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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

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Abstract South Africa is acclaimed for its water reform and the adoption of integrated water resources management (IWRM) as the framework for managing catchment water resources to achieve equity and sustainability. The proposed process is inherently adaptive, allowing for reflection and learning in complex, uncertain environments such as catchments. A decade on, attention has now turned to implementation. In this paper we present some key findings drawn from a three-year study in six major catchments in the water-stressed north-east of South Africa which examined factors constraining or enabling implementation. Factors critical for the evolution of tenable and appropriate IWRM include a practice-based understanding of policy, the role of leadership and communication, governance, collective action and regulation, and self-organisation and feedbacks. This paper concerns self-organisation, leadership and feedbacks. Their origins, drivers, development and role in building resilience are examined in two of the six catchments: the Letaba and Crocodile catchments. Self-organisation, leadership and feedback loops exist in both but are highly variable in terms of their contribution to IWRM. The underlying factors contributing to their functionality are identified. Despite good efforts to self-organise and functional feedbacks there is evidence of either vulnerability or of limited impact when processes are confined to a local scale, which constrains learning and transformation at a wider scale. In other instances, encouraging evidence is emerging in which leadership, governance and the ability to self-organise are central to effectiveness. We conclude that self-organisation and responsive multi-scale feedback loops are essential for management in catchments understood as complex systems as they provide the basis for learning and response to an evolving context.

Keywords Water reform · Integrated Water Resources Management · Complex systems · Self-organisation · Leadership · Multi-scale feedbacks · Resilience · Responsiveness · Adaptive management · Transboundary governance · Southern Africa

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1 Introduction: The Context of South African Water Reform

South Africa has embarked upon an ambitious water reform process which emerged from a new, democratic dispensation after 1994, for which it is widely acclaimed. Central to this is the abolition of riparian rights, the establishment of the principles of equity and sustainability as cornerstones in water management and allocation, and the recognition that catchments—rather than administrative boundaries—form the basis for water resources management (WRM). These changes underscored the emergence of a holistic approach that recognised the political, technical, socio-economic and environmental and technical dimensions of water. The guiding framework and philosophy for this process is captured in the concept of Integrated Water Resources Management (IWRM) which, as envisaged in the National Water Act (DWAF 1998), is regarded as a process rather than an end in itself. Pollard and du Toit (2008) argued that the process of IWRM as explicated in South Africa inherently recognises catchments—albeit implicitly—as complex systems through acknowledging linkages (in scale and across disciplines) and the adoption of iterative and adaptive approaches. Adopting this framing allows for reflection and learning in a complex, uncertain environment (Kingsford et al. 2011).

Whilst it is recognised that the challenges of South African water reform are significant, requiring major institutional and administrative shifts, attention has now turned to implementation. To this end a three-year study known as the Shared Rivers Initiative (SRI), examined the multiple factors that both constrain or enable compliance with the National Water Act (NWA) and hence the implementation of IWRM (Pollard and du Toit 2011). The focus of the study was on the six river basins comprising the *lowveld*—a term referring to the vast plains between the escarpment in north-eastern South Africa and the coast of Mozambique (Fig. 1). Interest in this area partly reflects growing concerns that despite the enabling legislative frameworks for water reform and environmental flows since 1998, the integrity of most of these rivers has not improved, or continues to degrade both in terms of quality and quantity—despite political commitments to the contrary (Pollard and du Toit 2011). To illustrate this, concerned stakeholders pointed to the recurrent cessation of flows in the Olifants River since 2005 (Pollard et al. 2011) and increasingly precarious water quality conditions due to acid-mine drainage and sewerage effluent. Given that all the rivers involve transboundary governance, the implications are of wider significance than South Africa alone.

Whilst a detailed overview of policy is beyond the scope of this paper (see Pollard and du Toit 2008) we highlight the two principles of the NWA—namely sustainability and equity—to which IWRM must give effect. Over a decade on since the promulgation of the NWA, together with the Water Services Act (1997), improvements to the integrity of water resources and water security merit examination. However, this is no easy task requiring benchmarks for evaluation as well as cognisance of the enormity of the reform task at hand. In terms of sustainability—as well as to some degree equity—the *Reserve* provides such a yardstick. The Reserve refers to the quantity and quality of water required for two components, namely (a) for basic human needs (Basic Human Needs Reserve) and (b) to protect aquatic ecosystems to secure ecologically sustainable development and use (Ecological Reserve). South Africa is fortunate in having established widely-recognised approaches for determining the Ecological Reserve—a South African term used to describe what are globally referred to as environmental water requirements (EWR).

The aforementioned Shared Rivers Initiative study explored a number of underlying drivers and challenges for IWRM particularly in complex and dynamic environments where drivers and outcomes are often unpredictable, such as is the case of climate change and its

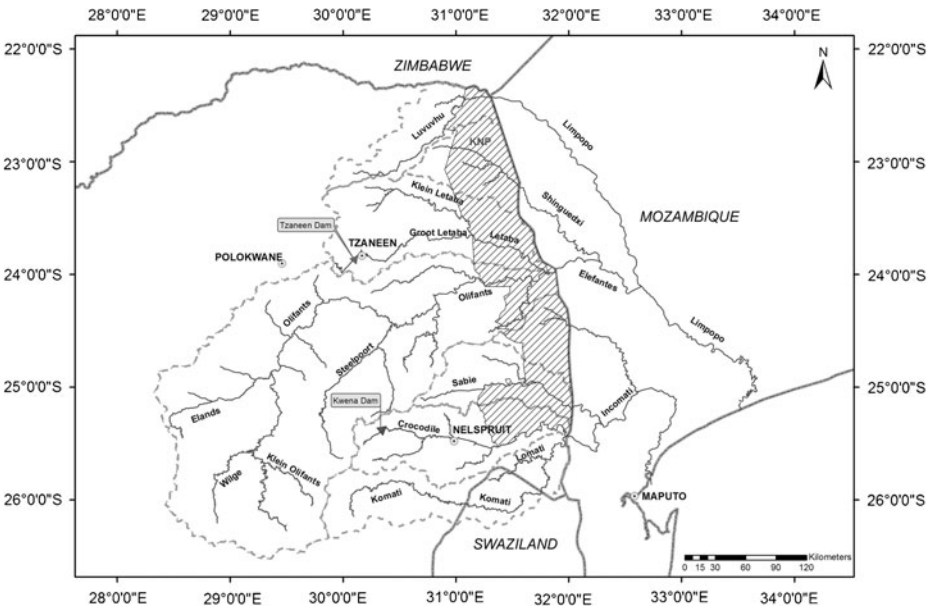

Fig. 1 Map of the six lowveld catchments and their rivers that comprise the study area: the Luvuvhu, Letaba, Olifants, Sabie-Sand, Crocodile and Komati Rivers. The two catchments referred to in this paper, the Letaba in the north and the Crocodile in the south, contribute to the international watercourses of the Limpopo and Incomati basins respectively

potential impacts. It concluded that a range of factors are critical in supporting the evolution of IWRM (and in particular, sustainability) in a way that is tenable and appropriate and that reflects the cornerstones of water reform. These factors were a practice-based understanding of policy, the role of leadership and communication, governance, collective action and regulation, and self-organisations (Pollard and Du Toit 2011). In this paper the focus is on two particular factors, self-organisation and feedback loops, as well as drawing attention to the role of leadership in determining successful outcomes in relation to these factors. We explore these factors conceptually and practically drawing on data from the Letaba and Crocodile catchments that were part of the broader study (Pollard and Du Toit 2011). Although the evolution of feedbacks, as an emergent property of complex systems, is evident in all six catchments, two specific cases are discussed. Both the Groot Letaba and Crocodile rivers have been the focus of intense management efforts aimed at addressing the growing water stress over the last decade. Hence these catchments are illustrative of the different contexts and ways in which self-organisation and feedbacks evolve, establish and function. In discussing how these issues relate to successful river management, we argue that self-organisation and feedback loops are key properties of complex and resilient systems particularly since they provide the basis for reflexivity and learning. As recognition for the central role of these functions grows so has interest in what underlies their genesis, development and functioning (see Pollard et al. 2011). In the Letaba Catchment feedback processes have been operative for over a decade whereas in the Crocodile they are more recent, being associated with IWRM efforts of the newly-established Inkomati[1] Catchment Management Agency. Both catchments are extremely water-stressed. Examining the

[1] The spelling *Inkomati* applies to the South African component of the wider international *Incomati* Basin

unfolding of institutional responses to water stress concurrent with embracing policy reform provides insightful lessons and reflections for implementing IWRM.

We start with an examination of a number of key concepts, followed by a description of both catchment cases, and close with an exploration of factors that support the emergence of self-organisation and feedback processes and the role these have in effective IWRM.

2 Conceptual Underpinnings: Complexity, Resilience and the Role of Self-organisation and Feedbacks

A central thesis of the following case studies is that water governance is concerned with the management of complex, dynamic and often unpredictable systems. Drivers of system dynamics, such as climate change, are inherently variable in space and time and across multiple scales thereby reinforcing uncertainty. The framework for management within such a context—in this case IWRM—needs to acknowledge rather than ignore uncertainty so that there is adaptation through learning (see Ison et al 2007; Ison 2010). Such systems—referred to as complex adaptive systems—display a range of essential properties including self-organisation and feedbacks (Holland 1999). These properties, the focus of the case studies, together with the key concepts that underlie such a view of water governance have not been widely engaged within IWRM to date and thus are briefly reviewed.

Complexity theory is part of a wider body of systems thinking that arose as a critique to the reductionist approaches of the conventional scientific method, considered to be ill-equipped to deal with complex inter-dependencies such as those found in natural resources management. The essence of concern for the 'natural' sciences was that despite the enormous focus on research and management of natural systems, sustainability remains—for the most part—an elusive goal (see for example Levin 1999; Holling 2001; Gunderson and Holling 2002; Folke et al. 2002; Folke 2003; Walker et al. 2004; Allison and Hobbs 2006). Challenging reductionism is not new; indeed complexity thinking builds on *general systems approaches* pioneered in the 1930s, which examined 'wholeness' and connectedness (see von Bertalanffy 1972; Checkland 1981; Forrester 1992). The overarching characteristic of complex systems is that they are not entirely predictable (although they show pattern) and therefore have to be managed through a process of strategic adaptive management that embraces learning-by-doing (Biggs and Rogers 2003). The underlying causes of not adopting such an approach appears varied including (i) the general failure of science to recognise the linkages between disciplines (i.e. systems) through the persistent endorsement of silo approaches as 'good science' (see Biggs 2003), (ii) the use of the conventional scientific method based on a Newtonian world view to inform management (e.g. stable systems in a state of equilibrium) leading to, for example, the development of single-value harvest rates (maximum sustainable yield), irrespective of variations in the socio-economic, political and natural context, and (iii) the lack of a meaningful and reflexive interaction between science and society (see Lubchenco 1998).

One initiative, the Resilience Alliance (http://resalliance.org; accessed 11 July 2010) has popularised the handling of complexity through the concept of *resilience*, by exploring the dynamics of social, economic and biophysical 'systems' which they view as a single interacting, integrated socio-ecological system—or SES—with feedback and interdependence (Berkes and Folke 1998). They note that the boundaries between social and ecological systems are artificial and arbitrary and emphasise the 'humans-in-nature' perspective.

'Resilience thinking' holds three concepts at its core (Walker and Salt 2006). Firstly, social and ecological systems are inextricably linked and changes in one will reverberate in the other. Secondly, these SESs are complex adaptive systems and thus do not behave in a linear, predictable fashion. Thirdly, they have the capacity to absorb disturbance, to change and still retain essentially the same function, structure and feedbacks. That is, such systems have resilience. A number of attributes appear to confer resilience (e.g. Walker and Salt 2006; Pollard et al. 2008) including self-organisation and feedbacks to which we now turn.

Although the role of feedbacks in WRM is the focus of this paper, they are conceptually inseparable from the concept of self-organisation (amongst other attributes of complex systems). As noted, self-organisation is a key feature of the complex adaptive systems where the system 'arranges itself' (through relations between components and adaptation). Heylighen et al. (2007) coin the term 'creative evolution' to describe this development that is not only unpredictable but also creative—producing emergent organisation and innovation. The concept is now so widely applied by different disciplines that it is difficult to determine whether discipline-specific phenomena are all fundamentally the same process, or the same label is applied to different processes. Cilliers (1998 p. 90) provides an elegant working definition of self-organisation as follows:

> "The capacity for self-organisation is a property of complex systems which enables them to develop or change internal structure spontaneously and adaptively in order to cope with or manipulate their environment."

The essence of self-organisation is that organisation or form results from the interactions between systems components arising from constraints that are internal to the system. As Cilliers (1998) states 'this process is such that structure is neither a passive reflection of the outside nor a result of active pre-programmed internal factors, but the result of complex interaction between environment, the present state of the system and the history of the system'. The organisation can evolve in either time or space, maintain a stable form or show transience. The concept is closely linked to others in complexity literature such as networks and self-regulation.

Like self-organisation, feedbacks are widely used in various disciplines. Feedbacks describe situations when the output from an event or phenomenon in the past will influence an occurrence of the same in the present or future. A *feedback loop* is the causal path that leads from the initial generation of the feedback signal to the subsequent modification of the event either as reinforcing (increasing the input) or balancing (reducing the input) loops. An examination of the nature of complexity and the role of feedbacks has underpinned some of the major theoretical shifts such as for example, in the field of economics (see for example Ormerod's (1997) critique of economics).

A complex system shows *feedbacks* which usually because of its operation at different scales, cause *emergence* (i.e. they generate surprising new properties not predictable from the original individual components of the system). Importantly, feedbacks are one of a number of attributes believed to confer resilience through learning and reflexivity (e.g. Meadows 1999; Walker and Salt 2006; Holling 2001; Gunderson and Holling 2002).

Feedbacks have been examined both in biophysical and social systems but less attention has been paid to their emergence and role in the management of complex systems such as catchments, particularly within the context of water governance. In this regard the social sciences view of complex systems where a dynamic (dispersed and decentralized) network of agents (e.g. individuals, organisations, institutions, nations) acts and reacts to each other, is important. Coherent behaviour in the system can arise from competition and cooperation among the agents themselves.The feedback loops described in the two case studies of

WRM are examples of the hierarchies of social networks that exist for the management of a socio-ecological system—in this case the catchment or basin. Cilliers (1998, citing Lyotard 1984) points out that self-organisation in social networks is not a designed characteristic but is rather emergent in response to contingent information in a dynamic way. Individuals may co-operate but also compete for resources and the history of the system is vital for understanding how feedbacks emerge. We start therefore by giving a brief overview of the context and history of the two catchments before describing the self-organisation and feedback processes as well as critical leadership features that our research revealed. We then move on to an analysis of their development and strengths as part of a process of 'looking for leverage' in complex systems (see Meadows 1999) and which might be taken up in the evolving landscape of IWRM.

3 Overall Approach and Contextual Overview of Catchments

3.1 Overall Approach

The overarching 3-year study on which this paper rests involved a two-pronged methodological approach. The first was to examine compliance with EWRs as a measure of the progressive realisation of the NWA. This comprised a quantitative assessment of compliance with the Ecological Reserve (quantity requirements) prior to, and following, the promulgation of the NWA (see Pollard et al. 2011 for details). The Reserve requirements (see Introduction) have been established through a process known as a Comprehensive Reserve Determination for the Letaba and Crocodile catchments in 2006 and 2010 respectively. The second approach, central to this paper, focused on a participatory scoping process to understand the nature and extent of factors that both enable or constrain meeting the Reserve. The research was based on semi-structured interviews, with questions framed by four key strategic themes for IWRM in South Africa, as outlined in the framework for catchment management strategies (see DWAF 2007; Pollard and du Toit 2008). These four themes focused on (i) understanding context and futures (ii) water resources management (protection and regulation), (iii) facilitatory actions (public engagement, information management and finances) and (iv) integration (co-operative governance across scales, institutions, nationally and internationally). Although all categories were covered in interviews the emphasis was on management actions related to water resource protection and regulation (see Pollard and du Toit 2008). The final set of interview questions were developed after an initial round of preliminary interviews and discussions with key stakeholders.

The research entailed interviews and follow-up interactions with 125 stakeholders both within catchments and at the national level over the course of two years (Pollard and du Toit 2011). Stakeholders were defined as those involved in water management or use and included representatives of local municipalities, various departments (provincial and national), the Department of Water Affairs (DWA) regional and national offices, irrigation boards, water users associations, commercial forestry, industry, mining, conservation and other interested and affected parties.

For analysis, the interview data were organised into emergent themes for each of the catchments. These were as follows (i) understanding of the Reserve and EWRs; (ii) the presence of implementation lags in relation to management actions; (iii) the status of integration of WRM and water supply efforts; (iv) the status of unlawful use; (v) skills, capacity and ability of the regulator to monitor and enforce; (vi) adaptive capacity and

responsivity to change; (vii) learning within changing contexts and; (viii) feedback loops and self-organisation. This paper deals only with the last theme, that of feedback loops and self-organisation. Elaboration of other themes is currently underway with papers being prepared around each theme. Whilst the research focussed largely on stakeholders within South Africa, international considerations were also part of the wider, systems analysis.

3.2 Overview of the Letaba and Crocodile Catchments

3.2.1 Broad Contextual Profile

The key characteristics of the two catchments are highlighted in Table 1 whilst detailed descriptions are available in DWAF (2004a, b) and Pollard and du Toit (2011). The catchments share similarities in terms of many biophysical and land-use parameters but their histories and WRM experiences are sufficiently different to provide useful lessons and reflections. Both catchments stretch from the highveld in the west to the Mozambique border in the east. Both catchments are in water deficit, and the Crocodile has experienced a reversal in flow seasonality so that high flows have been experienced during the normally

Table 1 Summary of the main biophysical and socio-economic characteristics of the study catchments

Characteristic	Letaba Catchment	Crocodile Catchment
Area	13,500 km^2	10,400 km^2
Main urban centre	Tzaneen	Nelspruit
Catchment context	Catchment comprises Groot and Klein Letaba sub-catchments. Falls into the Luvuvhu/ Letaba WMA	Crocodile River falls into the Inkomati WMA which forms part of the Incomati international watercourse shared between the Republic of Mozambique, the Kingdom of Swaziland and the Republic of South Africa.
Topography and rainfall	• Varies from a western, mountainous area of high rainfall (1500 mm) to the low lying plains in the east with a rainfall of less than 450 mm.	
	• Rainfall is seasonal occurring mainly during summer (October to March).	
Water resources land and water use	• Highly stressed; catchments in water deficit	
	• Intensive, irrigated agriculture and forestry predominate in terms of land and water use.	
	• Subsistence, dryland agriculture is prevalent but restricted to former Bantustan areas (see below)	
	• Both catchments include conservation areas—most notably the Kruger National Park which lies in the eastern, downstream portion of the catchments.	
Major water resource infrastructure	• Extensively developed.	Extensively developed.
	• Tzaneen Dam on Groot Letaba River	Kwena Dam on upper Crocodile River
Demographic and socio-economic factors	• Juxtaposition of wealthy and poor.	
	• Population is largely rural; Most of poor areas are former apartheid Bantustans (into which the majority of the black population was moved under the apartheid regime) characterised by major socio-economic problems (poor education standards, high unemployment (formal—estimated at 49% of the workforce), and high level of HIV-Aids	

low, stable winter flows. The DWA policy has been not to issue any more water use licences to irrigation although there is still some unlawful development.

3.2.2 Institutional Arrangements

Whilst the contextual profile of both catchments is similar, the institutional arrangements for WRM (and water supply to some extent) are quite different. Moreover organisational transformation is still underway leading to a somewhat confusing picture of roles and responsibilities, both nationally and at local levels. For example, the assignment of WRM functions from National DWA to local level organisations (see below) is still unclear in most catchments. In some catchments, so that local government officials have assumed, incorrectly, that they are responsible for WRM (Pollard and du Toit 2011). Throughout the country a number of bodies are being established or transformed in accordance with the NWA (Table 2), and key to this are the Catchment Management Agencies (CMA) which preside over mega-basins or Water Management Areas (WMA). The Crocodile catchment falls under the Inkomati CMA—the first to be established in the country.

With agriculture as the biggest water user in the study area, water user associations (WUAs) or irrigation boards have a long history of involvement in WRM albeit focused on their own sectoral needs until recently. The Groot Letaba WUA is well-established and even as the former irrigation board, played a key role in WRM and regulation from the Tzaneen Dam along the length of the river to the border with the Kruger National Park (KNP; see Fig. 1). The Tzaneen Dam is currently managed by a DWA manager according to operating rules that have been developed and adapted with experience over the last decade. Since 2003 interactions between the WUA and the Kruger National Park have become increasingly collaborative. In the Crocodile it is only recently that, under the guidance of the Inkomati CMA water resources manager, the irrigation boards have become involved in a more holistic focus on the entire river from the Kwena Dam to the Mozambique border. Aside from political reform, a major catalyst for this has been the need to consider international flow requirements.

4 The Emergence of Self-organisation and Feedback Loops in Water Resources Use and Management

We noted above the importance of the Ecological Reserve (or EWRs) as a benchmark for sustainability and to some extent for equity. Findings from a related study suggest that in general, compliance with the quantity component of the Ecological Reserve has improved in the Letaba but worsened in the Crocodile River over the past decade (Pollard et al. 2011). In the case of the Crocodile, this compromises the ability to honour the international flows to Mozambique and Swaziland as set out under an interim, trans-boundary agreement (although indications are that the situation is starting to improve). What then lies behind both of these situations and what can we learn from these cases? Amongst many factors self-organisation (underpinned by responsive and effective leadership) and feedback loops appear to be critical and will now be examined in greater detail.

4.1 The Letaba Catchment

Not only does the Groot Letaba River below Tzaneen Dam experience regular water shortages and restrictions, but also a high incidence of non-compliance with the ER. Nonetheless this has improved notably since 1994 with the average incidence of non-compliance declining from

Table 2 Summary of existing or proposed institutions for water resources management and their current status with respect to the study area

Institution	Functions	Summary of current status
International water management bodies	Facilitate international cooperation and the development and operation of large international water resource infrastructure or for co-operative sharing and management of a shared water resource.	For the study area international obligations pertain in the case of the Crocodile River mediated through the Tripartite Permanent Technical Committee (South Africa, Mozambique and Swaziland;)
National Department of Water Affairs (DWA)	Oversight function. Certain key functions to remain national responsibility (strategic international agreements, determination of class and Reserve, transfers, assignment of functions, approval of Catchment Management Strategy)	Still in the process of transformation
National Water Resources Infrastructure Agency (NWRIA)	Newly-established to manage certain dams (flood control; dams that supply more than one sector) and former 'government controlled areas'	Operational in the study area but roles and functions are poorly understood by most stakeholders. In particular, their active participation in establishing and monitoring operating rules is unclear (Pollard and du Toit 2011).
DWA Regional offices (RO)	Will assume an oversight and support function once the CMAs are established and operational (i.e. they have been assigned functions by the Minister of DWA)	Still largely responsible for WRM functions although their scope differs in each case. In the Letaba the Regional Office, together with the NWRIA, is responsible for WRM functions. In the Crocodile, they still retain certain functions but in practice many are being carried out by the Inkomati CMA.
Catchment Management Agencies (CMA)	Manage water resources in each of 19 Water Management Areas (WMA). The two WMAs of focus for this study are (a) the Inkomati WMA and (b) the Letaba/ Luvuvhu WMA.	Nationally still in the process of being established. a) The Inkomati CMA (Crocodile River) has been gazetted but is still in the process of being assigned functions and most WRM functions *de jure* still fall under the DWA Regional Office (see above). b) In the Letaba, the process for establishing the Letaba/ Luvuvhu CMA is still underway and DWA assumes overall WRM
Water User Associations (WUA)	WUAs are an association of individual water users who wish to undertake water related activities for their mutual benefit. Either newly-established or being established through transforming former irrigation boards to include all water users beyond commercial agriculture alone (e.g. forestry, conservation, municipalities, mining).	a) Groot Letaba WUA is well-established and has a long history of involvement in water resources management and regulation from the Tzaneen Dam along the length of the river to the border with the Kruger National Park. b) In contrast, the Crocodile River Major Irrigation Board (MIB) has yet to become a WUA.
Statutory and non-statutory bodies Catchment Management Forums (CMF) or Committees (CMC)	Ensure stakeholder participation in WRM created for each sub-catchment	In both catchments these bodies are still in the process of being established and/or becoming operational

41% between 1960 and 1993, to 22% between 1994 and 2008 (Pollard et al. 2011). In 1991 a new manager took responsibility for the management of water resources from the Tzaneen Dam and developed operating rules based on the monitoring of dam levels, flows and climate data. These—together with the required restrictions—were communicated to water users, mainly through the Groot Letaba Water User Association (GLWUA). Additionally planning together with representatives at the start of the water year was initiated although this did not actively include the Kruger National Park until about 1999 (J. Venter, SANParks, 2008, pers. comm.). Already the experience of financial losses incurred during droughts had resulted in highly efficient water use by irrigators who often operated on 50% of their allocation.

Despite overhauling the management system, it remained largely focused on water for commercial agricultural needs. However, in the late 1990s the Kruger National Park started to voice concerns about the flows of the Letaba entering the Park and a minimum flow of 0.6 m^3s^{-1} was agreed on as an interim arrangement until a final Reserve requirement was established in 2006. Meeting these flows was therefore another stakeholder requirement that had to be built into the operating rules. However given the irrigation of high-value crops had expanded to fully utilise the water resources prior to any allowance for the Reserve, further discussion between all three stakeholders was initiated. Initially the relationship was acrimonious and the Kruger Park even received an invoice from the agricultural sector for the 'costs' associated with the delivery of these flows. However the situation improved once the park staff started to attend farmers meetings in 2003 (Dr. Gyedu- Ababio, SANParks, 2010, pers. comm.).

Today the system displays inherent self-organisation between the regulator, the 'watch-dogs' (the Kruger Park, managers and bailiffs), the users and the dam operators to mitigate against flows that fall below the minimum level (Fig. 2). The Water Affairs manager plans annual allocations based on monitoring and communicates with and responds to concerns from stakeholders (mainly the Groot Letaba WUA and the Kruger National Park). Once the Groot Letaba WUA has discussed and received their annual water allocation, they distribute it across the users and months and monitor flows and use through a system of bailiffs. Transgressions such as over-abstraction are dealt with first as a warning after which charges are laid with the police. The Kruger National Park monitors the flow at the entrance to the Park against the minimum flow requirement. If problems are noted the water resources manager is alerted, who in turn alerts the WUA to reduce use. Importantly, the emergent feedback loops that characterise the system locally (Fig. 2) provide the basis for self-regulation and learning since the water resources manager leads a process of reflection and adaptive management. Although this is not an explicit managerial objective, it has emerged through a process of trial and error.

There are a number of factors behind the success of these feedbacks including the requirements of the law (the Reserve), the availability of benchmarks against which to monitor (the 'Reserve', albeit a static value), the presence of a 'watchdog', the responsiveness of the manager and users, communication and the ability to self-organise and self-regulate. Leadership is undertaken by a manager with authority and who, over time, has become sufficiently trusted. Moreover, the capacity for self-regulation amongst long-standing WUA members (users) is high, although bringing new, 'emerging' farmers (i.e. formerly disenfranchised) on board has proved more difficult.

However, the system is fragile in other respects (Pollard and du Toit 2009). Firstly, one of these feedbacks is potentially vulnerable in that it depends on one key person with little evidence of this capacity being more widely present. Secondly, the feedbacks are confined to a local scale and lack key *supportive* linkages to wider scales that would confer strength and resilience (see Fig. 2). This is because feedbacks at a wider scale are needed to secure

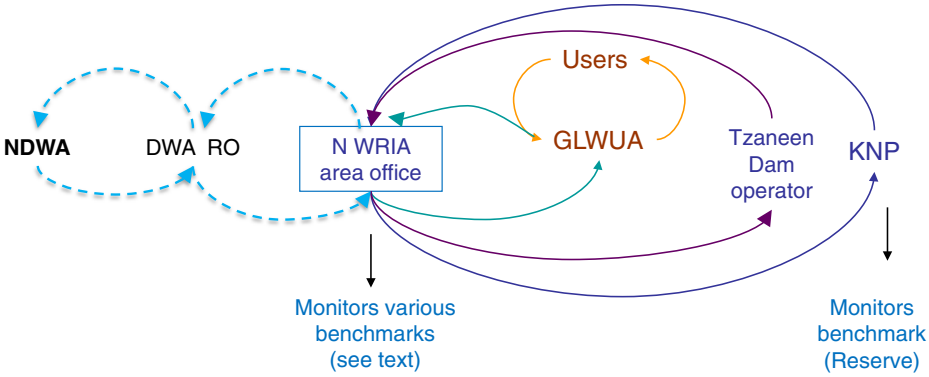

Fig. 2 Feedback loops in the Groot Letaba Catchment. Dashed lines indicate linkages that are still to be established. Note that the water resources manager referred to in the text is part of the NWRIA = National Water Resources Infrastructure Agency. KNP = Kruger National Park; GLWUA = Groot Letaba Water User Association; DWA RO = Department of Water Affairs Regional Office; N DWA = National DWA

lawful water use through an integrated approach. Currently there is little support from the national or regional offices of DWA despite repeated attempts from local stakeholders. Finally, widening the scope of management to consider the catchment as a whole is needed. Although the GLWUA manages some 520 registered water users, most tributaries are outside of the area of control, potentially undermining the overall management towards a compliant system (GLWUA, February 2008, pers. comm.). In theory WUAs represent all water users (including municipalities) but, in reality, they are plagued by non-attendance and lack of participation.

Collaboration and co-learning with water users are vital so that in the Groot Letaba the feedbacks, although fragile, are functional at a certain scale. Historically distrustful—and even acrimonious—sectoral positions began to change once stakeholders started meeting and planning collectively in 2003 (see above). In contrast the dearth of participation by users is acutely evident in the neighbouring Klein Letaba. Although the same manager is involved in operational systems, local feedbacks are virtually non-existent and the system is in an almost permanent state of crisis and water deficit.

4.2 Crocodile River

The water requirements of the Crocodile River exceed the available resources and the catchment is highly stressed (DWAF 2004b). Pressures on the system to meet the demands of new (historically-disadvantaged) farmers, the Reserve and international agreements are high and increasing. The incidence of non-compliance with the Ecological Reserve is high and has worsened from an average incidence of non-compliance of 24% between 1984 and 2000, to 50% between 2000 and 2008 (Pollard et al. 2011).

The early 2000s saw improved WRM systems with some key feedbacks initiated around 2005 (Fig. 3). Users were required to register their water use as part of a system to re-licence users within the bounds of available water resources. Also active monitoring of the international flow requirements into Swaziland and Mozambique through the Interim Inco-Maputo Agreement (signed in 2002; (TPTC 2002) meant that concerns were raised through the national DWA in South Africa. At about the time the Inkomati Catchment Management Agency (ICMA) was established in 2004, the Kruger National Park started to monitor the

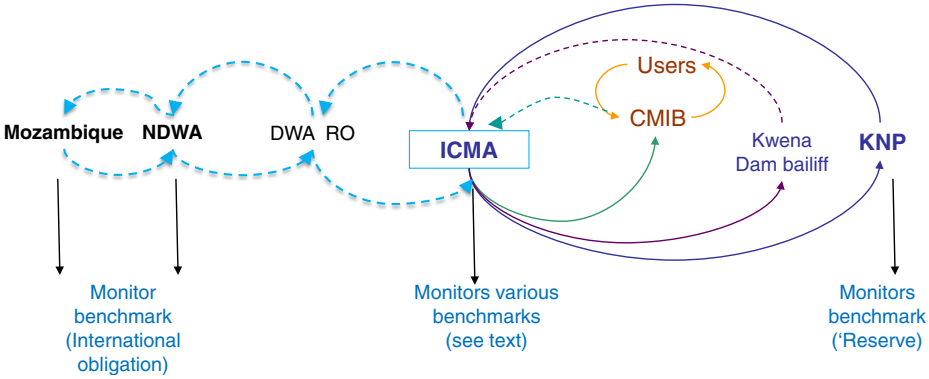

Fig. 3 Feedback loops in the Crocodile Catchment. Dashed lines indicate linkages that are still be established. Note that the international linkages currently happen through NDWA. KNP = Kruger National Park; CMIB = Crocodile Major Irrigation Board; ICMA = Inkomati Catchment Management Agency; DWA RO = Department of Water Affairs Regional Office; N DWA = National DWA

Ecological Reserve more actively. The National Park now alerts DWA and the ICMA when infringements occur. In terms of water use, the Crocodile Major Irrigation Board actively regulates irrigation use in much the same way as the Groot Letaba WUA. Also, like the Letaba case, prior to about 2008 board members focussed almost exclusively on defending their sectoral needs.

Despite change the catchment has continued to experience water stress and non-compliance with the Ecological Reserve requirements and most feedbacks are weak or absent (although as we explain below, this is likely to change in the near future). Only recently has agriculture, as the major water user in the catchment, considered catchment-wide issues rather than sectoral interests alone. Moreover without the transformation of the irrigation boards to WUAs and the associated increases in the availability of skills and resources, bringing other users such as the municipalities, mining and industry on board has been difficult and regulation has been extremely weak. There has been little clarity and support from DWA who themselves are attempting to establish new systems for oversight. For example, a key aspect of IWRM is that of regulation (especially monitoring and enforcement) and this has been very weak with only a handful of staff nationally until very recently. Attempts to strengthen feedbacks in this regard have been constrained by lack of clarity on which organisation is to assume such responsibilities.

In addition to the more complex WRM environment, a number of issues distinguish the Crocodile from the Letaba. The Incomati WMA including the Crocodile, has been a key site nationally for institutional reform and decentralisation through the establishment of the ICMA—the first in the country. Whilst this has had a number of positive outcomes, the roles and responsibilities for WRM—and in particular allocation, monitoring and enforcement (regulation)—have been unclear for a significant period. In effect, these functions have largely fallen 'between two stools'. Thus whilst the nascent ICMA attempted to improve WRM this was under a cloud of institutional confusion and occurred largely without any assigned functions and associated resources from the national minister. The regional DWA office on the other hand was of the view that WRM was the responsibility of the ICMA, citing lack of senior staff and resources for their inaction (Pollard and du Toit 2011).

The establishment of the ICMA together with a growing emphasis on IWRM for the catchment as a whole has required that stakeholders look beyond their own individual needs

to the wider context (Pollard and du Toit 2008). Part of this context is the need to ensure equitable water-sharing arrangements with sectors of the population that were denied access during the apartheid era. Two additional obligations also driving transformation are the increased focus on compliance with the finalised Reserve as well as with the international obligations for water-sharing. Although cross-border international flows have been in place for nearly a decade, this is likely to change under the new transboundary comprehensive agreement.

Like the case of the Letaba the water resources manager, in response to growing water resource pressures, has now taken on a more active management approach despite the lack of clarity on roles and functions. More recently, improved technical and management systems such as the establishment of a real-time operating system and the development of the catchment management strategy (DWAF 2007), together with greater collaborative efforts between the ICMA, irrigators and other users suggest that the situation will improve in the foreseeable future. In the meantime there are a number of feedback loops such as widening stakeholder participation that are being strengthened by the ICMA to keep the management process responsive to contextual changes.

5 Factors Enabling and Constraining Self-organisation and Feedbacks

This research has traced the success of feedbacks to a number of factors. Firstly, an overarching appreciation of IWRM as an adaptive and learning management approach for water governance (rather than a 'silver-bullet') in complex environments is central. Secondly the ability to plan, monitor and enforce within a complex context is reliant on a nuanced and related suite of factors. These include an understanding of the legal requirements for water reform by the regulator and stakeholders; the availability of catchment-scale benchmarks against which to monitor (the Reserve, international requirements); the presence of a 'watchdog' to monitor benchmarks; the role of leadership with authority (a champion)l the responsiveness of the manager and users; the ability to self-organise; the development of trust, collaboration and learning between the role-players; the internal mechanisms for monitoring and action; and the development of a flexible management system that is understood and respected by the users.

A critical issue is that of leadership and authority. The trusted point of contact—the water resources manager—can and does respond appropriately whilst considering the risk that this may pose to other users. Users may not necessarily fully endorse other demands but trust in leadership is sufficiently strong to garner support. In terms of leadership, Kotter (1996) cautions against conflating leaders and managers, asserting that leadership produces change. In both of the catchment cases the managers have been instrumental in introducing transformative approaches and actions, suggestive of Kotter's definition of leadership. In contrast to some of the other cases examined where catchments are characterised by almost non-existent feedbacks, both managers have assumed responsibility for integrated and adaptive management in institutionally difficult circumstances (Pollard and du Toit 2011). One of the important roles for leadership is that of recourse, such that issues raised by stakeholders do not 'fall on deaf ears' when the leadership role is absent or shared (and potentially lost) between a number of role-players. Moreover enforcement, which is an important component of recourse, is critical to the success of feedback loops and whilst this is well-developed internally for certain sectors (such as through bailiffs in commercial agriculture) it is weak in others which, at a catchment scale, severely compromises the sustainability of feedbacks.

Within each catchment, the ability to self-organise is evident at certain scales. Over time for example, the users of the WUA or irrigation boards have developed and organised themselves into a system that is responsive to—although not always entirely supportive of—the needs of downstream users. An important driver has been the need to share a scarce resource internally—a well-recognised determinant of co-operative management around natural resources (e.g. Murphree 2004; Meinzen-Dick and Nkonya 2005; Pollard and Cousins 2008). Thus the driver is primarily one of self-interest (not necessarily in a pejorative sense) that has allowed wider interests such as the EWRs, water for the poor and neighbouring states, to be served. Most importantly, the locally-developed operating system is sufficiently flexible to accommodate change and surprise.

Transformation has introduced changes to feedbacks in terms of scale and detail, most specifically with respect to the inclusion of stakeholders. For example, the role of the Kruger National Park as 'watchdog' is not only more active but is more widely recognised than it was 15 years ago. However, as the catchment case studies show, the existence of feedbacks is highly variable and nuanced from non-existent to emergent in the lowveld rivers. Moreover ensuring higher-scale linkages is critical. Although regulation and feedback is still constrained to specific sections of both of the rivers rather than for the system as a whole, this is changing in some areas, notably in the Crocodile River as described above. The leadership role of ensuring participation, co-ordinating stakeholders and ensuring a reasonable flow of information has been assumed by the ICMA in the case of the Crocodile and the water resources manager in the case of the Groot Letaba. This critical component of feedbacks is extremely weak outside of the Groot Letaba below Tzaneen Dam and merits further attention. Critically attention must be paid to strengthening linkages at higher scales (such as to DWA and sovereign states in the case of the Crocodile catchment).

As we move into these relatively uncharted waters, an important feedback requiring attention is that between academics, practitioners and managers. In particular is the need to develop tenable approaches such as those for water allocations that have emerged in the Groot Letaba in response to the needs and concerns of the users. Failure to adequately and meaningfully think into the reality of practice will simply frustrate, turning one-time supporters into critics and thus breaking the loop of learning and action. This was certainly the case in the Letaba where users and managers, discouraged by sophisticated Reserve requirements that were difficult to translate into practice, simply defaulted to a minimum flow interpretation (Pollard and du Toit 2011).

6 Conclusions

The imperatives of equity and sustainability together with the increasing pressure on water resources in southern Africa, not only at a national but also at an international scale, have meant that water-sharing arrangements are under much closer scrutiny than in the past. Moreover critical change factors such as climate change and cross-scale economic drivers (such as the capture of virtual water) will require water governance approaches that are more sensitive and responsive to complex dynamics than ever before. As South Africa and its neighbours embark upon the transformation of WRM to a more holistic approach guided by IWRM, attention has turned to implementation. In this context we argue that functional, responsive multi-scale feedbacks are essential for management in complex systems since they provide the basis for learning, reflection and response to an evolving context (see Ison 2010). Although the emergence of functional feedbacks is highly variable it would

nonetheless be naïve to assume that progress in this regard would not be as diverse and nuanced as the existing and nascent complexities of each context. The behavioural and technical reorientation that is required to rise to the challenges of reform mean that lags are to be expected (Pollard and du Toit 2011). Of greater importance is to reflect on and learn from current practices (Ison et al. 2004, 2007). Research programmes that attempt to understand and support feedbacks where they exist in respect of water management provide practitioners with guiding principles for more effective and sustainable practice.

The evolution of IWRM in South Africa as elaborated in these two catchment case studies, highlights some important learnings that have wider global applicability. This is particularly pertinent within the context of governance innovation that addresses climate change since the rapid changes and attendant uncertainties confronting water governance beg the question—how can water resource managers and users be better equipped to respond to complex, changing and often unpredictable environments? The challenge will be to develop appropriate practices that are responsive to learning *from*—and learning *for*—change. There are no blueprints and arguably, this can only be done with a certain level of self-organisation, and feedbacks nested at different scales. Neither of the cases examined in this paper set out with either self-organisation or feedbacks as water management objectives; rather they are emergent properties of the evolving context of IWRM. In this regard, governance systems have yet to explicitly recognise the importance of feedback loops and self-organisation, not just as a consequence of engagement but as processes that can be actively encouraged and sustained, or conversely, undermined and impaired. With acknowledgement of the central role that feedback loops and self-organisation principles play, it is vital that support be given to developing and strengthening leadership and coherent, robust and multi-scale feedbacks that provide the basis for action and learning. Thus what we have seen in the case studies is a self-organising process where meaning is generated through dynamic development, stakeholder participation and collective action—not through the passive reflection of an autonomous agent.

Equally, if we accept that learning has a vital role to play in ensuring that feedback loops have an impact on self-organisation and regulation then it becomes a critical process in supporting (or hindering) the establishment of resilient, sustainable systems. In this regard, learning is taken to be a social process where engagement, communication and dialogue provide the basis for reflecting on and response to feedback in a way that is open to change and that encourages creative and innovative responses to an ever-evolving context (see Doll 1993; Ison et al. 2004).

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