Copyright © 2014 by the author(s). Published here under license by the Resilience Alliance.
Pollard, S., H. Biggs, and D. R. Du Toit. 2014. A systemic framework for context-based decision making in natural resource management: reflections on an integrative assessment of water and livelihood security outcomes following policy reform in South Africa. *Ecology and Society* **19**(2): 63. http://dx.doi.org/10.5751/ES-06312-190263

Insight, part of a Special Feature on Applied Research for Enhancing Human Well-Being and Environmental Stewardship: Using Complexity Thinking in Southern Africa

A systemic framework for context-based decision making in natural resource management: reflections on an integrative assessment of water and livelihood security outcomes following policy reform in South Africa

Sharon Pollard[1], *Harry Biggs*[2] *and Derick R. Du Toit*[1]

ABSTRACT. We aimed to contribute to the field of natural resource management (NRM) by introducing an alternative systemic context-based framework for planning, research, and decision making, which we expressed practically in the development of a decision-making "tool" or method. This holistic framework was developed in the process of studying a specific catchment area, i.e., the Sand River Catchment, but we have proposed that it can be generalized to studying the complexities of other catchment areas. Using the lens of systemic resilience to think about dynamic and complex environments differently, we have reflected on the development of a systemic framework for understanding water and livelihood security under transformation in postapartheid South Africa. The unique aspect of this framework is that allows researchers and policy makers to reframe catchments as being recognizable as complex social-ecological systems, and by doing so, the possibility is opened to understand resiliency in the face of rapid transformation and crisis. Ultimately, this holistic approach can be used to understand the translation of policy into practice. We have emphasized our reflections on the development and use of the framework and the challenges and successes faced by collaborators in the process of adopting such an orientation. Because these are likely to characterize policy and decision-making processes in NRM in general, we have suggested that such a systemic framing can assist researchers, practitioners, and policy makers to adopt systems and resilience analyses in the process of planning and implementation.

Key Words: *complexity; decision making; dynamic; governance; IWRM; livelihood security; resilience; SES; social-ecological systems; transdisciplinarity; transformation*

INTRODUCTION

There is evidence of a growing discomfort with governance and management based on linear cause-and-effect paradigms, often supported only by reductionist science (Forrester 1992, Holland 1999). Alternatives to these orientations are emerging in many sectors from natural science (Gunderson et al. 1995, Meadows 1999, Folke et al. 2002, Walker and Salt 2006) to business (Snowden 2000), education (Forrester 1992, Ison et al. 2007, Wals 2007), service delivery by government (Radzicki and Taylor 1997), and in disaster relief (Ramalingam et al. 2009). These concerns are supported by philosophical and epistemological critiques by scholars such as Edgar Morin, Paul Cilliers, and others (see Nowotny 2005, Heylighen et al. 2007).

Although alternative approaches are emerging from such diverse interests, the development of alternatives that embrace nonlinear cause-and-effect paradigms have been slow in the field of natural resource management (NRM). We offer an alternative approach that contributes to a systemic framing for planning, research, and decision making in complex environments. The framework is based on experiences from catchment-based work that started in the early 2000s regarding water governance reforms and the adoption of integrated water resources management (IWRM) in postapartheid South Africa. Although the work is ongoing, we reflect on a three-year study from 2005 to 2008 that sought to understand the impacts of policy-related transformation specifically on water and livelihood security in the Sand River Catchment (SRC), but to do this in a way that acknowledged the complexities and uncertainties typical of the management of catchment areas in general (Pollard et al. 2008). By viewing the catchment as a complex, dynamic social-ecological system (SES), we sought to examine the coupled nature of degradation, vulnerability, and resilience, i.e., social and biophysical, so as to explore the potential multiple outcomes, and lags, of policy reform as it plays out in complex environments.

The unique aspect of this framework is that it allows researchers and policy makers to collectively reframe catchments as recognizable complex SESs, and by doing so, the possibility is opened to understand resiliency in the face of rapid transformation and crisis. Although the concept of resilience was incorporated (sensu Berkes et al. 2003) when the study started, work on applying resilience in practice was still under development, notably, the resilience workbooks (RA 2007*a*, *b*), so that the work we report took place in parallel with those developments. Although the approaches share many features, some distinctions are elaborated.

Our emphasis is on our reflections on the development and use of the framework. Thus, the focus is not on the primary results reported in Pollard et al. (2008), although some illustrative exemplars are given, but rather to probe the extent to which such approaches can offer an effective way of dealing with systemic complexity in similar contexts. It is suggested that such a systemic framing can assist researchers and policy makers to adopt systems and resilience analyses in the process of planning and implementing policies dealing with water and livelihood security.

We define one of the two central concepts, water security, as "sustainable access, on a watershed basis, to adequate quantities of water of acceptable quality, to ensure human and ecosystem health" (Norman et al. 2010:10). The second concept, livelihood security, derives principally from the work of Chambers and Conway (1992), and as a component of this, household livelihood security is taken as "adequate and sustainable access to income

[1]The Association for Water and Rural Development, [2]SANParks

and resources to meet basic needs (including adequate access to food, potable water, health facilities, educational opportunities, housing, and time for community participation and social integration" (Frakenberger and McCaston 1998:31). Within this, access to water, for human and livestock needs, as well as for food production and other economic activities, which is the focus of this work, is an obvious contribution.

We begin with a brief description of the national policy and local catchment context, as well as the conceptual framing underlying the approach. Practically, the framework manifests as a suite of 10 inter-related steps presented in the *Methods*. The results focus primarily on our reflection on the use of this approach, although some case detail is provided to illustrate how the approach was used and the key outputs, which are discussed in relation to the wider implications for planning and management processes. We conclude by reflecting on some of the challenges and successes that the collaborators encountered in the process of adopting such an orientation and that are likely to characterize policy and decision-making processes for water governance in dynamic situations in general.

South Africa: a country of transforming policies

Political transformation, such as that experienced in South Africa with the transition from apartheid to democracy, can provide windows of opportunity to change such linear orientations and perspectives. In 1994, most South African policies underwent a major overhaul under the first democratic government. Social grants were introduced to support the vulnerable, and education was reformed. In the natural resource arena, water received concerted attention because of the country's chronic water insecurity and disparities in access (DWAF 2004*b*). Equity and sustainability were key principles of the new water policy, and, in recognition of water's pivotal role in socioeconomic development, holistic approaches such as IWRM together with cooperative governance and stakeholder involvement are now central (Schreiner and Hassan 2010). Although overall IWRM falls under the national minister, water governance is decentralized, with domestic water supply a municipal responsibility and delegation of water resources management to nine catchment management agencies (CMAs), which are in the process of being established.

The new national water acts, i.e., Water Services Act No. 108 (Republic of South Africa 1997) and National Water Act No. 36 (Republic of South Africa 1998), pertaining to water supply and management were promulgated in 1997 and 1998, respectively, and implementation was begun in earnest. In the many water-stressed areas, questions soon emerged regarding the extent of biophysical degradation and socioeconomic vulnerabilities, such as the role of water in poverty alleviation, and what remedial actions were necessary. A decade after promulgation, questions were arising concerning the seemingly slow pace of change and impacts of policy on water and livelihood security and whether resilient futures were being built. Despite ostensibly enabling policies and emerging institutional arrangements, there often appeared to be little wide-scale change on the ground. Single cause-and-effect analyses and responses used, e.g., building more dams, were starting to be regarded as overly simplistic in dealing with real-world realities and complexities, and more holistic and innovative ways to understand the continued water and livelihood insecurity were thus being sought by some. In many cases, the application of questions regarding durability and unintended consequences pointed to systemic failures of individual interventions. One such area of concern is in the SRC in the far northeast of the country, which thus offered an opportunity to be reframed as an SES with resiliency providing the capacity for renewal, innovation, and stability (sensu Holling 2000) in the face of rapid transformation and crisis (Berkes et al. 2003)

The Sand River Catchment: an area under transformation?

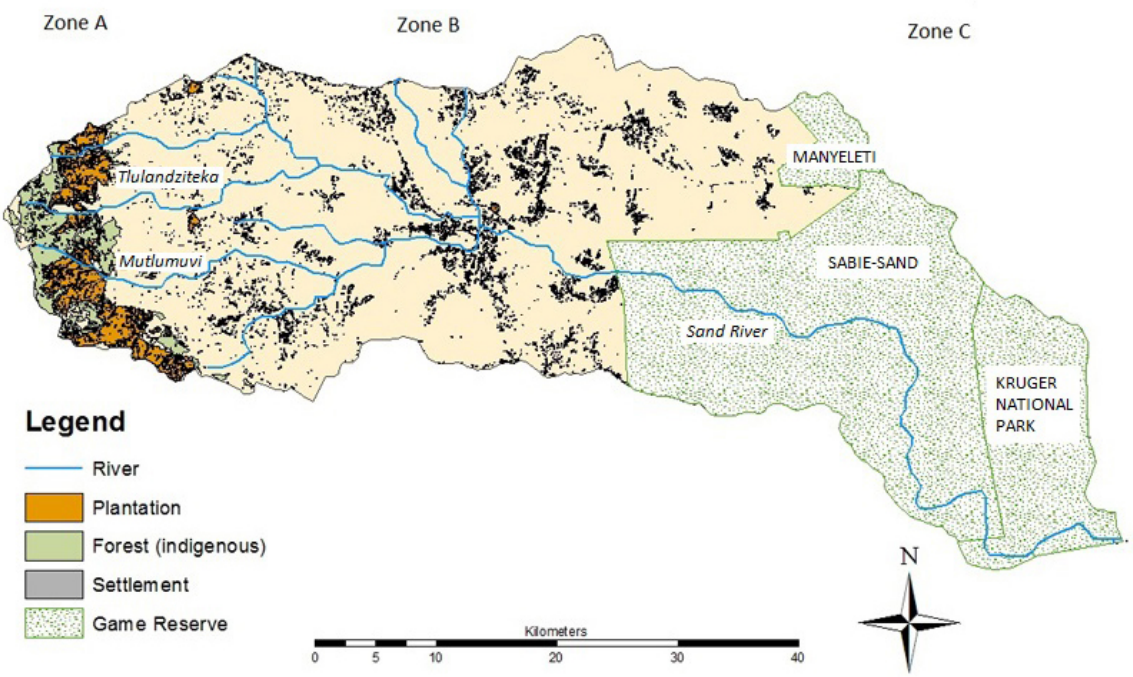
Our focus concerns the SRC, which is located in the northeastern part of South Africa (Fig. 1). Nonetheless, it encapsulates many of the issues and challenges faced by other catchments in South Africa as moves are made toward transformation for more sustainable and equitable futures. It is widely regarded as degraded and vulnerable, particularly because already stressed water resources are under pressure to meet further developmental demands (Pollard and Du Toit 2011*a*, Pollard et al. 2011). The area exemplifies many densely populated rural settings where juxtaposed characteristics of wealth and poverty, ecosystem health and degradation, and increasing contestation around natural resources together test giving effect to the principles of equity and sustainability. Like many catchments, the imperatives to generate and share wealth through redress of racial discrimination, land reform, and development must be balanced with long-term environmental security. Institutional arrangements are currently in transition, highly dynamic, and often confusing on the ground (Pollard et al. 2011).

Relatively small in area (2000 km²) and home to some 383,000 people, the SRC is regarded as severely degraded biophysically, and vulnerable and underdeveloped from a socioeconomic perspective (Pollard et al. 1998). It forms part of the Incomati Basin, an international watercourse, the South African portion of which forms one of 9 legally constituted water management areas. With the exception of the wetter, western mountainous region, the catchment is semiarid and is increasingly in water deficit, i.e., water demands exceed water availability, with the result that the once perennial Sand River now experiences flow cessations in some dry years (DWAF 2004*a*, Pollard et al. 2011).

For the purposes of analysis, we used the three broad zone areas (A, B, C) described by Pollard et al. (1998) that had emerged by the mid-1960s (Fig. 1). The three zones represented an afforested higher rainfall upland zone; a densely populated zone with intermediate elevation and rainfall, stock, and crop farming often at subsistence level; and a more arid western zone dominated by private and state conservation areas and ecotourism. These zones also reflect politico-historical factors that influenced land tenure and land use. Although each zone represented relatively homogeneous land uses, systemic links are evident in the pejorative downstream impacts of land use in Zone A and in the labor and cash flows from and to Zone B.

A striking feature today is the dense concentration of people (350 per km²) in so-called rural areas of Zone B juxtaposed with the sparsely settled, often affluent areas of Zone C, which are dominated by conservation. These differences reflect the legacy of apartheid where large numbers of people classified as "black" were forcibly moved into two former *bantustans*, i.e., land set aside for the exclusive occupation of black people, which made up Zone B, where levels of unemployment, illiteracy, and poverty were

Fig. 1. Map of the Sand River Catchment, showing the three major zones that comprise the catchment.



high, and livelihoods vulnerable (Beinart 2001, Pollard et al. 2008). Environmental degradation increased as people turned to natural resources to make or supplement a living (Shackleton et al. 1995, Pollard and Du Toit 2013). Males migrated to the urban areas in search of work, and female-headed households were prevalent (M. Collinson, S. Tollman, K. Kahn, and S. Clark, *unpublished manuscript*). Some government agricultural schemes were established in Zone B in an attempt to address the high levels of unemployment and poverty. Although beset by lack of access to water and other resources, these continue today and support between 600 and 1000 small-scale farmers, each with 1 ha of land. The high-altitude Zone A, where more than half of the catchment's water production occurs, was dominated almost exclusively by forestry, i.e., afforestation, mixed with indigenous forest and grassland (Pollard et al. 1998). Forestry enterprises were established in the 1970s in an attempt to provide employment for the burgeoning population in Zone B, but multiple perverse incentives rendered this activity largely uneconomical. In an attempt to meet contractual commitments for timber, vulnerable areas, such as steep slopes, riparian zones, and wetlands, were cleared for plantations. The impacts were felt through reductions in base flows to the Sand River and increased sediment production and transport (Pollard et al. 1998). Ambitious and visionary attempts to transform this situation post-1994 through zoning the area as a national park and the removal of forestry have stalled more recently as political commitments and interests have changed. Zone C, which includes both the Kruger National Park and the exclusive Sabi-Sand Game Reserve, has enjoyed relative economic prosperity as both tourism and land values have increased in the past 15 years. Interestingly, although economically powerful, as downstream residents of the catchment, these players have experienced growing water insecurity leading them to participate more broadly beyond their own fences (Pollard et al. 2003).

Changes in policies regarding NRM have been more nuanced through the strengthening of protected area policies, stewardship initiatives, and massive job creation programs, epitomized by Working for Water, meant to remove alien invasive plants with the aim of improving water supply, which became operationalized and commonplace, and all very visible in the SRC. Many other reforms influenced the catchment, the details of which are beyond the scope of our discussion but which included major educational and health care reforms, land tenure reform, restitution for the dispossessed, and the introduction of child-care grants for the indigent. Noteworthy among new drivers were the increase in HIV/AIDS and the pejorative impacts thereof (see, e.g., Hunter 2007). Nonetheless, the seemingly slow pace of change raised concerns regarding transformation. Despite enabling policies, there appeared to be a number of "sticking points" or blockages and lags in the SRC, which were being dealt with through approaches that we hypothesized failed to recognize the systemic nature of water security.

Conceptual framing

The key conceptual underpinning of this work is that of systems thinking. Systems thinking (Von Bertalanffy 1972, Checkland 1981, Forrester 1992) includes theories that concern themselves with complex phenomena; such theories arose partly as a critique to conventional reductionist approaches, which were considered to be ill-equipped to deal with complex interdependencies such as those found in NRM. The overall thrust in dealing with complex phenomena is to foster a broader view of overall context, challenging notions of optimization, maximum sustainable yield, and linear thinking (see, e.g., Gunderson et al. 1995, Cilliers 1998,

Levin 1999, Holling 2001, Folke 2003, Walker and Salt 2006). As stressed by Meppem and Bourke (1999), conventional NRM unrealistically abstracts, usually unidisciplinary, interests from real-world complexity.

Focusing on the complex inter-relationships among constituent parts, and thus on the whole through systems thinking, is a complement rather than an alternative to specialized views. Indeed, systems approaches incorporate both systemic and systematic perspectives (see, e.g., Laszlo and Krippner 1998). Important concepts contained in systems approaches include interdependence; holism and emergence; goal-seeking behavior; feedbacks and regulation; hierarchy; differentiation; equifinality, alternative ways of attaining the same objectives, i.e., convergence; and multifinality, attaining alternative objectives from the same inputs, i.e., divergence. These concepts are reviewed by various authors (see, e.g., Cilliers 2000).

Work on an integrative theory for coupled human-ecological systems, an SES, had culminated in a book entitled *Panarchy: Understanding Transformations in Human and Natural Systems* (Gunderson and Holling 2002). Panarchy was a term coined to describe the structure in which systems, e.g., SESs, are interlinked in never-ending adaptive cycles of growth, accumulation, restructuring, and renewal, known as the generalized adaptive cycles (GACs). These transformational cycles take place in nested sets at different scales. The authors suggested that by understanding these cycles at multiple scales, it seemed possible to identify points at which a system would be capable of inducing change that could be used as leverage points to foster resilience and sustainability deemed positive to stakeholders. Earlier work by Holling (2000) had also suggested that in trying to understand complex, evolving systems, there is a requisite level of simplicity that, if identified, can support understanding that is rigorously developed but that also can be lucidly communicated. He argued that if one cannot retain a handful of causes in an explanation, then the understanding is simplistic; whereas if more than a handful of causes are elaborated, then it is unnecessarily complex. That level of understanding is built on a sound integrative theory, rooted in empirical reality, and communicated clearly with metaphor and example.

This integrative theory has been further developed through the closely related concept of resilience, which broadly refers to the capacity of a system to absorb disturbance and reorganize so as to retain essentially the same function, structure, and feedbacks (see Berkes et al. 2003). Indeed, the Resilience Alliance (RA; http://www.resalliance.org) has popularized the handling of complexity through the exploration of resilience based on the central tenet that because variation absorbs shocks and confers resilience it should be embraced, not ignored. Further, a focus on resilience shifts the attention from purely growth and efficiency to recovery and flexibility and supports learning and adaptation. Ongoing work has asserted that a number of attributes confer resilience including feedbacks, diversity, innovation, polycentric and overlapping governance, social capital, ecological variability, openness, and reserves (Walker and Salt 2006, RA 2007*b*).

Our discussion encompasses these ideas and focuses particularly on feedback loops and their role in systemic issues associated with NRM. For example, feedbacks, often operating at different scales, cause emergence, i.e., the feedbacks generate surprising new properties not predictable from the original components making up the system. In feedbacks, an output from an event or phenomenon in the past influences an occurrence of the same in the present or future (Holland 1999). Understanding feedbacks also proved central to exploring the so-called lock-in traps, i.e., situations in which the adaptive cycle becomes "stuck" at one particular point and cannot continue its normal cycle of change, described by Allison and Hobbs (2006) that have led to continued degradation despite changes in policy and practice. More recently, Pollard and Du Toit (2011*b*) have suggested that multiscale governance feedbacks are essential for supporting resilient IWRM systems.

When considered together, these theoretical framings suggested that by adopting a systems view based on the notion of catchments as coevolving, complex systems, it might be possible to understand cyclical transformation and the leverage points of Gunderson and Holling (2002), as well as the factors that confer or undermine resilience. In effect, such endeavors form part of a broad body of work on resilience assessments, which elucidate how linked SESs respond and adapt in the face of disturbance such as changes in land use (Walker et al. 2002), identifying key social and ecological variables and thresholds that determine system status. This helps develop strategies assisting system recovery following disturbance. For example, Allison and Hobbs (2006) used these constructs to understand ongoing degradation on the agricultural lands of Western Australia through a combination of systems thinking and a form of a resilience assessment. They explicated the historical and policy context and the evolving epistemologies of NRM. This was used as the basis for model conceptualization as related to resilience theory and systems dynamics of their case study, and it was followed by a synthesis that included the use of scenarios and an elaboration of the implications for governance and institutions.

Nevertheless, as an emerging field of inquiry, not only were the approaches for resilience analysis still relatively unclear, but the literature did little to shed light on the convergence between various conceptual and analytical frameworks such as systems analysis and resilience assessments or analyses. For example, understanding an issue through the lens of the GAC only partly elucidated for the authors whether the system could be considered resilient and did not help them see what the implications for practice might be.

METHODS: THE DEVELOPMENT OF A SYSTEMIC FRAMEWORK FOR UNDERSTANDING CONTEXT AND CHANGE

As noted, the specific purpose of the initial work on which our discussion is based (Pollard et al. 2008) was to explore the potential impacts of policy changes on water and livelihood security, but to do this in a way that acknowledged the complexities and uncertainties typical of the management of catchment areas. Using the lens of systemic resilience as a means for thinking about such challenges differently, a holistic, systemic framework for understanding context and transformation was developed. This framework was adapted from that of Allison and Hobbs (2006) who combined systems thinking and an early form of a resilience assessment to understand degradation on the agricultural lands of Western Australia (as discussed previously). In our adaptation, the following key changes feature:

- An explicit inclusion of learnings from strategic adaptive management (Rogers and Biggs 1999), specifically the V-STEEP process, a heuristic prompting a comprehensive inclusion of factors, namely values, social, technological, ecological, economic, and political.

- In the resilience analysis "step," the GAC used by RA and Allison and Hobbs (2006) and certain attributes that confer resilience (Walker and Salt 2006, RA 2007*b*), plus others added by the authors, were all applied.

- A transdisciplinary, participatory review process by specialists including social scientists, ecologists, climate change specialists, educationalists, agriculturalists, and medical practitioners, the majority of whom had worked in or were familiar with the catchment, was included. This process of specialist involvement was designed to develop and test systems representations of the catchment, to discuss and evaluate thresholds and state changes, and to use these to develop and debate scenarios. The specialists were also asked to reflect on whether the approach generated a systemic understanding of resilience in such catchments and could meaningfully enhance management decisions and practice among a variety of stakeholders and levels. Our key concerns included the opinions of these participants.

Our integrative framework comprised 10 key steps outlined subsequently, the order of which implies a broad sequence, although there were several iterations between a number of steps. In practice, the specialists were engaged informally by the core team, i.e., the authors, from the start and more formally at a collaborative workshop after the authors had synthesized steps 1-6. This engagement allowed for the development of a broadly collective understanding from the earlier steps, as well as being important for the analysis of resilience and the evaluative steps 9 and 10.

1. Literature review: review of existing catchment data, relevant concepts, tools, and their application.
2. Bounding the system of interest: elucidating external and internal drivers considering resilience of what and to what (Carpenter et al. 2001).
3. Development of a GAC: used together with a timeline to identify timescales, i.e., eras, for analysis.
4. Development of timelines: to elucidate drivers and variables across time and to inform the selection of eras.
5. Holistic framing of context: description of the socio-political, institutional, and environmental context of eras, using the V-STEEP process described subsequently.
6. Develop systemic view of the SES, i.e., ongoing iterations: development of causal-loop diagrams (CLDs) as descriptions of "the SES system" for the selected eras.
7. Broad specialist engagement: with iterations of steps 4-6; initiation of collaborative approaches to steps 8-10.
8. Narrate the systemic view: through the consolidation of qualitative and quantitative data, i.e., through iterations of CLDs in which additional data were incorporated.
9. Qualitative resilience analysis and scenario development: both done collaboratively with the specialist group.
10. Implications and recommendations: consideration of these for management.

Apart from reflecting on experiences from the development and implementation of the previous suite of tools, we also reflect on some examples of the wider societal influence in terms of policy and outcomes that the work appears to have had in the five odd years since the work was initiated or that it may have in the future. These examples were chosen from the authors' own further experiences, and hence the list is not exhaustive and carries qualifiers.

RESULTS: REFLECTIONS ON ADOPTING A SYSTEMIC FRAMEWORK

Table 1 provides a synthesis of each step, its purpose, and the various evaluative inputs of both the authors and specialist group. The discussion provides more generic reflections regarding the application of our approach by practitioners and researchers in similar contexts.

The notions of resilience and vulnerability were critical components of the framework in terms of understanding policy reform and change. As noted, because a framework for a resilience analysis (RA 2007*b*) was not yet available when this work began, the team thus used a combination of systems thinking and the Allison and Hobbs (2006) approach together with published criteria known to confer resilience (Walker and Salt 2006), plus three criteria added by the authors, i.e., cross-scale, variability, and nature of learning. Comparison between our approach and that of the subsequently published RA workbooks shows a high degree of congruence. The most important differences relate to (1) high levels of effort in understanding history through timelines; (2) more formal scoping of context using the V-STEEP framework, which explicitly includes societal values; and (3) the greater emphasis placed on a systemic model of the SES through the collaborative development of the CLDs.

Step 1: In this step, studies that described the socio-political and ecological context of the catchment were reviewed as the basis for constructing the systemic view. This is a critical step in that it provides the basis for the systems analysis and a review of the empirical data on which to proceed through to the next steps. Further, a review of the conceptual framing also identified gaps in understanding or the need for greater coherency between different, although related, processes and approaches.

Steps 2 to 4: Although "systems" are models created to support understanding, and hence system boundaries are artificial, the selection of boundaries is designed to best suit the purpose of the work (see Ulrich and Reynolds 2010) so that studies and processes can be bounded as internal, external, or ignored (see Allison and Hobbs 2006). Given the focus on catchment water security, the catchment represented the spatial boundary with land-use zones, i.e., A, B, and C, as described previously, as subdivisions. Initially, the temporal boundaries chosen represented the arrival of

Table 1. Summary of the broad steps comprising the integrative framework, the purpose of each, and an evaluation of its application in this study.

Broad steps	Purpose	Evaluation
Step 1. Literature review (catchment, concepts and tools)	Deals with variability across disciplines and eras. Starts the process.	An important step that provided the conceptual grounding of multiple approaches and an overview for V-STEEP (acronym for values, social, technological, economic, environmental, and politico-legal).
Step 2. Description of the system boundary	Facilitates consideration of "resilience of what, to what" (Carpenter et al. 2001). Bounds data needs and analytical scales. Allows for identification of external and internal drivers.	Catchment was chosen as the system in keeping with policy and the focus of the work. Internal zones proved useful to bound the analysis. Delineation of eras helped focus the analysis.
Step 3. Generalized adaptive cycle (with time line); and panarchy analysis of nested GACs	Recognizing that systems go through collapse and renewal, the purpose is to identify such phases and to use these to elucidate windows of opportunity. The panarchy analysis does the same but for a nested hierarchy of GACs (see Holling 2001) and thus aims to identify multiple and cross-scale factors.	Because no methodological guidance is given for their application, the process was largely a subjective "retro-fitting" of historical events. GAC may offer a useful heuristic but given the above constraints they added only marginally to overall analysis. The GAC helped understand some concepts such as brittleness, lags, and opportunities provided by renewal.
Step 4. Development of timelines	Helped (a) set the temporal boundaries; (b) elucidate drivers across time and informed the selection of eras for analysis.	Informed the selection of temporal boundaries. Supported the categorization of events as broadly biophysical, political, and social which was important for naming drivers and the causal-loop diagram (CLD) construction.
Step 5. Holistic description of the system using V-STEEP and collection of data for characteristics of resilience	Broad but holistic scan of the context (bounded in time), helping to indentify drivers and factors; data sources and availability; Compilation of data pertaining to the characteristics of resilience.	Started the process of developing cause-and-effect linkages and understanding of the catchment as a system. Broaden scope of team understanding beyond specialist comfort zones to focus on water and livelihood security. Useful compilation of data and discussions pertaining to characteristics of resilience although often only qualitative in nature.
Step 6. Development of causal loop diagrams (CLD)	Collaborative and visual consensus-seeking process to develop a depiction (model) of the system, and to identify key drivers and inter-relationships and feedbacks.	Represented the heart of the work. Strength lies in the coconstruction process especially from different perspectives. Useful to seek joint understanding on feedbacks. The "3-8 rule of hand" is used to identify critical drivers (see Allison and Hobbs 2006).
Step 7: Broad specialist engagement with iterations of steps 4-6; and initiation of collaborative approaches to steps 8-10. This step included a formal evaluation of the each of the steps	The purpose was to develop a collaborative (specialist) understanding of the system through comment and discussion; and to initiate steps 8-10.	Strength lies in the coconstruction process especially with participants from different backgrounds/disciplines. Useful to seek joint understanding on feedbacks. Extremely useful for specialist views on resilience and scenarios that were evaluated collaboratively. If unconstrained by participants' time, this process could be undertaken a number of times and should include key stakeholders, e.g., government officials, sector representatives.
Step 8. Consolidate data to populate systems the CLD	Data were synthesized using overarching CLD. Linkages in particular were explored.	Reviewing huge amounts of data requires a framework (such as the CLD) for synthesis; Collaborative analysis and synthesis is imperative
Step 9. Qualitative resilience analysis and the development of scenarios	The key aim of resilience analysis is to identify drivers and system thresholds, their nature, and what determines movement of a system from one system configuration to another, e.g., from desirable to undesirable (Walker et al. 2002).	This study did not have the benefit of the steps outlined in the workbooks. However, when compared later, this framework was broadly parsimonious with that of the Resilience Alliance (RA). The attributes for assessing resilience (Walker and Salt 2006) are a useful set of criteria that can be added to. However there is little guidance on using these criteria in practice to assess resilience. Allison and Hobbs (2006) used only GAC and related cycles for this step; here more emphasis placed on RA criteria which were later expanded through this work.
Step 10. Implications and recommendations for management	To find out whether this approach is useful and exactly how to use it for managers, policy makers and in practice.	This process emphasizes the cocreation of knowledge rather than developing credible ex post facto recommendations to an independent decision maker. However many credible and more resilient decisions will be taken if this includes key stakeholders. Having this, a wide diffusion of this type of approach in a variety of natural resource management settings in the region, is underway.

colonizers in the late 1800s to the present. Subsequently, however, a narrower timescale was used to reflect the core focus of the work, i.e., the impacts of policies on water and livelihood security, namely 1950-1993 and 1994 to the present. Refining the timescale was supported by the construction of the timeline (Appendix 1) together with the first conceptualization of the system using the GAC (see Appendix 2). The timeline is, as Cilliers (2000) points out, an important part of understanding the role of historic events in determining key drivers within a system. This iteration suggested that previous policies, i.e., prior to 1994, developed after the Nationalist Party came to power in 1948 (Appendix 1), gave rise to key political and economic drivers that fundamentally influenced water and livelihood security in the study system. They shaped the creation of separate homelands for people classified as "black" and forced removal into parts of the SRC in the late 1960s, the reduction in quality and scope of education in these homelands, and the need to access cheap labor pools for mining around Johannesburg (Beinart 2001).

This stage of the work included various iterations between the timeline and the GAC. The application of the GAC (see Appendix 2) suggested that the apartheid era had become extremely resilient, meaning that intended outcomes were persistent, but "brittle" in the RA parlance, i.e., little room for new ideas or adaptability to changing external drivers. Following collapse, the post-1994 period could be interpreted as one of renewal. Steps 3 and 4 included the compilation and synthesis of data pertaining to the characteristics of resilience.

Steps 5 to 8: The collaborative construction of CLDs of the SRC as an SES during different eras was assisted by a detailed description of five broad categories of attributes of a system abbreviated as V-STEEP, namely values, social, technological, ecological, economic, and political (Biggs and Rogers 2003; Appendix 3). The V-STEEP description produces a more comprehensive scoping of contextual factors than conventionally examined, which, importantly, assist in identifying a wide spectrum of key drivers. This "SES system" was then represented visually, with inputs from specialists, as CLDs that provided a broadly consensual and systemic graphic model of the drivers, variables, and interlinkages during the era 1950-1993 (Fig. 2) and the postapartheid era after 1994 (Fig. 3). This suggested that economic and political drivers during the apartheid era had been instrumental in shaping the SES system so that water and livelihood insecurity, including weakening social capital and distorted family composition, emerged from persistent reinforcing feedbacks. This analysis further suggested that despite new policies (Fig. 3), inherent lags have meant that these reinforcing feedbacks have persisted. Nonetheless, some changes are emerging such as new institutional arrangements for water and the introduction of child-care grants, which have had a significant impact on livelihood vulnerability (DSD et al. 2012).

Following this, the group examined qualitative and quantitative data regarding the proposed characteristics of resilience such as diversity, ecological variability, the role of slow variables, polycentric governance, social capital, the breadth of ecosystems services, innovation, and openness. With little guidance from the literature on how to use these to assess resilience, they were finally ranked as low, moderate, and high under each of the scenarios examined. In terms of the current scenario, most of these were either moderate or high, except for feedbacks, social capital, and innovation, all of which were low. In contrast to commonly held perceptions, most specialists agreed that although degraded, the terrestrial ecological system had not shifted states. In contrast, conclusions regarding regime shifts were less clear in terms of the riverine ecosystem of the Sand River, which has experienced some flow cessations in dry years, although recent work points to a high degree of resilience of the riparian vegetation in Zone B (K. Kotschy, *personal communication*), highlighting the multidimensional nature of change. However, the consensual view was that social states had shifted. With the migration of adult males to the mines in the 1970s and 1980s, the extended patriarchal family, and even the nuclear family unit, appears to have been replaced by a more dispersed sibling social network (Niehaus 2002; I. Niehaus, *personal communication*). These social networks have been further challenged by ongoing shocks such as high HIV/AIDS infection rates (Hunter 2007, Kahn et al. 2007).

Fig. 2. Causal–loop diagram exploring a systemic view of water security in the Sand River Catchment social-ecological system for the era 1950-1993.

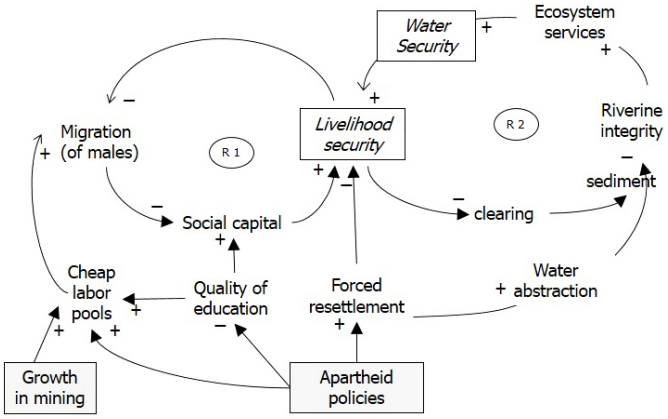
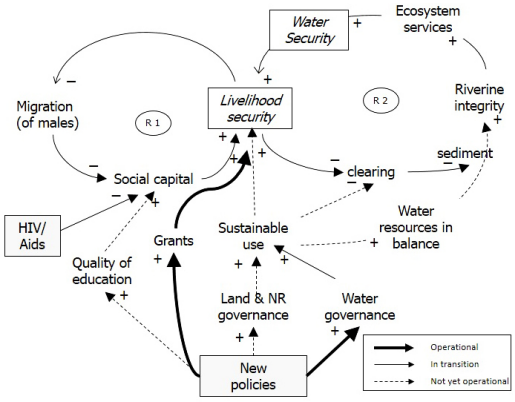


Fig. 3. Causal–loop diagram exploring a systemic view of water security in the Sand River Catchment social-ecological system for the postapartheid era (after 1994).



Steps 9 to 10: The CLDs and preceding information were used to formulate, collaboratively, three scenarios relevant to water governance. This approach contributed to the resilience analysis through emphasizing trends in space and time; issues of polycentric governance; learning and leadership in the catchment; decisions regarding key fast and slow variables, which were operative at different scales; and the major reinforcing and counterbalancing feedbacks. Finally, the group reflected on whether, and how, this approach might be useful for management and policy analysis (see Table 1).

To conclude, Table 2 summarizes the authors' reflections on the potential influence that such thinking has had on wider NRM issues by looking at the longer term outcomes. Although it is always difficult to determine when these effects can be deemed to be the specific result of this original work, as opposed, for instance, to the general spread of these ideas more broadly in society, the cases shown in Table 2 are very closely aligned to persons and specific ideas from this original work, suggesting a strong influence. The results featured in Table 2 in no way suggest that the thinking discussed by us has been singularly or even predominantly responsible for all the broader changes listed, but rather that this approach and decision-making style has been influential in the transformation of both policy and practice in some way. Time will tell how significant this is.

DISCUSSION

The combined suite of steps based on systemic approaches described previously provided a fresh approach not only to assessing systemic degradation and resilience, but also for understanding the impacts of policy changes in shaping water security and livelihoods in the SRC. The exercise pointed to a tightly coupled, resilient system during the apartheid era, which despite major policy changes, will take time to transform to one that gives meaning to the principles of equity and sustainability espoused in the postapartheid policy changes.

Nonetheless, those involved in the reflections, i.e., the authors on an ongoing basis and the specialists at the collaborative workshop and informal interactions, felt that some steps proved more useful than others, with boundary setting, a holistic understanding of context through timelines, and the V-STEEP scoping, a collaboratively derived systems view through CLDs and the resilience analysis, being the most valuable. To a lesser extent, scenario generation proved useful to some. Although the first steps of conceptual and literature reviews are obvious prerequisites for subsequent steps, our experience was that it took a while to convince all participants of the need to invest effort in defining the system boundaries or to understand history and context as thoroughly as intended in the framework. We assert that it was only by constraining the system through spatial and temporal boundaries, and through carefully inter-relating historical elements, that a credible systemic description emerged. Moreover, deriving as holistic a contextual understanding as possible greatly facilitated the subsequent transdisciplinary interactions and helped identify multiple cross-scale drivers. The discussion of values, i.e., deeply held beliefs, identified by the V-STEEP heuristic proved an important exploratory area with the specialists. The use of the GAC, although offering a useful heuristic to consider collapse and renewal, proved difficult to use at multiple scales as part of a resilience analysis and added only marginally to an overall understanding.

The contribution of systemic representations such as CLDs to interdisciplinary interaction was central because it is in the process of coconstruction that a shared integrative view becomes possible. The process also highlighted key areas of contestation. An advantage of such system-wide depiction is that social, economic, biophysical, and other drivers are captured in a visual, systemic view facilitating dialogue between participants. The systemic representation of the catchment over two eras facilitated the identification of key drivers, interlinkages, and feedbacks that may otherwise have been overlooked. For example, the link between livelihoods and the migration of adult males (see Fig. 2) helped participants think about history and to reflect on the notion that the strongest drivers over the past hundred years were indeed political and economic in nature, and cross-scale in their effects. Clear acknowledgement of the feedbacks in the two persistent reinforcing loops, i.e., ecosystem and social, in Figure 2 prompted important discussions. Many felt that unlike the "lock-in" traps described by Allison and Hobbs (2006), these persisted because of lags, rather than being permanently "locked in," so that when the CMAs are operational, these may well change.

Additionally, the systemic representation highlighted the nuances of mediating social-ecological interactions. For example, instead of opting for simplistic solutions, such as "government must regulate," when considering the illegal use of various natural resources, participants could appreciate the complex nature of interactions and cross-scale influences that had led to this situation. Poverty, weakening local-level institutional arrangements together with the lack of governmental capacity to act, and the uncertainties rendered by land reform have all meant that natural resources are increasingly vulnerable to opportunistic interests (Cousins 2007, Pollard and Du Toit 2011*b*). This suggested that without strong local-level and polycentric governance systems, a key factor thought to confer resilience, the sustainability of systems is likely to be compromised (Ostrom and Cox 2010).

The involvement of a transdisciplinary group of specialists proved invaluable, but upon reflection, the authors felt that this group should have been more broadly selected, including policy makers and a wider range of practitioners, and more intensely involved from the start. In addition to the aforementioned benefits of collaboration, the varied group was able to contribute to ideas on factors that might confer resilience in addition to those that are conventionally recognized by the RA. For instance, much discussion focused on the nature of learning within SESs where ultimately it was suggested that the content of the learning is far less important than the nature of the learning process. Social learning approaches suggest that there is a greater likelihood of sustainability emerging within a particular context through learning that is based on reflexive and adaptive social processes (Ison et al. 2007, Pollard and Du Toit 2007, Wals 2007), and exercises like these as well as "interventions" need to be attentive to this.

The several years that have elapsed since this work have provided the opportunity to trace examples of the medium-term and perhaps longer term influence of the thinking that was developed in this work (Table 2). For example, the framing of the South African catchment management strategy guidelines is almost wholly based on the paradigms used in this work. Several key Water Research Commission projects build on this foundation,

Table 2. Recent examples of how the thinking developed in this paper has influenced, or is potentially likely to influence, policy change and implementation regarding water and livelihood security in catchments in South Africa. The work was initially described in a detailed report (Pollard et al. 2008) by which time some of the initiatives below had already begun. Many other factors and influences often also contributed to these changes.

Situation or policy influenced	Timing and nature of influence	Expected or possible future influence
Catchment Management Strategy Guidelines promulgated for use in all catchment management agencies (CMAs; Pollard et al. 2007)	2007. Guidelines were written by two of the three authors of this paper, whose selection was presumably influenced by their understanding of this thinking. The guidelines have entrenched understanding of complexity and a V-STEEP approach (acronym for values, social, technological, economic, environmental, and politico-legal), along with adaptive feedbacks that allow emergence and learning in a multistakeholder context.	Catchment Management strategies expected to be developed and used across all CMAs in South Africa by 2020.
WatRes Research Project	2011/2012. The Water Research Commission in South Africa commissioned this work to investigate possibility of enhancing the eco-literacy and functional empowerment of diverse groups of stakeholders when participating in multistakeholder platforms such as those prescribed under the National Water act of 1998. At this stage the work is still in the action research phase but draws heavily on the principles in this paper, drawing especially heavily on the use of causal-loop diagrams (CLD) in describing benefits from ecosystem services under different allocation options.	Depending on outcomes, this collaborative use of CLDs will be taken forward into RESILIM (see next program below) and possibly also be considered later for general use as catchment management strategies are developed and as catchment stakeholders go through the various steps of participating in decisions.
Wise Use of Wetlands Project of the national Working for Wetlands Programme	The Wise Use project was initiated in 2009 in an attempt to build local custodianship over wetlands being rehabilitated through the Working for Wetlands Programme. The Wise Use approach is founded on a systemic, social learning approach that supports local land owners or users to develop a systemic view of degradation and sustainability. The approach is being developed and tested at learning sites.	Scheduled to continue to support Working for Wetlands through upscaling into policy and practice throughout the country.
RESILIM (Resiliency in the Limpopo Basin, a USAID-funded program (see http://sa.usaid.gov/southern_africa/node/71). It has a basin wide component and a component dealing with the most significant sub-basin, the Olifants (RESLIM-O).	RESILIM-O began December 2012. The aim is to build improved transboundary governance and management of the Olifants Catchment of the Limpopo Basin for enhanced resiliency of its people and ecosystems to environmental change through systemic and participatory approaches Fundamental approach of RESILIM-O is based on system dynamics (with CLDs) and social learning.	Scheduled to run for five years. Represents a major and influential research and management support intervention in one of the biggest and most challenging of South Africa's catchments.
Strategic Adaptive Management in National Parks (see http://www.koedoe.co.za/index.php/koedoe/issue/view/82)	Since 1995 but systemic approaches more particularly since 2005 after visit of Helen Allison to Kruger National Park. There has over this whole period been close coevolution of concepts and thinking between those described in this paper and the Kruger National Park, which also has a special interest in rivers crossing the park, including the Sand River. For instance, SANParks now uses CLDs (local use pioneered mostly by authors of this apper) in most of its Science-Management in 20 national parks across the country.	Because of the concern around rivers in National Parks, and because of a key link between persons working in and outside parks in the same catchment, it is possible that this collaboration will continue.

e.g., studies of collaborative approaches to water-related ecosystems services, and large current development-oriented projects aimed at adaptation to climate change, e.g., Resilience in the Limpopo Basin, or RESILIM, hold these concepts at their core. Although there are many other significant influences, it is thus justifiable to suggest that policy changes in South Africa regarding water and related livelihood security have been materially influenced by this approach, which has thus enhanced understanding in the way intended.

CONCLUSION

The unique contribution of this systemic approach is that it engages with SES issues such as water and livelihood security in a manner that acknowledges the importance of (1) systems and resilience thinking and (2) consensus seeking through approaches that enable coconstruction of the processes of engagement and problem framing. This approach is similar in many respects to the mainstream RA workbook approach but differs in the emphasis it places on deriving a systemic view and on the wide scan of drivers elaborated through the V-STEEP process, as well as the moderately greater emphasis on history through explicit timelines.

The general combination of systems thinking and resilience analysis approaches facilitated the development of an integrative, systemic understanding of change and transformation at a catchment scale by a diverse group of specialists who, to some extent, represented multiple groups of stakeholders. These specialists agreed generally that the framework elucidated key

drivers, inter-relationships, and feedbacks in the system; highlighted data needs; and was useful for "seeing managerial issues" from a broader systemic perspective.

On the other hand, there was ongoing frustration on the part of some at not having "sufficient" empirical data to develop a "quantified systems view." Although they felt that comprehensive empirical data were critical for a "full" understanding of the system to manage it, the fact that our work was better endowed with data sets than most in the country indicates that this is extremely unlikely in practice: catchment managers have to act in a world of uncertainty and "incomplete" information. This is not to suggest that systematic and empirical inquiry is not critical. Rather, the realization is that we face a world of uncertainty and rapid transformation that also requires dealing with the unknown, highlighting ongoing learning and adaptation. In catchments, everything cannot be known or verified with empirical data (Heylighen et al. 2007), even as we promote as many empirical studies as practicable. Catchments, therefore, constitute contexts that lend themselves to the application of systems thinking as a core approach, not as one that is simply tagged onto a systematic or evidence-based drive. We suggest that multiple groups of stakeholders in the arena of IWRM are indeed starting, in various ways, to use this approach, and that policy-influential documents and programs are adopting these.

Finally, depictions of systems such as those presented by us should not be conflated with attempts to depict the truth. Rather, they are better seen as models or heuristics of what is known about the system, which, through participatory processes of representation and narrative, can suggest potential constraints, bottlenecks, and feedbacks. In turn, these enrich managerial responses and stakeholder dialogue. As Cilliers (2001:3) points out, "This is not because of some inadequacy in our modeling techniques, but a result of the meaning of the notions 'model' and 'complex'. There will always be a gap between the two. This gap should serve as a creative impulse that continually challenges us to transform our models, not as a reason to give up."

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/6312

Acknowledgments:

The authors thank the Water Research Commission for support of the work. The numerous experts and participants who formed part of the team are thanked for their time and inputs especially at the collaborative workshop and various meetings. A number of students assisted in developing the framework and conceptualizing the SES. Ariane Laporte-Bisquit assisted with editorial changes and final copies of the diagrams. We are very grateful to the several rounds of anonymous reviewers whose recommendations greatly improved the manuscript. One particular reviewer went to the trouble of suggesting text changes in a few key paragraphs, changes that far better captured the essence of our work for the target audience.

LITERATURE CITED

Allison, H. E., and R. J. Hobbs. 2006. *Science and policy in natural resource management: understanding system complexity.* Cambridge University Press, Cambridge, UK. http://dx.doi.org/10.1017/CBO9780511618062

Beinart, W. 2001. *Twentieth-century South Africa.* Oxford University Press, Oxford, UK.

Berkes, F., J. Colding, and C. Folke. 2003. *Navigating social-ecological systems: building resilience for complexity and change.* Cambridge University Press, Cambridge, UK. http://dx.doi.org/10.1017/CBO9780511541957

Biggs, H., and K. H. Rogers. 2003. An adaptive system to link science, monitoring and management in practice. Pages 59-80 *in* J. T. D. Toit, K. H. Rogers, and H. C. Biggs, editors. *The Kruger experience: ecology and management of savanna heterogeneity.* Island, Washington, D.C., USA.

Bundy, C. 1988. *The rise and fall of South African peasantry.* David Philip, Cape Town, South Africa.

Carpenter, S. R., B. Walker, J. M. Anderies, and N. Abel. 2001. From metaphor to measurement: resilience of what to what? *Ecosystems* 4:765-781. http://dx.doi.org/10.1007/s10021-001-0045-9

Carruthers, J. 1995. *The Kruger National Park: a social and political history.* Natal University Press, Pietermaritzburg, South Africa.

Chambers, R., and G. R. Conway. 1992. *Sustainable rural livelihoods: practical concepts for the 21st century.* Institute of Development Studies, Brighton, UK.

Checkland, P. 1981. Systems thinking, systems practice: assessment tool for sustainable agroecosystem management. *Ecological Applications* 11:1573-1585.

Cilliers, P. 1998. *Complexity and postmodernism: understanding complex system.* Routledge, London, UK.

Cilliers, P. 2000. What can we learn from a theory of complexity? *Emergence* 2:23-33. http://dx.doi.org/10.1207/S15327000EM0201_03

Cilliers, P. 2001. Boundaries, hierarchies and networks in complex systems. *International Journal of Innovation Management* 5:135-147. http://dx.doi.org/10.1142/S1363919601000312

Cousins, B. 2007. More than socially embedded: the distinctive character of 'communal tenure' regimes in South Africa and its implications for land policy. *Journal of Agrarian Change* 7:281-315. http://dx.doi.org/10.1111/j.1471-0366.2007.00147.x

Department of Social Development (DSD), South African Social Security Agency (SASSA), and United Nations Children's Fund (UNICEF). 2012. *The South African child support grant impact assessment: evidence from a survey of children, adolescents and their households*. UNICEF South Africa, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF). 2004*a*. *Internal strategic perspective: Inkomati WMA.* PWMA 05/000/00/0303. DWAF, Pretoria, South Africa.

Department of Water Affairs and Forestry (DWAF). 2004*b*. *National water resources strategy*. DWAF, Pretoria, South Africa.

Ebony Consulting International. 2002. *The food security effects of the deregulation of agricultural marketing in South Africa.* Final report by Ebony Consulting International to the National Agricultural Marketing Council, Pretoria, South Africa.

Everatt, D., M. Smith, and Khanya-aicdd. 2008. *Building sustainable livelihoods in Bushbuckridge and Maruleng (formerly Bohlabela).* Department of Social Development, South Africa.

Folke, C. 2003. Freshwater for resilience: a shift in thinking. *Philosophical Transactions of the Royal Society B Biological Sciences* 358:2027-2036. http://dx.doi.org/10.1098/rstb.2003.1385

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C. S. Holling, and B. Walker. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio* 31:437-440. http://dx.doi.org/10.1579/0044-7447-31.5.437

Forrester, J. W. 1992. *System dynamics and learner-centred-learning in kindergarten through 12th grade education.* Massachusetts Institute of Technology, Cambridge, Massachusetts, USA.

Frakenberger, T. R., and M. K. McCaston. 1998. *The household livelihood security concept*. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. [online] URL: http://www.fao.org/docrep/X0051T/X0051t05.htm

Garenne, M. L., S. M. Tollman, M. A. Collison, and K. Kahn. 2007. Fertility trends and net reproduction in Agincourt, rural South Africa, 1992–2004. *Scandinavian Journal of Public Health* 35:68-76. http://dx.doi.org/10.1080/14034950701355650

Gunderson, L. H., and C. S. Holling, editors. 2002. *Panarchy: understanding transformations in human and natural systems*. Island, Washington, D.C., USA.

Gunderson, L. H., C. S. Holling, and S. S. Light. 1995. *Barriers and bridges to the renewal of ecosystems and institutions*. Columbia University Press, New York, New York, USA.

Hansen, B. 1998. *Changing patterns of natural woodland resource dependency and use: intergenerational perceptions, traditions and customs*. Thesis. University of Copenhagen, Copenhagen, Denmark.

Harries, P. 1989. Exclusion, classification and internal colonialism: the emergence of ethnicity among the Tsonga-speakers of South Africa. Pages 87-117 *in* L. Vail, editor. *The creation of tribalism in South Africa.* University of California Press, Berkeley, California, USA.

Hazlett, T. W. 1988. Economic origins of apartheid. *Contemporary Economic Policy* 6:85-104. http://dx.doi.org/10.1111/j.1465-7287.1988.tb00549.x

Heylighen, F., P. Cilliers, and C. Gershenson. 2007. Philosophy and complexity. Pages 117-134 *in* J. Bogg and R. Geyer, editors. *Complexity, science and society.* Radcliffe, Oxford, UK.

Holland, J. H. 1999. *Emergence: from chaos to order.* Perseus Books, Reading, Massachusetts, USA.

Holling, C. S. 2000. Theories for sustainable futures. *Conservation Ecology* 4(2): 7. [online] URL: http://www.consecol.org/vol4/iss2/art7/

Holling, C. S. 2001. Understanding the complexity of economic, ecological, and social systems. *Ecosystems* 4:390-405. http://dx.doi.org/10.1007/s10021-001-0101-5

Hunter, M. 2007. The changing political economy of sex in South Africa: the significance of unemployment and inequalities to the scale of the AIDS pandemic. *Social Science & Medicine* 64:689-700. http://dx.doi.org/10.1016/j.socscimed.2006.09.015

Ison, R., N. Röling, and D. Watson. 2007. Challenges to science and society in the sustainable management and use of water: investigating the role of social learning. *Environmental Science & Policy* 10:499-511. http://dx.doi.org/10.1016/j.envsci.2007.02.008

Kahn, K., M. Garenne, S. M. Tollman, and M. Collinson. 2007. Mortality trends in a new South Africa (Agincourt 1992-2003): hard to make a fresh start (draft). *Scandinavian Journal of Public Health* 35:19.

Laszlo, A., and S. Krippner. 1998. Systems theories: their origins, foundations, and development. Pages 47-74 *in* J. S. Jordan, editor. *Systems theories and a priori aspects of perception*. Elsevier Science, Amsterdam, The Netherlands. http://dx.doi.org/10.1016/S0166-4115(98)80017-4

Levin, S. A. 1999. *Fragile dominion: complexity and the commons.* Massachusetts Helix Books, Cambridge, Massachusetts, USA.

Madhavan, S., and E. J. Schatz. 2007. Coping with change: household structure and composition in rural South Africa, 1992–2003. *Scandinavian Journal of Public Health* 35:85-93. http://dx.doi.org/10.1080/14034950701355627

May, J. 2000. The structure and composition of rural poverty and livelihoods in South Africa. Pages 21-34 *in* B. Cousins, editor. *At the crossroads: land and agrarian reform in South Africa into the 21st century.* Programme for Land and Agrarian Studies, University of the Western Cape, Cape Town, South Africa.

Meadows, D. H. 1999. *Leverage points: places to intervene in a system*. Sustainability Institute, Hartland, Vermont, USA.

Meppem, T., and S. Bourke. 1999. Different ways of knowing: a communicative turn toward sustainability. *Ecological Economics* 30:389-404. http://dx.doi.org/10.1016/S0921-8009(99)00053-1

Mullis, I. V. S., M. O. Martin, A. M. Kennedy, and P. Foy. 2007. *PIRLS 2006 international report: IEA's progress in international reading literacy study in primary school in 40 countries.* Trends in International Mathematics and Science Study (TIMSS) & Progress in International Reading Literacy Study (PIRLS) International Study Center, Lynch School of Education, Boston College, Chestnut Hill, Massachusetts, USA. [online] URL: http://pirls.bc.edu/pirls2006/intl_rpt.html

Nel, J. L., D. M. Richardson, M. Rouget, T. Mgidi, N. Mdzeke, D. C. Le Maitre, B. W. van Wilgen, L. Schonegevel, L. Henderson, and S. Neser. 2004. A proposed classification of invasive alien plant species in South Africa: towards prioritising species and areas for management action. *South African Journal of Science* 100:53-64.

Niehaus, I. 2002. Ethnicity and the boundaries of belonging: reconfiguring Shangaan identity in the South African lowveld. *African Affairs* 101:557-583. http://dx.doi.org/10.1093/afraf/101.405.557

Norman, E., K. Bakker, C. Cook, G. Dunn, and D. Allen. 2010. *Water security: a primer*. Library and Archives Canada Cataloguing in Publication, Ottawa, Ontario, Canada.

Nowotny, H. 2005. The increase of complexity and its reduction: emergent interfaces between the natural sciences, humanities and social sciences. *Theory, Culture & Society* 22:15-31. http://dx.doi.org/10.1177/0263276405057189

Ostrom, E., and M. Cox. 2010. Moving beyond panaceas: a multi-tiered diagnostic approach for social-ecological analysis. *Environmental Conservation* 37:451-463. http://dx.doi.org/10.1017/S0376892910000834

Pike, A., and R. Schulze. 2000. *Research into the development of a distributed hydrological modelling system to assist in managing the ecological reserve to the Sabie river system within the Kruger National Park.* Report for project k5/884 to the Water Research Commission, Pretoria, South Africa.

Pollard, S. R., H. Biggs, and D. Du Toit. 2008. *Towards a socio-ecological systems view of the Sand River Catchment, South Africa: an exploratory resilience analysis.* Report for project K8/591 to the Water Research Commission, Pretoria, South Africa.

Pollard, S., and T. Cousins. 2014. Legal pluralism and the governance of freshwater resources in southern Africa: can customary governance be embedded within the statutory frameworks for integrated water resources management? Pages 220-241 *in* M. Sowman and R. Wynberg, editors. *Governance for justice and environmental sustainability: lessons across natural resource sectors in sub-Saharan Africa.* First edition. Earthscan from Routledge, London, UK.

Pollard, S., and D. Du Toit. 2007. *Guidelines for strategic adaptive management: experiences from managing the rivers of the Kruger National Park, South Africa.* Report of UNEP/GEF Project No. GF/2713-03-4679, Ecosystems, Protected Areas and People Project, Pretoria, South Africa.

Pollard, S., and D. Du Toit. 2011*a*. *The Shared River Initiative Phase I: towards the sustainability of freshwater systems in South Africa.* Report for project K5/1711 to the Water Research Commission, Pretoria, South Africa.

Pollard, S., and D. Du Toit. 2011*b*. Towards adaptive integrated water resources management in southern Africa: the role of self-organisation and multi-scale feedbacks for learning and responsiveness in the Letaba and Crocodile catchments. *Water Resources Management* 25:4019-4035. http://dx.doi.org/10.1007/s11269-011-9904-0

Pollard, S., and D. Du Toit. 2013. The emergence of a systemic view for the sustainable governance and use of wetlands in complex and transforming environments: experiences from Craigieburn, South Africa. Pages 112-137 *in* A. P. Wood, A. B. Dixon, and M. McCartney, editors. *Wetland management and sustainable livelihoods in Africa.* Earthscan from Routledge, London, UK.

Pollard, S., D. Du Toit, J. Reddy, and T. Tlou. 2007. *Guidelines for the development of catchment management strategies: towards equity, efficiency and sustainability in water resources management.* Department of Water Affairs and Forestry, Pretoria, South Africa.

Pollard, S., S. Mallory, E. Riddel, and T. Sawunyama. 2011. *Towards improving the assessment and implementation of the reserve: real-time assessment and implementation of the ecological reserve.* Final Report for project K8/881/2 to the Water Research Commission, Pretoria, South Africa.

Pollard, S., J. C. P. Mendiguren, A. Joubert, C. M. Shackleton, P. Walker, T. Poulter, and M. White. 1998. *Save the Sand: phase I. Feasibility study: the development of a proposal for a catchment plan for the Sand River Catchment.* Report for the Department of Water Affairs, Pretoria, South Africa.

Pollard, S., C. Shackleton, and J. Carruthers. 2003. Beyond the fence: people and the Lowveld landscape. Pages *in* J. T. D. Toit, K. H. Rogers, and H. C. Biggs, editors. *The Kruger experience: ecology and management of savanna heterogeneity.* Island, Washington, D.C., USA.

Radzicki, M. J., and R. A. Taylor. 1997. *Introduction to system dynamics: a systems approach to understanding complex policy issues (Version 1.0)*. Report for U.S. Department of Energy, Washington, D.C., USA.

Ramalingam, B., H. Jones, T. Reba, and J. Young. 2009. *Exploring the science of complexity: ideas and implications for development and humanitarian efforts.* Overseas Development Institute, London, UK.

Republic of South Africa. 1997. Water Services Act No. 108 of 1997. Republic of South Africa, Pretoria, South Africa.

Republic of South Africa. 1998. National Water Act No. 36 of 1998. Republic of South Africa, Pretoria, South Africa.

Resilience Alliance (RA). 2007*a*. *Assessing resilience in social-ecological systems: workbook for practitioners*. [online] URL: http://www.resalliance.org/index.php/resilience_assessment

Resilience Alliance (RA). 2007*b*. *Assessing resilience in social-ecological systems: a workbook for scientists*. [online] URL: http://www.resalliance.org/index.php/resilience_assessment

Rogers, K., and H. Biggs. 1999. Integrating indicators, endpoints and value systems in strategic management of the rivers of the Kruger National Park. *Freshwater Biology* 41:439-451. http://dx.doi.org/10.1046/j.1365-2427.1999.00441.x

Schreiner, B., and R. Hassan, editors. 2010. *Transforming water management in South Africa: designing and implementing a new policy framework*. Springer, New York, New York, USA.

Shackleton, C. M. 1993. Are the communal grazing lands in need of saving? *Development Southern Africa* 10:65-78. http://dx.doi.org/10.1080/03768359308439667

Shackleton, C., and S. Shackleton. 2000. Direct use values of savanna resources harvested from communal savannas in the Bushbuckridge Lowveld, South Africa. *Journal of Tropical Forest Products* 6:28-47.

Shackleton, C. M., S. E. Shackleton, T. R. Netshiluvhi, and F. R. Mathabela. 2005. The contribution of direct-use value of livestock to rural livelihoods in the Sand River catchment, South Africa. *African Journal of Range & Forage Science* 22:127-140. http://dx.doi.org/10.2989/10220110509485870

Shackleton, S., J. J. Stadler, K. A. Jeenes, S. R. Pollard, and J. S. S. Gear. 1995. *Adaptive strategies of the poor in arid and semi-arid lands: in search of sustainable livelihoods. A case study of the Bushbuckridge district, Eastern Transvaal, South Africa*. Wits Rural Facility, University of the Witwatersrand, Acornhoek, South Africa.

Smits, S., S. Pollard, D. Du Toit, J. Butterworth, and P. Moriarty. 2004. *Modelling scenarios for water resources management in the Sand River Catchment, South Africa.* Natural Resources Institute, Chatham, UK.

Snowden, D. 2000. The ASHEN model: an enabler of action. Part one of basics of organic knowledge management. *Knowledge Management* 3(7):14-17.

Ulrich, W., and M. Reynolds. 2010. Critical systems heuristics. Pages 243-292 *in* M. Reynolds and S. Holwell, editors. *Systems approaches to managing change: a practical guide*. Springer, London, UK. http://dx.doi.org/10.1007/978-1-84882-809-4_6

van Niekerk, A. W., and G. L. Heritage. 1993. *Geomorphology of the Sabie River: overview and classification.* Centre for Water in the Environment Report 2/93. University of the Witwatersrand, Johannesburg, South Africa.

Von Bertalanffy, L. 1972. The history and status of general systems theory. *Academy of Management Journal* 15(4):407-426. http://dx.doi.org/10.2307/255139

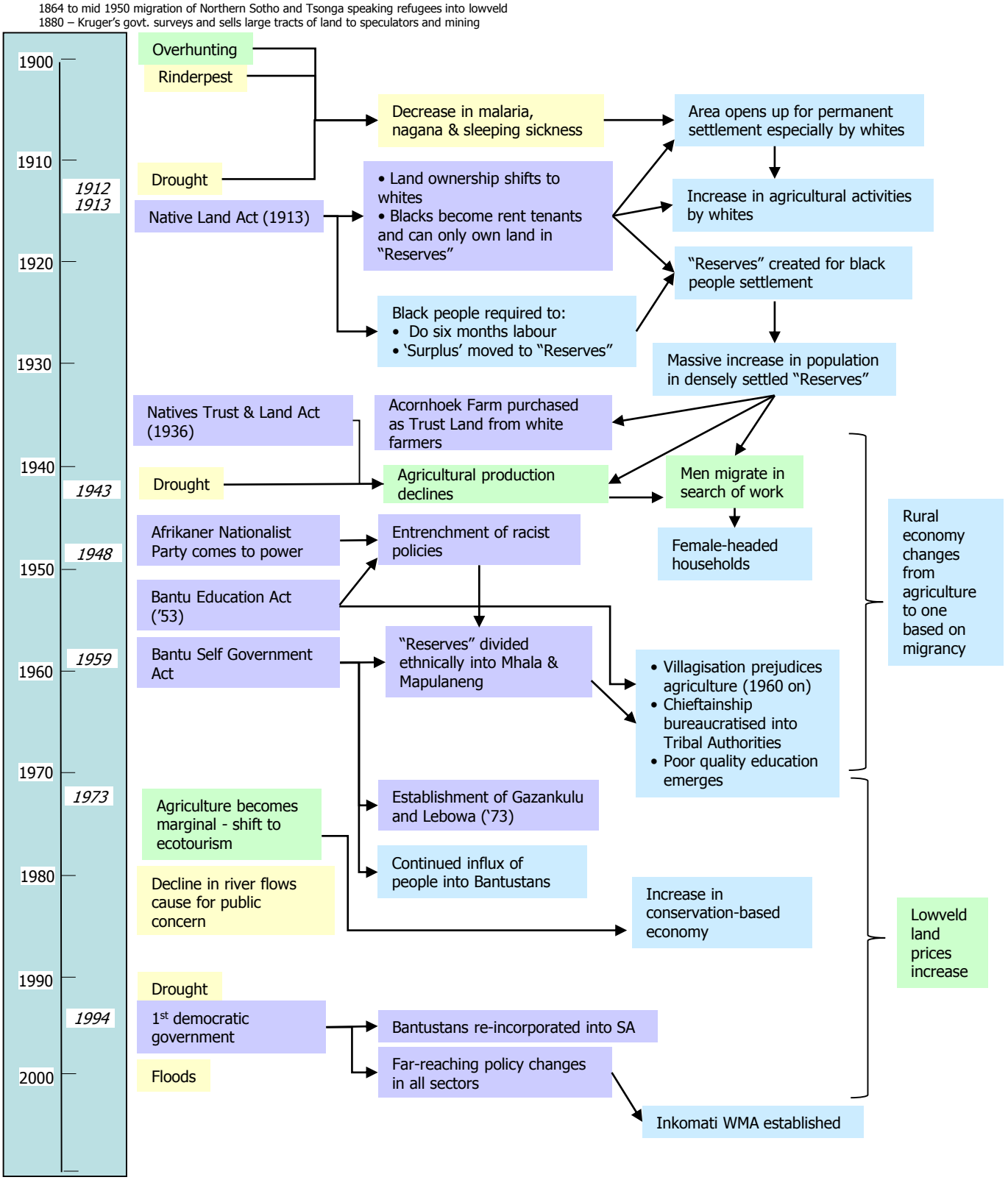
Walker, B., S. Carpenter, J. Anderies, N. Abel, G. S. Cumming, M. Janssen, L. Lebel, J. Norberg, G. D. Peterson, and R. Pritchard. 2002. Resilience management in social-ecological systems: a working hypothesis for a participatory approach. *Conservation Ecology* 6(1): 14. [online] URL: http://www.consecol.org/vol6/iss1/art14/

Walker, B., and D. Salt. 2006. *Resilience thinking: sustaining ecosystems and people in a changing world.* Island, Washington D. C., USA.

Wals, A. E. J. 2007. *Social learning towards a sustainable world*. Wageningen Academic, Wageningen, The Netherlands. http://dx.doi.org/10.3920/978-90-8686-594-9

Appendix 1.

Figure A 1.1. Timeline developed for Zone B of the Sand River Catchment showing key events and outcomes. Primary drivers are grouped into political, economic and environmental categories (purple, green and yellow respectively). Major outcomes are shown in blue. Evidence for this is given in chapters 3 and 4 of Pollard et al. (2008), and in contextual scoping (see Appendix 3). Note that these interpretations are those of the authors and reviewed by the specialist group (see text). Similar timelines were also drawn for Zones A and C. WMA = Water Management Area.



Appendix 2.

Table A2.1. Interpretation of political drivers in the Sand River Catchment over the last 100 years using the framework of GAC (Holling 2000, Gunderson and Holling 2002). Note that these interpretations are those of the authors which were reviewed by the specialist group and regarded as reasonable given (a) the clear development of generally recognized phases in the historical timeline (Appendix 3), and (b) the scale at which the interpretations were made. An evaluation of the GAC framework is given in the text.

Time periods	Loop	Comment
Circa 1890 - 1913	Ω	***Omega phase of release*** ("things fall apart") with the prevailing livelihoods collapsing with the advent of the immigration of hunters and entrepreneurs.
1914 – 1935	α	***Alpha phase*** of new ideas being tested, namely labour recruitment plans, Native land Act, Black Reserves. Conditions favourable for permanent white settlement. The 1913 Land Act symbolized the formal initiation of the separate development philosophy which came to be the dominant one (of one competing idea over another).
1936 – 1947	R	***R phase*** which is the beginning of the 'conservation' phase, ideas being consolidated.
1948 – 1988	K	***K phase consolidation*** of power of the whites under the apartheid regime.
1988 – present	Ω	***Omega phase – 'crisis' and re-organisation***

Appendix 3.

Table A3.1. An example of the contextual scoping of Zone B based on a V-STEEP description of the Sand River Catchment.

Factors and characteristics	Detail
General	- Densely-populated rural area where populations increased by 1000% in some areas due to forced removals into the area between 1965 and 1974 (Pollard et al. 2008) - Only 30% of households had access to fields for agriculture (Ebony Consulting International 2002) - Labor migration is prominent; 60% of men and 20%, of women are temporary migrants (M. Collinson, S. Tollman, K. Kahn, and S. Clark, *unpublished manuscript*)
Values (predominant)	- Colonization in the Lowveld was relatively recent; in mid-1800s the socio-economic landscape was transformed in favor of whites. At that time much of the Lowveld was regarded as worthless and inhospitable for permanent settlement due to erratic rainfall and high temperatures, poor soils, and endemic and sometimes fatal livestock and human diseases (Carruthers 1995). However, with the reduction in malaria and demise of the tsetse fly (due to rinderpest in 1896 and drought between 1897 and 1913) this perception changed and the Lowveld opened up for denser settlement (Pollard et al. 2003) - At this time nascent conservation areas were established in the drier eastern regions, and the Kruger National Park was proclaimed in 1926 but it was only in the 1970's that a wide-scale landuse transformation from livestock to conservation occurred and land values increased substantially heralding a strong conservation ethic in some (see Carruthers 1995, Beinart 2001) - As noted in the main text, 1948 marked the formalization of racist values in whites which entrenched so-called 'separate development' effectively denying the majority black population access to socio-economic opportunities (see Bundy 1988, May 2000). In 1994 this changed with the first democratic government under Nelson Mandela with a constitution espousing values of equity and sustainability
Social	- Following forced removals into the area in the '70's onwards, the population of the SRC grew substantially and patterns emerged quite unlike most rural economies. These are highlighted below: - Female-headed households high (68% according to Everatt et al. 2008) due to male migration in search of work (M. Collinson, S. Tollman, K. Kahn, and S. Clark, *unpublished manuscript*)

	- Rate of unemployment[1] was and remains high at 68% (Everatt et al. 2008) - Remittances and grants are important income sources e.g. in the 80s between 50 – 75% of households were dependent on migrant remittances (Harries 1989) - 84 % of population classified by municipality as "indigent," earning < R1,300/ household/m - Household with no annual income[2] - 37.7% (Everatt et al. 2008) Percentage of orphans increased significantly between 1997 and 2003 (Madhavan and Schatz 2007)
- Access to water	- 60% of households do not have access to potable water, 16% have some access to tap water, 11% rely on boreholes and 3% access water via spring and rivers
- Education/ illiteracy[3]	- Under apartheid, unequal spending on education for children of different race White : Black expenditure ratio was 4:1 (Hazlett 1988) - Today education still vulnerable: 21% no schooling, - 14% matriculate (IDP 2011-2016) - Illiteracy - 46.5% (Everatt et al. 2008)
- HIV/ AIDs	- HIV prevalence is high (19.4%); large gender gap (10.6% for men and 23.9% for women) (Dr. Gomez-Olive, personal communication)
- Reliance on natural resources	- 85% of households collect firewood and herbs from rangelands (Hansen 1998) - Natural resources contribute significantly to peoples' livelihoods (Shackleton and Shackleton 2000, Shackleton et al. 2005)
- Vulnerability	- Between 1992 and 2003, major demographic changes have occurred in Agincourt an area of BBR. Fertility rates have fallen dramatically (Garenne et al. 2007). Life expectancy has declined significantly as mortality has risen in certain age groups: children (0-4) and young adults (20-49), primarily due to HIV/AIDS (Kahn et al. 2007). The percentage of orphans increased significantly between 1997 and 2003 (Madhavan and Schatz 2007)
Technical	- Bulk water supply infrastructure is extensive but largely inoperative (Pollard et al. 1998, Smits et al. 2004) - Three small dams in the catchment
Environmental	- Rainfall is the primary driving force with regard to ecological and hydrological processes - Large areas are degraded with a conservation status of critically endangered (Nel et al. 2004) - However concept of degradation has been contested by (Shackleton 1993)
- Terrestrial	- In Zone B over 60% of indigenous landcover is estimated to now been converted

[1] Proportion of the economically available population who are unemployed (Stats SA Measuring poverty)

[2] Proportion of households with no annual income based on sub-set data

[3] Prop. of pop. (15+) who have not completed Grade 7

	- Harvesting rates of woodland resources exceeding production
- Aquatic	- Flows have declined significantly over the record period (DWAF 2004a) - River now experiences regular flow cessation - Estimated 80% runoff is generated in upper 20% of Sabie River Catchment (Pike and Schulze 2000) - Sediment production highest west of the Kruger National Park due to overgrazing and land degradation (van Niekerk and Heritage 1993)
Economic	
- Employment	- Unemployment varies between 40% and 80% although accurate figures are confounded by the difficulty in distinguishing between formal and informal economic activities. - An estimated 50% of men are economically active outside of the catchment (Mullis et al. 2007).
- Formal	- Livelihoods are based on migrant remittances and social welfare rather than agriculture. Indeed, natural resources and land are under such pressure that they can only form a supplementary, although critical part of peoples' livelihoods (Shackleton and Shackleton 2000) - Direct use values of home consumption from livestock, agriculture and natural resource harvesting are high, accounting for more than 50% of total livelihood streams (Shackleton and Shackleton 2000) - Estimated jobs from agriculture - 6,488 people (1.6% of population, Pollard et al. 1998). Dependency ratio of 1:6 the livelihood benefits accrue to 39,000 people (10% of population)
- Tourism	- Tourism through the Kruger National Park and the private Sabi-Sand Game Reserve is an important contributor to the local GDP. In 1998 the latter was estimated R6 million in gross income per annum per individual concern but major part of this income may little benefit internally to the catchment due to the closed nature of the reserve's operating system (A. Spencely, personal communication)
Political	- Historically large proportion of the catchment fell under two apartheid bantustans: Lebowa and Gazankulu which were incorporated into South Africa after 1994 - Many of the apartheid-linked structures were heavily contested - Today there are three tiers of government: national, provincial and local. The area now falls under Bushbuckridge Local Municipality - Existing in parallel to statutory bodies are various forms of customary systems which are often better understood than the statutory systems (Pollard and Cousins 2014)