updated.
9 Water pricing reflects the costs of water services, operations and maintenance of infrastructure, and pollution control.
10 Subsidies for the poor, if necessary, are transparent and well-targeted.
11 In the case of public utilities, water fees are used to provide/improve services and ensure maintenance of infrastructure.
12 Others:

Section B: Institutional Roles

1-4 Organisational Frameworks

(Aim: define status quo in regards to implementation of the act and principles of Dublin/IWRM and effectiveness of water governance)

Section B: Management Instruments

5-7 Institutional Capacity Building; 8-10 Water Resources Assessment; 11 Demand Management; 12-14 Social Change Instruments; 15 Conflict Resolution; 16-18 Regulatory Instruments; 19-21 Information Management and Exchange

(Aim: evaluate effectiveness of water governance)

1 Water managers have clearly defined responsibilities and the authority to carry them out, and there is an absence of jurisdictional ambiguities and overlapping functions between organizations.
2 Coordination mechanisms between organizations responsible for sectors that impact and are impacted by water resources development, management and use.
3 Coordination mechanisms are in place between different levels of government - from local, to province, to basin, to national.

4 No power vacuum exists into which shadow networks or lobbies may move in and corrupt the system.
5 Organizations have the capacity - in terms of human, resources, funding and equipment - to fulfil their mandates.
6 Organizations have regularly updated capacity building plans that reflect changing needs.
7 Individuals and institutions (public and private) are provided with incentives to improve their practices and approaches.
8 Regular collection and analysis takes place of relevant physical and socio-economic data needed for decision-making at various levels.
9 Mechanisms are in place for feeding results into decision making and planning processes.
10 Assessment results are communicated to stakeholders, and are available in accessible form.
11 There are incentives for water use efficiency, conservation, recycling and reuse at the river basin level, at the system level, and at the individual user level.
12 Investments exist for empowering and involving excluded social groups such as women and the poor.
13 Water issues are incorporated into school curricula.
14 Communication plans / campaigns are attached to major water initiatives.
15 Relevant staff receives training in conflict management.
16 Regulatory instruments address water quality and quantity, are consistent and comprehensive, and cover both public and private water service providers.
17 Regulations are consistent with institutional capacity for implementation, compliance monitoring and enforcement.
18 Effective co-operation takes place on regulatory decisions between land-use planners and water managers (for issues such as e.g. flood protection).
19 Short-term political involvements / pressures are not passed down to implementation level.
20 User-friendly platforms exist for sharing information among water-related, governmental and non-governmental organizations and with the general public.
21 Decision-support tools feed information into water and development planning.
22 There is participation in water-related international benchmarking, monitoring and information exchange initiatives and networks, e.g. the World Water Assessment.

Section C: Reality Check for SA
1-2 Implementation; 3-4 Transformation; 5-6 Future Issues; 7-17 Relevant Sectors
(Aim: assess barriers and drivers for change in SA; pin-point leadership in the SAn context)

1 The Reserve determination has been implemented.
2 Awards of licences and authorisations are fair and the process transparent.
3 Cross-sectoral activities with the Department of Environment exist
4 Cross-sectoral activities with the Department of Tourism exist
5 Cross-sectoral activities with the Department of Finances (Treasury) exist
6 Cross-sectoral activities with the Department of Science and Technology exist
7 Cross-sectoral activities with the Department of Land Affairs - Spatial Planning exist
8 Cross-sectoral activities with the Department of Agriculture exist
9 Cross-sectoral activities with the Department of Housing exist
10 Cross-sectoral activities with the Department of Minerals & Energy exist
11 Cross-sectoral activities with the Department of Provincial & Local Governments exist
12 Cross-sectoral activities with the Department of Social Development exist
3 Cross-sectoral activities with the Department of Trade & Industry exist
14 Others

Section D: Other Questions
(Aim: assess barriers and drivers for change in SA; pin-point leadership in the SAn context)

1 Please assess the implementation of the NWA on a scale of 1 to 5 (0=do not know, 1=not at all, 5=fully implemented).
2 Please assess the implementation of the WSA on a scale of 1 to 5 (as above).
3 How far have the principles of IWRM in general been incorporated (please scale between 1 to 5 as above) in
- the regulatory frameworks of RSA, and
- day-to-day decision making processes.

4 What are the 3 main challenges in implementing the NWA? Are there any obvious failures?
5 Please list the 5 strongest barriers to change in RSA.
6 Please list the 5 most relevant drivers to change in RSA.
7 Does leadership exist that reflects or builds capacity in the following arenas (as enhancing performance so that climate change can be mainstreamed into day-to-day decision making processes):
   (i) Political capacity (are there influential champions for the reform, can the reform produce results within a politically relevant time-scale, can opposing ministries be brought on board or isolated?).

   _____

   (ii) Professional capacity (are there the professional skills needed to draft legislation, provide regulation or adjudication, provide conflict resolution etc.?).

   _____

   (iii) Implementation capacity (have the agencies likely to be charged with implementation the technical, financial and human resources necessary to fulfil the task?).

   _____

   (iv) Compliance capacity (many of the tools are designed to change water using behaviour; do users have the knowledge and ability to respond?).

   _____

8 Pinpoint leadership that currently is, or should, be:
   (i) initiating adaptive cycles,
   (ii) carrying out the evaluation process, and
   (iii) implementing accordingly.
9 How are 'missing' organisations / institutions / structures compensated?
10 Do only CMAs equal participation? Or are there other levels and organisations successfully involved in participation already?
11 Weigh the importance between lacking leadership and missing skills.
12 At what level of government/water management is the mainstreaming of CC most relevant?

CHAPTER 12: UNDERSTANDING THE POLICY AND MANAGEMENT CYCLE AND THE EFFECTIVENESS OF TOOLS FOR POLICY IMPLEMENTATION, USING THE UMNGENI CATCHMENT AS A CASE STUDY

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12.1 Setting the Scene

The central role of water to all life on earth cannot be over-emphasized. This natural resource is vital for the welfare of all humankind socially as well as economically, and is essential for the healthy functioning of the world's ecosystems (UNDP, 2004; Batchelor, 2007; Dukhovny, 2009). Moreover, water is often seen as 'a catalytic entry point to help developing countries deal with poverty and hunger, maintain human health, reduce child mortality and both manage and protect their natural resources' (UNDP, 2012). The role of water and its associated intrinsic value of sanitation in poverty eradication are recognised under target 10 of the Millennium Development Goals (MDGs): "Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation" (UNDP 2003; Folifac, 2006).

Of late, most countries especially in the developing world (e.g. Ghana, Mauritius, South Africa, Uganda and Zimbabwe) have reformulated and modified their water policies in order to align them with achieving not only the MDGs, but also to make water management equitable, sustainable and efficient (Chikozho, 2005; Folifac, 2006). Countries such as South Africa have re-written their laws partially in order to overcome past injustices and inequalities and ultimately to achieve more equitable, sustainable and efficient use of water resources. Unfortunately, no matter how attractive and ambitious some of these laws are, for almost all of the world's poorest citizens, the equitable and efficient provision of water services still remains an unfulfilled promise (Folifac, 2006; Gowland-Gualtieri, 2007; Plummer and Slaymaker, 2007; Tissington *et al.*, 2008; Brisbane Times, 2011). This implies that there is a significant gap between policy and actual water allocation and hence, distribution (Folifac, 2006; Batchelor, 2007; Naster and Hansen, 2009; du Toit *et al.*, 2011).

Various studies depict that a water challenge is mainly a crisis in governance (Al-Eryani, 2002; GWP, 2003; Solanes and Jouravlev, 2003; Plummer and Slaymaker, 2007; Miranda *et al.*, 2011). Hence, severe scarcity seldom results from natural limitations or insufficient funds and technical support, but rather from intense water governance failures (UNDP, 2004; Plummer and Slaymaker, 2007; Miranda *et al.*, 2011). This implies that problems arise from the manner in which individuals and societies have assigned value to, made decisions about and managed the water resources available to them (UNDP, 2004; Solanes and Jouravlev, 2006).

Additionally, various studies indicate that water governance challenges should be dealt with through improving institutional capacity of water management institutions. These studies suggest that institutional capacity of management institutions can be achieved by developing institutional capacity to implement policies (IUCN, 2009; Tewari, 2009). In the case of South Africa, the National Water Act (No 36 of 1998) acknowledges that the key to effective water management is to appreciate the links between water and other natural resources through an integrated approach, hence Integrated Water Resource Management (IWRM) was incorporated within water management institutions and is seen as the best way to undertake water resources management (Pollard and du Toit, 2008; Dent, 2009; DWA, 2011).

The IWRM framework is characterized by decentralized decision making within a framework that brings together all water stakeholders in an innovative form of communication, particularly those of marginalised groups (Pollard and du Toit, 2010). A mix of centralised and decentralised management instruments aiming at integrated and adaptive management has created considerable complexity (Naster and Hansen, 2009). This much more therefore calls for integrative instruments to allow for greater coordination and enhanced stakeholder participation to produce an integrated management outcome (du Toit *et al*., 2011). Although a set of instruments is available under the South African set-

up these do not seem to be sufficient as it appears that they are currently used in isolation to each other, with the links between them ignored (Plummer and Slaymaker, 2007).

The term “policy instruments” is used to describe tools, methods and measures used by government authorities to achieve desired outcomes (CASA, 2013). Policy instruments can also be defined as tools that can be used to provide solutions to problems and achieve objectives (OECD, 2008; Clean Strategy Alliance [CASA], 2013). The different types of instruments used worldwide include economic, technical, institutional, legal, administrative and participatory or social policy instruments (Plummer and Slaymaker, 2007; OECD, 2008). Various studies show that due to the complexity of environmental issues, there is no single universal policy instrument that can provide solutions to all problems, and therefore a number of instruments have become available (OECD, 2008; EEA, 2012). Often several instruments are integrated or combined with the aim of addressing certain policy problems and in that manner the notion of integrative policy instruments or a policy instrument mix results (OECD, 2008; EEA, 2012).

“Integrative policy instruments” in relation to water can therefore be defined as a mix of various policy tools, measures and methods created to enable greater co-ordination and cooperation between different water users with (OECD, 2008; du Toit *et al*., 2011; EEA, 2012) different stakes and views on how water should be managed. These instruments integrate, i.e. link, various government departments because of their interests and impacts on water resources.

Integrative policy instruments are required especially in the water sector since water issues have many different Bearing in mind the above, the research objectives for this study are:

- To identify integrative policy instruments for implementation of the National Water Act;
- To identify major constraints and challenges affecting the process of policy implementation of the National Water Act;
- To examine suggestions proposed by the relevant stakeholders in relation to the major constraints and challenges affecting effective implementation of the National Water Act; and
- To acknowledge the important links between the National Water Act (NWA) and the Water Services Act (WSA).

These objectives are discussed following a literature review on water Governance.

12.2 A Literature Review on Water Governance

The term “governance” is given various definitions by different users and over the past decades has gained prominent attention from various government departments and agencies. Paproski (1993) defines governance as the management process which involves interaction between the public sector and the various actors in civil society. On the other hand, the United Nations (2006) asserts that a more inclusive and precise definition of governance was given by Hirst (2000) when he expressed it as a means of “creating an effective political framework conducive to private economic action”. Hirst further stated that good governance included stable governments, clear laws, well-organized State administration modified to the roles that Governments can perform, and a strong civil society which is free from the State’s influence (UN, 2006).

From the stated definitions by Praspoki (1993) and Hirst (2000) it can be clearly seen that the fundamental difference between governance and government is the role of civil society and the interaction between the two, whereby civil society refers to the individuals and institutions which are independent of state control (Harpham and Boateng, 1997). Moreover, according to the United Nations Development Programme (UNDP, 2013) good governance incorporates four poverty-centred dimensions, *viz*. political, economic, social and environmental dimensions. Notably, from the above definitions of good governance only three dimensions of governance are visible: the political framework, economic action and civil society. The fourth one, the environmental dimension, is not evident. The main cause for concern associated with this is that lack of recognition of the environmental dimension when defining governance may result in ignoring the environment-related impacts when dealing with water management issues.

Thus, drawing from the existing definitions of good governance by both Hirst (2000) and the UNDP (2013), this study defines good governance as a management process that includes interaction

between the government, or public sector, and civil society with the hope of creating an effective political system that is conducive to sustainable economic action, natural resource management and livelihood wellbeing.

Governance as applied specifically to water is also defined differently by different users. Probably the most widely accepted definition of water governance has been given by the Global Water Partnership (2003), in stating that water governance comprises of a "range of political, social, economic and administrative systems that are in place to develop and manage water resources, and manage the delivery of water services at different levels of society". Various other authors have incorporated a similar definition (e.g. Rogers and Hall, 2003; JCWRE, 2006; Plummer and Slaymaker, 2007).

Expanding from the GWP's definition, Castro (2007) states that "water governance involves interactions between governments, businesses, political parties, civil and other organizations representing sector interests, international agencies, NGOs and other relevant power holders". The roleplayers mentioned in Castro's definition are involved in socio-political engagements about how water and the necessary water services should be administered, by whom and for whom. Additionally, these engagements are guided by the democratic water governance which is not only characterised by discussions and negotiations, but also, unfortunately, by increasing uncertainty and socio-political conflicts (Miranda *et al*., 2011).

According to the UNDP (2013), it is important to note that the water sector is a part of wider social, political and economic development of a country. Thus, decisions from such developments impact on the water sector as a whole. Castro (2007) accordingly notes that while a high level of advancement has been reached in water related fields of science and technology, it is still going to take some time for anyone to understand the historical, cultural, socio-economic and political processes underpinning water governance and hence, the water crisis. Castro (2007) thus concludes: "achieving water governance that is grounded on the principles of equity and sustainability is by far the most cause for concern in the water sector today".

As a means of developing an enabling environment in order to address the existing water governance predicament, the IUCN (2009) and UNDP (2013) suggest considering the following key issues:

1. Principles of equity, sustainability and efficiency in water resource and services allocation and distribution,
2. The need to incorporate an integrated approach to water management and the urgent need to balance out water use between socio-economic activities and ecosystems,
3. The development, reformulation and implementation of water policies, legislation and institutions, and
4. The clarification of the roles and responsibilities of government institutions, civil society and the private sector concerning ownership, management of water resources and associated services.

Notably, the above four stated suggestions have been widely explored in South Africa through the principles of the NWA, yet their full implementation remains a major challenge. Thus the scope of this chapter includes an examination of the reasons associated with the lack of implementation of these suggestions as they form the main principles of the NWA.

Having briefly discussed the notion of water governance, it should be noted that there is no universally accepted definition of this term. However, this chapter rests its understanding around water governance on the definition given by GWP (2003).

12.3 Water Governance Capacity

Water governance capacity (also known as governability) is defined as the society's ability to implement effective water arrangements through policies, laws, institutions, regulations and compliance mechanisms (Kauzya, 2002; MacKay *et al*., 2004; Plummer and Slaymaker, 2007; IUCN, 2009). The IUCN (2009) further adds that in order to achieve a system of effective water governance, it is necessary for a country to develop all of the components of water governance capacity (policies, laws and institutions and the four dimensions of effective water governance, *viz*. the social, political, economic and environmental dimensions) and implement them effectively.

Notably, water governance capacity requires clear policies, clearly established legal structures, effective institutions, appropriate and sufficient financial and human resources for water supply activities, dedicated people and experts performing allocated roles, improved access to information and, most of all, integrative policy instruments in order to allow for effective water governance (UNDP, 2004; Plummer and Slaymaker, 2007; IUCN, 2009).

One way in which the country can assess the efficacy of its water governance is through looking at it governability, which is also known as governance capacity and is defined as the ability of a country to implement water policies. Hence, the next section will consider more closely the water policy implementation situation in South Africa as the case study under investigation lies within this country.

12.4 Water Policy in South Africa

12.4.1 Introduction

Overall, South Africa experiences has semi-arid climatic conditions with an average annual rainfall below 500 mm and characterised by high inter-annual variability and unpredictability (McKay, 2004; Nomquphu, 2005; Stein, 2005; Ashton *et al.*, 2006; Folifac, 2006; Naster and Hansen, 2009; du Toit *et al.*, 2011; DWA, 2012). Prior to democratisation in 1994, water supply responsibility in South Africa was highly centralised, with the national government being the body largely responsible for water resource management (Tewari, 2009; Movik and de Jong, 2011; du Toit *et al.*, 2011). This resulted in an uneven distribution of water resources and water services between various ethnic groups (Anderson *et al.*, 2008; Naster and Hansen, 2009; Movik and de Jong, 2011). Further exacerbating the issue was national water legislation that was dated (Muller and Lane 2002).

Abrams (2000) and Thompson (2006) note that before democracy, the policy and functions of the Department of Water Affairs and Forestry (DWAF) were concentrated on water supply, irrigation and forestry. As a consequence, this impacted badly on the water sector and the environment in general i.e. out of a total population of about 41 million at the time, an estimated 15.2 million (of which 12 million lived in rural areas) did not have adequate access to basic water supply (Thompson, 2006).

Therefore, the post-apartheid government developed a new legal framework and policies which initiated an extensive reform process in the water sector (RSA, 1999; Eberhardt and Pegram, 2000; Pegram, 2000; Thompson *et al*, 2001; Ashton *et al.*, 2006; JCWRE, 2006; Naster and Hansen, 2009; Tewari, 2009; du Toit *et al.*, 2011). This reform process will still continue for years to come, owing to fact that reforming the entire governance system is time consuming, dynamic and costly (Medema *et al.*, 2008; Tewari, 2009; Movik and de Jong, 2011). Eberhardt and Pegram (2000) and Tewari (2009) refer to this process of reform in water policy and its associated institutional structure as an 'evolutionary process' occurring over a long period.

The reform process was driven mainly by the need to address and rectify the inequity issues that resulted from the previous political system, together with the need to ensure that sufficient water is continuously supplied in order to meet the increasing demands accruing from increased industrialization and urbanization and, lastly, to encourage efficient use of water (Pegram, 2000; Farolfi, 2004; Ashton *et al.*, 2006; Movik and de Jong, 2011).

Notably, the National Water Act (No 36 of 1998) and the Water Services Act (No 108 of 1997) are the two core pillars of the new water legislation. These are linked through the sanitation business cycle, details on which will be given later.

12.4.2 Integrated Water Resource Management

As mentioned earlier, one of the major drivers of the formulation of the new water policies in South Africa was to allow for greater coordination between water managers and other water users in order to facilitate the equitable, sustainable and efficient use of water resources. Therefore, new national water policy, specifically the NWA makes provision for the management of water resources in an integrated manner through Integrated Water Resource Management (IWRM; Anderson *et al*., 2008; Pollard and du Toit, 2008; Naster and Hansen, 2009; DWA, 2012). IWRM is primarily concerned with the reformulation of water governance arrangements (Medema *et al*., 2008) and is defined as a "process for coordinated planning and management of water, land and environmental resources. It

takes into account the amount of available water, water use, water quality, environmental and social issues as an integrated whole in order to ensure sustainability, equity and efficiency" (Global Water Partnership, 2000).

IWRM allows different water users with different stakes and views to influence water management. This should enable them to arrive at a single strategic plan for specific hydrological planning (du Toit *et al*., 2011) and overall management. Hence, IWRM is designed for to enable collaborative planning and improved participation of all citizens to influence water related. The idea is to decentralize decisions in order to promote coordination and integration as a means of achieving improving water resource sustainability thereby achieving a more holistic management of water resources and services (Medema *et al*., 2008).

Working hand in hand with IWRM is the concept of Adaptive Management (AM) which is defined here as "an integrated, multidisciplinary and systematic approach to improving management and accommodating change by learning from the outcomes of management policies and practices" (Medema *et al*., 2008). In other words, while IWRM is concerned with reformulating the system of water governance it order to implement good change in the way in which water is managed, AM on the other hand is concerned with focusing authorities and citizens at large on the idea of learning (even from previous governance failures) as a key way of governing social-ecological systems during periods of sudden change, thereby promoting adaptability. In this way AM is trying to change the way in which relevant authorities view and management water resources in times of unexpected change (Medema *et al*., 2008; Pahl-Wostl, 2010).

Specifically in the case of South Africa AM is highly relevant as it will provide measures to adapt to a new democratic and decentralised system, considering the protracted process of change in the country (du Toit *et al*., 2011).

The main objectives of both the NWA and WSA are for equity in water allocation; sustainability and efficiency in water use (DWA, 2005). This implies that there are important links that should be acknowledged between the two Acts. The next section therefore provides an overview of these linkages through the sanitation business cycle.

12.5 Linking the WSA and the NWA Through the Sanitation Business Cycle

The provision of water services and the management of water resources are inseparable. This is shown explicitly by the water and sanitation business cycle, as demonstrated in **Figure 12.5.1**.

Figure 12.5.1 shows that implementation of the National Water Resource Strategy (NWRS) and the Catchment Management Strategy (CMS) of the NWA, the protection, development, management, and control of use of raw water will be ensured. It also ensures the safe storage of raw water in dams through the DWA. Raw water abstraction and bulk water treatment are guided by both the NWA and WSA as it is in terms of the NWA that the municipalities, water boards and bulk water suppliers obtain legal use of the water that they require for distribution to consumers (by means of water use licence applications to DWA; DWA, 2005; DWA, 2006).

The NWA also guides municipalities on how they may return effluent and other waste water back to the water resource. The WSA then has to ensure that the municipalities allocate the obtained water accordingly to consumers and also has to ensure that the used water is treated accordingly and returned to the relevant water resources in a required state of quality (DWA, 2005). This is where the links between the two acts lie. Both the NWA and the WSA aim at equity, sustainability and efficiency in water management (DWA, 2005). Hence both these Acts contribute to social and economic development.

Notably, cooperation between all role players in water resource management and services delivery is essential and this can be best achieved by treating the NWA and the WSA as integrated Acts (DWA, 2005; DWA, 2006; NWRS, 2013). Having identified the links between the main two Acts guiding the management of water resources and services, the next section will review literature on the implementation of policies using a governace cycle with specific reference to the NWA.

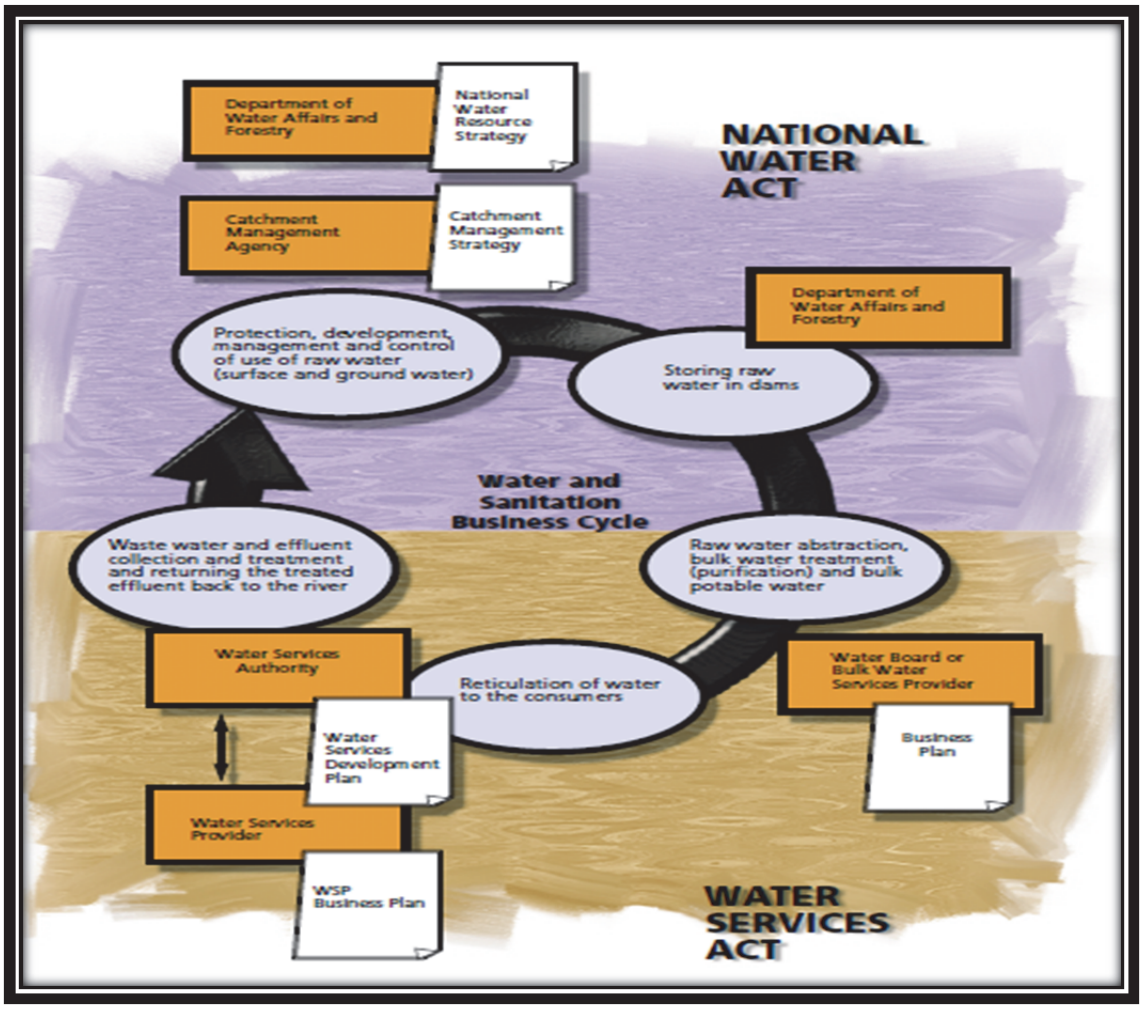


Figure 1 Error! No text of specified style in document..**5.1**Appreciating links between the National Water Act and the Water Services Act through the Sanitation Business Cycle (DWA, 2005)

12.6 Implementation of Water Policies: The Governance Cycle

The Water Resource Management Reform Process documented by Abrams (2000) provides a plan for implementation of the water sector reforms that had been introduced by the National Water Policy and the National Water Act of 1998. Those reforms included the introduction of the Water Services Act and NWA which called for more reforms to be implemented in the form of sector institutions. According to Abrams (2000) and Moriarty *et al.* (2007), effective implementation of water policy can be obtained through a governance / management cycle as shown in **Figure 12.6.1** below.

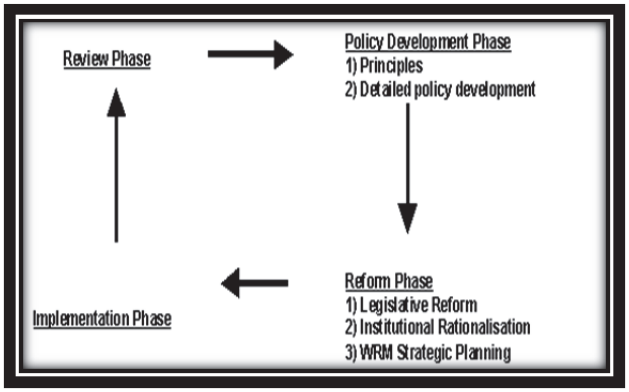


Figure 12.6.1 Phases of the governance cycle (Source: Abrams, 2000)
The governance cycle consists of four phases, of which all are important and should be followed carefully. It must, however, be noted that the reform phase is considered the most important phase in achieving effective implementation of policies as it constitutes the phase where approved policy is integrated into legislation, institutional arrangements as well as to the planning activities associated with water resource management (Abram, 2000). The latter includes strategic planning which determines whether the policy will be implementable or not and what time periods are needed for effective policy implementation. The governance / management cycle is continuous and, therefore, after the implementation phase, it continues to the review phase (**Figure 12.6.1)**, so as to ensure the continuous monitoring of progress (Abrams, 2000).

Various studies show that the described cycle has proven effective in policy implementation. Yet, these "cycles" are not treated as cycles in practice (Abrams, 2000; Moriarty *et al.,* 2007). Usually after the implementation phase the cycle ends and there is then no continuous monitoring and evaluation of the process. This mostly leads to the process of policy implementation being hindered (Abrams, 2000) and the aims of adaptive management being defeated.

So the question must be raised as to what tools – especially in the implementation phase - would be needed to achieve policy implementation. As discussed previously, this will strongly rest on the existing legal framework that is pre-given. In South Africa, the implementation of policies such as the Free Basic Water has mainly been in the form of tools such as strategies, procedures and guidelines through the Implementation Strategy for Free Basic Water of 2002 (Gowland-Gualtieri, 2007). Some countries have incorporated social or participatory instruments such as community of practice and social learning activities (Wenger, 1999; Pahl-Wostl *et al*., 2007).

Table 1 Error! No text of specified style in document..**6.1** Instruments for policy implementation (Source: Plummer and Slaymaker, 2007)

Policy Instrument	Description
Technical	Mechanisms used in water resource management mainly in the design of structures that are used to control, store and supply water for different purposes
Economic	Mechanisms for responsible allocation and efficient use of water resources such as pricing, charges, subsidies and penalties
Administrative	Management tools and decision support such as information systems, maps/models, plans, guidelines and others
Legal	Laws and regulations underpinning the restrictions or prohibitions of different water uses such as abstraction, discharge, and disposals permits, codes of conduct, municipal bylaws, and minimum standards
Institutional	Mechanisms for enhanced coordination and partnership, regulatory / governing bodies on different levels of government, management arrangements and planning procedures,.
Social/Participatory	Mechanisms to increase the level of awareness on water issues and for mobilizing users to participate in planning, management and financing of water resource development.

Policy instruments can be described as tools and methods used by governments or policy makers to achieve desired objectives (OECD, 2008). Plummer and Slaymaker (2007) present a blend of policy instruments in **Table 12.6.1**.

Each policy instrument in **Table 12.6.1** represents an important aspect of water governance and various studies reveal that much useful research has been done in relation to each (Herbertson and Tate, 2001; Batchelor, 2007; Plummer and Slaymaker, 2007; OECD, 2008). According to the European Environmental Agency (EEA, 2012) and Australian Public Service Commission (APSC, 2008) there is no one universal policy tool or instrument that can provide solutions to all policy problems. Thus, it means that policy instruments displayed in **Table 12.61** should be all integrated or applied in an integrated way. Additionally, the links between them should be recognized (Plummer and Slaymaker, 2007). The benefits of acknowledging the links between policy instruments is that the implementers would be able to see a broader perspective of how various water components fit together into one logical system (Dent, 1998; Plummer and Slaymaker, 2007; OECD, 2008).

Additionally, environmental issues often have many different aspects and as a result several policy instruments may be required to be combined in order to adequately address each issue (OECD, 2007). Governments may therefore consider using a number of different types of instruments when dealing with policy issues (OECD, 2008; EEA, 2012). Usually an 'instrument mix' is formulated to address water governance related issues (OECD, 2008). The benefits associated with using a mix of instruments is that it allows greater flexibility in discovering ways to ensure compliance with various government policies while at the same time reducing the uncertainty in the cost of doing so.

However, instrument mixes need to be carefully formulated in order to ensure that that the individual mechanisms within them do not underestimate each other or create unnecessary costs in ensuring compliance.

Relating specifically to South African water policy, the NWA makes provision for water management strategies as one type of tool to ensure implementation. These are the National Water Resource Strategy and the Catchment Management Strategy.

National Water Resource Strategy

The National Water Resource Strategy is meant to integrate and coordinate all water institutions and water users. Its main purpose is to ensure the implementation of the NWA through facilitating the proper management of the nation's water resources; providing a mechanism "for the protection, use, development, conservation, management and control of water resources for the country as a whole" (NWRS, 2013). The NWRS should also provide a framework that will guide the management of water resources and services at regional or catchment level in defined water management areas (DWA, 1999). Information about all aspects of water resource management in South Africa must be provided in the NWRS (DWAF, 1999).

According to the NWA (1998), the Minister is obliged to update the NWRS every 5 years. Moreover, the NWRS must ensure that there are enough water resources available to satisfy basic human needs and the ecological reserve, and to cater for socio-economic development both now and in the future. In order to achieve these goals, stakeholder consultation and participation is critical (DWAF, 2005; du Toit *et al*., 2011; NWRS, 2013).

Catchment Management Strategy

Water resource management functions in South Africa are divided into 9 (previously 19) Water Management Areas (WMAs). The NWA requires that a strategy to guide water management at catchment level should be developed. Hence this strategy is referred to as the Catchment Management Strategy (CMS). The NWA also requires that a Catchment Management Agency (CMA) be established for each WMA. The CMA is then responsible for developing a CMS for its WMA (DWAF, 2002)

This implies that the Catchment Management Strategy is developed as a main tool to enable the implementation of the NWA at catchment level. Key elements of the CMSs include that it be aligned with the national and regional plans, the classification of the resource, licensing issues and to enable public involvement in facilitating management of water resources (DWAF, 2002).
This Strategy furthermore needs to guide the way Water Management Institutions (WMIs) in a Water Management Area should perform their functions. However, where there is no CMA established the DWA regional offices should perform the CMA functions as a Proto-CMA (DWAF, 2002).

Current Situation of the NWA Implementation in South Africa

Mandated in the National Water Policy (NWA, 1998) are the institutional reforms designed with the aim of redressing mistakes of the past and to provide adaptive capacity to the paradigm shift in water governance (DWA, 2011). However, recent literature reveals that the envisaged institutional reforms have not been fully implemented (Simpungwe, 2003; Naster and Hansen, 2009; Tewari, 2009; du Toit *et al*., 2011; Movik and de Jong, 2011; DWA, 2011). Moreover, the water sector is at a critical juncture where water resource management and service delivery are not at the level that they should be at. Progress with the essential transformation in the sector, particularly related to delegation of water resource management to the regional level, has been much slower than anticipated (Naster and Hansen, 2009; du Toit *et al*., 2011; DWA, 2011; Carden and Armitage, 2013). Moreover, the *status quo* threatens water security and carries with it the unacceptable economic and socio-political risks for the country (DWA, 2011; Movik and de Jong, 2011). Instead of bringing the anticipated change, the

slow establishment of the sector reforms has created more problems than at the time of policy reform i.e.

- It has lowered staff drive and morale and therefore has resulted to poor water resources management performance and outcome (DWA, 2011).
- It has weakened the Department's performance of its direct water resource management functions as well as on the regulatory, oversight and support roles (DWA, 2011).
- The uncertainty around the establishment of Catchment Management Agencies (CMAs) in particular, has weakened staff interest, i.e. it has taken too long to establish CMAs in such a way that staff's enthusiasm of being part of these has faded and there is now hesitation to move across to CMAs once they are established. Furthermore, staff recruitment and retention have been negatively impacted (DWA, 2011; Meissner *et al*., 2013).

According to the DWA (2011), even though a range of factors contribute to the current poor state water management and services, the two key underlying factors are incomplete institutional reforms and performance of the department itself. The existing institutional arrangements are failing to ensure sustainable water resources management.

Resultantly, the Department has made efforts to rectify the situation and to support the implementation of the envisaged institutional reforms. The following section will therefore give an overview of the progress that the departments have made to date with regards to the implementation of the institutional reforms.

Progress to date on sector reforms

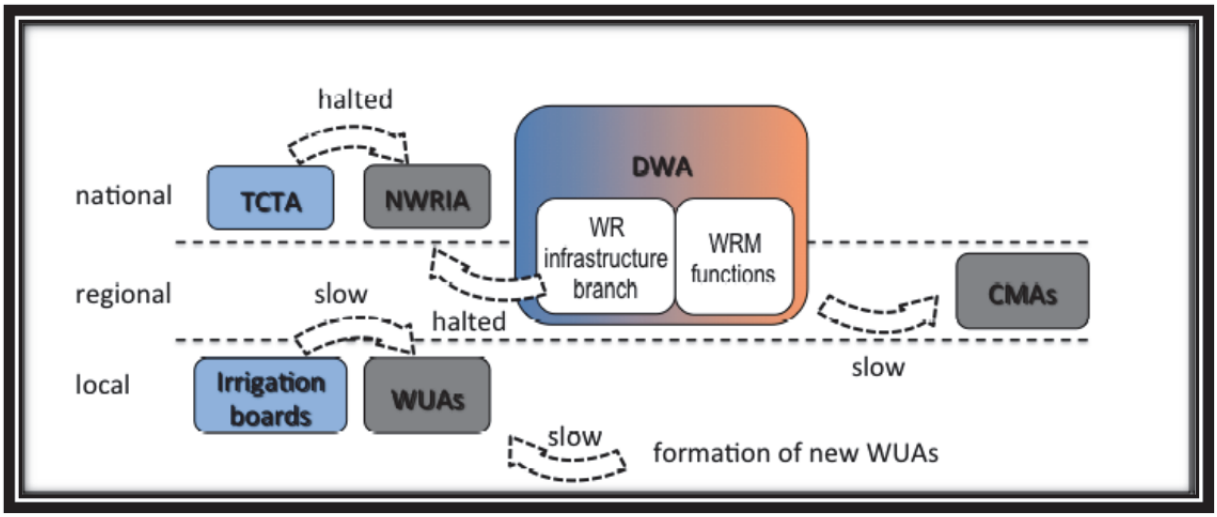


Figure 12.6.2 Incomplete water resource institutional reform (Source: DWA, 2012)

To date, the Department has developed various institutional options for improving the management of water resources infrastructure, including:

- The establishment of the public entity Trans Caledon Tunnel Authority (TCTA) which included the establishment of the National Water Resource Infrastructure Agency and the internal water resources infrastructure branch at DWA; and
- The establishment of Catchment Management Agencies:

Following the concerns that some of the initial 19 WMAs were not economical viable due to the limited capacity, skills and expertise in some of them, these have instead been reduced to 9 in order to enable integrated planning. These are: Limpopo; Olifants; Nkomati / Usutu / Pongola; KZN Rivers; Vaal; Orange; Eastern Cape Coastal Rivers; Western Cape South Coast Rivers; and Western Cape West Coast Rivers (Naster and Hansen, 2009; Movik and de Jong, 2011; DWA, 2011).

Progress to date also includes the establishment of Water User Associations and transformation of irrigation boards to Water User Associations. However, evaluation of the latter is outside the scope of this study, and hence it will not be discussed in the literature review.

Facilitating a Way Forward: Considering a Mix of Instruments for Implementation of the NWA
A previous section defined and discussed the instruments for policy implementation (also known as water governance instruments). From this section it became evident that generally in the water sector, there was a tendency to ignore, or a failure to recognise, the links between various policy instruments which usually resulted in serious implications on the implementation process of policy.

Various studies indicate that there is no shortage of policy instruments in the South African water sector (Batchelor, 2007). However, the studies indicate that there is need to integrate the available policy instruments and tools as they are currently treated in isolation to each other (Plummer and Slaymaker, 2007).

Moreover, the studies suggest that integration of these instruments in a systematic manner has the potential to increase the ability to implement various approaches to water management, and therefore there is need for further research to be undertaken on integrative policy instruments and their role in achieving the desired implementation of the NWA (Herberson and Tate, 2001; Batchelor, 2007; Plummer and Slaymaker, 2007; Pahl-Wostl, 2010; Tailor, 2010; Woodhill, 2010).

Regarding this, Dent (1998), affirms that we cannot hope for successful implementation if we do not understand the relationships between different policy tools. The challenge is therefore to combine or mix these instruments in a more systematic manner in such a way that they are brought into everyday use (Batchelor, 2007; Plummer and Slaymaker, 2007).

Even though a wide range of policy instruments are practised in South Africa and have proved to be effective to a certain extent, various studies suggest that more attention should be given to social / participatory instruments (MacKay and Rogers, 2000; Mack *et al*., 2005; Batchelor, 2007; Plummer and Slaymaker, 2007). This is mainly so because social / participatory instruments provide a platform for using all other policy instruments in an integrative manner. These instruments can be used to create stakeholder platforms to achieve effective water governance which is characterised by approaches which are transparent, inclusive, integrative and accountable. Additionally, participatory policy instruments assist water resource managers mobilize users to participate in planning and management of water resource development.

12.7 Discussion and Conclusions on the Implementation of Water Policies

Owing to its unquestionable importance and its central nature as a shared resource, water should be managed in a manner that will ensure its long term availability in both quantity and quality. This is recognised by the NWA through the provision of an integrated approach to water management. This approach is characterised by decentralised decision making and allows all water stakeholders to participate in water management in their prospective catchments. The overall aim is to arrive at a single strategic plan for a specific catchment. However, it appears that the principles of equity, efficiency and sustainability in water distribution still remain difficult to achieve, especially since there have been delays in the establishment of key sector institutions such as CMAs.
South Africa requires policy instruments that are suitable for planning and enable enhanced cooperation and integration between various water stakeholders that impact on the water resources, considering the nature of water. Most importantly these integrative policy instruments should be practical to the extent that they are brought into everyday use in order to provide immediate solutions where required, as in the agricultural and mining sectors. Integrative policy instruments should be designed in such a manner that they allow enhanced participation of the local stakeholders and civil society at large in managing their catchments. Over and above, integrative policy instruments should enable external coordination between various catchments and even outside South Africa, considering the heterogeneity in the spatial distribution of water.

The NWA made provision for the integrative policy instruments in the form of the NWRS and the CMS. It seems as though only the NWRS has, as yet, partially served its purpose of being an integrative policy tool since only two editions have been published to date, with the second one only published in June 2013 instead of the scheduled 2009. There are yet no CMS developed for most WMAs as most CMAs have not yet been established. Ideally, the NWRS has to inform the CMS and the two must function as integrative entities in such a way that National Government uses the NWRS

to regulate and monitor water management and local government, on the other hand, has to follow the CMS as a guide to manage water management at catchment level.

12.8 Case Study on the Effective Implementation of the National Water Act: The uMngeni Catchment

In order to facilitate effective implementation of the NWA, the integrative policy instruments should not only sound good and all-encompassing in theory, but should also be practical on a daily basis. Overall this calls for more research to investigate these and other integrative instruments in order to facilitate the implementation of the NWA. For the purpose of this study, the uMngeni Catchment has been chosen based on its ecological and socio-economic characteristics as a good catchment to suit the proposed investigation.

The uMngeni Catchment is currently faced with increasing demands for water linked to urbanisation as well as to agricultural and industrial development. It would appear that although the catchment has a catchment management plan and the associated water management initiatives such as CMFs in place, these do not seem effective and sufficient to solve the current and future water management challenges facing this catchment.

Hence, in order to plan ahead and in order to derive the best possible solutions, this catchment has been chosen as the study area for the proposed research on integrative policy instruments for implementation of the NWA. It should be noted that even though the study will be concentrated in the uMngeni Catchment, the outcomes of this investigation can also be applied in other catchments due to the nature of the research problem. Given this background on the research problem and the study area, the next section will outline the methodology that was used in conducting this study.

12.9 Background and Methodology

This subsection s aims at providing a description of the research methodology that was undertaken in order to satisfy the objectives of this study. The research design, the data sources, the sampling strategy, and the study areas are discussed in the sub-sections that follow.

12.9.1 Background to the uMngeni Catchment

The uMngeni Catchment (**Figure 12.9.1**) comprises an area of approximately 4 387 km^2 and is one of South Africa's' most well developed catchments, supporting industrial and agricultural developments and contributing a significant percentage to South Africa's Gross National Product (GNP; Tarboton and Schulze, 1991; Jewitt and Kotze, 2000; Schulze *et al*., 2004; Archer, 2006). The uMngeni

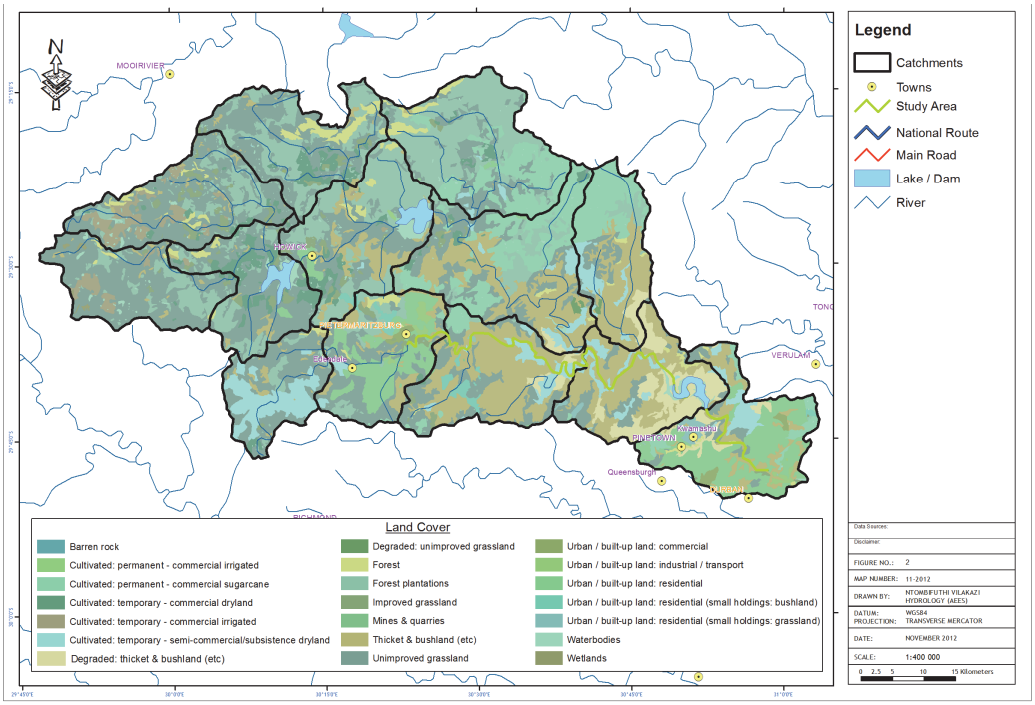


Figure 12.9.1 The uMngeni Catchment

Catchment is home about 45% (3.5 million) of the population of the KwaZulu-Natal province (Stats SA, 2011). Currently, the water engineered system within the Mgeni Catchment consists of four main dams, namely Midmar dam with a supply capacity of 237 million m^3 supplying mainly Pietermaritzburg and parts of Durban, Albert Falls, Nagle and Nanda dams with a respective supply capacities of 289 million m^3, 23 million m^3 and 242 million m^3 supplying the City of Durban (Jewit and Kotze, 2000; Summerton, 2008; Warburton *et al*., 2010). Additionally, there are more than 300 farm dams within the catchment supplying water for 18 500 ha of irrigation (Summerton, 2008; Warburton *et al*., 2010).

Furthermore, Inter Basin Transfers from the Mooi River, with further transfers planned for the Mkhomazi River, are currently supplementing the uMngeni system (Jewitt and Kotze, 2000; Archer, 2006; Umgeni Water, 2010). However, recent studies reveal that uMngeni is a relatively stressed system with high possibilities of streamflow reduction activities predicted for the future (Summerton, 2008; Warburton *et al*., 2010). The reason for this is directly associated with the rapidly growing demand for water resources and services stemming from increased population, urban and agricultural development and from lack of knowledge of how development and land cover changes impacts on quantity and quality of water resources (Tarboton and Schulze, 1991; Warburton *et al*., 2010).

Moreover, even though the Mgeni Catchment Management Plan (MCMP) and the Mgeni Catchment Management Forum (MCMF) were established in response to a major need to manage water resources holistically and to ensure sustainable water resource management in this catchment; these do not seem to be sufficient to solve the current and future challenges facing water resource management in this catchment. Hence, more research attention should be directed to this catchment in order to investigate the best possible solutions and adaptation measures that can be employed now and in the future.

The uMngeni Catchment is especially relevant as a research area for this study because this catchment's demand currently exceeds the available yield and it is projected that the situation is going to get worse in the near future. This then calls for more attention to be paid to management of water resources at this catchment. Additionally, the existing participatory activities, although insufficient (CMFs and CMCs), are suitable for the objectives of this study which include examining the water resource management and servicing delivery issues that are associated with the lack of water policy implementation in the form of the establishment of the sector reforms.

12.9.2 Mixed sampling scheme: Selection of cities

The study adopted a purposive sampling strategy for the selection of cities. The City of Durban (DBN hereafter) and the City of Pietermaritzburg (PMB hereafter) were selected based on important characteristics such as their geographic location in relation to the uMngeni System, where the City of PMB is located nearer the source of the Mgeni River and the City of DBN is located near the mouth of the uMngeni River. Furthermore, these two cities are major urban centres situated within the Catchment and therefore play significant roles in influencing the increase in water demand in uMngeni Catchment (Umgeni Water, 2011).

Of most interest to the study is the fact that both these cities are supplied by water from the uMngeni System. This therefore implies that both these cities will have to strengthen their water management strategies in order to overcome the water management issues that are likely to intensify with the expected increases in the demand for water stemming from economic development and the associated population increase in both these cities. Another important factor about both these cities is that they comprise of both low income and high income communities and therefore it will be interesting to compare the social equity issues in terms of water supply between these cities. It will also be interesting to compare the level of satisfaction of the social different households between these cities, with the aim of coming up with better strategies to improve both water management and water supply in the greater uMngeni Catchment. However, it should be noted that the rationale behind studying the water related social issues at household level in this study is for enabling the achievement of an important objective of the study, *viz*. to acknowledge the links between the NWA and WSA and fulfilling the Sanitation Business Cycle in order to achieve effective water governance.

Given the background, this study utilized mixed research techniques comprising of key informant interviews which focused on investigating water governance issues in the Catchment and household surveys of which focused on investigating water supply issues in the uMngeni Catchment. Moreover, it should be noted that in preparation for data collection, desktop studies were undertaken for both the key informant interviews and the household surveys in order to obtain important basic information relevant to both research methods. However, it should be noted that this chapter will only cover the methods and results of the key informant interviews and not the household surveys.

12.9.3 Research hypothesis

The formulated research hypothesis of the study is that effective implementation of the NWA will only be achieved with proper establishment of integrative policy instruments and through building the required capacity in various water institutions.

12.9.4 Methodology on key informant interviews

This subsection will discuss the methodology that was undertaken in the preparation of key-informant interviews, starting from the formulated research questions up to the actual data analysis process.

The key informant interviews included face-to-face interviews with the water stakeholders at institutional and society level from both Pietermaritzburg (PMB) and Durban (DBN).

Research Questions (RQs)
A set of 7 research questions was developed and included the main research question and the specific research questions which were separated into quantitative, qualitative and mixed research questions.

Main research question: Is the challenge of implementing the National Water Act in South Africa a result of a lack of or slow establishment of relevant integrative instruments for implementation, and can the same instruments be shared by the different management levels?

This research question was formulated with the purpose of assessing integrative policy instruments for implementation of the NWA, the major constraints associated with the poor implementation of the NWA and the key informants' suggestions in relation to the perceived major constraints in the implementation of the NWA. This question was also partially relevant to evaluating the major constraints associated with achieving the objectives of the NWA.

The *specific research questions* included the following:

Quantitative:
1. What are the integrative instruments for policy implementation of the NWA?

Qualitative:
1. What are the perceived constraints to the implementation of the NWA?
2. What are the key stakeholders' suggestions in relation to major constraints?

Mixed research questions:
1. What is the prevalence of each of the perceived constraints?
2. How do the perceived major constraints relate to each other?
3. Does the National Government ensure monitoring, evaluation and learning for the process of water policy implementation and if yes how, and how is the overall water sector involved in this process?

Selection of key informants
Thirteen key water stakeholders were purposively selected between PMB (6) and DBN (7) as key informants for the study's primary data collection. By definition "key informant interviews are qualitative in-depth interviews done with individuals who are experts at particular topic" (water management in this case; UCLA Centre for Health Policy Research, 2005). The purpose of key informant interviews was to obtain data from a range of people including community leaders, professionals and residents since these are usually the individuals who have first-hand knowledge about the topic of interest (UCLA Centre for Health Policy Research, 2005). Moreover, these experts,

with their particular knowledge and understanding of the topic, can provide insight on the nature of problems and give recommendations for solutions (UCLA, 2005).
It should be noted that owing to the nature of the research technique (key informants) the size (13), which may seem small and not representative, is not important because of the value and quality of the information that accumulates from such individuals.

The type of sampling method that was used when selecting the individual key informants is a purposive sampling. This type of sampling is a non-probability sampling technique whereby a researcher makes a decision on whom to choose and then picks those who best suit the study purpose (Bailey, 1994). With regard to key informants selection, this type of sampling was used to include the stakeholders utilizing and managing the uMngeni Catchment because the rationale behind this was to target only those stakeholders who actually hold a stake in water management and those who are familiar with water management issues in the uMngeni Catchment.

Participants included municipal officials from the Department of Water Affairs, the Department of Environmental Affairs, eThekwini Water Services, Department of Agriculture and Environmental Affairs; uMgungundlovu District Municipality NGOs such as Gearsphere, Imvula Trust, Dusi Umgeni Conservation Trust (DUCT), parastatal organisation such as Umgeni Water, community councils and academic researchers on water issues from the University of KwaZulu-Natal. At a local level, key informants were community leaders. The same water stakeholders interviewed as key informants were also to be invited to attend a workshop later in the study.

Because all the 13 interviewees participated in both quantitative and qualitative phases of the study, and the quantitative and qualitative data were collected simultaneously, the type of mixed sampling design used was a Concurrent Sampling Design (Onwuegbuzie and Collins, 2007; Benge and Onwuegbuzie, 2010).

Mixed research design
Using the Benge and Onwuegbuzie (2010) research methodology, this study was categorized as a fully mixed concurrent design because of the following:

- quantitative and qualitative research methods were mixed or combined within several stages of the investigation process, *viz*. the data collection, data analysis, and data interpretation stages;
- the original quantitative and qualitative data were gathered and analysed concurrently, and
- both the quantitative and qualitative phases were treated approximately equally.

The purpose for mixing was for complementarity such that the quantitative and qualitative methods were used to measure many aspects of water management in the uMngeni Catchment (Olsen, 2004; Benge and Onwuegbuzie, 2010). Mixing was also done for triangulation purposes (i.e. mixing quantitative and qualitative methods to ensure that different viewpoints are captured in the study) and for expansion purposes (i.e. using both quantitative and qualitative methods to increase the breath of the study) to ensure that various points of view were captured and also to assess different components of water management in the uMngeni Catchment and (Benge and Onwuegbuzie, 2010; Onwuegbuzie and Collins, 2007).

Instruments and procedures: Mixed data collection
Data for the study were generated using both primary and secondary data sources. Initially, a broad range of information in the form of secondary data was sourced and used in the background and literature review of the study. The review of current and past literature provided an informed understanding of the context of water governance and issues that are associated with water policy implementation. Furthermore, literature provided a starting point for further exploration and participatory / interactive activities. The consulted secondary data sources for this study included: books, accredited academic journals, reports, newspaper articles, electronic journals, conference papers, databases, government communications and legislation, internet sites, interviews, and other published literature.

The review of current and past research studies on water governance allowed for appropriate questions to be formulated for the interviews, the questionnaire survey and observations of respondents. Primary data on the other were sourced from the face-to-face interviews with key

informant water stakeholders in the uMngeni Catchment. An additional workshop was held later with some of the key informants in order to present the key findings of the study.

One data collection instrument used for primary data collection was a key informant research questionnaire (**Appendix A**) which consisted of both open-ended questions (what are your suggestions in relation to the major constraints associated with the lack of implementation of the NWA?) and fixed answer questions (Which of the following do you think forms the most relevant integrative instruments for water policy implementation of the NWA?).

The stakeholders were contacted via email and cell-phone in the months of April and May 2011. Initially, seventeen water stakeholders were invited through email to voluntarily participate in the interviews. The email sent to them also included an informed consent form (**Appendix C**) as an attachment which they had to sign for ethical treatment purposes. Thirteen of the seventeen invited responded agreed to participate in the study. Arrangements were then made to set up the date and venue of the interview. Most key informants were interviewed at their work offices while others were interviewed at their homes and few at venues of their preference such coffee shops and restaurants.

Before each interview each participant signed an informed consent form indicating that they participated voluntarily in this research project. The informed concern form also gave the respondents the option to remain anonymous should this be preferred.

A pilot test was undertaken with two respondents before the commencement of the actual interviews. This was done to test the research questionnaire in order to detect weaknesses in questionnaire design and to provide proxy data for the selection of a probability sample. Notably, the questionnaire was tested / piloted by simulating the actual field conditions to assess the respondents understanding of the style, format as well as the questions and to monitor the time taken to complete interview. The pilot test revealed that some questions were ambiguous and the interviews were taking too long to complete. Some questions were then reformulated and some were excluded in the questionnaire so as to reduce the time it takes to complete one questionnaire. It should be noted that the data collected from the pilot test were not taken into consideration for the study's data analysis.

Therefore in total, fifteen interviews were conducted, but only thirteen were analysed for inclusion in the study. Of the thirteen interviews six were conducted in PMB; the other seven conducted in DBN of which three were with DWA officials.

Notably, it could be argued that the sample of 13 participants used in the study was not a true representation of all the water stakeholders from the Mgeni Catchment. However, as the data collection method used catered for the sample representative factor this was considered not be a major problem. The key informant interviews were designed in such a way that they were as informative as they can possibly be. The chosen stakeholders were chosen based on the position they held in their departments and based on their experience in the water sector. Most of them held managerial and directorate level positions and had more than five years' experience in their respective positions and, hence, were considered to represent a high level of expertise and knowledge. A sample of 13 was therefore seen as a representable sample judging from the level of information and knowledge that would accumulate from such high level of expertise of the stakeholders.

Data analysis: Mixed analysis

A Sequential Mixed Analysis (SMA; Onwuegbuzie and Teddlie, 2003; Benge and Onwuegbuzie, 2010) was conducted to analyse the data collected through key informant interviews. This analysis involved the use of both quantitative data and qualitative analysis procedures in a consecutive manner, specifically commencing with quantitative analyses, followed by qualitative analyses that built upon the quantitative analyses, and then followed by quantitative analyses of the qualitative data. Oscillation between inductive reasoning and deductive reasoning in the research method enabled abductive reasoning on the sequential analysis used in the study (Morgan, 2007). The SMA consisted of four stages that comprised descriptive, exploratory, or confirmatory analyses:

Stage 1: Quantitative analysis of quantitative data

The first stage involved performing descriptive analysis in SPSS for all the quantitative data that was collected using closed-ended tables from Section A to F of the key informant questionnaire

(**Appendix A**). This analysis helped in obtaining the answers for the main research question as well as for Research Questions 1 and 6.

Stage 2: Qualitative analysis of qualitative data
This stage involved an exploratory analysis to examine participant's major constraints associated with the lack of effective implementation of the NWA. This process, modified from Benge *et al* (2010) analytic methodology, included the following:

- understanding the collected data through reading repeatedly all the participants' written words, phrases and sentences in order to become familiar with them;
- separating participants' responses into parts in order extract non-overlapping significant statements, and eliminating repetitions;
- focusing the analysis through formulating meanings and by explaining the meaning of each significant statement; and
- categorising information into themes or patterns from formulated meanings, with each theme consisting of units that were considered to be similar in content and in that way each theme is unique.

The same process was repeated for the interviewees' suggestions in relation to the perceived major constraints of the effective implementation of the NWA. Consequently, this analysis assisted in obtaining the answers for Research Questions 2 and 3.

Stage 3: Quantitative analysis of qualitative data (exploratory analysis)
This stage involved obtaining the prevalent rate for each of the identified themes in Stage 2. The prevalent rates were measured according to the number of times that each theme was mentioned alone or together with other themes by the 13 participants during interviews (number of participants that provided a response that fell into a particular theme). The results obtained from this stage provided answers to Research question 4.

Stage 4 Quantitative analysis: exploratory analysis
An additional exploratory analysis was conducted (i.e. Stage 4 analysis) and involved using the prevalent rates for each theme to form an inter-respondent matrix table of themes in order to conduct a hierarchical cluster analysis to examine the relationship between the identified themes (Research Question 5). The analysis included a dendogram plot and the method was specified to be a Wards method. This method is different from other methods (e.g. nearest neighbour, further neighbour and between groups) because it uses an analysis of variance approach to evaluate the distances between clusters and aims at joining cases in order minimise variance within clusters. In order to do this, each case begins as its own cluster. When using Ward's method, two clusters are merged if a merger results in the minimum increase in the error sum of squares (Field, 2000). The output of the analysis included an agglomeration table which provides a solution for every possible number of themes from 1 to 8 and a dendogram supporting the table showing three clear clusters.
All research questions for the key informant research technique were answered. The next section will now present the research methodology that was undertaken for household surveys.

Ethical Treatment of Respondents
Research must be designed in such a manner that respondents are protected from suffering any physical harm, pain, discomfort, embarrassment, or loss of privacy just because they agreed to participate (Cooper and Schindler, 1998). Hence for this study ethical clearance was applied for and granted by the Humanities and Social Sciences Research Ethics Committee at the research office of the University of KwaZulu-Natal.

One of the requirements for ethical clearance was the informed concern form to ensure ethical consideration if the participants of the study during data collection. For both key informant interviews and the household surveys, an informed consent form was designed (see **Appendix D**) to ensure that participants voluntarily partake of the study. The informed concern form also assured the participants that that their anonymity or confidentiality would not be disclosed to anyone if they so wished.

Prior to the commencement of each interview (for both key informant interviews and household surveys), it was clarified to the participants that:

- their participation was voluntary and that they need not answer questions which made them feel uncomfortable.
- they were free to stop the interview at any point if they did not want to proceed.
- no names and addresses were required as part of the research survey and that
- the interview would only proceeded provided that the potential participant verbally agreed to participate in the study.

Limitations and challenges of the study's fieldwork
The following limitations and challenges associated with the fieldwork of the study were identified:

- The fieldwork was planned to take place in March 2011, but only commenced in mid-April owing to application for ethical clearance from UKZN which had to be granted first before data collection.
- Getting the key informants to participate in the study was partially challenging due to their many commitments.
- Additionally, the theme of the interview was sensitive to some key informants and, hence, some chose not to participate at all and preferred to remain anonymous.

It should be noted that the limitations mentioned above were properly managed and hence did not prevent the study from achieving it objectives.

***Conclusion*s**
This section presented the research methods that were used in this study in order to achieve the stated research objectives. A secondary data literature search on past and present studies was conducted to establish a contextual and background understanding of water governance and policy implementation. The mixed research design consisted of primary data collected using interviewer completed empirical surveys of 13 water stakeholders and 40 households from designated study areas in the uMngeni Catchment. The research (target) population, the sample size and the sample procedures used were established and discussed. In addition, the methods used to collect the data were described and the roles of research ethics and the ethical treatment of respondents which was important to maintaining the ethical integrity of the study were discussed. The data analysis methods used and the presentation of the findings were clarified. Finally, the limitations of the study clarifying the parameters of the research were noted at the end of the chapter.

12.10 Results and Discussion

12.10.1 Setting the scene

The most important part of policy development and policy reform is the implementation phase as this is the actual proof of policy reform. This is why this study interrogates whether the National Water Act (Act No. 36 of 1998) provides relevant and implementable water management strategies as integrative policy instruments for its implementation. The literature review suggests that the development and application of these policy instruments has not been effective to a level that was envisaged in the NWA. The slow establishment of the sector reforms, especially in regards to the CMAs, defeated some of the key elements and policy instruments respectively for reforming the water sector such as the implementation tool 'Catchment Management Strategies' (CMS). The main concern in regard to the available instruments for policy implementation of the NWA is that they are currently seen to be used in isolation to each other (i.e. NWRS used without a CMS) and the links between them appear to be overlooked. The associated risk is that implementers and practitioners might lose sight of a broader perspective of how the various components fit together logically. Additionally, the NWA prescribes adequate representation of all stakeholders as the most important factor in its implementation. However, this factor has not yet been achieved since some stakeholders, especially the poor, are rarely given the opportunity to express their opinion on water management in their prospective catchments areas.

It should be noted that the results of the inquiry are divided into two sections, *viz*. key informant results and household results, since two separate research techniques were undertaken in obtaining the respective data. Also, the level of water management was considered different, *viz*. the key informants were aimed at water resources management in the catchment, while the household results

aimed at the actual water supply at a local level. The results from the two separate sections will be integrated in the final conclusion at the end of the chapter.

12.10.2 Key Informant Results: Water Resource Management in the uMngeni Catchment

This section presents the results of the data that were collected through key informant interviews. It should be noted that the views expressed in these results are the provincial views as the majority of the interviewees were from local and regional level.

Demographic Profile of Key Informants
Five demographic variables were measured in the context of key informant interviews, i.e. age, gender, highest level of education attained and employment status. The 13 interviews that were conducted came from various sectors related to water management, i.e. regional, local government and civil society. The rationale behind including the demographic profile of the key informants was to demonstrate that various sectors that impact the water resources were represented in the study in order to obtain views from all possible angles on the current status of water management in the Mgeni Catchment.

Presenting the demographic profile of the key informants is also relevant in this study for the purpose of showing that the views demonstrated in the results of the come from high level of expertise and should be trusted considering that some may feel that the sample number of 13 key informants may be not a good representation of the views of the whole population.

The analysis of the results (**Table 12.10.1**) revealed that 7 of the 13 stakeholders were males while 6 were females. Most stakeholders fell into the age group of 51-60 and 31-40 (both 5/13) followed by 61-70 (2/13) and then 21-30 (1/13).

Table 12.10.1 Demographic characteristics of the stakeholders interviewed (N=13)

Age (in Years) N=13	
<20	0
21-30	1
31-40	5
41-50	0
51-60	5
61-70	2
Highest Education Level Attained	
Certificate / diploma	2
Undergraduate degree	4
Postgraduate degree	7

In terms of level of education of the stakeholders, 7/13 key informants held postgraduate degrees, 4/13 held undergraduate degrees and 2/13 indicated that they held certificates / diplomas. In terms of stakeholder's employment status, the majority (10/13) worked full time as professionals while 2/13 were self-employed and one key informants worked as environmental ambassador and activist (NGOs and Volunteers).

Integrative Instruments for Policy Implementation of the NWA
This section reflects the participants' general understanding of integrative policy instruments. **Table 12.10.2** indicates that the key informants had a similar understanding of integrative policy instruments as the majority (10/13) understood integrative policy instruments as the policy tools that allow and enhance greater cooperation between various water stakeholders.

Two of the stakeholders indicated that integrative policy instruments were those such as the Blue Drop or Green Drop systems and Catchment Water Management Agencies integrating both the water services management and water resource management dimensions in South Africa.

Table 12.10.2 Stakeholders' understanding of integrative policy instruments

Definition	Frequency N=13
Combining policy instruments that allow greater cooperation and integration between water stakeholders, i.e. CMFs	8
Instruments that allow different departments to work together, i.e. DWA and DEA	2
Instruments such as Blue Drop, Green Drop and CMAs	2
Instruments that recognize the link between the NWA and WSA or, where you have different policies joined together (e.g. catchment management forums) create a stakeholder platform where both water resource management and water services issues are discussed.	1

Only one stakeholder indicated that integrative policy instruments are policy measures that recognise the existing links between the NWA and WSA. One example of such instrument that this one key informant gave was the NWRS. It was mentioned that though most WMAs do not yet have the CMS in place, ideally the NWRS is aimed at informing the CMS for each of the WMAs, thereby integrating the national government with the local government in order to ensure that everyone was on the same page and working towards the same goal of effectively managing water resources countrywide.

Participant's Ratings of the Identified Policy Instruments

When the stakeholders were asked to rate the integrative policy instruments that were initially identified through desktop studies (*viz*. Appendix A: Section E: Question 5.2) according to their importance, 12/13 rated the combination of all general instruments for policy implementation (technical, legal, institutional, social / participatory, economic, and administrative policy instruments) with the National Water Resource Strategy and the Catchment Management Strategy as most integrative policy instruments; however, only when established and applied together.

The Sharing of Integrative Policy Instruments

In relation to the research question whether the identified integrative policy instruments can be shared equally amongst different management approaches (*viz*. Centralised, Decentralized, IWRM and AM), all 13 interviewees answered 'no' and specified that the integrative policy instruments can only be shared amongst the management approaches that have the same objectives, i.e. decentralised, IWRM and AM, and not amongst the management approaches that are contradictory to each other, i.e. Centralised contradictory to Decentralised as well as to the IWRM approach (**Table 12.10.3**).

Table 12.10.3 demonstrates that according to the interviewees, the NWRS (8/13) and Enforcement Mechanisms (9/13) function at their best in a centralised water management framework while the CMS is judged as performing best in a more decentralised (11/13), integrated (11/13) and adaptive (11/13) water management framework.

Interestingly, more than half (8/13) of the participants strongly emphasised the belief that a centralised approach to water management is not needed in the South African policy context. They expressed that this approach complicates the water management process as it contradicts the endeavours of decentralisation and likewise for IWRM and AM. Instead, the participants expressed that the centralised approach should only come into play in the format of regulatory, monitoring and oversight functions of the national government.

Major Constraints Associated with the Lack of Implementation of the NWA

A total of 8 emerging themes were identified in regard to the perceived major constraints for implementing the NWA, *viz*. a

- lack of institutional capacity (skills, human and financial resources),

- lack of integrative policy instruments,
- lack of integration,
- inadequate water infrastructure,
- limited monitoring / learning/evaluation,

Table 12.10.3 Policy instruments for implementation of various water management approaches

Policy instrument	Centralisa-tion	Decentralisa-tion	IWRM	AM N=13
Combination of general policy instruments (integration of all the general policy instruments (technical, legal, institutional, social / participatory, economic, and administrative policy instruments	1	2	3	5
Enforcement Mechanisms	9	0	1	0
NWRS	8	7	7	5
CMS (CMAs, CMFs, CMCs and WUA) and other participatory related instruments	1	11	11	11
"We do not need this approach; we only need DWA to monitor and regulate"	8	0	0	0

- wrong mind-set / thinking / attitude,
- lack of political will, and a
- lack of clearly defined roles and responsibilities.

Table 12.10.4 presents these eight major constraints to effective implementation of the NWA. Interestingly, lack of institutional capacity was the highest rated theme, with all but one participant (i.e. 12/13) providing a response that fell into this category. This was closely followed by the lack of integrative policy instruments (8/13) and the lack of integration between water stakeholders and other government departments (6/13). Inadequate water infrastructure was found to be a major constraint by 4/13 of the participants. The monitoring, learning and evaluation theme followed with 3/13. The lowest relevance, *viz*. 2/13, was given to all the themes of wrong mind-set / attitude, lack of political will / commitment and lack of clearly defined roles and responsibility.

Table 12.10.4 Major constraints to effective implementation of the NWA

Theme / Constraint	Frequency	Formulated Meaning	Sample Participant Statement N=13
Institutional Capacity	12	All institutional capacity related constrains including Human resources, skills shortage, financial resources that affects the proper functioning and competence of water institutions.	*"lack of dedicated people with passion for water and environment in the water institutions"* *"there are insufficient funds to cover water management issues"* *"There is shortage of skills specially in the hydrology and engineering disciplines"*
Integrative Policy Instruments	8	Ineffective and lack of establishment of the available	*"we need to establish the CMAs so they develop the*

		integrative policy instruments	*CMS in their designated WMAs"*
Integration	7	Lack of integration between water stakeholders and between different government departments.	*"the main problem is lack of integration between water stakeholders themselves and also between DWA and other government department"*
Water Infrastructure	4	Lack of or insufficient water infrastructure	*"Water infrastructure is a huge problem, especially in rural areas".*
Monitoring, Learning and Evaluation	3	Limited monitoring, learning and evaluation of the water policy implementation process	*"There is little monitoring and evaluation of the implementation process" There is no formal guideline for monitoring and evaluation of the implementation of the NWA".*
Thinking /Attitude and Mindset	2	Thinking, attitude and mindset of water stakeholders towards water management responsibility.	*"Thinking and mindset of the water stakeholders is a biggest constraints" "DWA needs to change their mind-set and decentralize water management responsibility to the appropriate level".*
Roles and Responsibilities	2	Confusion of roles and responsibilities.	*"There is no clear definition of roles and responsibilities in water institution and as a result there is often confusion and duplication of functions".*
Political Will	2	Lack of political will or political authority / commitment to enforce implementation of the NWA.	*"I personally think that the department is just not yet willing and committed to making the implementation of the NWA happen".*

Relationship between the major constraints associated with the lack of implementation of the NWA

Through careful observation during data categorisation it was found that various themes had a tendency to consistently occur together, i.e. whenever one theme was stated, the other one would also be mentioned. It was then decided that some of the identified connections suggested some form of causal relationships and therefore for enhancement and confirmation of the relationship between the themes a hierarchical cluster analysis was performed to determine both the relationship and the distance of the relationship, between the themes.

Figure 12.10.1 shows a dendogram demonstrating both the relationship between the identified major constraints and the distance of such a relationship. From **Figure 12.10.1** it can be clearly observed that all the clusters are interlinked and that the level of similarity between them decreases with the height of the horizontal lines in the figure (the longer the line the greater the difference). These lines represent the similarity coefficient which is the level of similarity between the themes.

Figure 12.10.1 shows that themes 1 and 2 are the most similar in the dendogram (and therefore form their own and longest cluster respectively in the dendogram) with a similarity coefficient of 7.867. The second most relevant cluster in the dendogram is the case of themes 2 and 3 (second longest cluster in **Figure 12.10.1**) with a similarity coefficient for this cluster of 4.653.

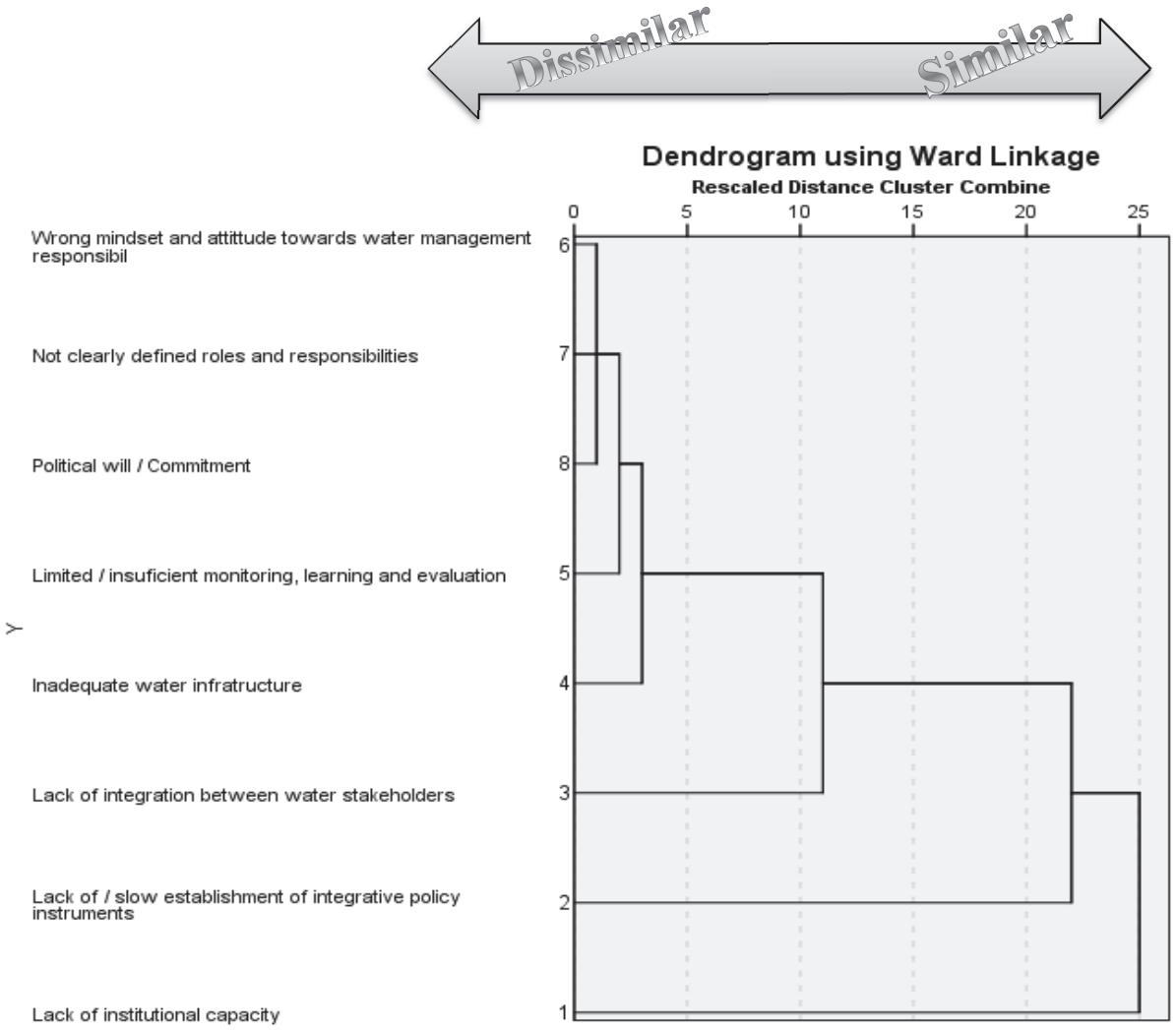


Figure 12.10.11 Dendogram demonstrating both correlation and the distance of the relationship between the perceived major constraints to the implementation of the NWA

The third most relevant cluster is the case of themes 3 and 4, and with a similarity coefficient of 1.948 they form the third longest cluster in the dendogram.

All other similarity coefficients were less than one and, hence, have been discarded for further analysis.

Suggestions in overcoming the identified major constraints

Table 12.10.5 presents a number of suggestions given by the participants in relation to the perceived major constraints. For the institutional capacity constraints almost all of the participants, i.e. 12/13, suggested that capacity building mechanisms, such as training of staff in water institutions, should be employed. It was also suggested that the recruitment departments need to ensure that only the right people are employed for the right positions and, furthermore, that it must be ensured that the water budget is allocated to water related expenses.

Another significant majority of the participants, *viz*. 10/13, who had identified integration as one of the major constraints, suggested that this constraint could be overcame by employing an integrated, holistic and an inter-, trans-, multi-disciplinary approach whenever dealing with water management. With regard to the lack of integrative policy instruments, 7/13 of the participants suggested that the CMA establishment in KwaZulu-Natal should be fast-tracked as that would enable the development of

a CMS which in turn would enhance local stakeholder participation and, hopefully, allow for equity, sustainability and efficiency in water allocation at the catchment level. The participants also suggested that attendance and participation of local stakeholders of the CMFs should be encouraged and that decision making should be undertaken collectively between the key stakeholders, taking into consideration the views of civil society.

Relating to the monitoring, learning and evaluation constraint, just over half the key informants, *viz*. 7/13, suggested that the National Government should develop a guideline for monitoring and evaluation of the implementation process of the NWA itself. In order to enable learning, the stakeholders suggested the National Government should continually conduct research surveys in order to investigate whether the anticipated outcomes of the implementation process of the NWA are achieved or not. Furthermore, it was suggested that monitoring and evaluation of the implementation process of the Act should be continuous and to allow for improvement of the implementation process where required and also to enable learning from the previous mistakes of the implementation process. The key informants further suggested that DWA should engage in joint social learning processes of all sectors influencing water management.

In relation to the constraint 'lack of water infrastructure', the interviewees suggested a strong focus on establishing the required water infrastructure, especially in rural areas. The participants also highlighted that existing water infrastructure should be well maintained, i.e. identifying and fixing leaks, in order to avoid future water restriction that might results from such water loss.

With regard to the wrong mind-set and attitude constraint, the key informants suggested that the water stakeholders need to change their attitude and mind-set towards water management responsibility and understand that water management if everyone's responsibility. The participants further suggested that people must understand their direct and indirect impact on water resources and hence, that water management is every South African citizen's responsibility. Last, but not least, the suggestion was made to delegate water management more to the catchment or regional level as envisaged in the NWA (1998) and NRWS (2004).

Pertaining to the constraint 'lack of political will', 2/13 interviewees recommended that the DWA should use their political power and authority to enforce the implementation of the NWA. The participants also mentioned that the DWA needs to put more effort and commitment in fast-tracking the implementation of the NWA through establishment of the CMAs.

Table 12.10.5 Suggestions in relation to major constraints (N=13)

Major Constraint	Frequency	Theme /Suggestion	Formulated Meaning	*Sample Participant Statement*
Institutional Capacity	**12**	○ Capacity building measures / mechanisms ○ Employing the right people for the right positions ○ Strengthen human resources ○ Allocate more budget to water management	○ Employ capacity building mechanisms and place the right people in the right positions ○ The challenge lies in employing dedicated people with passion for the environment and for water. ○ Improving human resource development to produce an effective workforce ○ Use the budget in water related issues and allocate more financial resources in different institutions	"*Water institutions need mechanisms for capacity building such as training of staff*" *"The Department needs to employ / hire right people for the right positions"* *"There is need to strengthen human resources for water management"* *"The water sector needs to use the budget allocated to water for water related activities and nowhere else."*
Integrative Policy Instruments	**8**	○ Establish CMAs ○ Develop CMSs ○ Participation of local stakeholders ○ Enforcement mechanisms ○ Collective decision making	○ There is need to carefully plan and strategize the available integrative policy instruments to enable their proper establishment i.e. NWRS, CMAs, CMFs, CMS ○ Delegate implementation responsibilities to catchment level, i.e. CMAs ○ Encourage more participation of local people in CMFs ○ There is need for strong enforcement mechanisms ○ There is need to encourage collective decision making	*"Need for carefully planned integrative policy instruments with a clear strategy"* *"Establish CMAs and get them up and running"* *"CMAs to develop CMS"* *"Delegate implementation responsibilities to local level CMAs"* *"Encourage more participation of local people in CMF's"* *"Need strong enforcement mechanisms"* *"Encourage collective decision making"*
Integration	**6**	○ Integrated approach ○ Stakeholder participation ○ Holistic approach ○ Interdisciplinary, multidisciplinary and transdisciplinary approach	○ There is need to employ an integrated approach to water management ○ There is need to encourage active stakeholder participation in in water related programs, i.e. CMFs ○ There is need to encourage a holistic approach to water management ○ There is need to employ an interdisciplinary, multidisciplinary and transdisciplinary approach to water management.	*"We have to employ an integrated approach to water management"* *"We need to encourage active stakeholder participation in in water related programs, i.e. CMFs"* *"We need to encourage a holistic approach to water management"* *"We need to employ an interdisciplinary, multidisciplinary and transdisciplinary approach to water management"*
Lack of Water Infrastructure	**4**	○ Develop and establish required water infrastructure ○ Prevent future water restrictions through maintaining water infrastructure. ○ Identify and fix leaks ○ Lifespan of water pipes	○ There is a need to develop and establish the necessary water infrastructure ○ There is need to take the right precautionary measures to prevent future restrictions in water usage ○ Focus on fixing leaks to avoid wastage of water ○ Implement mechanisms for water demand management ○ Calculate and extend the life span of water pipes	*"The water sector needs to develop and establish the necessary water infrastructure, especially in rural areas"* *"We have to take the right precautionary measures to prevent future restrictions in water usage"* *"We needs to focus on fixing leaks to avoid wastage of water"* *"We need to implement mechanisms for water demand management"* *"The water sector needs to calculate the life span of water pipes"*
Monitoring, Learning and Evaluation of the Implementation Process	**3**	○ Develop guidelines for monitoring and evaluation ○ National Government to continue conducting research surveys to investigate whether the anticipated outcomes of implementing the NWA are achieved or not, and evaluate and improve the process of implementation where	○ There is need for DWA National to develop guidelines for monitoring and evaluation ○ There is need for National Government to constantly conduct surveys to investigate whether the implementation process of the NWA is effective or not. ○ There is need for more stakeholder platforms that enable learning by doing, such as communities of practice. ○ There is need for interactive awareness to ensure learning ○ There is need to encourage water education countrywide	*"Every sector should be represented in a social learning process in order to allow for enhanced cooperation hence enhanced learning"* *"We need to educate people about implications of climate change, i.e. need to encourage rain water harvesting at household level as alternative source of water"* *"Need to implement alternative methods to save water such as human compost and bi-digest toilets in new developments"* *"There is need for interactive awareness in the form of art or stage plays to ensure learning"* *"There is need to encourage water education at schools and through media"* *"Need for on-going monitoring to establish what is working and what is not, as well as learning from effective practices in selected countries"* *"Need for mitigation and adaptation measures against the impacts of climate change"*

		required, and also learn from the previous mistakes. o Social learning processes, i.e. communities of practice o Interactive awareness to allow learning o Water education o Develop a knowledge-based water economy	o Need for on-going monitoring and evaluation of the implementation process to institute what is working and what is not, as well as taking lessons from other countries' experiences o Need for mitigation and adaptation measures against the impacts of climate change	
Thinking, Attitude and Mind-set of Water Stakeholders	**2**	o Change mind-set / attitude and thinking of water stakeholders	o Huge need for change in thinking, attitude and mind-set of water stakeholders through cogeneration of knowledge	*"Water stakeholders need to change their mind-set and attitude towards water management responsibility"* *"DWA needs to change its mind-set and attitude in terms of decentralizing or delegating implementation responsibilities to the appropriate level"*
Lack of Political Will / Commitment	**2**	o Political commitment and support to establish the anticipated sector reforms	o The National Government needs to use its political power / authority to establish the anticipated sector reforms	*"DWA National needs to use it political power to enforce the anticipated sector reforms thereby facilitating the implementation of the NWA"* *"DWA needs to put more effort and commitment and come up with ways to facilitate the implementation process".*
Lack of Clearly Defined Roles and Responsibilities	**2**	o Clear definition of roles and responsibilities	o There is need for clear definition of roles and responsibilities in the water sector	*"The water sector needs to use the NWA as a guide to clear definition of roles and responsibilities where possible".*

Indicators of Limited Monitoring and Evaluation of Implementation of the NWA

The participants' response to the statement: "There is no monitoring and evaluation of the process of water policy implementation" showed that the majority (7/13) of the stakeholders either strongly agreed (3/13) or agreed (4/13) with the statement (**Figure 12.10.12**). Moreover the participants who agreed and disagreed with the statement also indicated that monitoring and evaluation of the implementation process was one of the barriers associated with the slow implementation of the NWA. On the other hand, a lower number (5/13) of the participants indicated that they disagreed and mentioned that "there is monitoring and evaluation of the implementation process to a certain extent, even though it is not enough".

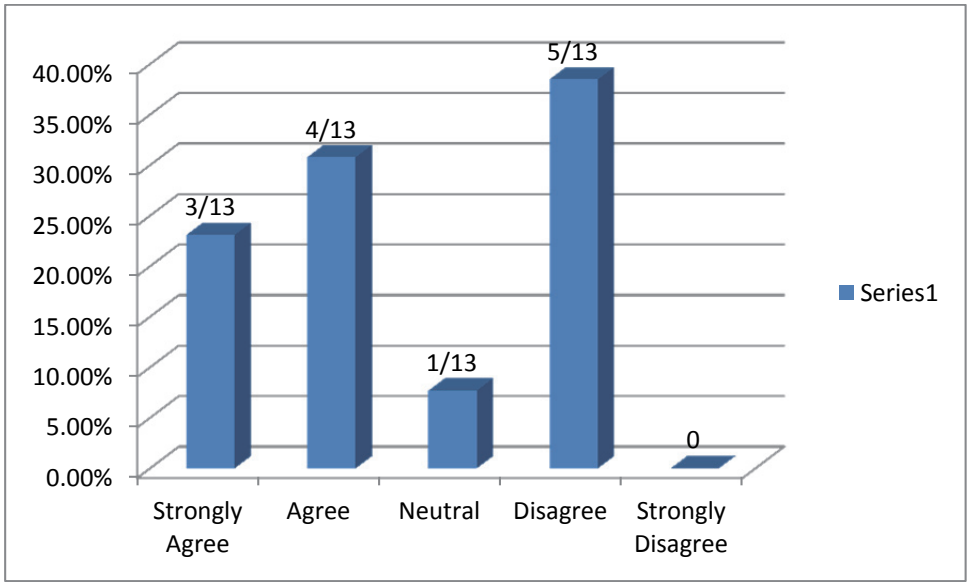


Figure 12.10.12 Stakeholders' level of agreement with the non-existence of effective monitoring and evaluation of the implementation of the NWA

Additionally, in relation to the research question in the questionnaire on whether or not the National Government does monitor the implementation of the NWA, the DWA key informants (4/13) indicated that monitoring and evaluation is the National Government's responsibility. They also specified that even though there is monitoring and evaluation of the implementation process to a certain extent, it was neither formal nor sufficient since there was as yet no formal document that guides the processes of monitoring and evaluation of the implementation of the NWA. The rest of the interviewees (8/13) indicated that there was monitoring and evaluation of the implementation process of the NWA, but it was not enough and it was not properly done as there is no scope that is assigned to it.

Additionally, it should also be borne in mind that limited monitoring, learning and evaluation was mentioned by a third of the key informants as one of the major constraints in the implementation of the NWA. Therefore this serves as an indication that monitoring and evaluation of the implementation process of the NWA is inadequate.

12.11 Discussion of Key Findings

The initial aim of the study was to examine possible reasons associated with the lack of policy implementation and to investigate integrative instruments for effective implementation of the National Water Act and the associated challenges in the establishment of the policy instruments. This section therefore discusses the key findings that were obtained from analysing the data that was collected through key informant interviews.

12.11.1 Identified integrative policy instruments

The results in relation to the first research question which was on integrative policy instruments are in agreement with the desktop studies that integrative policy instruments for implementation of the NWA include the general instruments for policy implementation such as the technical, institutional,

economic, legal, administrative and participatory instruments, the NWRS as well as the CMS. These results are also consistent with the assertions of Plummer and Slaymaker (2007) that the technical, institutional, economic, legal, administrative and social / participatory tools are the policy instruments for effective water governance.

Notably, the participants mentioned that there are more than enough policy instruments for implementation of the NWA in the South African water sector. The main concern, however, was that the available policy instruments were not integrated themselves and as a result they were not achieving their initial goal of enhancing cooperation between water stakeholders and other government departments. These results are aligned with previous research and have provided relevant answers to the research questions of the study (Research Question 1).

Additionally, in relation to these results, Dent (2009) and du Toit *et al.* (2007) advise that an integrated approach needs to be employed when applying policy instruments in managing water related matters.

12.11.2 Perceived major constraints of the implementation of the NWA

The results in relation to the second research question on the perceived major constraints towards effective implementation of the NWA showed that the most important major constraints include lack of institutional capacity (financial and human resources); lack of integration between water stakeholders and between the water sector and various government departments; lack of or slow establishment of integrative policy instruments and limited monitoring, learning and evaluation of the implementation process.

The constraint of 'institutional capacity', including both lack of financial resources and human resources in water institutions, was that most highlighted (12/13) by the participants. These findings are in line with the assertions of various other studies (Mackay and Rogers, 2000; Plummer and Slaymaker, 2007; Anderson *et al*., 2008; Medema *et al*., 2008; Tissington *et al*., 2008; Iza and Stein 2009; UNDP, 2012) that governability or the competence and ability to implement water policies requires human and financial resources for activities associated with both water resource management and water supply. These studies also clearly link to the lack of institutional and management capacity as a major barrier in implementing national water policies.

Also in line with these results are the assertions of Naster and Hansen (2009) that South Africa is not capacitated with specialists with water resources skills, i.e. there is a shortage of water engineers, hydrologists, implementers and compliance monitors at the DWA (and in other departments related to water management) and one will likely find a high number of vacant positions in these fields when looking at the government department's circular. This clearly indicates that there is a significant lack of human resources in South Africa's water institutions. Additionally, Naster and Hansen (2009) state that resignation of many experts such as scientists and practitioners to private consultancies is very common in the DWA and this has resulted to degradation and loss of institutional memory in the water sector.

The second mostly highlighted (8/13) theme by the participants was the lack of, and / or the slow establishment of, integrative policy instruments. With regard to this theme, the stakeholders specified that the NWA does make provision for integrative policy instruments for its implementation through the NWRS and the CMS. However, the main issue here is that these instruments have not yet been effective as currently there are serious delays in their proper establishment and functioning. The key informants were concerned that:

1. The first edition of the National Water Resource Strategy was developed in 2004 and was effectively established, but there were concerns that it took a very long time (9 years) for the second edition of the NWRS to be completed in 2013 while it is supposed to be renewed in a five year cycle.
2 No Catchment Management Strategy has been developed for most of the water management areas since the process of the establishment of CMAs has been longer than anticipated. In regard to this reasoning, the stakeholders expressed that it had proven to be very difficult to develop a CMS since the power to manage water resources and implement policies had not been fully delegated to the appropriate levels, i.e. DWA regional had not been authorized by the National Government to take decisions.

3. The participants also emphasized that the national government should be responsible for developing policy but should not be implementing it - implementation should be the DWA regional's responsibility, i.e. DWA National should concentrate on regulating, giving oversight and on monitoring the whole process of the NWA implementation.
4. Catchment Management Forums are functional, but most of them are not yet designed for public participation as the local stakeholders are poorly represented in the meetings. The key informants also emphasized that even if the local stakeholders attend the meetings, they rarely benefit in these meetings because they do not understand the scientific terms being used. Furthermore language is also a barrier to many stakeholders because some of them have limited understanding of English or they do not understand it at all, while most of the CMFs meetings are conducted in English (Karrar, 2000; Simpungwe, 2003; du Toit and Pollard, 2008).

The above findings agree with other studies on policy implementation of the NWA (Naster and Hansen, 2009; DWA, 2011; Movik and de Jong, 2011), are eye-opening and provide significant information on a way forward and on how improvements could be made.

The results with regard to the current status of the CMSs and CMFs are consistent with those of du Toit *et al.* (2007) that, while CMFs are intended to be more than platforms where water stakeholders defend their interests in water resources, South Africa has not yet implemented an all-inclusive and practical approach to stakeholder engagement at the catchment level (WMAs). Furthermore, du Toit *et al.* (2007) referred to the CMS as the basis for public engagement and in that way recognize the direct link between proper functioning of the CMFs and the development of the CMS, i.e. once the CMAs have been established and once the CMSs have been developed, stakeholders will then be able to plan for water security through engaging in strategic planning on water security..

Lack of integration between waters stakeholders themselves and also between the water sector and other government departments was the third most highlighted theme, *viz.* 6/13. These results are consistent with findings of Rahaman and Varis (2005) and Naster and Hansen (2009) that one of the major problems of implementing the NWA is centred on lack of integration, such that there is poor level of cooperation and 'togetherness' between various government departments and water stakeholders. This is, however, in contrast with the constitutional mandate that "all organs of state must co-operate with each other in mutual trust and good faith by co-ordinating their actions and legislation with each other" (Dent, 2009).

Dent (2009) further adds that the most important aspect of integration between water stakeholders and among various departments is the fact that water is a shared resource and is directly linked to other natural resources and, therefore, cannot be managed without taking consideration of other natural resources. This means that effective water management and policy implementation can only be achieved if the dynamics of water and how it is related to other natural resources is understood and acknowledged.

Inadequate water infrastructure and the limited monitoring, learning and evaluation of the implementation process of the NWA were also identified as major constraints to the implementation of the NWA, but with a lower frequency of 4/13 and 3/13 respectively.

With regard to the inadequate water infrastructure constraint, the interviewees specified that water infrastructure was specifically a crucial issue in rural areas. These results are consistent with those of the UNDP (2007) that inadequate water infrastructure has generally prevented improved water services supply to domestic consumers, and especially, to the poor. In most urban areas population growth has placed immense pressure on water resources to the extent that the existing water infrastructure now urgently requires redesign and upgrading.

In relation to the 'monitoring, learning and evaluation constraint', the key informants indicated that monitoring and evaluation of the implementation process of the NWA itself is limited. Furthermore, they also indicated that the absence of a formal guideline for monitoring and evaluation might be the reason behind the current narrow monitoring and evaluation process. The current state of the process of monitoring and evaluation of the implementation process of the NWA is in contrast with the suggestions of Abrams (2000) in the Water Resources Management Reform Process Paper. In this paper the author recommends that every implementation process should be accompanied by continuous monitoring and evaluation in order to ensure that implementation remains a continuous

process and also to make certain that the sector learns from previous mistakes. In order to demonstrate this Abrams used a governance cycle which clearly shows that the implementation phase was part of a cyclical process, indicating that it is non-stop, but continuous. This implies that more work still needs to be done on the monitoring and evaluation side of things in the implementation process of the NWA.

Interestingly, the results also showed that there was strong support in the literature reviewed (e.g. Folifac, 2006; UNDP, 2007; Plummer and Slaymaker, 2007; Iza and Stein, 2009; Naster and Hansen, 2009; du Toit *et al*, 2011; DWA, 2011; Nkondo *et al.*, 2012) that the hindrance of effective implementation was based on a lack of political commitment and a lack of clearly defined roles and responsibilities. However, the key informants rated this issue only very weakly (2/13).

12.11.3 Relationships between the perceived major constraints

In regard to the relationships between the perceived major constraints, the analysis revealed that all the major constraints to effective implementation of the NWA are interrelated with the lack of institutional capacity, lack of or slow establishment of integrative policy instruments and lack of integration between different sectors related to water management. The results of the analysis also proved to be true in reality because, according to the literature reviewed, institutional capacity is a component of integrative policy instruments. Hence, inadequate institutional capacity results in the lack of, and / or slow establishment of, integrative policy instruments depicting a cause and effect relationship between the two (Plummer and Slaymaker, 2007; DWA, 2011).

Moreover, these results are also the practical reality and are consistent with the recent studies on integrative policy instruments (DWA, 2011; du Toit *et al.,* 2011; NWRS; 2013) that more than anything else, integrative policy instruments are meant to be increasing the level of cooperation between water stakeholders and other government departments. This therefore means that slow establishment of integrative policy instruments results in poor cooperation between water stakeholders and other government departments, thereby hindering effective water management (cause and effect relationship).

12.11.4 Participants' suggestions in relation to major constraints

Table 12.10.5 in the results section listed the various suggestions proposed by the participants in relation to the identified major constraints. In relation to the highest rated constraints of lack of institutional capacity, the key informants suggested building this through incorporating relevant training courses in various water institutions.

The key-informants suggested that following to be taken into consideration:

- Employ capacity building mechanisms and place the right people in the right positions by employing dedicated people with passion for water and the environment;
- Use the budget for water solely for water related expenses and allocate more financial resources in different institutions;
- Carefully plan and strategize the available integrative policy instruments to enable their proper establishment, i.e. NWRS, CMAs, CMFs, CMSs;
- Fast-track the establishment of the CMAs and delegate implementation responsibilities to catchment level, i.e. CMAs;
- Employ an integrated approach when dealing with water management issues;
- Employ interdisciplinary, multidisciplinary and transdisciplinary approaches to water management in order to ensure cooperation between water stakeholders and stakeholders from all disciplines;
- Encourage active stakeholder participation in in water related programmes, i.e. CMFs.

These suggestions by the participants correspond with some of the recommendations by other studies (MacKay and Rogers, 2000; Al-Eryani, 2002; Batchelor, 2007; Naster and Hansen, 2007; Wagener *et al*., 2010; Woodwill, 2010; du Toit *et al*. 2011; Kondo *et al*., 2012) and present an opportunity to implement appropriate change in the water sector in terms of policy implementation.

These proposed suggestions by the stakeholders are in line with various recommendations forwarded by previous studies (Naster and Hansen, 2009; du Toit *et al*., 2011; DWA, 2011; Kondo *et al*., 2012) on the way forward for implementation of the NWA.

12.11.4 The level of sharing of integrative policy instruments among the water management approaches

The overall key informant results can be used to provide an answer to the main research question which enquired whether lack of implementation of the NWA results from the lack of integrative policy instruments. The results show that the answer is 'yes', considering that the perceived major constraints were the ineffective or lack of integrative policy instruments (taking into consideration that institutional capacity is a component of policy instruments), and in the sense that there as yet only one existing integrative policy instrument (the NWRS) is operating in isolation of the not yet developed other integrative instruments of the NWA (CMSs in most WMAs). Moreover, the general policy instruments such as economic, institutional, legal, administrative, technical and participatory instruments also need to be treated integratively in order to obtain better implementation results.

These results, together with the findings of previous research, support the initial hypothesis of the study that poor implementation of the NWA results from ineffective integrative policy instruments and water institutional capacity. These results have in many ways clearly shown that the delayed development and establishment of the CMSs and the associated CMAs are the main problems associated with poor implementation of the NWA.

The second part of the main research question queried whether or not integrative policy instruments could be shared by different management approaches. The results provided evidence that integrative policy instruments can only be shared amongst the management approaches that have the same objectives (i.e. decentralised, IWRM and AM) and not amongst management approaches that are contradictory to each other (i.e. Centralised contradictory to Decentralised as well as to IWRM vs. AM approaches).

For example, the results indicated that the NWRS and the enforcement mechanisms function best in a centralised water management framework. Contrarily, the CMSs perform best in a more decentralised, integrated and adaptive water management framework.

The results indicated that the participants of the study felt that the reality that the NWRS is functioning on its own, without a CMS in most water management areas, is an indication that the South African water sector still operates in more centralised water management framework, which is contradictory to the country's supposedly "democratic" policy context, and that this therefore creates confusion and complexity in the overall implementation of the NWA.

These results are supported by various studies (Ashton *et al*., 2006; Newater, 2006; Du Toit *et al*., 2011) which show that while the South African policy framework is designed for decentralisation, under democracy the water sector still shows major elements of centralisation and therefore considerable complexity and confusion within the country's water sector have resulted from a mix of contradictory management systems existing together.

According to Du Toit *et al* (2011) and Naster and Hansen (2009) the existing water governance problem in the South African water sector initiated from the pre-1998 water governance system which was mainly characterised by an essentially centralized water governance and that it was only in 1998 that the new water legislation based of decentralised decision making was introduced. Previous studies revealed that even though it is understood that with the introduction of the new water legislation the overall water sector needed to be given time to adapt to this relatively radical transition, there are concerns that it has taken too long for the water sector to adapt in such a way that more complications in terms of implementation of the NWA have resulted (Schreiner, 2013).

This study found that the issue of slow implementation of the NWA is no longer a matter of failing to adapt from change, but it now largely a matter of ignorance and unwillingness to delegate management functions to appropriate levels (Folifac, 2006).

12.12 Summary of Key Findings

The initial aim of the study was to examine possible reasons associated with the lack of policy implementation and to investigate integrative instruments for effective implementation of the National Water Act and the associated challenges in the establishment of policy instruments. This was achieved by the study through conducting key informant interviews with water management experts in the uMngeni Catchment, where the results showed that there are a number of factors associated with the lack of implementation of the NWA. The most significant factors included ineffective integrative policy instruments and institutional capacity, lack of integration between water stakeholders and different departments that impact on the water resource, insufficient monitoring and evaluation of the implementation process and lack of water infrastructure, the latter especially in rural areas.

The first objective of the study was to identify integrative policy instruments for policy implementation of the National Water Act. This objective was achieved by the study, and the results revealed that the key informant interviewees indicated that the integrative policy instruments for implementation of the NWA were the two water management strategies provided for by the NWA (1998), *viz.* the NWRS and CMSs.

The second objective was to identify major constraints and challenges affecting the process of policy implementation of the National Water Act. The results indicated that the major constraints to the implementation of the NWA included lack of institutional capacity (financial and human resources), lack of integration between the water sector and other sectors that impact on water resources, lack of, or slow establishment of, integrative policy instruments such as the CMAs and limited monitoring, learning and evaluation of the implementation process of the NWA.

The third objective was to examine suggestions proposed by the relevant stakeholders (both institutional and local) in relation to the major constraints and challenges affecting effective implementation of the National Water Act. **Table 12.10.5** presented the proposed suggestions by the key informants as follows:

- There is need to employ capacity building mechanisms and place the right people in the right positions.
- More financial resources should be allocated in different water institutions.
- The budget for water should be spent in water related expenses,
- There is need to carefully plan and strategies the available integrative policy instruments to enable their proper establishment, i.e. NWRS, CMAs, CMFs, CMSs.
- There is a huge need to fast track the establishment of the CMAs.
- There is need to employ an integrated approach to water management.
- There is a need to develop and establish the necessary water infrastructure, especially in rural areas.
- There is need for DWA National to develop guidelines for monitoring and evaluation of the implementation process of the NWA.

The fourth objective was to acknowledge the important links between the NWA and the WSA. The results indicated that that the NWA and WSA were directly related to each other with the NWA informing the WSA, i.e. insufficient fresh water resources and poor water quality results to small quantities of water to be supplied and therefore results to poor water service delivery.

Using the concerns of the key-informant interviewees with regard to the future state of water management in the uMngeni Catchment, numerous concerns arose around the issue of increases in demand for water resulting from population growth. It was specified that an increase in demand would place a strain on water availability in terms of both quantity and quality as there would also be increases in waste produced with population increase. This would result in waste water treatment works dysfunctionalities which would, in turn, result in declining of river water quality due to the quality of water being released from waste water treatment works to the rivers. As a result the purpose of the NWA, which includes protection and management of water resources in an integrated manner, would be contradicted. The same would happen with the purpose of the WSA in terms of providing sufficient and safe water to households and other municipal water users because there would be less or no clean water resources would be left to provide water to be supplied.

The results revealed that the relationship between water resources and water services is cyclic and causal, where water resources management informs water services and therefore it means that water resources and if we are to achieve the objectives of equity and sustainability water services should be dealt with integratively.

12.13 Recommendations

This section provides recommendations on mechanisms and activities that are believed to successfully facilitate the implementation process of the NWA. The following recommendations are made based on the findings and discussion from the previous sections.:

Local stakeholder participation and involvement
Steps should be taken to increase community participation and involvement in the water management platforms such as CMFs in order to ensure effective water management at local level. More social learning stakeholder platforms where key water stakeholders, different sectors related to water management as well as civil society are represented should be considered to allow for effective management of water resources and allow learning by doing among various stakeholders.

In order for water management to bring about positive change to all parts, but especially those impoverished part of society, local communities must have a say in how they want their water resources to be managed. This can be achieved by adopting and maintaining a more consultative and inclusive approach in the planning and management of water resources through community meetings with residents and residents' associations. Involving residents in the entire process will encourage mutual respect between stakeholders, but more importantly will guarantee effective water management as a result of the level of support and participation of the residents.

Communication and dissemination of information to local level
Effective communication and the distribution of information are key to increasing the levels of awareness. Key water stakeholders should provide communities with regular feedback and updates pertaining to water issues concerning them. This could assist in minimising the potential for future water restrictions and domestic water quality issues. Concerns related to water problems that could potentially occur should be addressed and communicated using a multi-media approach well in advance, so that communities are aware and well prepared. Information should be made available freely to society by, for example, assigning a dedicated call centre, radio broadcasts, print media and electronic media such as websites.

Integrative management of water resources and water services
Owing to the importance of the identified links between water resource management and water services, this study highly recommends that the management of water resources and water services be done integratively. This implies, *inter alia*, that:

- Mechanisms for better co-ordination between water resource management and water services should be established to ensure the sustainable use and protection of water resources;
- Water service needs for a Water Management Area must be incorporated in guidelines for preparation of the CMS;
- Upon their full establishment, CMAs must have an input on the Provincial Water Sector Plan (PWSP) to ensure that the catchment water needs are incorporated, in that way ensuring that the priorities set by the CMAs and the priorities set by the Water Services Sector are integrated in order to efficiently plan water resources and their uses;
- There must be continuous cross-communication between CMAs and WSAs, i.e. CMAs must be consulted when the Water Services Development Plans are compiled; and
- The relationship between the CMAs and WSAs must be clearly stated in the CMS guidelines.

12.14 Conclusions

The NWA is regarded as the one of the most advanced pieces of water legislation in the world. However, the findings of this study indicate that effective implementation of this Act has not yet been achieved. The prevailing issues of implementation of the NWA result from a lack of various factors with the most significant being the lack of institutional capacity in the water sector, ineffective integrative policy instruments such as CMAs, lack of integration between the water sector and the

other sectors that impact on water resources and last, but not least, the limited monitoring and evaluation of the implementation process as a whole.

Furthermore, the findings of this study present a range of opportunities for future research:

- There is need for continued and further research into integrative instruments for implementation of the NWA, especially those that are specifically designed for the NWA, i.e. the NWRS and the CMSs, in order to ensure that the current establishment of the 9 CMAs is as effective as possible, and thereby ensuring effective implementation of the Act and continued monitoring of the overall process.
- The results also indicate that future research needs to concentrate on investigating measures to overcome the existing major constraints associated the implementation of the NWA, i.e. lack of institutional capacity, limited integration between water stakeholders, poor usage of integrative policy instruments, poor water infrastructure and water stakeholders' wrong attitude towards water management responsibility.
- The overall results of this study drawn from both the key informants and household surveys indicate that understanding stakeholders (both local and institutional) perceptions and attitudes towards water management can enable water policy implementers to strategically plan and manage the implementation process effectively while also taking into account the community's satisfaction with the water services delivered to them.
- The overall findings of this study calls for more research to be undertaken in the uMngeni Catchment in the form of longitudinal studies to assess changes in household / community level awareness, perceptions and attitudes towards water management including supply.
- This research should be replicated in other catchments in South Africa, especially in the most rural areas of South Africa, in order to measure and assess households', awareness, perceptions and attitudes towards water resource and service management in a consistent manner using a standardised questionnaire.

In closing, it seems that there is a huge conflict of interests between the existing centralised and decentralised water management approaches and instruments in the South African water set-up, but that the interplay between the two approaches should not be a problem as long as cooperation between all levels of government is maintained on an on-going basis.

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APPENDIX A

UNIVERSITY OF KWAZULU-NATAL
SCHOOL OF AGRICULTURAL, EARTH AND ENVIRONMENTAL SCIENCES
INSTRUMENTS FOR POLICY IMPLEMENTATION OF DIFFERENT MANAGEMENT APPROACHES IN THE SOUTH AFRICAN WATER SECTOR:
THE CASE STUDY OF UMNGENI CATCHMENT

SECTION A

1. Stakeholders' general understanding of water governance

1.1. What is your understanding of the term governance?

Definition of the term governance	**Code**
Management process	1
Management process / interaction between public sector and civil society	2
Political process	3
Administrative process	4
Same meaning as government	5
Other (specify)	6

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1.2. What is your understanding of the term water governance?

Definition of the term water governance	**Code**
Water management	1
Whole range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society	2
Water politics	3
Water government	4
Other (specify)	5

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1.3. What is your understanding of the National Water Act?

National Water Act	**Code**
Law and policy framework for water	1
Principles of water and related legislation in South Africa	2
Water policy and legislation	3
State that everyone has a right to have access to sufficient water	4
All of the above	5
Same as Water Services Act	6
Other (specify)	7

SECTION B

2. Stakeholder's general understanding of water management

2.1. What is your understanding of the centralised approach to water management?

Centralised approach	**Code**
Top-down approach to water management	1
Bottom-up approach to water management	2

Water resource management responsibility is concentrated to the state	3
Encourages sharing of management responsibility	4
Public participation	5
Other (specify)	6

2.2. What is your general understanding of a decentralized approach to water management?

Decentralised approach	**Code**
Bottom-up approach to water management	1
Top-down approach to water management	2
Water resource management right transferred to local level	3
Encourages sharing of management responsibility	4
Promotes public participation	5
Other (specify)	6

2.3. What is your understanding of an integrated (IWRM) approach to water resource management?

Integrated Water Resource Management	**Code**
Systematic process of sustainable development	1
A concept of water resources management	2
A concept to implement the National Water Act	3
Process, which promotes the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.	4
All of the above	5
Other (specify)	6

2.4. What is your understanding of an adaptive (AM) approach to water management?

Adaptive management	**Code**
Concept of Integrated Water Resource Management	1
Systematic process for improving management policies	2
An integrated, multidisciplinary and systematic approach to improving management and accommodating change by learning from the outcomes of management policies and practices	3
Management of water resources in such a way that they adapt to any change	4
An evolving concept	5
Other (specify)	6

SECTION C

3. Stakeholders' general understanding of policy implementation

3.1. What is your understanding of effective water policy implementation?

Effective water policy implementation	**Code**
Putting policy into practice using effective institutions, integrated tools and expert knowledge	1
Phase of a governance cycle just after policy reform phase and is followed by the review phase	2
Result from a combination of water governance capacity and a strong enabling environment	3
All of the above	4
None of the above	5
Other (specify)	6

3.2. Does your department / organisation / institution currently have a role in facilitating water policy implementation?

Yes	No

3.2.1. If yes, what is your department's / organization's role in water policy implementation?

Role :facilitate implementation at :	Code
National level	1
Provincial level	2
Local/community level	3
Institutional level	4
Don't implement / no role	5
Others (specify)	6

3.2.2. If no, why not?

_____
_____
_____

3.3. Do you think your department / organisation / institution can have an effective role in facilitating water policy implementation?

Yes	No

3.3.1. If yes, what could that role be?

_____
_____
_____

3.3.2. If no, why not?

_____
_____
_____

3.4. Based on your understanding of policy implementation, do you think that the National Water Act is currently being implemented effectively?

Yes	No

3.4.1. If yes, why do you say so?

_____
_____
_____

3.4.2. If no, what do you think is causing the problem of lack of implementation of the NWA?

_____
_____
_____

SECTION D

4. Reasons associated with the lack of policy implementation

4.1. Which of the following do you think is the main reason associated with the lack of effective water policy implementation?

Reason	**Code**
Lack of institutional capacity	1
Lack of management capacity	2
Lack of policy instruments	3

Lack of integrative and integrated policy instruments	4
Lack of Integration between water stakeholders	5
Lack of political will	6
Lack of experts in the National government	7
Lack of monitoring and evaluation of the implementation process	8
Others (specify)	9

4.2. Please provide reasoning for your answer in question 4.1

_____
_____
_____

SECTION E

5. Identifying most relevant integrative / integrated policy instruments

5.1. What is your understanding of integrative / integrated policy instruments?

_____
_____
_____

5.2. Which of the following do you think forms the most relevant integrative instruments for water policy implementation?

Policy instruments	**Code**
Technical	1
Instrumental	2
Legal	3
Social / Participatory	4
Economic	5
Administrative	6
National Water Resource Strategy	7
Catchment management strategy	8
The integration/combination of all of the above	9
Other (specify)	10

5.2.1. Can the same instruments in question 5.2 be used to implement different management approaches of the NWA i.e. centralized, decentralized, IWRM, adaptive management?

Yes	No

5.2.1.1. If no, why not?

5.2.1.2. Which are the specific instruments / tools to implement:
5.2.1.2.1. Centralized

Policy instruments for centralized approach	**Code**
The integration / combination of all the policy instruments in 5.2	1
Enforcement mechanisms (e.g.)	2
National water resource strategy	3
Catchment management strategy	4
Participatory process	5
Catchment management agencies	6
Catchment management forums	7
Catchment management committees	8
Water user associations	9

Other (specify)	10

5.2.1.2.2. Decentralized

Policy instruments for decentralized approach	**Code**
The integration / combination of all the policy instruments in 5.2	1
Enforcement mechanisms	2
National water resource strategy	3
Catchment management strategy	4
Participatory process	5
Catchment management agencies	6
Catchment management forums	7
Catchment management committees	8
Water user associations	9
Other (specify)	10

5.2.1.2.3. IWRM

Policy instruments for IWRM	**Code**
The integration / combination of all the policy instruments in 5.2	1
Enforcement mechanisms	2
National water resource strategy	3
Catchment management strategy	4
Participatory process	5
Catchment management agencies	6
Catchment management forums	7
Catchment management committees	8
Water user associations	9
Other (specify)	10

5.2.1.2.4. Adaptive management

Policy instruments for Adaptive Management	**Code**
The integration/combination of all the policy instruments in 5.2	1
Enforcement mechanisms	2
National water resource strategy	3
Catchment management strategy	4
Participatory process	5
Catchment management agencies	6
Catchment management forums	7
Catchment management committees	8
Water user associations	9
Other (specify)	10

5.3. What do you think are the major constraints / challenges associated with the lack of water policy implementation?

Major Constraints	**Code**
Financial resources	1
Human resources / capacity	2
Skilled labour/staff in water institutions	3
Experts	4
Lack of water infrastructure	5
Policy instruments	6
Integration	7
Integrated policy instruments	8
Other (specify)	9

5.4. What are your department's /organization's /institution's concern's in relation to the issue of water policy implementation?

Concern	**Code**
SA will never be able to implement the NWA effectively	1
Level of water allocation is likely to go from bad / poor to worse in future	2
It is still going to take a while for SA to achieve effective water governance	3
SA is facing a water crisis and could start having critical shortages as early as 2020	4
The problem of water provision severely affects slums and shantytowns	5
Access to water is mainly a crisis for the poor	6
Water is also a crisis for women and children, because they bear the burden of collecting water	7
Most water use is in agriculture	8
Global climate change is another threat to water availability	9
The lack of adequate water services is the cause of much disease and illness	10
The major problem is water quality more than quantity	11
Other (specify)	12

5.5. What are your suggestions in relation to your concerns? Or what can be done to better the situation of water policy implementation.

SECTION F

CODES
1= Strongly Agree; 2= Agree; 3= Neutral; 4= Disagree; 5= Strongly Disagree

6. Perceptions and attitudes towards water management (allocation and water resource management)

	SA	A	N	D	SD	
6.1 The water sector will achieve effective implementation of the NWA by 2015						
6.2 More management responsibility should be transferred to the local government						
6.3 Equitable water allocation will never be achieved in the water sector						
6.4 The SA water sector lacks skilled and dedicated people						
6.5 The SA water sector is full of corruption						
6.6Tthe SA water sector lacks integration between stakeholders						
6.7 The SA water sector lacks water governance capacity						
6.8 The SA water sector needs an enabling environment						
6.9 There is a need for more policy instruments for implementation						
6.10 There is a need for integrative policy instruments for implementation						
6.11 Lack of infrastructural facilities exacerbate the issue of water allocation						
6.12 Population growth will increase demand for water						
6.13 Social learning activities will facilitate effective decision making to matters related to water						
6.14 There is absolutely no monitoring and evaluation of the process of water policy implementation						
6.15 Different water management approaches require the same policy instruments for policy implementation						
6.16 The same policy instruments can be shares by different water management approaches						

6.17 Is your department / organization / institution satisfied with the process of water management in the uMngeni Catchment?

Yes	No

6.17.1. If no, why not?

_____
_____
_____

6.18. Do you have any suggestions related to your major constraints, and what are those suggestions?

_____
_____
_____

6.19. Do you see any possible problems with water management in future?

Yes	No

6.19.1. If yes, what could be those problems?

_____
_____
_____

6.20. How does your department / organisation / institution ensure public participation by local communities?

_____
_____
_____

SECTION G

7. Stakeholder's profile

7.1 What is your age?

<20	21-30	31-40	41-50	51-60	61-70	>70(specify)

7.2 Gender

Male	Female

7.4 Race

African	Indian	Coloured	White

7.5 Highest Educational Level attained

No formal education	Partial primary	Primary completed	Secondary completed
Certificate/diploma	Undergraduate degree	Postgraduate degree	Other (specify)

7.6 Employment Status

Student / Scholar	Retired	Sales / marketing	Unemployed
Administrator/Manager	Business person	Artisan/technician	Professional
Self-employed	Home executive	Labour/unskilled	Other

Thank you so much for your participation!!!

APPENDIX C

UNIVERSITY OF KWAZULU-NATAL
SCHOOL OF AGRIULTURE, EARTH AND ENVIRONMENTAL SCIENCES

SAMPLE: INFORMED CONSENT FORM FOR INTERVIEWS

Preamble

Title: Integrative Policy Instruments for Implementing the National Water Act: A Case Study of Mgeni Catchment

Ntombifuthi Pretty Vilakazi (student researcher)
Mrs Sabine Stuart-Hill and Professor Graham Jewitt (Supervisors)
0834778794 (contact number)
206513194@ukzn.ac.za
Science and Agriculture (faculty name)

I am a student researcher at University of KwaZulu-Natal. I am doing Masters by research in Hydrology (HYDR8SYP2). I am studying instruments for policy implementation of different management approaches in the South African water sector.

During the interview you will be asked to answer some questions on **your level of satisfaction with water provision in your area (for household participants**) and on **your take on the implementation of the National Water Act (for key informants)**. This interview is designed to be approximately 20 minute in length (estimated duration). However, please feel free to expand on the topic or talk about related ideas. Also, if there are any questions that you feel you cannot answer or that you feel uncomfortable answering, feel free to indicate and we will move on to the next question.

All the information will be kept confidential. The data will be kept in a secure place, i.e. in my supervisor's office. Only the researchers and faculty supervisors mentioned above will have access to this information. Upon completion of this research project, all data will be stored in a secure place.

Participant's Agreement

I am aware that my participation in this research is voluntary. If for any reason, at any time, I wish to stop the interview, I may do so without having to give an explanation. I understand the intent and purpose of this research.

The researcher has reviewed the individual and social benefits and risks of this project with me.

I am aware that the data will be used for a paper, post and a research dissertation. I have the right to review, comment on, and withdraw information prior to the submission of the paper, post and dissertation. The data gathered in this project are confidential and anonymous with respect to my personal identity unless I specify/indicate otherwise.

I grant permission for the use of this information for a research thesis.

Participant's Signature Date

_____ _____

CHAPTER 13: EXPLORING CO-DESIGN OF ADAPTATION TO CLIMATE CHANGE AND PRIORITISING INTERVENTIONS

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13.1 Introduction

Recent studies for South Africa have shown that certain land use and other change issues can sometimes override the climate change signal in its impacts. Furthermore, the higher the level of modification of land use, the stronger the amplification *via* the hydrological response (Warburton *et al*., 2012). Additionally, when looking at a more distant future under climate change, the joint impact of land use and climate change can, under some circumstances, be significantly amplified *via* hydrological responses such as runoff (Warburton and Schulze, 2010). Furthermore, when taking into consideration that for South Africa a 10% change in rainfall can result in a change in runoff of up to 20 – 30% (Schulze, 2008), then pre-planning for both projected land use and climate changes will be crucial. At the same time, however, there are issues of uncertainty surrounding not only the biophysical, but societal and economic impacts as well, and accounting for feedbacks becomes crucial (Pahl-Wostl *et al*., 2011; Isendahl *et al*., 2009). It is the uncertainties that, in many regions of the world, seem to hinder certain activities which are indispensable to design interventions for warding off severe impacts that might be beyond our capacities to cope and adapt.

Thus, a key question is how we may gain, or at least inform, relevant answers for policy making, policy implementation and local water management practices within this highly dynamic landscape of our catchments which is often dominated by change. Based on work by Stuart-Hill and Pahl-Wostl (in preparation) as well as by Stuart-Hill and Schulze (2010), three areas of water management are critical in this context, *viz*. the knowledge around the impacts of change and climate change respectively, an understanding of vulnerabilities and risks which may be critical at a certain time and in a certain place, as well as the resulting design and prioritisation of adaptation activities. This type of sense-making cannot be limited solely to the water sector (Roux *et al*., 2006; Ison *et al*., 2011; Jones, 2011; Stuart-Hill *et al*., in review) but needs to take place by negotiation within a process of dialogue (Vogel *et al*., 2007; Loorbach, 2010). Such dialogue needs to take relevant policy and day-to-day decision making of water managers and other critical stakeholders into consideration (Folke, *et al*., 2005; Someshwar, 2008; Inderberg and Eikeland, 2009). Hence, a space is necessary where local and regional knowledge and needs meet policy guidance and is placed within the 'bigger picture' of water management.

However, many challenges in regard to South Africa's water management and the wider stakeholder landscape exist. These include:

- Limited capacities (Stuart-Hill and Schulze, in preparation)
  - of management to act and to take on complex policies and environments, and
  - of the biophysical and social monitoring networks:
- High levels of disparities in our societies (DEAT, 2006; NPC, undated)
  - High levels of poverty and malnutrition
  - Weak health and educational systems
  - Low levels of social capital in wide parts of our societies.

Based on the above the research questions for this chapter are:

1. How can climate change information be incorporated into the water sector so that it is relevant on a day-to-day basis?
2. How can adaptation and resulting interventions be negotiated by taking local pressures, needs and knowledge as well as the national regulatory framework and policies into account?

13.2 Proposing a Space for Dialogue and Negotiation

For clarification of the process envisaged, the analogy of a pressure cooker is used: receiving pressure from the bottom by local authorities and water users, often guided by the regulations from the Water Services Act (RSA, 1997) as well as local political agendas and issues surrounding livelihoods will play a major role and hence place pressure on the system for delivery. On the other hand is the pressure cooker's cap / lid, representing guidance from national policies and laws driven by the National Water Act (RSA, 1998) as well as possible political agendas represented by the national and regional offices of the Department of Water Affairs. The Minister of the latter is the custodian of South Africa's water resources (RSA, 1998). Within this pressure cooker a space exists that will be potentially characterised by tension and conflict, high levels of uncertainty as well as an uneven landscape in regard to knowledge, power and influence as well as in regard to climate change adaptation and the co-design thereof.

Hence, leadership will be needed in this space in order to jointly make sense of impacts of climate change on the water resources, which adaptation options are acceptable in the context of the basin and what trade-offs to negotiate. Such leaders will need to bridge the gap between their organisational origin, which often has to function reliably, and a responsive learning environment which displays decisiveness and promotes order (Termeer, 2009). Here the concept of champion driven leadership processes come into play, as described by Taylor *et al*. (2011); champions that represent all relevant organisations - governmental and private - as well as stakeholder groups that are important for water usage and protection respectively, and hence are imperative for water management in the catchment. Such leadership, or rather champion teams, will have to debate on a regular basis, i.e. repetition of meeting in the space of dialogue (Hjerpe and Glaas, 2012; Holling, 2001), as deemed to be appropriate by the champions, as well as incorporate new knowledge and be responsive to short-term and long-term issues of water management (MacKay *et al*., 2003; Taylor, 2010).

As in most of South Africa's Water Management Areas and catchments, the so-called Catchment Management Agencies (CMAs) have not yet been established or are not functional yet. However, where they exist, even only partially, they offer a unique space for contextualising information, building complex adaptive processes, understanding the uncertainties of water and water management, as well as creating space for innovations (Dent, 2012). As alluded to earlier, negotiations on water management in general, and adaptation in particular, will have to take place in an appropriate 'arena'. The authors chose this to be the catchment in the South African cases because the catchment is also supported by the notions surrounding Integrated Water Resources Management (IWRM; TEC GWP, 2004). Furthermore, CMAs leave enough flexibility to tailor activities even at a sub-catchment scale. Additionally, barriers and drivers specific to the catchment and wider spatial, as well as administrative, scale can be taken into account (Pahl-Wostl *et al*., 2007; Huntjens *et al*., 2012). The co-design of adaptation and relating interventions designed in this space should therefore be more authentic / valid and implementable (see also Folke *et al*., 2005). Based on the new knowledge gained in the social learning process, innovations are highly probable (Woodhill, 2010) and also create a window of opportunity to mainstream adaptation into the partakers' daily work. Therefore, in collaboration with all water users in the arena, an inclusive process can be established that embraces both top-down and bottom-up practices. Such an arena does not need to be a designed champion network, as was done in the case of this chapter, but could be represented by an open community of practice that has emerged through self-organisation, or by existing organisations such as a Catchment Management Fora[22].

A champion network is understood here as a group of influential decision makers from relevant organisations as well as water users and stakeholder groups from a water management area and catchment respectively. These champions need to meet in the catchment, thereby forming a 'Space for Dialogue'. This concept is also based on the idea of Transition Arenas as Loorbach (2007; 2010) has developed. Within these 'Arenas of Dialogue' the champions communicate knowledge, needs and interests, aiming at negotiating outcomes and strategies that are based on their local knowledge, with

[22] CMFs are non-statutory bodies. Their main purpose is "to develop a trusting and constructive relationship between all the stakeholders and interest groups and to find a common vision." They "have been found to play a key role in terms of participation and representation." (de la Harpe *et al*., undated)

a focus on livelihoods and already existing vulnerabilities. It is envisaged that such champions have an internal dimension which represents their specific knowledge of the catchment and capacity for critical thinking as well as an external dimension, which is characterised by their leadership ability, institutional memory and communicative skills and resultantly enables them to act as agents of change in their home organisation (Loorbach, 2010).

It needs to be noted here that it seems critical for any process of implementation to have clear definitions of leadership, responsibilities, appropriate design of communication plans and rules of negotiation (Mostert *et al*., 2007; Pahl-Wostl *et al*., 2007). This is especially true for integrative and adaptive management approaches, such as the one to be initiated here. In order to perform in an environment of change, such a dialogue needs to be undertaken on a regular basis and include times of evaluation and consolidation (Kotter and Rathgeber, 2005; Stuart-Hill *et al*., in review). Hence it is suggested by the authors that if such processes would be incorporated into decision making, a detailed communication strategy and capacity modules would need to be included in the long term (Pahl-Wostl, 2007; Sherwill *et al*., 2007), e.g. different forms of capacity building and social learning. This would ensure that needs and viewpoints of the different participants are understood and, in the end, sum up to a holistic strategy and implementable interventions.

13.3 Methodology

The aim of this research is to discuss the level of the individual decision maker within the water governance system of South Africa. Hence, the work focuses on the management environment, which frames the decision maker's ability to design adaptation and resulting management interventions. This is done by a process (*viz*. workshops, see below) that offers the opportunity to co-design adaptation plans with the wider water community (*viz*. champions, see below) guided by understanding the unique set-up of the relevant catchment and therefore understanding the vulnerabilities of its biophysical as well as social-ecological systems. Furthermore, the process should enable the champions who are part of the process (the internal dimension, i.e. bringing personal as well as organisational knowledge into the co-design process) to demonstrate leadership within their home organisation on such issues (external dimension, i.e. feeding the new knowledge gained from the social learning processes into their home organisation, creating opportunities for implementation and potentially innovative approaches) leading to the mainstreaming of climate change into the wider water sector and potentially beyond.

Ensuring the consistency and overall sustainability of such a process will need a safe space and regular repetition (Hjerpe and Glaas, 2012; Holling, 2001) as well as evaluation and monitoring. Furthermore, it will need a shared commitment for collective action (Folke, *et al*., 2005) if the interventions negotiated are to be sustained beyond the process itself and workshop respectively.

Four main aspects need to be elaborated upon here:

1. Two case studies have been chosen to explore the options and potential scope of such a designed process, both being climatically and socio-economically divergent catchments: One is the Berg catchment in the Western Cape province (south westerly part of South Africa) which is a winter rainfall region, the other is the uMngeni catchment in the province of KwaZulu-Natal (eastern part of the country) representing a summer rainfall region. Both have a significant climate change signal in the current projections, with the Western Cape's rainfall and corresponding runoff projected to decrease, while for the uMngeni increases in rainfall and runoff are projected (Schulze, 2012). Furthermore, the uMngeni catchment is made up of a mix of land uses, including urban settlements, rural areas, subsistence and commercial farming as well as various open spaces and degraded areas (Warburton *et al*., 2010). Most of the catchment area is rural with many poverty stricken rural communities. The Berg catchment consists of a mixture of land uses, including urban settlements, rural areas, subsistence and commercial farming (dryland wheat and mainly irrigated export orientated high value deciduous fruit products), as well as various open spaces and degraded areas. Good contacts to the relevant decision-makers and stakeholders in both catchments existed before commencement of this research. This was assumed to be a good starting point for a trustworthy and open relationship, creating a foundation for a 'safe space' environment needed for the workshops envisaged.
2. The champions identified in both catchments were drawn from existing communities of practice and represented varied expertise, coming from different authorities and stakeholder groups. A

fair representation of major organisations involved in the management of the specific catchment areas was ensured. Furthermore, the participants had previously been identified as 'champions', i.e. leaders and experts in their respective spheres of influence, they had a good understanding of the catchment area, were considered critical thinkers and possessed the required institutional memory to provide valuable inputs to the discussions. Based on the idea of the pressure cooker, the catchment was chosen as the appropriate spatial scale and two sets of workshops were run in either catchment; the first in the beginning of 2011, the second in mid-2012. The aim was to accommodate not more than 10-15 participants in order to avoid the group splitting into sub-groups in the course of the discussions. Another, more technical, workshop in the uMngeni catchment was run at the beginning of 2013 which included some of the uMngeni champions but also a variety of other stakeholders.

3. Group modelling was used in the first two champion workshops, aimed at evening out the knowledge landscape of the champions and also ensuring a participative atmosphere for the workshop. The use of Group Model Building (GMB) to create a common understanding of a specific situation is particularly relevant for the water sector as water resource management at the catchment level is a very complex process (Vennix, 1999) involving a variety of organisations operating at different scales with different knowledge and understanding of the catchment area and the water resources therein. Hence, in this type of environment it becomes crucial to first create a common basis of engagement among the participants each with their quite different relations to the catchment, before key drivers and major issues can be identified. All other sessions of the workshops were run as open discussions during which the facilitator ensured that all present had a fair chance to speak and bring across their point of view. In all the workshops held, the majority of champions had been working together, or had at least known each other already from previous interactions. Especially when co-design activities were undertaken, the facilitator ensured that individual insights from each champion were gained.
4. Short questionnaires were designed in order to evaluate the outcomes of the workshops on the day, as well as follow up questionnaires which were sent out a few months later to all champions present at the first set of workshops held. The first evaluation was to verify the relevance and usefulness of the actual activities carried out during the workshop, the latter to gain insight into the potential mainstreaming of knowledge into the champions' decision making environment within their home organisation. For the second set of workshops an evaluation was not carried out due to that workshop being an extension of the first set of workshops held. For the technical uMngeni workshop an immediate evaluation was carried out as well as a follow-up evaluation a few months later.

13.4 Results

This section reflects on the results gained from each workshop. Much of the material produced by the partakers cannot be presented here, owing to limited space. However, the authors have focussed on the main results gained in order to answer the aforementioned research questions.

13.4.1 First set of workshops

The first two champion workshops in the uMngeni and Berg catchments were successful, based on good attendance and more time by the champions spent at the workshop than was originally intended, as well as a positive evaluation.

uMngeni

The first uMngeni workshop took place in mid-February 2011 and was attended by 9 participants (other than project team members). Major emphasis in the discussion was placed on the poor state of existing infrastructure, the impact of streamflow reducing activities and the current wastage and pollution of existing water resources. It was pointed out that the ecological reserve determination had not been finalised yet for the catchment and that this was expected to further impact negatively on the water availability for ecological systems in the uMngeni catchment. Current urbanisation trends and population growth were also drivers that would impact water availability in the uMngeni. Overall, the modelling exercise helped the participants to understand the non-linear feedback loops between the different factors and also provided some common understanding in preparations for the scientific presentation to follow on climatic and hydrological trends under climate change in South Africa and more specifically in the uMngeni catchment.

The exercise of mapping sensitive areas was of great value for everyone (participants and scientists) as it really allowed the location of important vulnerability hotspots in the catchment and associated causes. Interestingly, the majority of areas were arranged along the mainstem of the river, but also reaching far into the hinterland, emphasising the relevance of an overall catchment approach. The participants agreed, without difficulty, on the envisaged impacts for the catchments. The list of needs for successful adaptation was also collated effortlessly, while the list of adaptation options and strategies took more time and intense discussion. However, at no time was there any real conflict. In summary, the champions came to the conclusion that if existing institutional and infrastructure challenges were not adequately addressed, climate change would amplify existing threats. This was particularly true when it came to pollution of the water resources and disaster risk management, as current projections seemed to indicate an increase in local and regional floods in the uMngeni catchment due to increased rainfall.

Berg

The first Berg workshop also took place in mid-February 2011 and was attended by 16 participants (other than the project team members). The number was slightly challenging for facilitation and it was difficult to motivate each champion to speak to each issue. The Group Model which was created showed a very differentiated and detailed picture on the issues of storage, both natural and in dams, within the catchment. Again, the water demand issue was very central as it had several interlinkages and connections to be considered. Furthermore, urbanisation and household water use were discussed in detail, with many explanations provided. The same applied to effluent problems. As in the uMngeni workshop, the Berg catchment participants quickly realised that several different factors and drivers influence water availability in the catchment. Some of the participants pointed out that water availability in the upper catchment was determined by different factors than in the lower catchment. Given that issues of water quality were of great concern in the Berg catchment, quite considerable emphasis was put on how pollution and alien invasive vegetation impact water availability and the water balance in the Berg. The discussion revealed that in-migration, in particular the steady and uncontrolled influx of people from low income brackets, places enormous stress on the water resources. However, this risk factor was seen to be given little attention at higher decision-making levels. When mapping the sensitive areas, most of the identified hotspots were linked to either pollution caused by the waste water treatment plants and associated infrastructure, urban areas along the river where waste from formal and informal settlements is directed into stormwater canals, or to terrestrial and aquatic alien vegetation. Illegal activities in some sub-catchment areas and non-sustainable agricultural land use practices also added to the problem of degrading water quality. The discussion which followed was lively and some moments of conflict arose, especially around the co-design of adaptation options and strategies. However, in the end all champions agreed on a list of impacts, needs and adaptation options. In conclusion, the fruit export sector was identified as highly threatened by degrading water quality, as especially European Union quality standards of the products could not be met. However, what seemed to be alarming was that the true extent of pollution levels in the Berg could not actually be determined as current hotspots had been identified based on historic data and sampling sites without taking into consideration all major pollutants. Consequently, a poor understanding of the real risks exists at all decision-making levels.

Evaluation

For both workshops the champions felt comfortable with regard to the atmosphere in the workshop and all agreed on the fair and transparent conversations that were possible between the parttakers. Furthermore, they agreed strongly that the participants presented a balanced and comprehensive mix of interests and roleplayers in water resources management of the catchment.

The follow-up evaluation in the uMngeni catchment was done in early June 2011. Only five answers were received, even after sending out two reminders emphasising the high relevance and urgency for sound scientific outcomes. In hind sight, all respondents still found the workshop useful. They all formulated very concrete ideas on the additional information needed for their working environment, and also highlighted cumulative and secondary impacts of climate change in this section. However, no longer term impact of the workshop could be established from their methods of decision-making or their patterns of thinking, although one respondent elaborated on his ability to now consider impacts of decisions on water availability as well as effects of climate change on the overall catchment, better than before. There was no indication of any knowledge or initiatives taken by the champions towards their home organisation (external dimension). Interestingly, all would like to be kept informed and even requested annual workshops like the one held. Overall, the thinking on long term impacts was

not as beneficial as expected, but the evaluation was still positive and gave a good grounding for the second workshop in 2012.

Also, for the Berg an email was sent out in early June 2011 requesting a follow-up evaluation of the workshop. Only three answers were received, after sending out two reminders emphasising the high relevance and urgency for sound scientific outcomes. Again the respondents still valued the information they gained at the workshop and also had very concrete ideas of what additional information they would need. For two respondents even longer term thinking of impacts could be established and it was seen that their decision-making and patterns of thinking had been influenced by the workshop, but both at the same time highlighted that they would need more detailed information to consider climate change impacts in their inclusive decision-making. There was no indication of any knowledge or initiatives taken by the champions towards their home organisation, i.e. the potential influences of the external dimension were not accomplished. However, all expressed the wish to be kept informed on issues of climate change and emerging vulnerabilities.

13.4.2 Second set of workshops

The second set of champion workshops in the uMngeni and Berg catchments were successful in their content, but had a lower attendance than the first workshop. In the Berg only a few of the former champions attended. Those present engaged well in the discussion and again spent more time at the workshop than was originally intended. The evaluation of both workshops was difficult and with limited feedback. Prior to the workshop the champions were offered a preliminary print of the so-called updated climate change atlas for South Africa *("A 2011 Perspective on Climate Change and the South African Water Sector"*). Therefore, part of the workshop was spent on reflecting on the relevance and 'translation' of such scientific information.

uMngeni

The second uMngeni champion workshop was held in mid-July 2012. Seven champions participated, 5 of whom had attended the first workshop.

The feedback session on the updated climate change atlas was a lively discussion. The section and discussion on uncertainty issues was highlighted as very useful, not hiding them and by accounting for them by using a confidence index. The champions emphasised that infrastructure needs to be incorporated into the issues of climate change and also water supply. Furthermore, it was suggested using environmental impact assessments (EIAs) as a tool to mainstream climate change more into decision-making. It was noted that agriculture was missing completely on the day, but none of the participants knew who the appropriate champion would be. Communication was identified as a key issue and was seen as missing badly in the uMngeni catchment. This was also seen as the reason for the absence of a united catchment approach. The opportunity of the Catchment Management Agency as a new and supportive structure for this was negated as its implementation was too far into the future and would have a provincial dimension, hence being considered too diffuse for localised relevance. Rather, a Catchment Management Committee specific to the uMngeni was called for by the champions, although no-one was sure how to take this forward. The Department of Water Affairs (DWA) was seen as not being interested and not supportive of such an initiative. Another major weakness and threat was the identification of the missing Ecological Reserve determination for the catchment. This was seen to exacerbate the impacts of climate change further. The review of the sensitive areas confirmed what had been done. The discussion on how to prioritise these areas reflected typical interests by the organisation which the champions represented. For example, the NGO wished to focus on the tributaries, the municipalities referred to dams, sewage works, and informal settlements as crucial to deal with first, while the bulk water supplier Umgeni Water saw Midmar Dam as the starting point. However, after having brought forward their preferences, the champions agreed swiftly on a source-to-sea approach, starting with the tributaries and the wetland in the headwaters (uMngeni Vlei) working down the main stem of the uMngeni to the sea. In contrast, the discussion on responsibilities for the 'needs' and 'adaption options list' was difficult and slow. For the 'needs' the responsibilities were very general, reaching from science, governmental departments on all levels, to NGOs. Nevertheless, the special role of the DWA, Department of Environmental Affairs (DEA) as well as of National Agriculture was stressed. In regard to the 'adaptation options' the responsibilities identified were far more concrete. Key actors and initiators were DWA, DEA (including the provincial department) and municipalities, with at least one of those having been mentioned in

each of the 15 strategies listed, often in combination with other issues. The DWA in two cases was identified as having the sole responsibility and playing a crucial role in 8 of the strategies suggested.

Berg

The second Berg champion workshop was held in mid-October 2012. Of the 12 participants only two had been at the first workshop. However, they felt comfortable and agreed with the outcomes and suggestions made in the first workshop.

The discussion on the climate change atlas revolved mainly around the interplay of land use and climate change. In between the conversation moved on to the relevance of climate change for actual water management. All champions agreed on the need to make use of additional observations such as those from citizens and especially those from farmers, to obtain a better and more detailed picture for the catchment. Identified as specifically relevant for the Berg catchment were evaporation (especially in the context of irrigation), changing licences (including issues on the re-use of water as well as the need for flexibility in regard to seasons and water availability), land management and land use (removal of aliens, restoration of wetlands, stopping pollution, holding users accountable), veld fires, and population growth mainly linked to water quality. However, at the end of this activity all champions questioned how far these issues, even if they were all dealt with, would delay actual climate change adaptation.

In the discussion on the sensitive areas there was unanimous agreement on the starting point of actions in the catchment, this being the upper stretches and wider catchment of the Berg. The next priority would be pollution, especially point pollution by farmers in the catchment. From there they suggested moving to the issues of new settlements, formal and informal, as well as the general impacts of urbanisation. Last but not least, the champions would tackle unlawful water use and water use management overall.

In regard to the responsibilities of tackling the needs list and implementing the adaptation options list, a strong focus was placed on national government as the custodian of South Africa's water resources on the one hand. On the other, the land owners were highlighted as key actors in the catchment. For the needs list the DWA, the CMA and the municipalities were found to be key actors in the Berg. In regard to the adaptation options, landowners and farmers respectively had also been identified as key players. Additionally, science and the WRC were seen to be of great relevance in tackling the challenges of adaptation and informed decision making. In summing up this session, the champions identified a Catchment Management Strategy as crucial to moving towards general successful river basin management.

13.4.3 Additional uMngeni workshop

As mentioned earlier, in the uMngeni catchment a more technical workshop on designing adaptation was held at the beginning of 2013 and used for further insight. The workshop had 27 participants, of whom 3 were champions of the previous uMngeni workshops. The senior author's role was that of an observer and an evaluator.

The workshop activities unfolded in four breakaway groups. These were:

- Resource water quality, treatment, health and sanitation,
- Storm water management, safety and disaster management,
- Water quantity and demand, infrastructure and distribution, and
- Ecosystem values.

The breakaway groups discussed so-called probable changes under climate change in the morning. This was informed by a scientific presentation on the latest research outcomes on the catchment. Convening back in plenary the aim was to gain consensus on all the adaptation activities which had been designed. The participants stressed the need to factor climate changes into the future national plan developed by the National Planning Commission as well as into the Presidential Outcomes. Improved land use and town planning was mentioned by most groups, but in order for this to be effective there was an urgent need identified for integrated spatial planning across scales. The continued trend of immigration and urbanization was likely to see more people moving into vulnerable zones in urban areas and also onto floodplains. The need to work with traditional leaders as well in

developing / implementing climate change adaptation plans was stressed, as the influence of rural communities in catchment areas and on water supply as well as water quality was significant in the uMngeni. The value of the Working for Water programme in clearing alien invasive species and thus releasing more water from catchments was emphasized. Going into the future, dam safety needs to be re-evaluated to ensure that original designs (and proposed modifications to increase storage) would still be appropriate.

In the afternoon session, the breakaway groups discussed the less probable changes. A significant challenge was that three different narratives had to be assessed, these being the very wet, the wet and very dry storyline. Therefore, the discussions revolved more around sense-making of the storylines and, as a result, assumptions had to be made by the participants in order to be able to co-design actual strategies. This, and most probably time constraints and fatigue, led to some assessment sheets not being filled in completely, especially in regard to the severity rating and adaptation options.

Because of other commitments the groups became smaller towards the later afternoon so that in the consensus session to finish off the workshop only 16 participants were left. In the wrap-up session it became clear that the main issues identified under climate change for the uMngeni were the cumulative impacts of small farm dams in the catchment, infrastructure, water quality, as well as the functioning of landscapes and river. Last, but not least, technology was highlighted as a very important aspect that needs to be included in adaptation, but caution was to be exercised not to use technology as the panacea for solving problems associated with climate change. Furthermore, it was concluded that the very dry and very wet storylines would be costly to deal with while the wet storyline would be more favourable in terms of financial implications.

Evaluation
Directly after the workshop 16 participants filled in the evaluation form, with all of the participants rating the level of awareness on climate change impacts and the need for adaptation at 5 out of a possible 10 and higher, with a high average of 6.9. All but one of the respondents requested further exchanges on the topic of climate change, its impacts and vulnerabilities. The type of knowledge gained was, not surprisingly, mainly on direct impacts of climate change. Therefore, knowledge gaps which had been identified as being related to other sectors, and which were lying beyond the biophysical impacts, were seen as being of a more complex nature.

These knowledge gaps included

- integrated planning (cumulative effects of impacts and adaptation),
- political interventions,
- long term financial planning (business sustainability),
- immediate impact mitigation,
- infrastructure impacts, including ecological infrastructure,
- governance and regulation aspects,
- adaptation of organisations,
- communication (including that with traditional leaders), and
- sector vulnerability.

Requesting a follow-up evaluation had limited response, with only 5 completed questionnaires being received despite two reminders. The answers indicated that only decision making of two respondents had been influenced by the knowledge gained, while two respondents' perceptions for daily-decision making had changed. Both cases related back to a moment of surprise around the very wet scenario being more problematic than the wet scenario. In order to make new information / knowledge available and the mainstreaming thereof, the respondents indicated that communication and expert as well as stakeholder engagement would be crucial. Furthermore, a continuous update on the latest research and other outcomes by appropriate write-ups and presentation was suggested, as were presentations by way of maps so as to be able to visualize impacts in detail and demonstrate clear cause and effect linkages. Another piece of advice from the respondents was to use the 'currency' of risk, vulnerability and resilience in communication with decision-makers and politicians.

13.5 Discussions and Conclusion

In all workshops the participants were aware that the water resources in their respective catchment areas were already under threat because of challenges relating to unsustainable development pathways (urbanisation and agriculture), fragmented and un-coordinated water resource management systems and the failure of enforcing existing legislation. However, the true extent of current risks and threats, especially under climate change, was not known to any of the participants. This was considered to be alarming, as this lack of knowledge inhibits the identification of priority areas and the proper allocation of resources. The participants found it challenging to make the projections more relevant to their respective spheres of decision making. All activities demonstrated that most South African catchments were unique in their biophysical and social characteristics and interventions, whether from government or the private sector, could not be of a generic nature, but should rather address the characteristics of the specific catchment, i.e. climate change information needs to be contextualised and localised. Nevertheless, all workshops identified ecological infrastructure as a first step for adaptation, as well as strengthening the institutional / governance set-up. Furthermore, the need was identified for a continuous communication platform at catchment scale, complemented by an implementing authority.

A review of the adaptation actions proposed in all workshops reveals that a number of themes emerge. These are:

- Governance
- Mainstreaming of climate change into water management (e.g. regulation, design criteria)
- Infrastructure and technology developments
- Planning
- Education / awareness
- Early warning systems.

Additionally, a variety of moments of surprise were observed in all workshops held:

- Stakeholders identified re-occurring champion workshops as an opportunity for policy implementation.
- Moments of surprise in the uMngeni were the identification of the headwaters as crucial in all future climate scenarios assessed, be they the future dry, wet or very wet scenarios. Furthermore, the wet scenario was, in certain aspects, considered to be more problematic than the very wet scenario. Building resilience via natural capital was identified as a key activity.
- Moments of surprise in the Berg were that strong social networks of decision makers and stakeholders existed and that these were accessible, but overall the majority of responsibilities identified pointed to higher levels of governmental actors. Furthermore, law enforcement and monitoring were identified as key activities.
- The technical uMngeni workshop also revealed unexpected outcomes such as the identification of positive impacts of climate change. Comparable to the uMngeni champion workshop, the participants recognized that although the very wet storyline had the positive impact of delaying the need for developing new water resources infrastructure, it was still deemed an expensive storyline since the need to review existing infrastructure and technology and to perform necessary upgrades (for safety and stability) would be costly.

The above clearly indicates the danger, especially for experts and water managers, of not making assumptions based on what they know, but to rather ‘dig deeper’ and reflect on issues in a participatory way and in a social learning environment in order to enable more informed decision making.

It needs to be noted here that a number of actions proposed involved improving current water management, e.g. clearing of drains, law enforcement and infrastructure maintenance. This underlines the well-known benefits that can already be derived by simply managing current systems in an optimal manner. In general, the design of adaptation options was based mainly on the champions and the participants’ very personal knowledge and experience within the catchment and that of their working environment, *viz*. the organisation at which they worked. Many of the activities were focused on current existing stressors as well as current initiatives and projects. In all cases it became clear that the design of adaptation activities needs a great deal of time and interaction. In

regard to governance and mainstreaming climate change into water management, the participants stressed that the transition towards a sustainable and adaptive water resources management system (on national and catchment level) would also need to be seen as a decision making and leadership challenge detected largely at a higher level, *viz*. DWA, DEA and municipalities. For informed decision making the need of an integrated communication strategy was emphasised, which also provides for successful vertical as well as horizontal integration. Another key discussion point was monitoring systems as being the backbone of sustainable water resource management. These need to provide accurate information on, and changes in, the catchment (e.g. water quality or water quantity) on a regular basis.

Overall, water managers already dealing with multiple stresses in the catchment cannot easily use much of the existing climate change information, in its current form, in their day-to-day decision making. This points to the great need to bridge the gap between knowledge produced by science and knowledge relevant for decision making. Neither the scientists nor the decision makers felt that they were currently in a position to take on such a role. However, for knowledge creation as well as communication, the need for a closer science-society as well as the science-decision maker interface was emphasised. This may often require a reframing and a translation of knowledge from a scientific to a societal and then decision making context by, for example, participatory scenario development and / or group model building).

Generally, the five workshops were successful in regard to moving towards a common understanding of the respective catchments, learning collectively about existing vulnerabilities and so-called hotspots, as well as gaining a better understanding of the projected impacts of climate change on the catchment areas. More long term engagement is required when it comes to identifying coordinated catchment and decision maker specific adaptation options. Long term engagement and future learning opportunities are also required for improving engagement and collaboration of the various organizations involved in water resources management. Therefore it seems crucial that the participants be provided with the time and support (including finances) from their respective organisations to participate in such workshops (i.e. capacity and training initiatives that cross organisational boundaries need to be encouraged much more). Participants valued especially the networking opportunities among each other and the information sharing with regard to existing initiatives.

In conclusion, adaptation design calls for an enabling environment that gives space for knowledge exchange and learning conversations and that caters for the interplay of systemic, organisational, and individual needs. Such conversations cannot be undertaken without a mix of decision makers and stakeholders because of the uncertainties of development trajectories, as well as limited data and knowledge of the impacts and their interlinkages. It needs to be further highlighted that adaptation design and implementation need to be combined with the necessary budgets and require substantial time commitments over and over again.

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CHAPTER 14: GETTING TO GRIPS WITH GOVERNANCE AND MANAGEMENT OF THE uMNGENI RIVER BASIN - AN INFORMAL COMMENTARY

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Acknowledgements

To all the stakeholders I interviewed, and the participants in various working sessions, thank you for your time, your effort and your intellect. I greatly appreciate it. The organisations I engaged are listed in the text.

- The Water Research Commission and uMngeni Water for funding
- Mrs Sabine Stuart-Hill of the University of KwaZulu-Natal, for commissioning and supporting this work.
- The uMngeni Water Research Chair in Integrated Water Resource Management, particularly the incumbent Professor Graham Jewitt, for supporting this work
- Professor Ahmed Bawa of the Durban University of Technology, Professors Chris Buckley and Charles Breen of UKZN, Dr Mark Dent of UKZN and Mr Riaz Jogiat of the uMgungundlovu District Municipality for providing additional support.

Preface

In the context of the University of KwaZulu-Natal being contracted and funded by the Water Research Commission to lead a research project on "Developing water related climate change adaptation options to support implementation of policy and strategies for Water for Growth and Development", and in the context of establishing the uMngeni River Basin Programme I was asked to:

1. Establish a river basin seminar series,
2. Conduct a follow-up session to the Water Research Commission WAT Indaba,
3. Enlist the participation of the business in the overall process,
4. Establish a foundation for the roll-out of the WRC Shared Rivers Research Programme case-study (the uMngeni River Basin has been identified as the case-study),
5. Establish the foundation for an international research programme on water security commencing in September 2013, details of which are embargoed until its launch, but with the uMngeni River Basin having been provisionally identified as a case-study, and
6. To continue to facilitate the establishment of linkages between various initiatives.

This commentary talks to all these activities, but specifically to points 4 and 5.

14.1 Introduction and Purpose

In 2012 a group of adventurous 'water resource advocates' from the Dusi-Umgeni Conservation Trust (DUCT) walked the length of the uMngeni River from its source to the sea, a distance of about 250 km. Their purpose was to profile and bring attention to various water resource management issues they encountered along the way. At Nagle Dam in the Valley of a Thousand Hills they discovered that the dam's sluice-gates were closed and, as a consequence, there was little flow in the river downstream of the dam. Not only was this compromising the ecology of the river system, but rural residents downstream were deprived of their rights to the benefits from the water and its flow. Why were the sluice gates closed? The dam is part of a system ensuring security of water supply to the eThekwini Municipality (Durban and surrounds). So, in insuring the rights of one group of people we are effectively compromising the rights of another group (Hay *et al*., 2013).

This is simply one example of many that illustrates where we find ourselves as development progresses and the competition for water resources increases. We are increasingly faced with complex and difficult choices. And the consequences of poor decision-making about these choices can fundamentally affect peoples' lives. Also, it is often those who can least afford to lose their rights,

viz. rural residents who are directly reliant on the natural resource base for survival, who endure the most serious personal consequences (Hay *et al.,* 2013). We have to learn to share and we have to learn to cooperate in the sharing.

Turning our attention to the river basin as the context for our choices, our trade-offs and our decision making, there is a compelling logic that water resource management and governance take place most appropriately at the scale of the river basin. To a large extent where water flows dictates what effect it has and what effect is had on it, and this usually happens within the confines of a river basin or sub-basin. We also increasingly appreciate that, irrespective of the landscape context, the governance and management of water resources is complex. Water is, by its very nature, a complex substance. It is a flux, here one moment and far downstream the next. We appreciate further that as our almost insatiable demand and competition for water resources increases, so does this complexity increase. Then take it to the next level - climate change and the uncertainty that it brings with it – and the complexity threatens to overwhelm us.

This brings me to the fairly crude proposition that informs this commentary. If we are going to intervene effectively to address climate change issues, we are going to have to get those things right that are required even without climate change. We have to get to grips with the fundamentals of water resource governance and management at a basin scale because it is largely in this context that climate change adaptation and mitigation will play itself out. The bottom line, as this commentary will graphically illustrate, is that we are not managing, we are not coping; there is crisis and panic in the air. We need to turn things round and fairly quickly. The question is, how? So, what do we need to do to get to grips with water resource management at a basin scale? This informal perspective does not set out to address climate change directly. Rather, it is a commentary on what is informing or might inform integrated catchment management efforts in the uMngeni River basin.

In this commentary I start by sketching some of my formative experiences of the Eastern Cape Estuaries Management Programme that have informed my own thinking. This is followed by a very brief snapshot of the uMngeni River basin. I then describe the key water resource management issues facing the river basin (as defined largely by the stakeholders) and provide a few generic ideas on how we might address some of them. This is followed by a description of some of the more obvious conceptual frameworks and models that might assist us to think about and analyse some of the issues. The commentary concludes with some thoughts on how we, as researchers, might move forward together on this collective journey.

14.2 Some Early Lessons

Between 1998 and 2012 I had the good fortune to be involved in and, notionally anyway, lead the Eastern Cape Estuaries Management Programme (ECEMP; Hay, 2007). Many of the ideas in this programme had their origins in another long term initiative, the Kruger National Park Rivers Research Programme. The ECEMP was a wonderful 'laboratory' in which to learn about the governance and management and of estuaries through research and, as importantly, engaging directly in supporting these processes. We learnt a multitude of lessons but those noted below resonate most in my own mind.

The first lesson I learnt arises, quite simply, from the first paragraph, *viz*. that long term research programmes can achieve a depth of understanding that is rarely achieved through short term efforts.

Early in the process of establishing a research programme to inform estuary management we conducted a workshop in which we excluded the researchers and invited only managers - conservation staff, national and local government officials and some local stakeholders. We asked a simple question, *viz*. what are the management priorities that research should address? Through this process we established a research programme that was driven almost entirely by the needs of management. As a result, managers embraced the research that was provided. How do we know? The national estuary management protocol that has been adopted by national government was derived directly from this work, as was the estuary management process that is being implemented in many coastal areas in South Africa. In our process of engaging managers it is likely that we temporarily alienated some members of the estuaries research community (we could have been a little more subtle in our own process), but we achieved the desired result which was needs driven

research. So lesson 2: if the research responds directly and practically to the perceived need of the user it is likely to be used.

In 2009 a colleague circulated a fascinating paper by Funtowicz and Ravetz (2008). Their names alone were unusual enough to catch my attention. Until that point I was continually frustrated trying to reconcile the often conflicting value systems of many of the stakeholders; that these stakeholders could have very different perspectives, but that all these perspectives were legitimate and 'right'; by the uncertainty of the outcomes of various management interventions, and of having to operate with so little factual information to guide decision making. This was not science or management - it was a mess!

I read the paper and discovered that I was not alone. Not only was I not alone, but there is an emerging discipline which aims at improving our understanding of these complex issues - post-normal science. I read further and discovered an entirely new language where 'messes' is actually a technical term used to describe some of these complex issues. A passage from Ison (2008) also caught my attention. He summarised how different researchers have described these complex problems. "…..Ackoff (1974) described as 'messes' rather than 'difficulties',…… Shön (1995) as the 'real-life swamp' rather than the 'high-ground of technical rationality', and Rittel and Webber (1973) as 'wicked' and 'tame' problems." I found the reference to a 'real-life swamp' particularly amusing as some of our current research focuses on freshwater wetlands! Lesson 3: what we are dealing with, particularly in a water resource management context, is complex. We have to engage the complexity and expect the unexpected.

The fourth lesson I learnt was about engaging people. In engaging and supporting estuary management processes at the local level there was a tendency to start with a covert or overt conservation agenda. This was normal as, at the time, I represented the Institute of Natural Resources and our primary funder was often what was then the national Department of Environmental Affairs and Tourism. What I learnt is that one should sublimate one's own agenda and respond rather to what stakeholders think is important. Lesson 4: if one is able to respond directly to the needs of people, particularly the developmental needs of poor people, one is far more likely to achieve success in addressing one's own needs.

In engaging at the local level it soon became apparent who the 'real managers' were. They were the harvesters of mangroves, the canoe-trail operators, the subsistence fishermen and the beekeepers. So, strongly informed by the concept and practice of Community Based Natural Resource Management (CBNRM), is the notion that it is people on the ground whose day-to-day activities affect the resources who are, in effect, the managers. Lesson 5: for effective management one has to build from the bottom up. But, as importantly, there needs to be someone at the top (the level of policy and governance) reaching down to the bottom to listen and respond.

Finally, while we trawled through many papers and discussed numerous concepts, models and frameworks that could guide our thinking, our most valuable experience was gained when we arrived in the field, engaged with stakeholders and began the process of supporting estuary management on the ground. Lesson number 6: real-life is the best laboratory in which to learn.

14.3 The uMngeni River Basin - A Snapshot

(Note that much of the information in this section is extracted from a presentation compiled by Riaz Jogiat of the uMgungundlovu District Municipality)

The uMngeni River Basin encompasses an area of 4 416 km^2 (0.36% of South Africa) and the river is 255 km in length from its source at uMngeni Vlei (elevation 1830 m) to its mouth at Durban. It has several tributaries of which the most important is the Msunduzi River, with its source in Vulindlela and passing directly through Pietermaritzburg, the provincial capital of KwaZulu-Natal. Because of an inter-basin transfer from the upper Mooi River to the uMngeni, the two basins are regularly referred to as the Greater-uMngeni River Basin (**Figure 14.3.1**).

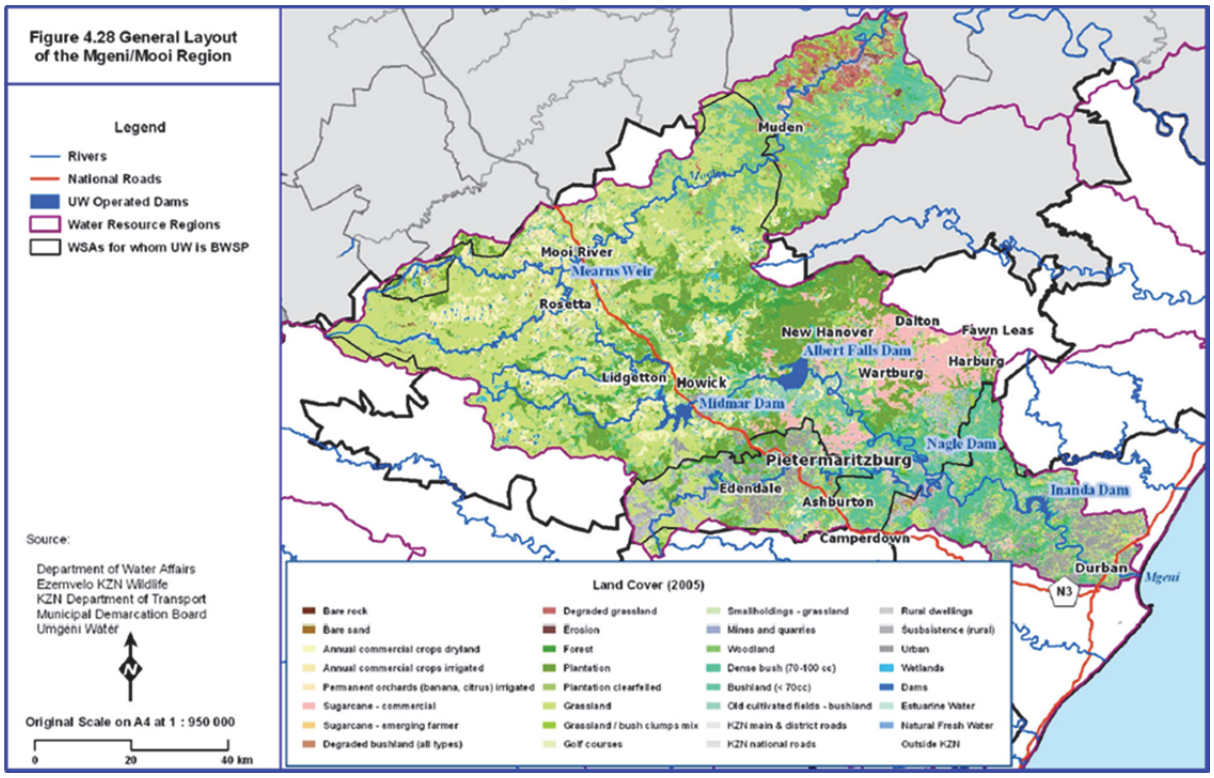


Figure 14.3.2 The uMngeni and Mooi River basins

Two municipalities constitute the major portion of the river basin, *viz*. the eThekwini Metropolitan Municipality towards the coast with a population of about 3.45 million people and, inland, the uMgungundlovu District Municipality with a population just over 1 million. The vast majority of these people, rich and poor, are entirely dependent on the water resources of this river basin for their well-being. The uMvoti to uMzimkulu Water Management Area, in which the uMngeni River Basin falls, contributes approximately 11.5% to South Africa's national GDP, with an estimated 80% of this coming from the Durban - Pietermaritzburg hub. The bottom line here is that the river basin is of significant socio-economic importance locally, regionally and nationally.

Census data for the uMgungundlovu Municipality from 2011 allows us to define the socio-economic character of the river basin fairly precisely. Average annual household income is about R 90 000 per annum, i.e. most people are not rich, but they live above absolute poverty levels. There are, however, huge disparities between rich and poor. There is a very strong urbanisation trend where rural municipalities reflect declining populations and urban municipalities reflect rapidly increasing populations. Nearly 10% of the population have no access to piped water and only 42% have water piped into their homes. Linked to this, 42% of the population have flush toilets in their home. 86% of households have access to electricity and household refuse collection is to less than 50% of homes. In urban settlements where there is no, or irregular, collection of refuse an river systems are regularly used as a disposal system. Around 30% of residents are unemployed. Government and agriculture are the lead employment sectors.

Environmentally, 40-50% of the uMgungundlovu Municipality's landscape has been transformed from the natural condition, primarily for urban residential and industrial use, and large-scale commercial agriculture, primarily sugar cane, timber, beef and dairy. The region is a climate change hotspot with projections that rainfall and temperatures will increase in both winter and summer seasons. Intensive storm events are projected to increase in magnitude and frequency and, with this, so will flood events. Water quality is already declining throughout the river-basin, driven primarily by poor sanitation infrastructure, inappropriate land use (especially overgrazing), agriculturally based organic inflows and industrial waste. Infestations of alien invasive plant species are increasing, especially in riverine habitats, despite significant investment in clearing and habitat restoration.

Institutionally (in a water resource governance and management context), as mentioned previously, the uMngeni River Basin falls within the uMvoti to uMzimkulu Water Management Area which, in turn, falls under the jurisdiction of what is loosely termed the KZN Catchment Management Agency. This is currently being established. Within the uMngeni River Basin itself are four Catchment Management Forums (CMFs) which cover the entire basin. At a more local level are several Water User Associations (WUAs) and irrigation boards. The irrigation boards are in the process of being converted into WUAs.

In terms of initiatives that address directly and indirectly water resource governance and management in the uMngeni River Basin, they are many and varied. This is not a comprehensive list, simply an indication of the level of activity.

- The CMA process being led by the Department of Water Affairs (DWA)
- Major infrastructure development, particularly Spring Grove Dam and its inter-basin transfer, and sewage works and reticulation upgrades/expansions
- Detailed water reconciliation studies and scenario planning led by DWA.
- Detailed hydrological and climate change research by UKZN and partners
- River health research and monitoring by numerous organisations
- Conservation stewardship programmes in the upper-basin being led by WWF and Ezemvelo-KZN-Wildlife
- Wetlands conservation and management being led by Mondi Wetlands Programme, WESSA and others
- Water quality research by UKZN and DUT
- Practical alien invasive clearing and natural system restoration led by DUCT
- A variety of educational programmes being led primarily by WESSA and UKZN
- Water pollution and sanitation systems research by UKZN and DUT
- Fairly detailed water quality monitoring, primarily by uMngeni Water
- Various spatial development frameworks and strategic environmental assessments of the municipalities
- Various citizen / community-based initiatives aimed at establishing conservancies, improving water quality, reducing pollution, improving land use practices, giving residents a voice and other advocacy-based activities
- An Ecological Infrastructure Partnership being led by eThekwini Municipality and the South African National Biodiversity Institute (SANBI) aimed at restoring and maintaining ecological infrastructure in the basin so as to enhance water security
- Mainstreaming biodiversity into land use regulation and management at the municipal scale - an advanced proposal to GEF being led by SANBI and uMgungundlovu Municipality
- A climate change adaptation programme - advanced proposal being led by uMgungundlovu District Municipality.

The Ecological Infrastructure Partnership is particularly encouraging. It has the full support of the three Water Supply Authorities (eThekwini Municipality, Msunduzi Municipality and uMgungundlovu Municipality) which have identified and are developing 'proof of concept' projects within their respective areas. A Memorandum of Understanding has been established and will be launched in November. Momentum has been built and it is being sustained. My concern is that, while there is an excellent partnership evolving that includes government, NGOs and researchers, those who are responsible for major river basin impacts are yet to engage effectively. These sectors include industry, commercial agriculture and forestry, and traditional leadership (possibly through the Ingonyama Trust Board).

14.4 What are the Issues?

*(**Sections 14.4** and **14.5** are extracted, for the most part, from a report I compiled on the WRC Wat Indaba hosted by UKZN and DUT in February 2013.)*

In June 2012 a meeting of UKZN researchers was held on the Pietermaritzburg campus. The purpose of the meeting was to start designing a research programme addressing the governance and management of the uMngeni River Basin. I was facilitating the session. Following a fairly disjointed discussion, a voice from the back (Professor Charles Breen) asked a salient question: "But what are we actually going to do?" He repeated it a little later, which is probably why it stuck. Following the

meeting I continued to dwell on this and my thoughts went back to the early experiences of the Eastern Cape Estuaries Management Programme where we engaged with management to define the research agenda.

I thought that this might be an appropriate starting point so, over a period of about 8 months, I engaged with a broad range of stakeholders in the uMngeni River Basin and canvassed their views about the major issues that we face. In many instances these were unscripted open-ended conversations. Fortunately, having lived in the river basin all my life and having worked in the natural resource research and management sector in the river basin for most of my adult life, I knew and know many of the players. This afforded me access that I might not otherwise have had and, because there were existing relationships accompanied by fairly high levels of trust, and candid views were expressed fairly easily.

This process culminated in a "Wat-Indaba" in February 2013 hosted by the University of KwaZulu-Natal, Durban University of Technology and Water Research Commission. This was, essentially, a knowledge sharing session and comprised a number of presentations by key basin stakeholders.

Who did I meet with? For the most part I met with executives and / or senior management from the following organisations:

- The KZN Planning Commission
- Department of Water Affairs (Regional Office)
- Water Research Commission
- Umgeni Water
- uMgungundlovu District Municipality
- eThekwini Municipality
- Greennetwork
- Dusi-Umngeni Conservation Trust (DUCT)
- Wildlife and Environment Society of South Africa (WESSA)
- Pietermaritzburg Chamber of Business (PCB)
- Durban Chamber of Commerce and Industry
- Upper-Umngeni Catchment Management Forum
- The Msunduzi Catchment Management Forum
- Msunduzi Innovation and Development Institute (MIDI)
- GeaSphere KZN
- The DWA led Catchment Management Agency process
- The National Water Resource Strategy process
- The International Water Governance Conference

Arising out of these conversations, presentations and engagements, what appear to be the emerging issues and themes?

Opportunity and competitive advantage

The alignment of the well-watered uMngeni River Basin with the most important socio-economic development axis in KZN is a major opportunity and provides the province with a competitive advantage. We are an economic gateway to South Africa and the rest of sub-Saharan Africa.

State of the uMngeni River Basin

- The state of the uMngeni River Basin reflects the state of society within the basin. (The river basin is a social-ecological system in which society, the economy and the ecology are bound. Changes on one inevitably result in changes in the other.) In order to improve the state of the system we need to improve our behaviour towards it.
- The Basin is under significant pressure from multiple uses. This is affecting economic development opportunities, human health and ecological integrity. The specific issues include:
  - Reduced water quality caused primarily by inadequate sanitation systems, unregulated industrial pollution and organic runoff from agricultural land
  - Reduced water quantity caused by massive losses, wastage, a lack of attention to demand side management (water conservation and rainwater harvesting) and under-pricing
  - Loss of ground cover and subsequent erosion, caused primarily by grazing pressure and infrastructure development

  - Reduced biodiversity through land transformation, alien invasive plant infestation and unregulated sand-winning
- The specific state of the river basin as a social-ecological system is largely unmeasured and unmonitored. The real costs are unknown. So it is difficult to plan specific interventions, and monitor and evaluate progress.

Governance and management

Governance and management of the uMngeni River Basin is fragmented and erratic

- The roles and responsibilities of various authorities are confused and not clearly understood
- There is a fundamental need to build significant leadership, management and regulatory capacity
- There is concern that the CMA process will take considerable time and will not serve the desired purpose for the Basin
- There is little to no regulatory enforcement taking place
- Business and industry are largely absent from the conversation
- The ecological 'Reserve' has not been established and so efforts to allocate water resources between users are compromised
- Knowledge and information is often lacking
- However, there are significant bodies of knowledge and information about the Basin
- Much this knowledge and information is not readily known, understandable or accessible to managers and stakeholders
- There is no shared information platform that can be fed into and fed off.

Skills, capacity and education

- There are insufficient leadership, management and technical capacity and skills in most sectors to deal with the issues
- There is insufficient focus on water resource education in schools and amongst adults.

Infrastructure, services and finance

- There are significant backlogs in the development of water supply and sanitation infrastructure and services
- There is insufficient maintenance of existing infrastructure
- Financing systems for infrastructure development and payment systems for services are unsustainable.

14.5 Possible Responses?

We all recognise that the opportunities and challenges facing the uMngeni River Basin are many and varied. We also know that in order to realise the many opportunities, we need to address the challenges that face us. So, in broad terms, what is our destination, what is our starting point and how do we make the journey between the two?

Our destination is relatively simple: we need to be able to equitably share the benefits that the uMngeni River Basin provides to us. Everyone should have access to adequate water supply and sanitation systems for domestic use; our refuse should be collected; we require water of adequate quantity and quality to drive our businesses; we require its sand to drive construction; we should be able to paddle down the river, or catch and eat its fish or wash our clothes in it without fearing infection and disease, and we should be able to enjoy its scenic splendour. Importantly we need to recognise that all these benefits come at a cost and we need to pay the costs. Also, we need to appreciate that the right to benefit comes with rules and responsibilities that we must accept.

What is our starting point? There is a classic joke in which a traveller asks directions to his destination and the response is: if I were going there I wouldn't start from here. That is the reality. We do not have a great starting point as has been graphically illustrated in the previous section. What we have is fragmented social-ecological system. There is plenty to fix.

How do we get there? Like any journey it is usually quite easy to describe the destination and the starting point. It is a lot more complex explaining how to get there. Even before we start we need to set out the rules of the game.

First and foremost there needs to be a paradigm shift in thinking and acting from one aptly described at the Wat-Indaba as a 'culture of impunity' to one of custodianship and caring. We require a sustained campaign of 'societal action' where every individual, group, sector and the entire community living in the basin sees themselves as custodians of the basin.

Secondly, we need to have the courage to talk truth to power. Many of those who are acting with impunity are the powerful: government, industry, commercial agriculture. They must be accountable and be held accountable for their actions.

The rest is also important, but will follow the first two - increased political will, improved governance and management systems, improved generation and sharing of knowledge, increased capacity and capability, better incentives, improved regulatory enforcement.

Beyond getting sectors, groups and individuals in the room to discuss issues and build a common understanding and purpose, practically what might we be doing now? Let us focus on those things that will bring immediate and long term benefits. Here are some suggestions for lead agents.

Department of Water Affairs
- Establish, with stakeholders, an institutional mechanism for the governance and management of the uMngeni River Basin
- Improve regulatory compliance capacity
- Increase focus on demand-side water conservation and management

KZN Planning Commission
- Facilitate increased provincial public sector participation in engaging the Basin.
- Align water resource supply with economic development aspirations

Municipalities
- Fix the leaks in both water reticulation and sewers and maintain the systems
- Collect refuse
- Improve revenue collection and price water appropriately (at its full cost)
- Monitor and regulate land transformation

eThekwini Municipality
- Support upstream municipalities in fulfilling their specific service delivery mandates

Umgeni Water
- Support local municipalities in reducing water loss and improving sanitation systems

Traditional Authorities
- Improve land use planning
- Regulate grazing practices

Business and industry
- Place water resource management high on the agendas of the Durban and PMB Chambers
- Accelerate focus on water conservation and rainwater harvesting
- Leverage regulatory compliance amongst polluting businesses

Department of Human Settlements
- Ensure there are rainwater harvesting systems are designed into every new housing development

Commercial agriculture
- Reduce nutrient runoff from commercial agricultural land, particularly in those sections of the basin feeding Midmar, Albert Falls and Spring Grove Dams
- Accelerate water conservation measures in irrigation
- Get organised into Water User Associations

NGO and public conservation agencies
- Monitor and manage land transformation

- Strengthen conservation stewardship programmes, particularly in areas of high water yield and high biodiversity.
- Accelerate and better coordinate alien invasive plant removal and habitat restoration

Universities and other research institutions
- Together with Umgeni Water and DWA establish a State of the uMngeni River Basin Report.
- Together with Umgeni Water and DWA establish a shared information and knowledge platform
- Ensure that research findings are accessible to managers and stakeholders
- Establish post-graduate training and education programmes that focus on high-end water resource leadership, management and technical skills

This might appear to be a long wish list, but is it unrealistic? For the most part, each action is already a mandate of the lead organisation. It involves people and organisations doing the jobs assigned to them.

14.6 What Might Help Us Think About These Issues?

"…… essentially, all models are wrong, but some are useful." (Box and Draper, 1987)

(This section is drawn in large part from Hay et al., 2012. The contributions of Breen and Kotze are gratefully acknowledged)

Changing gears and moving more deeply into the realm of research; there are numerous concepts, models and frameworks that might guide our thinking about the uMngeni River Basin, particularly as it relates to governance and management. What follows is not a detailed critique, but a rather a short commentary on some and how they might assist us. But before we comment, what are we trying to understand better?

- The well-being and livelihoods of those who live in the Basin
- The river basin as a complex social-ecological system
- The river basin as a supplier of ecosystem services
- Water resources in a river basin as a common pool resources subject to common property theory
- Adaptive governance and management
- How we share the benefits that aquatic ecosystem services supply

Well-being and livelihoods
"After all, life satisfaction is neither a direct, verifiable experience nor a known personal fact like one's address or age. It is a global retrospective judgment, which in most cases is constructed only when asked and is determined in part by the respondent's current mood and memory, and by the immediate context." (Kahneman and Krueger, 2006).

Well-being is notoriously difficult to define and measure, but these attributes, drawn from a number of sources (e.g. NEF, 2011; MEA, 2005), give us a fairly good idea of what well-being is all about:

- The freedom of choice and action
- The fulfilment of fundamental needs
- A sense of individual vitality
- The ability to undertake activities that are meaningful, engaging, and which make people feel competent and autonomous
- A stock of inner resources to help people cope when things go wrong and be resilient to changes beyond their immediate control
- A sense of supportive relationships and connectedness with others
- The dynamic process that gives people a sense of how their lives are going, through the interaction between their circumstances, activities and psychological resources.

The New Economics Foundation (NEF, 2011) proposes five steps to achieving well-being - 'connect', 'be active', 'take notice', 'keep learning' and 'give'. The primary constituents of well-being include health, nutrition, safety and protection, material possessions, education / learning, identity, social relations and creativity. What ultimately constitutes overall well-being is unique to each individual and unique to different groups of individuals.

Amongst materially poor people there is a strong positive correlation between income levels and well-being. As income grows so the correlation weakens to the point that, amongst affluent people, there is little or no correlation.

The concept and assessment of livelihoods gained traction in the late 1990s and early 2000s through work conducted for, and on behalf of, DfID (the British Government's Department for International Development). "A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base." (DfID, 1999).

While the concept of livelihood is more narrowly defined than that of well-being, it is apparent that they are complementary - in achieving livelihood options one achieves many of the constituents of well-being. An important advance in the development of the livelihoods concept was the recognition that cash (financial capital) was only one constituent of a basket of capital (or assets) that were required to fulfil livelihoods objectives. The narrower definition of livelihood also lent itself to a fairly objective framework for analysis that is illustrated below (**Figure 14.6.1**).

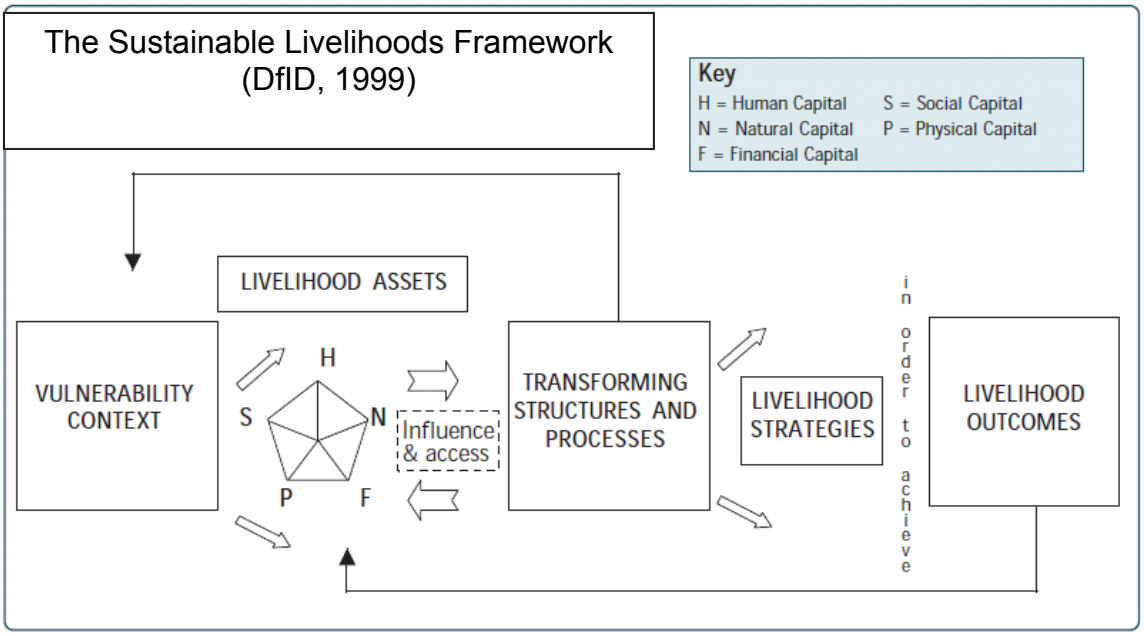


Figure 14.6.1 The Sustainable Livelihoods Framework (DfID, 1999)

Both the concept of well-being and the livelihoods framework are useful in guiding our thinking and our analysis, primarily because they force us to think far beyond the material. While the economic value of the aquatic ecosystem services in the basin are self-evident, their value is much more than that. They have significant spiritual, cultural, ecological, social and recreational values which need to be factored into decision making on the allocation of benefits from these services.

A river basin as a complex social-ecological system

Social-ecological systems have been defined variously as *people, their natural and human-made resources and the relationships among them* (Anderies *et al*, 2004); *linked systems of people and nature* (Roux *et al.*, 2009), or *"…. a bio-geo-physical unit and its associated social actors and institutions. Social-ecological systems are complex and adaptive and delimited by spatial or functional boundaries surrounding particular ecosystems and their problem context."* (Glaser *et al.*, 2008). While it is generally agreed that these systems are 'real things', Jahn *et al*. (2008) advance an additional view: *"It is yet also possible to understand social-ecological systems as models of knowledge about real-world phenomena."*

Complexity, adaptive systems and social-ecological systems go hand-in-hand in the academic literature. What is meant by complexity? Manson (2001) provides us with the key attributes:

- A complex system is defined more in terms of the relationships between constituent parts than the parts themselves.
- The internal organisation of a complex system is not an amorphous mass, but rather a multitude of discrete, but linked set of subsystems and subsystems of subsystems.
- A complex system owes its existence to the environment - anything outside the system's boundary.
- However, a complex system is not entirely beholden to its environment. It is able to shape, react and anticipate.
- A complex system has emergent qualities through which its capacity is greater than the sum of its constituent parts.
- It is able to change and evolve through and self-organisation and dissipation.

The final attribute would indicate that a complex system is, by its very nature, an adaptive system. An adaptive system is one which can respond to changes in the external environment and / or changes in the relationships between the constituent parts of the system - it is a self-organizing system.

Whatever systems we use or develop, they need to take into account the social-ecological system's internal organisation; the relationship and interactions between the internal and external environment; its adaptive, reactive and anticipatory nature, and those qualities that support emergence.

A recently completed Water Research Commission project developed an approach to support estuary-based economic empowerment (Bowd *et al*., 2012). Following the comparative analysis of a number of frameworks, that of Anderies *et al*. (2004) was chosen as the conceptual basis for the process (**Figure 14.6.2**).

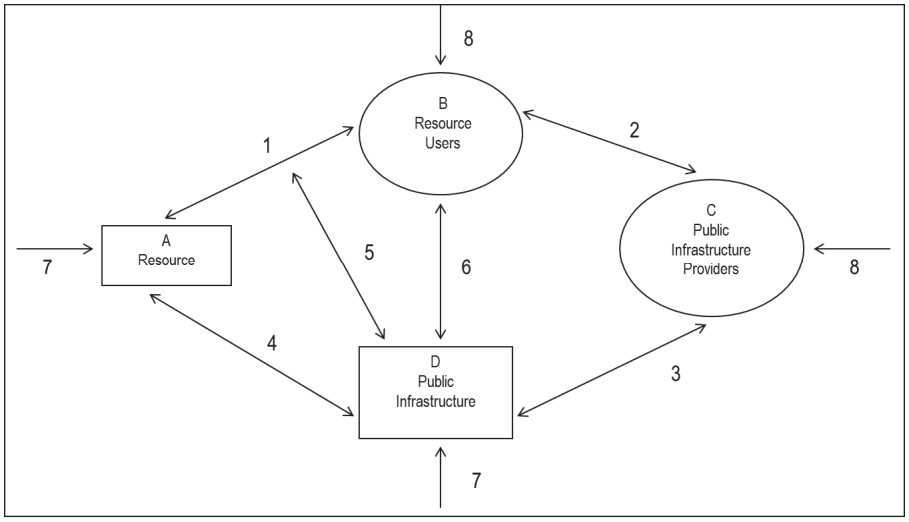


Figure 14.6.2 A framework illustrating a social-ecological system as conceptualised by Anderies *et al*. (2004)

We have found the Anderies *et al*. (2004) framework particularly useful because it forces us to engage the system as a whole rather than only the ecological, economic and social dimensions. It also forces to engage in defining in a systematic way not just the components, but also the relationship between the components. Below are a series of questions derived from the framework which allow us to understand much better how the system functions.

The resource

- What is the resource defined in terms of services?
- What does it comprise? (What are its key biophysical features?)
- How big is it?
- How does it connect to other resources?
- What is its history and its significance to people living at or around it?

The users

- Who makes use of the aquatic ecosystem services?
- Where are they from?
- What is the state (or states) of well-being of people using these services, how does the particular use affect the state, and are there any obvious trends?

The public infrastructure providers

- Who is responsible for governing the system?
- What government departments, systems of traditional leadership and other agencies are involved?
- Who makes the rules or laws that dictate how people use the resource?
- Who supplies the infrastructure, services and equipment that allow the use of the resource?

The public infrastructure

- What are the rules, conventions and norms that govern use?
- Are there formal rights of access that govern use?
- What infrastructure and services are in place to support use of the resource?

The relationship between the users and the resource (Arrow 1 in Figure 14.6.2)

- Who is using the resource?
- What is being used what is it being used for? (What ecosystem services are being supplied by the system?)
- How important are the uses? What is the contribution of various ecosystem services to the well-being of people in the system and at what scale? What proportion of household income is coming from the services?
- How are the various uses changing over time and what is causing these changes?
- How are the various uses organised and allocated to people? What property rights regime is in place for each ecosystem service?
- How does one use of the system affect another use or other uses of the system? Are there conflicting or contradictory property rights regimes in place?
- How are the uses of the system affecting its health? What is the impact of use on the ecosystem?
- Are there potential uses that have been thought of that would benefit people but are not being used?
- What is the trajectory of change? Is it rapid, slow, gradual, erratic, large spatial scale, small spatial scale?
- How would these potential uses benefit people?

The relationship between users and public infrastructure providers (Arrow 2 in Figure 14.6.2)

- How are rules of use made?
- How is infrastructure and service delivery planned and implemented?
- How are decisions recorded and circulated?
- Do the users play a role in making decisions? If so, how does this happen?
- Does the system work?
- What are the problems that are encountered?
- How might these problems be solved?

The relationship between public infrastructure providers and public infrastructure (Arrow 3 in Figure 14.6.2)

- How do the governors make the rules?
- How do the service providers plan the infrastructure and service delivery?
- Are rules monitored and regulated? If so, how?
- How does maintenance of infrastructure and services take place?

The relationship between public infrastructure and the resource (Arrow 4 in Figure 14.6.2)

- What impact are the rules having on resource levels / condition?
- What impact are the physical infrastructure and services having on resource levels / condition?

The relationship between public infrastructure, and the resource and the users (Arrow 5 in Figure 14.6.2)

- Do the users think that the rules of use are fair?
- Do the users think that the infrastructure and services are adequate?
- Are the users involved in making the rules, and managing and governing the resource?
- Are the users involved in developing and maintaining infrastructure and services?

The impact of external driving forces on any component or any relationship within the system (Arrows 7 and 8 in Figure 14.6.2)

- What are external forces impacting on the system?
- How are they impacting on the system?
- How are they affecting people's well-being?

The river basin as a supplier of ecosystem services

The concept of an ecosystem service based approach to natural resource management (**Figure 14.6.3**) was the central theme of the Millennium Ecosystem Assessment (MEA, 2005). It is still in its infancy. To quote Fish (2011*) "….natural and social scientists are still a long way from appreciating fully the practical needs and consequences of thinking about the natural world in this way."* However, despite arguments about what constitutes an ecosystem service and how we might measure it, the concept is here to stay.

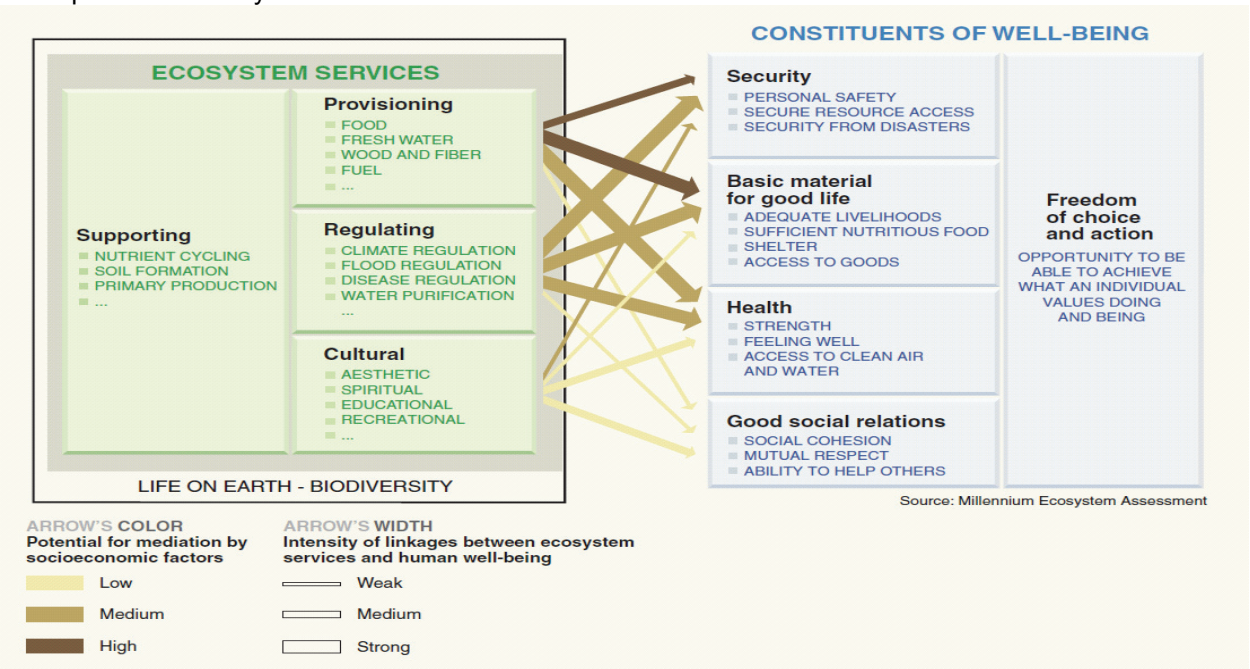


Figure 14.6.3 Relationships between ecosystem services and well-being as conceptualised in the Millennium Ecosystem Assessment (MEA, 2005)

The above framework is useful in attempting to explicitly link ecosystem services to the various constituents of well-being. However, the starting point in this framework is the ecosystem service supply, not well-being. To quote Fish (2011) again "*Advocates of the ecosystem services framework need to develop a more elaborate understanding of how a rich and variegated term such as 'well-being' maps back onto the services that nature provides."* He likens existing efforts to attempting to start a business without analysing the demand. We remain preoccupied with supply, not demand.

Water resources in river basins as common pool resources subject to common property theory

Nkhata *et al*. (2012), drawing on, amongst others, the seminal work of Ostrom and colleagues, reviewed the international research experience of property rights and aquatic ecosystem service management. To summarise two general points: first, many aquatic systems can be considered common-pool resources, i.e. the exclusion of users is difficult and each user has the potential to subtract from the welfare of others. Secondly, common-pool resources lend themselves to effective governance through the implementation of appropriate common property rights regimes.

Specifically, Nkhata *et al*. (2012) demonstrated that property rights regimes regulate and coordinate the allocation and sharing of benefits that accrue from ecosystem services; that clearly defined property rights build 'social capital' for the common good; that secure property rights provide incentives for investment in the management of the resource; and, finally, that secure property rights result in improved resilience of the social-ecological system.

Delving a little deeper into property rights: should an individual or a group of people wish to access, withdraw, manage or alienate (sell) ecosystem services that accrue from a resource they require a property right. A property right is an '*enforceable authority to undertake particular actions in specific domains*'.

At a technical level, property rights are categorised into five regime types (Coelho *et al*, 2009):

- Private property - individuals have the right to undertake socially acceptable use of the resource and exclude other users.
- State property - individuals have rules of access to a resource determined by a management agency.
- Common property - a group of clearly defined co-owners has access to the resource and can exclude non-members. The co-owners have both the rights and responsibilities of management.
- Open-access property - no defined group of users is set and the benefit stream from the resource is available to everyone.
- "Anti-Commons" property - a regime in which multiple owners hold effective rights of exclusion over a scarce resource resulting in, effectively, a stalemate where nobody benefits.

Building on this understanding it is evident that for a group of individuals to benefit from aquatic ecosystem services they require rights of access to these services. Some key questions include:

- What specific rights do specific users have and what are these levels of rights (see **Table 14.6.1**)?
- To what ecosystem service does the right relate - is it water for drinking or for irrigating crops?
- Are there variations in these rights in space and time?

Schlager and Ostrom (1996) disaggregated rights and positions (**Table 14.6.1**) and so provided a framework for analysing rights within the context of a social-ecological system.

Table 14.6.1 Bundles of rights associated with positions (Schlager and Ostrom, 1996)

Bundle of Rights?	**Owner**	**Proprietor**	**Claimant**	**Authorised user**	**Authorised entrant**
Access	X	X	X	X	X
Withdrawal	X	X	X	X	
Management	X	X	X	X	
Exclusion	X	X			
Alienation	X				

So, different individuals or groups might have different bundles of rights for different ecosystem services within different property rights regimes that might vary both in time and space. Understanding this will be critical in allocation of resources in the river basin. The general view is that these rights are poorly understood and have been eroded - by both omission and commission - they are not granted, not acknowledged and not honoured.

Strategic adaptive management

The theory and practice of strategic adaptive management (SAM) as it relates to freshwater resources is detailed in McLoughlin *et al*. (2011) and Kingsford and Biggs (2012). To highlight key aspects, shown also in **Figure 14.6.4**:

- It is designed to engage complex social-ecological systems where there are high levels of uncertainty;
- It is a learning-by-doing approach with ongoing negotiation, learning, iteration and adaptation;
- It facilitates social learning taking into account both social and ecological dimensions of a system;
- It focuses on achieving consensus through cooperation; and
- It recognises that while knowledge and understanding will always be incomplete, action is required.

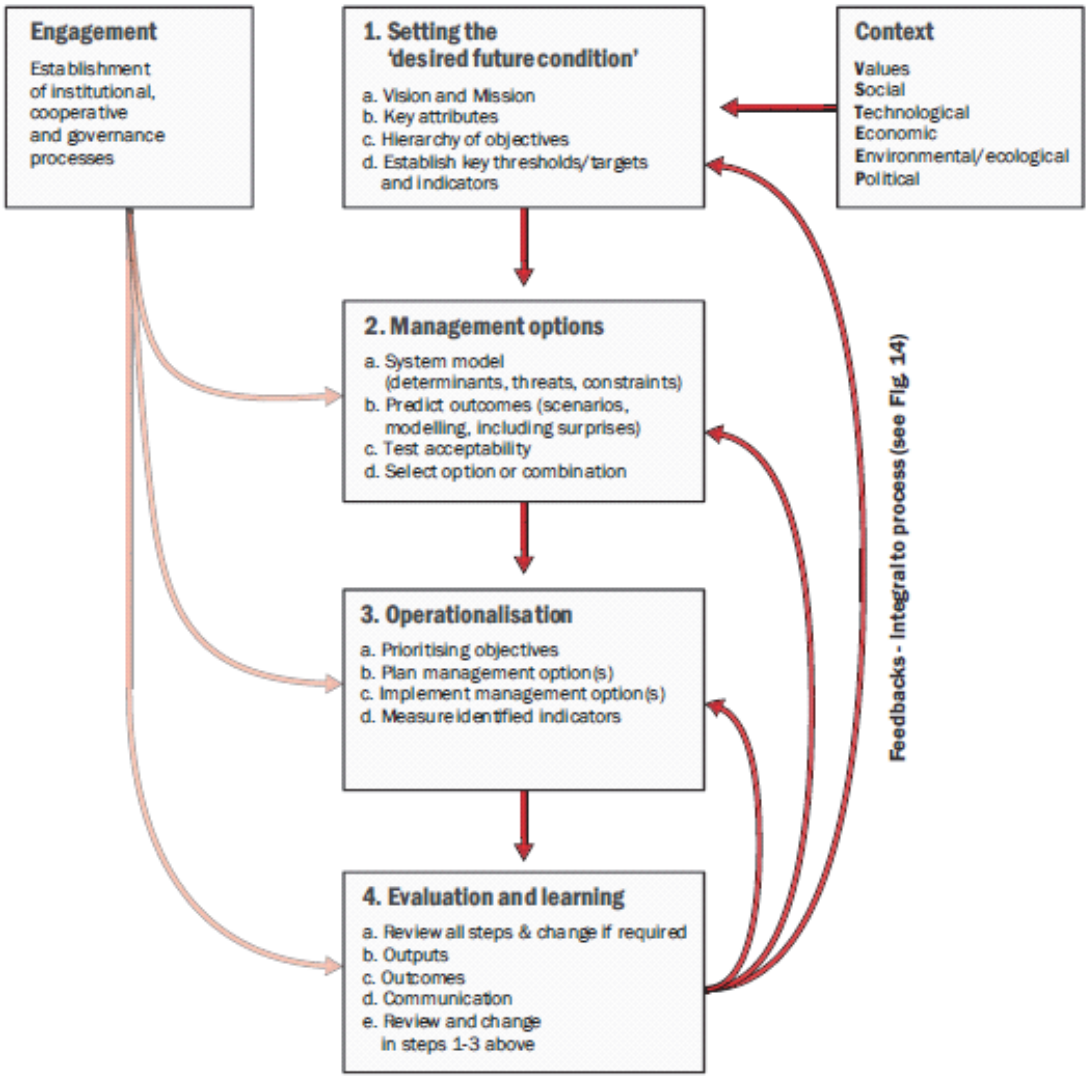


Figure 14.6.4 A generic strategic adaptive management framework (extracted from Kingsford and Biggs, 2012)

So, if we recognise river basins as complex social-ecological systems, it is inevitable that we should use an adaptive management, i.e. a 'management by experiment', approach in support of both social and ecological well-being.

SAM supports the realisation of our proposition. It is, in effect, a rigorous process followed by stakeholders to:

- Achieve a common vision about a resource's social-ecological system;

- Established the desired state;
- Set and implement operational objectives; and
- Monitor, review and refine.

Importantly, it engages the detail of what, how, when, who and how much.

Benefit sharing

The South African Department of Water Affairs logo "Some for all forever" reflects an intention for equitable sharing of the benefits from access to and use of the services deriving from aquatic ecosystems. The term 'benefit' generally implies an advantage or gain from something and so we may consider a benefit as something that promotes well-being. But, because what each of us needs to improve well-being may be quite different, individuals and groups value aquatic ecosystem services differently and we can readily appreciate that sharing issues will continue to form the core basis of debates about the governance and management of the use of these services. Given that the supply of, and demand for, aquatic ecosystems services are so variable in time and space (Koch *et al*., 2009), there are widely differing opinions on how to respond to the complexity surrounding benefit sharing arrangements. Complexity in turn is fuelled by heightened uncertainty about the likely consequences for wellbeing of both collective and individual choices. As demands for access to, and use of, aquatic ecosystem services become more diverse and grow, relative scarcity will increase fostering competitive rather than cooperative behaviours necessary for sustainable and equitable allocation of the associated benefits.

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It is increasingly appreciated that because the majority benefits derived from aquatic ecosystem services are accessed collectively, they should be governed as common pool resources. A governance system that provides an acceptable degree of security of access to ecosystem services is necessary for fostering sustainable use because investment (effort, finances etc.) is usually required to realize the benefits of these services.

In such complex contexts, governing and managing the use of the benefits of aquatic ecosystem services is not simply a matter of setting a utility function and selecting the alternative leading to the preferred set of consequences. On the contrary, it requires a systemic framing of key determinant variables which define the effectiveness, efficiency, equity and sustainability of benefit sharing arrangements. Knowledge about benefit sharing must be scientifically reliable and evolve to remain contextually relevant.

Something home-grown: The Treehouse Model

During 2000 - 2009 researchers and conservationists met regularly at the 'Treehouse' in the Kruger National Park (unfortunately, the 'Treehouse' burnt down). The purpose of these meetings was to design and implement a research programme focusing on the governance and management of protected areas. A model, or framework, that emerged became known as the 'Treehouse Model' (**Figure 14.6.5**). It has been adapted for various applications, but its fundamental design, when we link it to the issues described in the next section is likely to be highly relevant to the uMngeni River Basin.

I find the Treehouse Model particularly relevant, not because it attempts to link key components or actions, but that it simply identifies and so forces one to think about them. Learning about, developing the necessary capacity, understanding the context, supporting governance, managing the demand for ecosystem services and managing relationships are all absolutely critical if we are to achieve a more resilient uMngeni River Basin social-ecological system.

Some concluding thoughts on models, frameworks and concepts

To paraphrase Rogers (personal communication) we should not be held captive by the "tyranny of models". However, they are useful ways of helping us to organise our thinking. Of the various models, frameworks and theories described above, none are either 'good' or 'bad'. Also, no single model, framework or concept can service all our needs. We require a toolbox full of them. Each one or a combination is relevant in a particular context and / or for a particular purpose:

- The concepts of well-being and livelihoods allow us to focus on what we are ultimately striving for and to differentiate its various components.

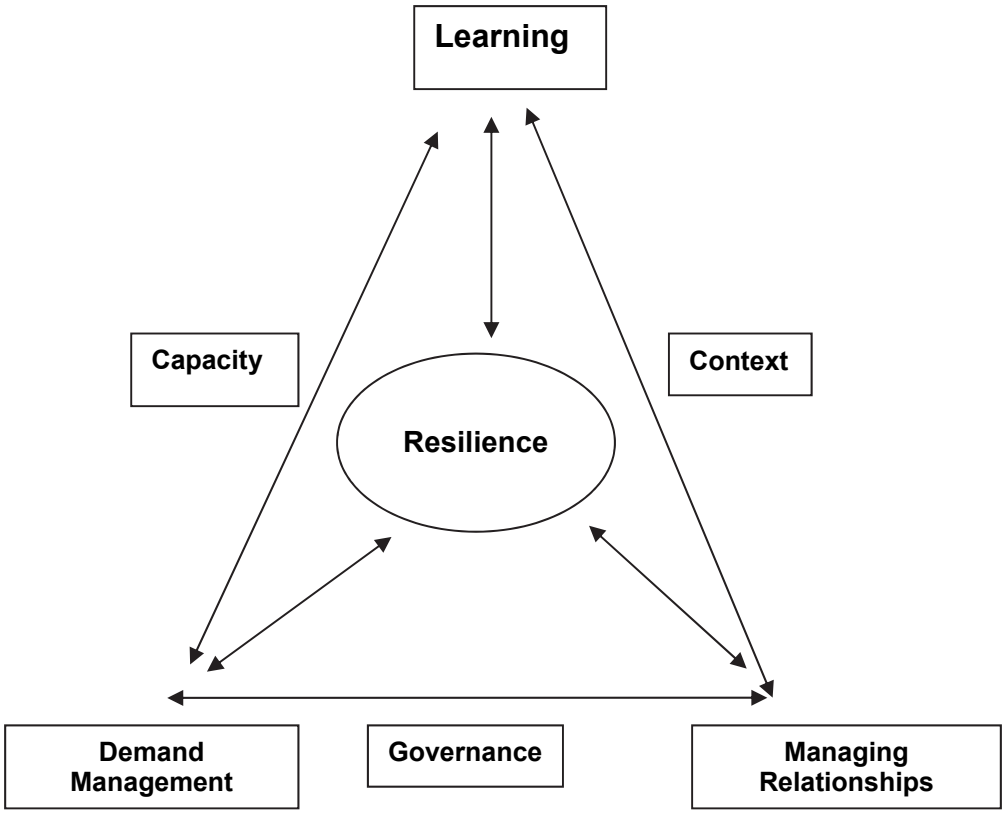


Figure 14.6.5 The 'Treehouse' Model

- The livelihoods framework helps us understand the components of, and the drivers for, improving livelihoods.
- The concept of a social-ecological system forces us to link society and nature, and the Anderies Framework helps us understand this system, the relationships between its various constituents and what questions we might use to interrogate it.
- The Millennium Ecosystem Assessment assists us in understanding the concept of ecosystem services and how they act as mediators of human well-being.
- The concept of water resources as common pool resources that require governance and management through a common property rights regime, the notion of bundles of rights with varying types of access provide a firm foundation for establishing rights of access to water resources. This is strengthened through the concept of benefit sharing.
- At the level of management, Strategic Adaptive Management (SAM) provides us with a practical way of incorporating complexity, and learning by doing and reflecting on what we have done.
- Finally, the Treehouse Model provides us with a framework that might be useful in conceptualising and implementing a water-resource focused research programme.

A concept which is coming to the fore and has not received attention as yet is that of ecological infrastructure. It was greeted with a certain degree of suspicion when it was first put forward, probably in the same way as ecolosystems goods and services was about ten years ago. However, as we begin to understand it as the 'generator' of ecosystem services, so its acceptance is growing. Also, it appears that people outside the environmental / ecological domain can relate to it quite well. With the establishment of the Ecological Infrastructure Partnership for the uMngeni River Basin it is likely to enjoy considerable prominence.

14.7 How Do We Take This Forward?

In the midst of complexity a few things are abundantly clear. The uMngeni River Basin is the cradle that sustains us. It is where we live, where we work and where we play. The water flowing through it sustains us physically, emotionally and spiritually, and it sustains our businesses, our farms and forests, and our natural systems. It is the lifeblood of our society and our economy - it is a social issue, a political issue, an economic issue and an ecological issue. As we grow and develop, so does

the demand for water resources - we use more and we pollute more. As the resource becomes scarcer so does its allocation - some, for all, forever - becomes more difficult and more complex. And when we add in possible climate change impacts, the complexity increases further. We all recognise that the governance and management of the uMngeni River Basin - its people and its resources - is a shared responsibility involving government, business and society. We know we cannot do it alone. We also know that, for very selfish reasons, we have to get it right. Getting it wrong will compromise our individual and collective well-being. It will also impact directly on the developmental trajectory of our country and our province. Getting it right improves our collective well-being and provides KZN with a competitive economic advantage in a country regularly short of water. Finally, we know full well that, with or without climate change we are currently getting it wrong. Governance and management efforts at the scale of the river basin are ineffectual. We know enough about the state of the system to know that it is in decline. Fundamental changes are required.

So, what should we be doing as researchers?

1. Grow our knowledge base in institutional and technical areas in support of effective governance and management of the river basin;
2. Build the capacity of our current and future generation of river basin leaders, managers, practitioners and researchers; and
3. Act as a catalyst for collective and coordinated action.

A partnership with UKZN and DUT as lead organisations is a logical starting point. Both are recognised leaders in knowledge generation in support of water resource management. We also have considerable depth in disciplines required to support water resource management. These range from filtration technology to water law. In addition, we are currently educating and training the leadership cadre of tomorrow and we can mobilise partners from numerous sectors. In short, together with our numerous partners we can deliver 'source-to-sea' solutions for many situations.

What might guide our thinking in the design of this partnership?

- It is a partnership programme focused on participative learning and improving our knowledge about water resource governance, management and technical issues at the scale of the river basin
- It is an integrated study dealing with the river basin as a social-ecological system
- It is demand or needs driven - regulators, managers, planners and users will be instrumental in identifying the key research areas
- It is a mechanism to provide existing research capacity with direction and focus, and to contextualise current and past research
- It is a vehicle to build new leadership, management and research capacity through post-graduate training and experiential learning.

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CHAPTER 15: MANAGING SOUTH AFRICA'S WATER RESOURCES IN THE CONTEXT OF CLIMATE CHANGE: A REFERENCE GUIDE TO IMPLEMENT ADAPTATION OPTIONS

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15.1 Introduction

As narrated in **Chapter 1**, the project team was required to adapt their approaches and research practices on an ongoing basis. An initial focus on a collaborative and integrative project approach gradually gave way to a diverse set of studies and research approaches. As a result, the seven deliverables specified in the terms of reference have been approached from different angles and often in several different ways, providing multiple perspectives on the key themes of uncertainty, vulnerabilities, adaptation options and mainstreaming.

During the fourth learning cycle of the project (**Chapter 1**), one group within the project team (John Colvin, Coleen Vogel and Beate Scharfetter) decided to focus on the development of a 'handbook' / reference guide which could provide praxis guidance on the key themes of 'starting the implementation process of the adaptation agenda', including 'mainstreaming climate change into governmental and other sector organisations' (**Figure 15.1.1**, work package 6b).

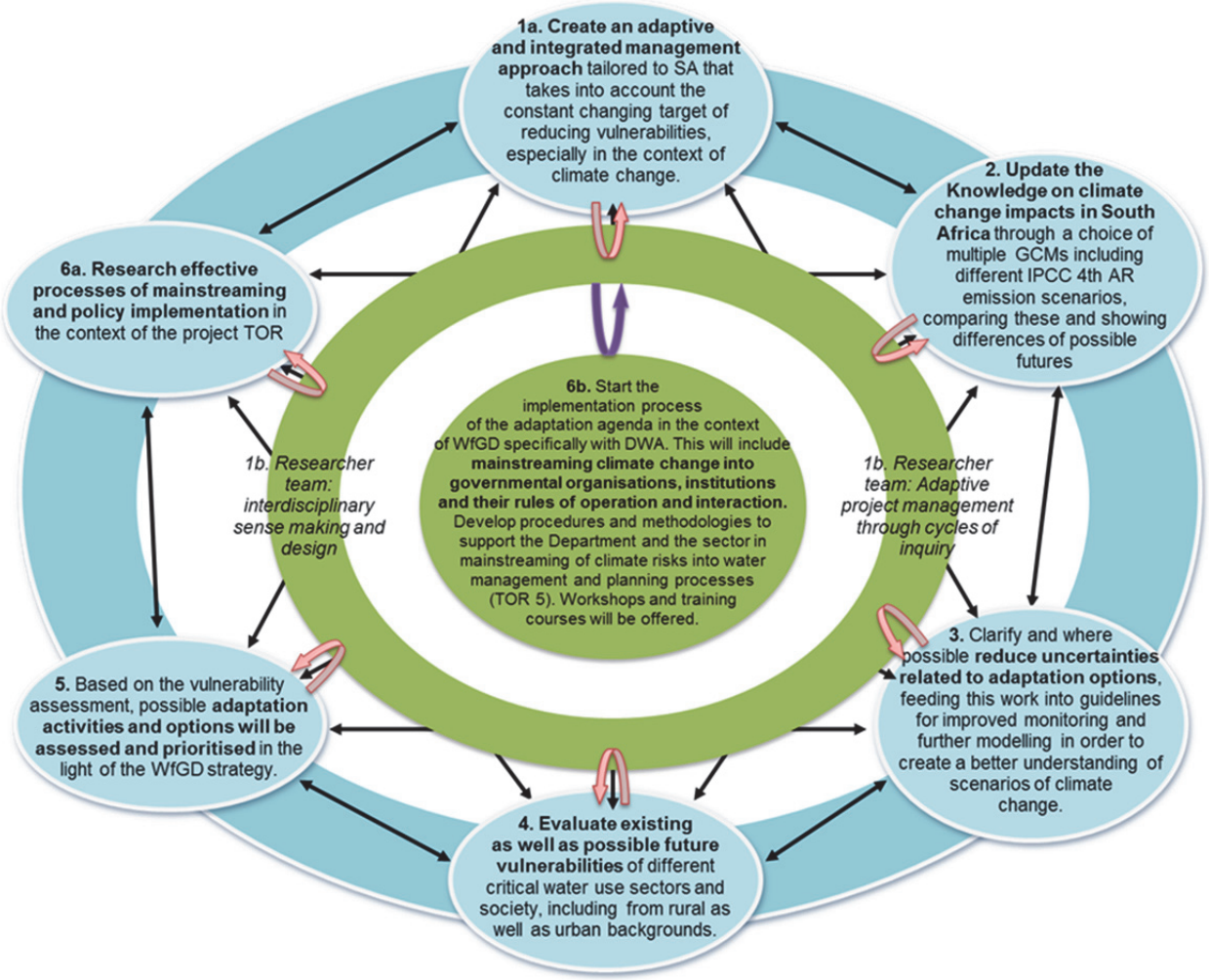


Figure 15.1.1 Diagram showing the six aims (and work packages) of the project and their potential inter-dependencies

There are **many** 'how to' guides and or reference books already available to South African policy makers and practitioners, focusing either on water resources management or on climate change adaptation, and sometimes on both. Some have a specifically South African focus (e.g. Sustainable Energy Africa, 2009; CSIR, 2010; SARVA, 2010), while others are positioned in more generic ways, either within an African or international context (e.g. CARE International, 2009; IUCN *et al*., 2010; Tearfund, 2010; Pettengell, 2010; AMCOW, 2012).

The books produced (both the expanded book and the shorter 'glossy' booklet), take a somewhat different approach, focusing on the work needed to rethink and reframe how one can couple climate change adaptation and water governance in its broadest sense. A core focus for the books is the way in which climate change both reinforces the IWRM approach which lies at the centre of South Africa's water resources reform process, while also reframing it. An intensified focus on designing for adaptive learning pathways, framings and reflexivities, shocks and stresses, transitions and transformations are shown to be fundamental to effectively progressing a complex system such as the water sector in a climate change world. Addressing the full implications of the fact that we are now living in a highly dynamic and uncertain world requires 'opening up' to methods and practices that involve flexibility, diversity, adaptation, learning and reflexivity, and an alternative politics of sustainability that highlights and supports alternative pathways (Leach *et al*., 2010).

One of the main take home messages is that how one understands and thinks about climate change adaptation is important, particularly for framing interventions and therefore for framing policy. It is also argued that framings play a critical role in helping to decide who or what is vulnerable, and how the voices of the vulnerable should be involved in building adaptive capacity and shaping adaptation options.

In order to develop a perspective on mainstreaming, the products consider all of the major themes within **Figure 15.1.1**, weaving these together in an integrated manner in the design of the narratives of the books and their unfolding. In particular, by taking an historical and contextualised approach, the whole of the narrative is designed to consider the issues involved in mainstreaming, and specifically, what is involved in mainstreaming an integrative adaptive management approach capable of dealing with climate change-related uncertainties and risks and of taking into account existing as well as possible future vulnerabilities. The guide books also build on relevant completed WRC projects, in particular WRC project K5/1843 (Colvin and Stuart-Hill, 2011).

15.2 The Intended Audience for the Reference Guides

The reference guides / handbooks are written with a number of intended audiences in mind (**Figure 15.2.1**). During the writing, a key audience emerged - that of 'innovation brokers' (Shaxson *et al*., 2012), sometimes also known as 'systemic intermediaries' (van Lente *et al*., 2003). Both terms are carefully defined within the books. While not a major constituency within South Africa, these individuals have the potential nonetheless to play a highly strategic role in mainstreaming effective practices for climate change adaptation within the water sector.

The products are also targeted at a number of other audiences within the water sector, including the Department of Water Affairs, the Water Research Commission, universities, business, NGOs and South Africa's major cities (**Figure 15.2.1**). The reference guides are written for any individual within these sectors who is keen to engage reflectively with the challenges facing the water resources reform process and the ways in which climate change adaptation reframes these challenges and the opportunities involved.

15.3 Executive Summary of the Full 'Handbook' / Reference Guide

Here we present the executive summary of the full book by chapters. For further engagement the reader is directed to both the summary and full versions of the book. The shorter version is essentially a more succinct presentation that includes the key messages of the more detailed and longer version.

15.3.1 Introduction and background

Climate change is an additional challenge that South Africa is facing that may significantly impact on development progress. Adaptation to the challenges posed by climate change and climate variability,

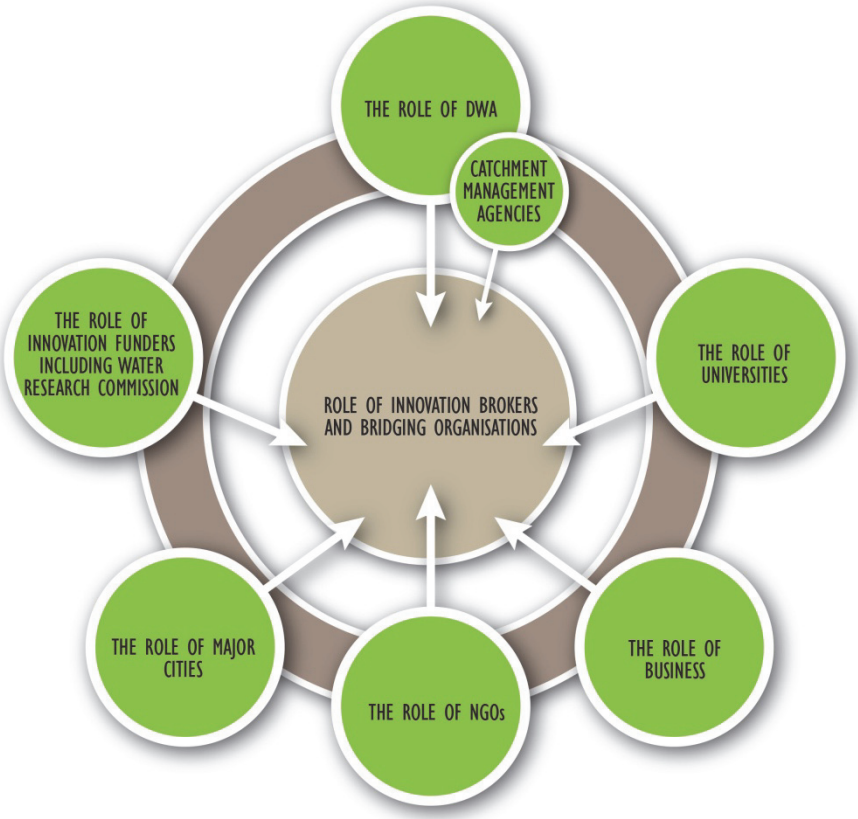


Figure 15.2.1 Intended audiences for the books, with a core focus on a (hypothetical) community of systemic intermediaries, innovation brokers and bridging organisations

both now and in the future, is of particular significance in South Africa's water resources sector.

- Much has been written related to South Africa's water resources reform process, including its emphasis on an Integrated Water Resources Management (IWRM) approach. What is missing from some of the narratives, as is shown in this book, however, is the radical way in which climate change both reinforces the IWRM approach while also reframing it.
- Besides setting out the structure of the book and summarising the focus of each chapter, this first chapter also introduces four key themes that guide the story developed through the book:
  - Climate change disrupts development
  - Climate change introduces new forms of risk and uncertainty
  - Why is radical reflection and reframing required?
  - The role of innovation and of innovation brokers.

15.3.2 How does South Africa currently manage its water resources?

Setting the scene

- Our purpose in this chapter is to set the scene for thinking about climate change adaptation in the context of the South African water resources sector.
- Because of the complexity and inherent challenges of water resources management in South Africa we set out what we see as some of the key dimensions of the 'problematique' of water resources management in South Africa, including both current successes and failings.

The challenge of transformation

- A key challenge for successive ANC governments since apartheid has been to refocus South Africa's hydraulic mission in such a way that the biophysical resilience of water supply is strengthened and restored and the human geographies of water-based apartheid are addressed.
- This is a significantly complex and difficult task, requiring not only a different way of managing water, but also an understanding of how best to transform the current system in the direction required and the ability to implement this.

Addressing the complexity of water governance

- One dimension of complexity, the so-called challenge of 'horizontal integration', concerns the need to mediate and allocate across a highly diverse and often competing set of stakeholder priorities.
- The challenge of water poverty is a key consideration here.
- Further complexity is added by the challenge of so-called 'vertical integration' - that is, the necessity that water must be managed and coordinated at several scales. This is particularly evident when considering the environmental requirements of healthy catchment functioning, which operate over a whole-of-catchment scale.
- These complexities are layered over climatic variabilities and uncertainties with which South Africa's water managers must also contend. Specifically, the rain-bearing systems that provide water are characterized by season and can be highly variable.
- It is against this highly variable climate that climate change needs to be understood. Water managers are used to dealing with and planning for a variable climate, variable water flows and the difficulty of managing a water system in such uncertainty. Climate change thus adds an 'additional layer' of change and complexity and uncertainty.

Water resources as a 'wicked issue'

- The complexities and uncertainties we have described in the previous sections are not simply technical, they are also social. That is, deciding how to govern and manage water at multiple scales, across catchments and across diverse stakeholder needs and priorities is socio-politically as well as technically complex.
- Key ingredients in solving or at least managing complex policy problems include successfully working across both internal and external organisational boundaries and engaging citizens and stakeholders in policy making and implementation.
- Recognition of water resources as a wicked issue is now well established in South Africa, as elsewhere in both the global north and south.

IWRM as a policy response

- The National Water Act (NWA) and the first National Water Resources Strategy (NWRS) are both pathbreaking attempts to face head on the issues of complexity and wickedness outlined above. While not using the language of complexity and wickedness, they drew on an earlier discourse of 'integrated water resources management' (IWRM) to engage with these issues.
- Critically, the NWA and NWRS can together be understood as a major reframing of the way water resources should be managed - both a major strength in policy terms but also a major challenge in terms of implementation. In contemporary discourse this reframing would be described as 'transformational'.

Barriers to implementing the NWA and NWRS

- Many authors have commented on progress in implementing the NWA and NWRS, describing it as 'uneven, inconsistent and often inadequate' (Pegram *et al*., 2006), and in many cases leading to a high degree of hidden 'path dependency' (i.e. failure to reform) between the old and new regimes.
- Multiple drivers impeding implementation within the DWA are highlighted in the literature, including leadership, ANC patronage, vested interests in the *status quo*, poor performance management, loss of institutional memory and significant skills shortages.
- There are also significant barriers to prevent other stakeholders taking leadership, as the interests of the some powerful stakeholder are likely to be economic and support a 'hydraulic mission' rather than IWRM perspective.
- Some researchers argue that the effective championing of an IWRM approach is therefore likely to depend on one or more of the following groups who do have a stakeholding in IWRM and the South African water resources reform process: the DWA; local, national and international NGOs; universities; international IWRM networks; and (international) donors.

15.3.3 Framing adaptation to climate change

Ways of framing adaptation

- In this and the following chapter we set out a number of ways of thinking about adaptation and what might constitute successful adaptation. These different 'framings' of adaptation carry

significantly different implications for how South Africa could manage its water resources given climate change and climate variability.

- Ways of framing and talking about climate change are considered historically in terms of a series of 'paradigms' or 'ways of thinking', focusing on: impacts; vulnerabilities and resilience; adaptation; adaptive capacity; and social-institutional learning pathways, with notable 'turns' and changes in perspective in the discourse between each paradigm. In some cases these advances result in extending and furthering the debates and ways of approaching issues and do not always entirely 'replace' a previous way of thinking about climate change.

From impacts to vulnerabilities (paradigms 1-3)

- The earliest thinking about climate change, before adaptation was explicitly conceptualised, focused on its impacts. During the second half of the 1990s, a significant reframing took place, introducing the notion of adaptation and shifting the focus from impacts to vulnerabilities, that is, "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes".
- Whereas early assessments focused on vulnerability to future climate change, later assessments, appearing in the early 2000s, shifted their focus to *current* vulnerabilities. In parallel with this, a focus on the ability to cope with these vulnerabilities - 'adaptive capacity' - also emerged.
- A further feature of this way of thinking was increasing contestation of how vulnerability itself should be conceptualised and measured, reflecting different underlying framings and discourses, some with a strong biophysical science bias and others reflecting discourses from the social sciences. Yet others sought interdisciplinary integration.

Adaptation policy assessments (paradigm 4)

- The emergence of 'adaptation policy assessments' in the mid- to late-2000s marked a further fundamental shift in assessment purpose. In this paradigm the primary purpose was to contribute to policy-making by providing specific recommendations to planners and policy-makers on the enhancement of adaptive capacity and the implementation of adaptation policies. In this paradigm the move towards interdisciplinary collaboration between scientists and between scientists and policy makers is further enhanced.
- Major South African climate change policy processes that emerged in the second half of the 2000s reflect this paradigmatic approach.

15.3.4 Adaptation as social-institutional learning pathways (paradigm 5)

Over the past five years, scholars and practitioners working on climate change adaptation have also become interested in processes of social learning and started to talk about adaptation as a process of 'developing pathways of social and institutional learning and capacity building'. Here they borrow from other fields - for example in health, agriculture, water and forestry - where social learning praxes have been actively explored over the past 20 years.

The climate change context provides a further and compelling rationale for why development in a climate change world should pay even greater attention to social learning approaches. Recognising climate change as a 'super wicked' issue, this argument is driven by the complex uncertainties and multiple contestations inherent in a climate change context, where prediction is difficult but what we can expect with more certainty is an increase in unpredictable and extreme events.

Examples of learning approaches and pathways for adaptation

- Several examples of learning approaches and pathways for adaptation are illustrated in this chapter (see the full/expanded reference guide). The findings of the European research project 'Adaptation and Mitigation Strategies' (ADAM) highlight that there is often no clear agreement about what exactly the adaptation problem is and there may be uncertainty and ambiguity as to how improvements might be made. One conclusion from these observations is that our understanding of adaptation must be framed differently, moving away from the 'predict and provide' approaches of impact modelling and decision analytical framing and towards a more inquiry-based and reflexive approach that enables stakeholders to question their underlying assumptions about what is happening and what needs to change.
- Another study, by the Africa Climate Change Resilience Alliance (ACCRA), highlights the importance of focusing on autonomous innovation as an entry point for an adaptive capacity

perspective. This involves understanding how people are currently experimenting and innovating in response to different pressures, and understanding the constraints to innovation and the uptake of new ideas. This inevitably includes having an understanding of institutional factors, power relations, and other socio-cultural factors and the recognition that the necessary changes to development practice are often not actionable by any single organisation or individual acting alone, but rather, are systemic, thus highlighting the importance of both horizontal and vertical governance dynamics.

- Three further examples of social institutional learning pathways are provided, each illustrating different dimensions, enablers and constraints of transformational change. The first focuses on the development of sustainable stormwater management practices in the city of Melbourne; the second on the development of climate change adaptation practices in WWF Colombia; while the third introduces an action research initiative to develop social-institutional learning pathways for integrated and adaptive water resources governance in South Africa.

15.3.5 How should South Africa's water resources sector be adapting to climate change?

In this section of the book, the challenges of implementing an IWRM approach in South Africa, first discussed in Chapter 2 of the book, are considered afresh through the lens of climate change adaptation. Two questions are addressed:

- In what ways do the challenges of climate change adaptation, and appropriate responses to these, help to reinforce the value of an IWRM approach?
- In what ways do the challenges of climate change adaptation and appropriate responses to these, extend, adapt or indeed reframe the IWRM approach?

Reinforcing the value of an IWRM approach

- As a 'super wicked' issue, climate change adaptation further reinforces the dynamic, uncertain and frequently contested nature of water resources management, thus also reinforcing the value of an IWRM approach, including the value of social learning practices underpinning multi-stakeholder engagement and dialogue. Good IWRM practices should thus provide the cornerstone for good adaptation practices in South Africa's water resources sector.
- A strong focus on vulnerabilities under climate change adaptation also reinforces the value of an IWRM approach. The relationships between poverty, vulnerability and the role of water in people's livelihoods remain poorly researched in South Africa - better understanding their dynamic inter-relationships will therefore be key to adapting current IWRM-based policies and practices in order to realise effective pro-poor water governance.
- IWRM also highlights the value of ecosystem services to catchment health and thus to a healthily functioning social ecological system. Ecosystems are both affected by climate change and have a key role to play both in mitigation and adaptation - for example by fixing carbon and by increasing resilience to impacts. 'Ecosystem-based adaptation' thus further reinforces the value of an IWRM approach and of the reform process set out in the NWA and NWRS.

Adapting the IWRM approach - developing adaptive capacity

- While adaptive management is implied by the IWRM approach, climate change adaptation places new requirements on the priority given to adaptive management practices and the skills that underpin these. It particularly reinforces the need to move beyond current approaches to risk management and to address uncertainties, ambiguities and unknowns in new ways. Furthermore, adaptive management strengthens the generic capacity to adapt (Ensor's 'building adaptive capacity'), improving the ability to shape, create or respond to change, as well as enabling measures to strengthen absorbing capacity and reduce vulnerability.
- Strengthening adaptive management practices can also challenge the IWRM approach. Research from Brazil highlights tensions and trade-offs between the different institutions and mechanisms perceived as desirable to support IWRM practices on the one hand, and adaptive management practices on the other.
- Research carried out in Tanzania suggests that good adaptive management shifts the start conditions of IWRM-based reform from 'ideal' to 'expedient' approaches, focusing on the development of local adaptive capacity to solve existing or foreseen problems in pursuit of stated goals. Here there is a strong emphasis on participatory, social learning approaches, leading gradually over time to the introduction of IWRM principles and practices.

Adapting the IWRM approach - managing for both short term shocks and longer term stresses
The issue of how to manage for both short- and longer-term futures - including short-term shocks and longer-term stresses - is a further defining feature of climate change adaptation, and one that to an extent reframes the IWRM approach. In this respect, techniques such as 'backcasting from normative futures' and 'transformative scenario planning', may have much to offer. Development of normative futures (visioning a possible future(s)) is already part of the Catchment Management Strategy Planning guidelines and it might be useful to consider how these guidelines could be adapted in the context of these and related techniques.

Water reform as an adaptive process
- While IWRM principles were placed at the heart of the NWA and the NWRS, the focus on new institutions such as CMAs and WUAs and a top down, expert driven and regulatory approach to implementing the water reform process has reflected a mechanistic way of thinking that in some ways has had the opposite effect to what was intended, closing down rather than enabling local innovation, experimentation and adaptive capacity. This has been further reinforced by leadership issues and overall governance from DWA (at both national and regional levels) on the value of the water reform process.
- This section therefore ends with five suggestions for managing South Africa's water resources in a climate changing world, based on a new and revised set of adaptive implementation pathways. Each of these involves a reframing of current practices and policy, enabling a move to water resources management which is understood as a social and institutional learning journey, consistent with a 'paradigm 5' approach to climate change adaptation. These are:
  - Shifting from ideal to expedient and adaptive approaches to IWRM;
  - Shifting from top down to self-organising approaches (while recognising that both are needed);
  - Enabling local self-organisation - from guidance and training to supporting learning approaches;
  - Designing for nationwide innovation 1. Investing in areas where autonomous adaptation/innovation is already happening ('innovation hubs');
  - Designing for nationwide innovation 2. Investing in vulnerability hotspots as well as innovation hubs and supporting hub-hotspot learning.

15.3.6 Who could do what? The role of different actors, with a central focus on innovation brokers and systemic intermediaries

Previous parts of the reference/guide book consider what may be needed for South Africa to manage its water resources in the context of climate change, reinforcing but also requiring adaptation of the current water resource reform process. This is captured in five suggested action areas set out at the end of Chapter 5 of the reference guide. However, no change happens without key actors driving and enabling that change. In this chapter we therefore consider examples of some of the actors who might be in a position to implement an adapted water reform process, noting the potential roles of a broad mix of actors from a broad mix of sectors. Our primary emphasis is on working with a dynamic, self-organising landscape and identifying additional 'high leverage', 'low input' actions and initiatives that can help to 'tip' the landscape in the direction of systemic and adaptive water resources governance.

The role of innovation brokers
- In the context of the above, we attach importance to the role of those individuals who can act in what we call an 'innovation brokerage' or 'systemic intermediation' role. We describe the qualities of this role from several perspectives, highlighting, not surprisingly, the ability to work effectively in situations of uncertainty and complexity, to broker innovation processes involving multiple actors, and to support learning and reflexivity in others. We also highlight the role of so-called 'bridging organizations', through which such individuals often operate.
- We believe that there are many innovation brokers, and a variety of organisations playing bridging or systemic intermediation roles, already in South Africa - some working in the water resources sector and many working in other sectors. Furthermore, many of these individuals/organisations carry out much of their work 'below the radar', in the sense that their unique contribution is yet to be fully appreciated by government or by other strategic funding organisations.
- These individuals are located in a variety of sectors, including NGOs, universities, business and city metropolitan government. In the remaining sections we provide examples of such individuals

and/or organisations from each sector, looking also to the contribution that each sector could be making to the further mobilization and upscaling of systemic intermediation practice for adaptive water reform.

The role of the DWA

- In the final sections of this chapter we ask: given the existence of proto/innovation hubs in a range of NGOs, universities, business and city metropolitan government, what roles could the DWA itself be adopting?
- Here we develop the argument that by viewing the water reform process through a more dynamic, emergent and self-organising lens, which could include stronger collaboration and mutual learning between existing systemic intermediaries, new opportunities are also opened up for the DWA to play a significant leadership role. This should comprise three interconnected elements:
  - Sponsoring the role of systemic intermediaries in innovation and vulnerability hotspots;
  - Implementing the development of Catchment Management Agencies and encouraging these agencies to work closely with local systemic intermediaries;
  - Demonstrating strong national leadership within the water - food - energy - climate security nexus.
- We also argue that there is value in the DWA supporting an emergent strategy for adaptive and integrated water governance, for example by fostering learning networks within and between CMAs.

15.3.7 Conclusions and recommendations

The suggestions offered and developed through the previous chapters are summarized in terms of the following, inter-linked recommendations

R1: The role of innovation brokers

We hope that this handbook will encourage innovation brokers to further value and develop their unique role in:

- R1.1 Supporting and enabling expedient and adaptive approaches to IWRM - for example through facilitation, capacity building and learning interventions;
- R1.2 Supporting and amplifying self-organising approaches to expedient and adaptive IWRM as these are emerging within local networks and governance systems;
- R1.3 Further investing in areas where autonomous adaptation/innovation is already happening ('innovation hubs') - for example by experimenting with new approaches to managing for futurities at different timescales, and / or by deepening adaptive management and governance practices.

R2: The role of the DWA

We hope that these reference guide books will encourage the DWA to view the water reform process through an expanded, dynamic, emergent and self-organising lens. Specific recommendations include:

- R2.1 Sponsoring the role of systemic intermediaries in both innovation hubs and vulnerability hotspots;
- R2.2 Considering a significant investment in a vulnerability hotspot, supported by catalytic learning networks with one or two innovation hubs;
- R2.3 In implementing the development of Catchment Management Agencies, encouraging these agencies to work closely with local systemic intermediaries;
- R2.4 Supporting an emergent strategy for adaptive and integrated water governance, for example by fostering learning networks within and between CMAs;
- R2.5 Demonstrating strong leadership at a national level within the water - food - energy - climate security nexus.

R3: The role of the Water Research Commission (and other funding agencies)

We hope that these books may encourage the WRC to reflect on areas where it can also exert maximum leverage within an expanded, dynamic, emergent and self-organising landscape of water reform. Specific recommendations include:

- R3.1 Investing in further research to map and highlight the work already being undertaken by systemic intermediaries;
- R3.2 Investing in action and transdisciplinary research approaches that can contribute to transformation reform approach outlined;
- R3.3 Working with DWA and with systemic intermediaries to develop an approach to monitoring and evaluation of the ongoing water resource reform process, based on an appropriate theory of change and relevant M,E&L tools such as developmental evaluation.

15.4 Next Steps: Using the Books as a Means to Engage in Effective Dialogue on Mainstreaming

Given the limits encountered in the project in developing the book products in an interactive way with stakeholders, the major consideration now facing the authors concerns the question of how to promote its use. In the new parlance of WRC, this is a question of designing for 'effective knowledge flows' (e.g. Burt *et al*., 2011). While this doesn't fall within the aegis of this project, there is a need to consider further how the project team might best use the handbook as a means to engage in effective dialogue on mainstreaming.

One of the first steps towards this has been to produce a short version of the handbook alongside the full-length version, for wider distribution and engagement.

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LESSONS LEARNED AND RECOMMENDATIONS FROM SECTION C

Mainstreaming Climate Change into Decision Making

Mainstreaming implies preparing management interventions and taking organisational issues into account to ensure success. Global change and climate change are ***why*** we should do things, vulnerabilities identify ***what*** we should be doing or prioritising, and IWRM and AM are ***how*** we should approach the design of adaptation options. It is crucial at all times that the partakers and decision makers be aware of the uncertainties and the constant change associated with climate change as well as with socio-economic features of communities.

Such processes of planning management interventions are complex and research indicates that certain characteristics are needed to do this successfully in an environment of sequential change, of periods of consolidation and of evaluation (points 1-4 below) and in order to move towards decision making (points 5-6). These characteristics are:

1. Dealing with uncertainty in order to increase resilience, expressed through ***flexibility***;
2. Enabling change and adjustment, expressed through ***responsiveness***;
3. Establishing a discourse amongst governmental departments as well as beyond the water sector, expressed through ***coordination***; and
4. Connecting across levels and scales, expressed through ***cooperation***.
5. While designing and prioritising adaptation options one needs to include all stakeholders, and ***leadership*** is needed for taking the decision of the final management intervention. This answers the question as to who should be implementing the catchment as a potential space and where the discourse should take place (including other spatial scales is advisable!)
6. ***Reflection*** of individuals and organisations is indispensable in order to evaluate and therefore optimise and revise decisions taken.

The diversity of issues that are needed for successful adaptation and mainstreaming thereof are vast and interlinked, and therefore the intensity of mainstreaming can vary. This is reflected by the development of a minimal versus a maximal approach:

1. Understand and include climate change into the planning of the water sector (minimum)
2. Integrate issues from outside the water sector (low optimum)
3. Understand and include climate change impacts on a relevant scale into decision making and the design of regulations within the water sector (high optimum)
4. Understand and include climate change into any daily decision making and design of regulations, but also integrate issues from all other sectors (maximum).

Increasing the level of intensity and integration respectively increases the complexity significantly. Three main challenges regarding the required skills for this arise:

1. The need for connection in the sense of cooperation and coordination of organisations and individuals beyond their day-to-day work which normally is focused on colleagues and activities within one department on one governmental level. This connective communication skill is needed to ensure the inclusion of new information, creating new knowledge, and understanding vulnerabilities.
2. The increasing complexity means dealing with more diverse knowledge and also negotiating trade-offs between players and sectors in order to prioritise and implement management interventions. This complexity management skill has two dimensions: that of the individual and that of his / her organization.
3. Finding ways of innovation in a rather rigid organisational set-up, which includes the utilisation of windows of opportunity, relates to a creative and visionary entrepreneurial skill that would need to include creative thinking and solution seeking. Most probably an existing visionary outlook of the individual, *viz*. knowing how the single decision fits into the long term development of water resources, would be rather helpful here.

The suggestions on the mainstreaming process and the capacity and skills needed by the actors will take time to implement and build. They demand new partnerships, potentially new organisational

arrangements and a strong focus on gathering a variety of socio-economic information that is included in robust and continuous monitoring processes.

Prioritising and Implementing Management Interventions

When exploring the legislative components of South Africa's water regulatory framework in the context of its ability to perform in an integrated and adaptive manner, it offers a unique and flexible set-up to understand existing as well as emerging vulnerabilities in order to proactively adapt to climate change. The framework even offers the flexibility to tailor regulations and water management to each catchment area. However, the research has shown that IWRM is the management approach to be followed, and despite many water policies having been in place for the past 10 years already, practice on the ground still shows high levels of fragmentation and limited integration. Holistic thinking and decision making approaches are reflected in only a few cases.

Overall, South Africa's water management system and sector shows a diverse set of emerging issues which urgently need to be dealt with:

- The Policy-Management Cycle is fragmented and not closed. Thus, change in general and climate change specifically cannot be dealt with easily. This also applies for current and emerging vulnerabilities and the further degradation of the water resources.
- The South African narrative of a 'lack of capacity and skills' needs to be differentiated into its components. Each level, *viz*. political, professional, implementation and compliance capacity, will require a tailored approach with certain tools, and only then will a sustainable solution be found to the capacity problem.
- Communication with stakeholders (the governance dimension) exists in the water sector in a systemic way, but is not effective, with genuine cooperation generally still lacking.
- Last, but not least, fatigue is embedded in many parts of the water management system because of constant change taking place through new policies, changes in leadership or re-organisation within the DWA. It seems that a time of consolidation is urgently needed.

The champion workshops have shown that the true extent of current risks and threats, especially under climate change, are not known or appreciated, which is alarming as this lack of knowledge inhibits the identification of priority areas and the proper allocation of resources. The workshop participants found it challenging to make the climate change projections more relevant to their respective spheres of decision making. All activities demonstrated that most of South African catchments are unique in their biophysical and social characteristics, and that interventions, whether from government or the private sector, cannot be of a generic nature, but must rather address the characteristics of the specific catchment, i.e. climate change information needs to be contextualised and localised. Nevertheless, all workshops identified the ecological infrastructure approach as a first step towards adaptation, with other steps being strengthening the institutional / governance set-up. Furthermore, the need was identified for a continuous communication platform at catchment scale, complemented by an implementing authority such as a CMA.

All workshops included moments of surprise by all partakers in regard to contextualizing climate change information, understanding vulnerabilities and designing appropriate adaptation options. This clearly indicates the danger, especially for experts and water managers, to not make assumptions based on what one thinks they know, but rather to 'dig deeper' and reflect on issues in a participatory way and a social learning environment in order to enable informed decision-making.

This also points to the great need to bridge this gap between knowledge produced by science and knowledge relevant for decision making. Neither the scientists nor the decision makers felt that they were currently in a position to take on such a bridging role. However, for knowledge creation as well as communication the science-society as well as the science-decision maker interface was emphasised.

Often this may require a reframing of the problem, which can be supported by relational practices that will allow translating a meaning from a scientific to a societal context, and then to a decision making context (e.g. through participatory scenario development and / or group model building).

In conclusion, adaptation design calls for an enabling environment that gives space for knowledge exchange and learning conversations, and that caters for the interplay of systemic, organisational,

and individual needs. Such conversations cannot be done without a mix of decision makers and stakeholders because of the uncertainties that exist in development trajectories (be they climatic, economic or political), as well as limited data and knowledge of the impacts and their interlinkages. Further, It needs to be highlighted here that adaptation design and implementation need to be combined with the necessary budgets and require substantial time commitments over and over again.

Implementing the National Water Act Successfully

Local stakeholder participation and involvement
Steps should be taken to increase community participation and involvement in the water management platforms such as Catchment Management Forums in order to ensure effective water management at local level. More social learning stakeholder platforms where key water stakeholders, different sectors related to water management as well as civil society are represented, should be considered to allow for effective management of water resources and allow learning-by-doing between various stakeholders.

In order for water management to bring about positive change to all parts, but especially those impoverished parts of society, local communities must have a say in how they want their water resources to be managed. This can be achieved by adopting and maintaining a more consultative and inclusive approach in the planning and management of water resources through community meetings with residents and residents' associations such a 'community's of practice'. Involving residents in the entire process will encourage mutual respect between stakeholders but more importantly will guarantee effective water management resulting from the level of support from, and participation of, the residents.

Communication and dissemination of information to local level
Effective communication and the distribution of information are key elements to increasing the levels of awareness on water issues. Key water stakeholders should provide communities with regular feedback and updates pertaining to water issues concerning them. This could assist in minimising the potential future water restrictions and domestic water quality issues. Concerns related to water problems that could potentially occur should be addressed and communicated using a multi-media approach well in advance, so that communities are aware and well prepared. Information should be made available freely to society by assigning a dedicated call centre, radio broadcasts, print media and electronic mediums such as websites, etc.

Issues identified in implementing the National Water Act successfully include the following:

- Integrative management of water resources and water services, i.e. mechanisms for better co-ordination between water resource management and water services must be established to ensure the sustainable use and protection of water resources.
- The water service needs for a Water Management Area must be incorporated in guidelines for preparation of the CMS.
- Upon their full establishment, CMAs must have an input on the Provincial Water Sector Plan (PWSP) to ensure that the catchment water needs are incorporated. In that way the priorities set by the CMAs and the priorities set by the Water Services Sector will be integrated to ensure efficient planning of resource use.
- There must be continuous cross-communication between CMAs and WSA, i.e. CMAs must be consulted when the Water Services Development Plans are compiled.
- The relationship between the CMAs and WSAs must be clearly stated in the CMS guidelines.

Using the uMngeni River Basin Initiative as an Example for Driving Sustainable Development Through Leadership

In this chapter actions were identified. For the most part, each action is already a mandate of one or the other lead organisation. It involves people and organisations doing the jobs assigned to them. Examples of actions identified were as follows:

Department of Water Affairs
- Establish, with stakeholders, an institutional mechanism for the governance and management of the uMngeni River Basin

- Improve regulatory compliance capacity
- Increase focus on demand-side water conservation and management.

KZN Planning Commission
- Facilitate increased provincial public sector participation in engaging the Basin.
- Align water resource supply with economic development aspirations.

Municipalities
- Fix the leaks in both water reticulation and sewers and maintain the systems
- Collect refuse
- Improve revenue collection and price water appropriately (at its full cost)
- Monitor and regulate land transformation.

eThekwini Municipality
- Support upstream municipalities in fulfilling their specific service delivery mandates.

Umgeni Water
- Support local municipalities in reducing water loss and improving sanitation systems.

Traditional Authorities
- Improve land use planning
- Regulate grazing practices.

Business and Industry
- Place water resource management high on the agendas of the Durban and Pietermaritzburg Chambers of Commerce
- Accelerate focus on water conservation and rainwater harvesting
- Leverage regulatory compliance amongst polluting businesses.

Department of Human Settlements
- Ensure that there are rainwater harvesting systems designed into every new housing development.

Commercial Agriculture
- Reduce nutrient runoff from commercial agricultural land, particularly in those sections of the basin feeding Midmar, Albert Falls and Spring Grove Dams
- Accelerate water conservation measures in irrigation
- Get organised into Water User Associations.

NGO and public conservation agencies
- Monitor and manage land transformation
- Strengthen conservation stewardship programmes, particularly in areas of high water yield and high biodiversity.
- Accelerate and better coordinate alien invasive plant removal and habitat restoration.

Universities and other Research institutions
- Together with Umgeni Water and DWA establish a State of the uMngeni River Basin Report.
- Together with Umgeni Water and DWA establish a shared information and knowledge platform
- Ensure that research findings are accessible to managers and stakeholders
- Establish post-graduate training and education programmes that focus on high-end water resource leadership, management and technical skills.

For the uMngeni basin a partnership with the University of KwaZulu-Natal (UKZN) and Durban University of Technology (DUT) as lead institutions is a logical starting point. Both are recognised leaders in knowledge generation in support of water resource management. They also have considerable depth in disciplines required to support water resource management. These range from filtration technology through hydrology to water law. In addition, they are currently already educating and training the leadership cadre of tomorrow and can mobilise partners from numerous sectors. In short, together with the numerous partners they can deliver ‘source-to-sea’ solutions for many situations.

What might guide our thinking in the design of this partnership?

- It is a partnership programme focused on participative learning and improving our knowledge about water resource governance, management and technical issues at the scale of the river basin.
- It is an integrated study dealing with the river basin as a social-ecological system
- It is demand or needs driven, with regulators, managers, planners and users being instrumental in identifying the key research areas
- It is a mechanism to provide existing research capacity with direction and focus, and to contextualise current and past research
- It is a vehicle to build new leadership, management and research capacity through post-graduate training and experiential learning.

SECTION D:
OVERARCHING LESSONS LEARNED AND KNOWLEDGE TRANSFER

Introduction of Section D

This section on overarching lessons learned and knowledge transfer refers to points 6 and 7 (a and b) in **Figure D1**. In this section an attempt is also made to capture the 'lessons learned' from the overall project as discussed during the last team workshop held in August 2013.

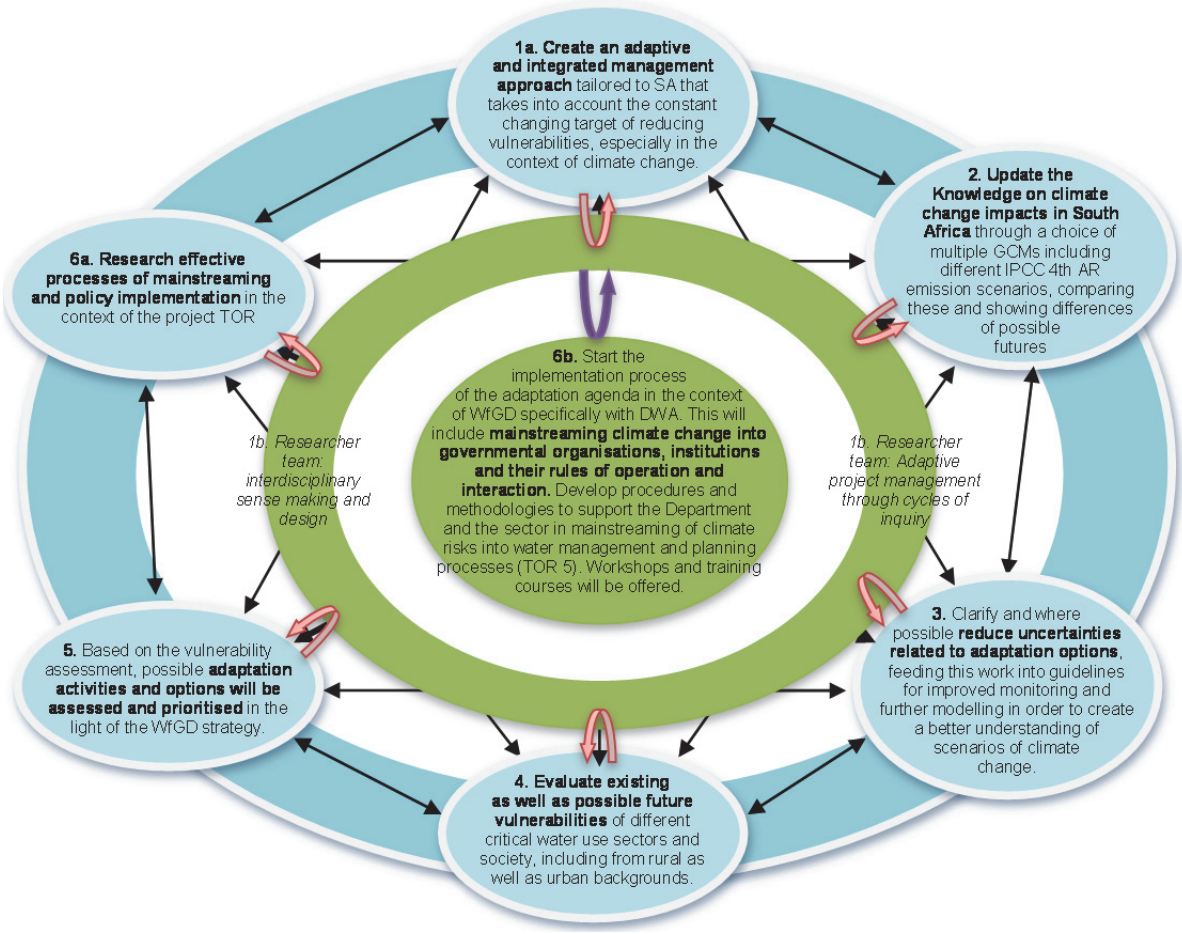


Figure D1 Diagram showing the six project work packages and their inter-relationships. The diagram shows how the research team intermediates the inter-relationships between the six work packages in the outer (blue) circle, and the work package focusing on knowledge co-production with stakeholders (inner green circle), through a process of interdisciplinary sense making and adaptive project management (middle green circle)

CHAPTER 16: CONCLUDING THOUGHTS AND KNOWLEDGE TRANSFER

16.1 Integrated Lessons Learned

This is an attempt to capture the 'lessons learned' from the overall project as discussed during the last team workshop held in August 2013.

16.1.1 General

- We need to recognize that environmental systems have biophysical limitations which vary between catchments, regions and nations.
- Transdisciplinary research is an experience that needs to be lived. Team workshops, for example, should be two days instead of one, to allow reflections and discussions of each other's work, beyond presenting and understanding each other's work, as well as to evaluate the implications for one's own work as one moves forward.
- We are certain of uncertainty. We need to learn to live with change.
- Communication platforms are required, including the considerable communication gap between research and practitioners.
- The basics (e.g. with regards to minimum living standards, education, natural resources management) need to be in place. Climate change adaptation builds on the basics. It is more and more important to "do the right things" and to "do things right".

16.1.2 Biophysical and vulnerability related issues

- Climate change uncertainties within the biophysical realm often tend to be overstated. Uncertainties in regard to, for example, population statistics or inconsistencies in irrigation databases (e.g. WARMS) are often as great if not greater than those from climate change scenarios. It is recommended that intermediate climate change projections (to around the 2050s) should be used, rather than the more distant projections to the end of the century.
- Outputs from the more recent downscaled global circulation models should be used in hydrological projections, with great care taken in making relevant adjustments when further downscaling to Quinary Catchments.
- We need to "teach the teachers" about climate change, e.g. extension officers.
- Land use can have severe impacts, especially locally, on water availability and other ecosystem services and these changes can dominate over those of climate change. The impacts of land use change can be modelled quite realistically and an ecosystem services change assessment should be included in the land use planning process. The impacts depend on the type and management of land use, as well as the amount of land transformed from natural land cover to other land uses.
- There are biophysical limitations to the services that ecosystems can provide. These depend on amount and type and management of a land use. Climate change places an added dimension of change.
- Vulnerabilities are created by local and national 'set-ups'. Therefore climate change adaptations need to reflect this 'split' of different scales. Social grants may lower vulnerability, but they also lower the adaptation potential and there could be grave effects if grants were to be discontinued.
- On dependencies on water vs. income in rural communities: In townships, infrastructure and maintenance are of key importance for water provision. People living in urban areas seem to be more aware of water scarcity and climate change. Climate change should be put in the context of, for example, rural, urban or township settings, and adaptation needs to suit the local needs.
- A lack of education on adaptation is lacking. Climate change education and creating awareness is an on-going learning process, especially in rural areas.

16.1.3 The governance and management dimension

- The roles, skills and tools of 'governance' and 'management' need to be differentiated
- Mainstreaming climate change adaptation is a long term and 'messy' process.
- The NWRS, the Reserve determination and water licensing present themselves as bottlenecks within the management and governance system.

- There seems to be lack of insight in regard to South Africa's policy instruments and their interplay.
- Innovative management needs agency as well as political commitment, and technical knowledge.
- Several innovation brokers have been identified, coming from various organisations. They have to be recognised and appreciated as individuals, as do the organisations they work for. Those innovation brokers require a specific skill set. The reference guides / handbooks will try to address that.
- The voices of the 'vulnerable' are critical (including power relations to be dealt with), and they are often not heard.
- Leadership by government on all levels is needed for out- and up-scaling
- Framing, or the point of departure, is critical to designing adaptation activities.
- "The runners are getting old". Particularly in technical departments of government younger people need to be mentored and capacity built, especially at middle management level, and institutional memory has to be built up.
- Depending on the individual or organisation there are various perspectives on, for example, management, governance and on climate change. Communication between individuals and (especially) organisations is required.
- Inertia in society often prevails, because basic needs have often not been met.
- Information must be in an understandable form.
- Holistic visions need to include the social and biophysical systems as well as the feedback and forwards associated with them.
- Information needs to be tailored to suit the targeted group through, for example, social media, pamphlets, or handbooks.
- Within their means local communities are trying to live with climate variability and change in their local context. Often a lack of resources is disabling them to bring adaptation to full fruition.
- Care should be taken by development practitioners and government to implement sustainable interventions in addressing the ills that may come with climate change.

16.2 Overarching Lessons Learned, Based on the Transdisciplinary and Adaptive Mode of Research

Confidence levels are increasing in regard to climate change projections as well as on the hydrological response and water quantity scenarios. Water availability, however, is also influenced by other aspects, such as water quality. Such additional multiple stresses are still difficult to capture, understand and model and they currently can inform decision making only in a limited way.

Science as such, and modelling in particular, will only be able to partially inform the understanding of climate change impacts and resulting vulnerabilities. Sub-catchment versus primary catchment and socio-economic issues are seemingly playing a greater role in overall water availability, access and use, and hence are critical when designing adaptation options. Therefore, an adaptive and participatory management style is key to current decision-making.

Participatory processes, action research approaches and social network building have shown that the complexities of vulnerabilities of different scales, as well as various organisational challenges, cannot be over-emphasised when designing management interventions. Furthermore, the interplay of systemic and organisational capacities and individual skills will be key to successful mainstreaming of climate change into day-to-day decision making. As the various workshops and interviews have shown in this project, implementation followed by adequate monitoring and law enforcement always needs to be driven, or at least guided, by governmental actors on all levels.

Notwithstanding these imperatives, an emerging reality, centered on learning and self-learning approaches, has also been shown to be invaluable in ensuring the mainstreaming of adaptation. Issues such as the initial framing of the adaptation challenge are critical for successful adaptation mainstreaming. Essential additional dimensions thus include,

- firstly, a transdisciplinary approach that can be central to building a co-created adaptation agenda,
- secondly, the need to embed any adaptation efforts into the existing context in the water history of South Africa (e.g. IWRM to AWRM),

- thirdly, the ability to be able to include elements of self-organisation into processes of adaptive management design that has elements of a 'history of learning' and,
- finally, a collaborative, mutually accepted process to backcast normative futures for future adaptive design.

Other key issues identified in the research that hinder successful adaptation to climate change in South Africa currently are centralised tools which can result in severe bottlenecks for integrative and participatory planning and implementation. Furthermore, the much-needed organisational capacities and individual skills are not displayed in the overall governance system.

This research project has shown that water will need to from an integral part of any decision making, particularly given that South Africa requires a successful development and growth trajectory that is sustainable. Water would need to be accepted as the main limiting resource for development across all levels and sectors.

16.3 Knowledge Transfer

Four aspects of knowledge transfer are highlighted:

- Capacity Building through the Award of Higher Degrees
  - 2 PhDs resulted directly from this project, *viz*. S. Stuart-Hill and S. Shisanya;
  - 2 further PhDs have / will result(ed) partially from this project, *viz*. N Methner and T. Lumsden;
  - 3 masters degrees resulted directly from this project, viz. S. Schütte, S. Ncgobo and N. Vilakazi; and
  - 2 Honours research projects came directly from this project, viz. B Scharfetter and T. Ngubane.
- Capacity Building through Workshop Participation
  - This includes the capacity built with the many participants who participated in the uMngeni and Berg Catchments by enhancing their understanding of climate change and adaptation, and by the capacity built during post-project workshops.
- Publication of Papers in the Scientific and More Popular Literature
  - In total 6 papers drived from chapters in this Report have been submitted to scientific journals, one of those has already published and others under review, and a further 3 papers are in preparation. Three further papers related to the project were published in the international literature. They, together with the one mentioned above, are listed below.
  - Furthermore, two papers were published in Conference Proceedings (see below)
  - A popular article on the project appeared in "Water Wheel" in 2013.
- Presentations at Symposia and Workshops
  - In total, 25 presentations were made based on research from this project. They are listed below.

Papers in Scientific Journals

Huntjens, P., Lebel, L., Pahl-Wostl, C., Camkin, J., **Schulze, R.E.** and Krantz, N. 2012. Institutional design propositions for governance of adaptation to climate change in the water sector. *Global Environmental Change*, 22. 67-81.

Ison, R., Collins, K., **Colvin, J.**, Jiggins, J., Roggero, P.P., Seddaiu, G., Steyaert, P., Toderi, M. and Zanolla, C. 2011. Sustainable catchment managing in a climate changing world: New integrative modalities for connecting policy makers, scientists and other stakeholders. *Water Resources Management (Special Issue),* 25. 3977-3992.

Ngcobo, S., Jewitt, G.P.W., **Stuart-Hill, S.I.** and Warburton, M.L. 2013. Impacts of global change on southern African water resources systems. *Current Opinion in Environmental Sustainability*, 5. 655-666.

Pahl-Wostl, C., Arthington, A., Bogardi, J., Bunn, S.E., Hoff, H., Lebel, L., Nikitina, E., Palmer, M., Poff, L.N., Richards, K., Schlüter, M., **Schulze, R.E**., St-Hilaire, A., Tharme, R., Tockner, K. and Tsegai, D. 2013. Environmental flows and water governance: managing sustainable water uses. *Current Opinion in Environmental Sustainability*, 5. 341-351.

Conference Proceedings

Schulze, R.E. 2012. Evaluation of Uncertainties when Assessing Climate Change Impacts on Hydrological Responses in South Africa. *Proceedings, 16th South African National Hydrology Symposium,* University of Pretoria, Pretoria. pp 13. On CD-Rom.

Stuart-Hill, S.I., Bulcock, L.M. and **Schulze, R.E.** 2012. Identifying Climate Change by Understanding Water's Link to Societal Vulnerability. *Proceedings, 16th South African National Hydrology Symposium,* University of Pretoria, Pretoria. pp 14. On CD-Rom.

Presentations on the Project by Prof RE Schulze

KZN Department of Economic Development and Tourism Green Economy Research Conference, Durban/RSA, February 2012. Invited presentation on ""The challenges of climate change and the demands of a green economy on the utilization of natural resources"

Chris Hani District Municipality Climate Change Summit, Queenstown/RSA, February 2012. Invited presentation on "Climate change and the Chris Hani District Municipality… What I would do if I were you".

National Business Initiative CDP Water Disclosue SA Launch, Johannesburg/RSA, March 2012. Invited presentation on "Assessing the value of water in regard to critical issues now and into the future: Business implications".

DEA-GIZ Long Term Adaptation Strategy Expert Workshop, Pretoria/RSA, April, 2012. Invited presentation on "Climate change scenarios over South Africa: A perspective in light of adaptation studies".

***Moi University 8th International Conference on Adaptations to Global Dynamics: Challenges and Opportunities**, Eldoret / Kenya, September 2012. Invited keynote speaker on "Climate Change and National Development: Challenges to Science and Engineering".

Long Term Adaptation Scenarios Technical Working Group Workshop, Pretoria/RSA, October 2012. Invited presentation on "Attempting to understanding links between water and socio-economic vulnerability in South Africa under conditions of climate change: Case study from two catchments".

DEA Climate Change Loss & Damages Workshop, Pretoria/RSA, October 2012. Invited presentation on "Are risks and damages likely to alter into the future with climate change? What are impacts models indicating over South Africa and other questions".

***International Conference on Fresh Water Governance for Sustainable Development**, Champagne/RSA, November 2012. Invited presentation on "Some challenges for water security arising from global and climate change: A perspective from southern Africa".

***African Science Academies' Conference on Climate Change in Africa: Using Science to Reduce Climate Risks**, Lagos/Nigeria, November 2012. Invited presentation on "Building a scientific knowledge base for climate change modeling: Experiences from South Africa with examples from the agriculture, health and disaster risk management sectors".

SA Institute of Civil Engineers Water Engineering Division, Pretoria/RSA, November 2012. Invited presentation on "Looking into the future: What are climate change projections indicating in regard to South Africa's water resources".

1st National Global Change Conference, Johannesburg/RSA, November 2012. Presentation on "Impact of land use change through past and proposed urban development on hydro-logical ecosystem services> Case study on the Mpushini / Mkhondeni sub-catchments of the Umgeni".

WRC/UKZN/UW Workshop on Adaptation to Climate Change in the Mgeni Catchment, Assagay/RSA, January 2013. Invited presentation on "What is climate change? Background, myths and facts".

eThekwini Workshop on Water Security & Service Delivery through Investment in Natural Infrastructure in the Greater uMngeni Catchment, Pietermaritzburg/RSA, February 2013. Invited presentation on "Climate change projections and response requirements: An uMngeni catchment's water security perspective".

WRC Water Currents Policy Dialogue on "Copping Out or Coping", Pretoria/RSA: Invited keynote presenter on "Climate change and the South African water sector: Are we on track?".

WRC Workshop on Dealing with Uncertainties in Climate Modelling Projections, Pretoria/RSA, April 2013. Invited presentation on "Uncertainties in climate change impacts modelling: A hydrological perspective"

Global Water Systems Project International Conference on Water in the Anthropocene, Bonn/Germany, May 2013. Member of the Scientific Programme Committee; Invited keynote address titled "Drilling deeper or dumbing down: Dilemmas of developing countries' climate change challenges" in Plenary Theme II Global Dimensions of Change in River Basins; invited presentation titled "Water Security: Some Perspectives from the Developing World" in session on Water Security: Challenges for Research and Policy; Chairman session on Global Change in southern African Watersheds: Vulnerabilities, Responses and Opportunities.

WRC Climate Change Lighthouse Workshop, Pretoria/RSA, August 2013. Invited presenter on "Planning for climate change fir the South African water sector - A tale of two approaches: NWRS2 or drilling deeper?'.

Long Term Adaptation Scenarios Flagship Planning Workshop, Johannesburg/RSA, January 2014. Invited participant and presentation on "Background preparation for applications of new climate change scenarios for agricultural, hydrological and other impact studies" (Kunz, Davis, Lumsden, Schulze)

UNESCO Geosciences Information for Teachers Workshop on Climate Change and Human Adaptation, Port Elizabeth/RSA, February 2014. Invited presentation on"Reflections on climate change impacts over South Africa: why focus on water?"

Presentations on the Project by SI Stuart-Hill

GWSP Conference: Water in the Anthropocene Bonn, Germany, 21st - 24th May 2013. "Making sense of vulnerabilities and mainstreaming climate change into decision making: a southern African perspective".

Cities at Risk Workshop - Africa (START Programme) Durban, South Africa, 26th March 2013. "Socio-Economic Data and Urban Systems",

International Conference on Fresh Water Governance for Sustainable Development Drakensberg, South Africa, 5th - 7th November 2012. "A Snapshot of South Africa's Water Resource Management Status and What this Indicates for Overall Water Governance",

13th WaterNet/WARFSA/GWP-SA International Symposium on Intergrated Water Resource Management, Johannesburg, South Africa, 31st Oct - 2nd Nov 2012. "Mainstreaming Climate Change and prioritising Adaptation Options: Assisting Decision Makers in South Africa's Water Sector".

Third Berlin Forum, Shaping innovation in governance? Inducements, opportunities and limitations of engaging with governance in-the-making, Technische Universität Berlin, Berlin, Germany. 31st May - 1st June 2012. "Pragmatic Solutions for South Africa's water sector by understanding governance and designing innovations".

Governance Think Tank of South Africa organised by the Water Research Commission and Department of Water Affairs, Johannesburg, South Africa, 4th Nov 2011. Invited keynote on "South Africa's potential for adaptive management, its day-to-day challenges and resulting windows of opportunity."