Open Research Online

The Open University's repository of research publications
and other research outputs

Toward adaptive water governance: the role of systemic feedbacks for learning and adaptation in the eastern transboundary rivers of South Africa

Journal Item

How to cite:

Pollard, Sharon Rae; Riddell, Edward; du Toit, Derick R.; Retief, Daniel C. and Ison, Ray L. (2023). Toward adaptive water governance: the role of systemic feedbacks for learning and adaptation in the eastern transboundary rivers of South Africa. Ecology and Society, 28(1), article no. 47.

For guidance on citations see FAQs.

© 2023 The Authors

Version: Version of Record

Link(s) to article on publisher's website:
http://dx.doi.org/doi:10.5751/ES-13726-280147

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's data policy on reuse of materials please consult the policies page.

oro.open.ac.uk

Copyright © 2023 by the author(s). Published here under license by the Resilience Alliance.
Pollard, S. R., E. Riddell, D. R. du Toit, D. C. Retief, and R. L. Ison. 2023. Toward adaptive water governance: the role of systemic feedbacks for learning and adaptation in the eastern transboundary rivers of South Africa. Ecology and Society 28(1):47. https://doi.org/10.5751/ES-13726-280147

Research, part of a Special Feature on Deeper Water: Exploring Barriers and Opportunities for the Emergence of Adaptive Water Governance

Toward adaptive water governance: the role of systemic feedbacks for learning and adaptation in the eastern transboundary rivers of South Africa

Sharon Rae Pollard [1], *Edward Riddell* [2,3], *Derick R. du Toit* [1], *Daniel C. Retief* [1] *and Ray L. Ison* [4]

ABSTRACT. This paper contributes to scholarship on adaptive water governance (AWG), following policy reforms in South Africa, through a focus on systemic feedbacks for learning and adaptation as critical aspects of AWG. We draw insights from three innovative and evolving water governance experiments. In 1998 South Africa adopted integrated water resources management (IWRM) as a transformative approach for achieving an equitable, sustainable, and decentralized stakeholder-centered water resources governance: all hallmarks of an enabling environment for a two-decade history of AWG, although not named as such. Progress in AWG is explored by using a longitudinal, evaluative exploration of three cases in two transboundary basins in South Africa, with a focus on the unfolding enabling environment for achieving sustainability and equity. Building on previous work, we present and discuss a range of enablers that are shown to function systemically to support feedbacks and build adaptive capacity and resilience in complex and uncertain river systems. In the Crocodile Basin, meta-governance arrangements that created an enabling space for collaborative experimentation and learning proved critical as feedbacks were progressively strengthened and embedded through evolving social and institutional arrangements. The enabling environment also supported a networked, blended system of stakeholder- and state-led platforms that have co-evolved through experimentation and learning. Despite progress, long-term persistence of action-learning feedbacks appears less certain in the Olifants Basin cases. We suggest that enabling meta-governance arrangements that offer an institutional home within which to embed learning is critical. The need to explore alternative networked governance arrangements and to explicitly manage for feedbacks that enhance learning at multiple scales is emphasized. We conclude with recommendations for future work on AWG, including reconciling differences between AWG and IWRM that originally framed South African reforms.

Key Words: *adaptive capacity, resilience, social-ecological systems, systems approach*

INTRODUCTION

This paper provides a contextual assessment of adaptive water governance (AWG) emergence in South Africa accompanying water sector policy reforms since the National Water Act of 1998. The evolution of AWG enactments within an initial framing of integrated water resources management (IWRM) is explored and exemplified on the basis of contemporary water governance praxis (theory-informed practical action) experiments. We track the evolution of AWG through changing institutional arrangements for realizing sustainability and equity in water resources management in three cases from two transboundary basins. The paper highlights the role of feedbacks as enablers in supporting learning-based collaboration and decision making (i.e., social learning) in water resources management (WRM). We suggest that understanding these systemic feedbacks within management and governance practices are central to creating enabling institutional arrangements for learning and adaptation in dynamic and often uncertain contexts, particularly under climate change (Berkes and Folke 1998, Ison 2010, Pollard and du Toit 2011). This learning-adaptation-reflection praxis lies at the heart of AWG.

As global water security becomes increasingly complex and uncertain, attention has turned to governance approaches that embrace different ways of knowing, learning, and doing: all attributes of adaptive governance (Ison 2010, Melo Zurita et al. 2018). In this paper we adopt a systemic, learning-based conceptualization of AWG by drawing on the definition proposed by Folke et al. (2005:463), where, in the context of natural resources management, they regard adaptive governance as "flexible and learning-based collaborations and decision-making processes involving both state and non-state actors, often at multiple levels, with the aim to adaptively negotiate and coordinate management of social-ecological systems and ecosystem services across landscapes and seascapes." A more operational definition is given by Hatfield-Dodds et al. (2007) as the "evolution of institutional arrangements" for the management and use of shared natural resources (in this case, water), where institutional arrangements refer to rules, norms, and organizations (Ostrom 2005).

South Africa was an early institutional innovator when it embarked on an adaptive policy and practice journey over two decades ago, following the major post-Apartheid policy reforms that began in 1994 (Pollard and du Toit 2014). The National Water Act of 1998 abolished private water rights and embraced an integrated, catchment-based approach framed by IWRM, committing to meeting basic water needs of all while ensuring long-term sustainability. This set the stage for the participation of civil society and decentralized water resources management through the establishment of catchment management agencies (CMAs; Schreiner and Hassan 2010). Against a vision of redress and within a highly dynamic, uncertain, and evolving context, the new Water Act was so different in its orientation that some were quick to recognize the need for an adaptive and reflexive approach that embraced learning and change (Biggs and Rogers 2003, Pollard et al. 2007). South Africa embraced an approach commensurate with AWG (although not explicitly named as such until later; see, for example, Jackson 2015) as it sought ways to overhaul traditional ways of doing things (Biggs and Rogers 2003, McLoughlin et al. 2011). In recognition that it was embarking on a new and uncertain path, specific reference was made to five-year reviews of strategies that "provide the opportunity to re-evaluate developments in the social and economic environments and to adapt approaches to water resources management to suit changing circumstances and needs" (DWAF 2004). This recognized the need for learning and that there is a co-evolution of social-ecological systems, for which traditional, reductionist, and linear management approaches are inappropriate (Ison et al. 2007, Pollard et al. 2007). This approach was commensurate with

[1]AWARD (Association for Water & Rural Development), [2]South African National Parks, [3]Centre for Water Resources Research, University of KwaZulu-Natal, [4]ASTiP (Applied Systems Thinking in Practice Group), School of Engineering & Innovation, Open University, UK

a developmental state, itself in the process of adapting to a new paradigm (i.e., IWRM), which was understood in different ways across actors, scales, and regions and involved navigating the relic complexities of established institutional hierarchies (Movik et al. 2016).

Post–National Water Act experiences in South Africa (e.g., insights from work on transboundary rivers in eastern South Africa: see Fig. 1) provide a unique opportunity to reflect on what has enabled or constrained practical AWG that emerged within a policy framing of IWRM. The work herein builds on baseline research (Pollard and du Toit 2011) that explored enablers and constraints to the evolution of tenable and appropriate IWRM arrangements needed for adaptation. Since then, a number of research and development (R & D) initiatives designed to support IWRM provide a rich source of experience and information on which to draw.

In this paper we first situate our work within a conceptual framing and in the context of IWRM and AWG (Theoretical Approach). As elaborated in our methodological approach (part three), the key question we address is: How are AWG praxes (referring to the evolution of institutional arrangements for sustainability and equity within IWRM) strengthening feedbacks for learning and adaptation? What has enabled and constrained this? This is done (Results) through three long-term case studies in the Crocodile and Olifants Basins (Fig. 1). We then discuss key findings and conclude with lessons and recommendations.

THEORETICAL APPROACH

Concepts central to this paper are those of complexity and systemic social learning (see Pollard and du Toit 2014) that underlie a shift from managing alone to managing and governing and that underpinned the uptake of social learning approaches in the water field (Ison et al. 2007). In complex AWG, we use governance to refer to the social-political process of managing relationships between people and rules and norms (i.e., institutional arrangements), which might not be easily observable but can operate only in the presence of, and through responses to, feedback in relation to social purpose (Holling 2001, Ison and Straw 2020). We start with two underlying concepts, namely IWRM, an explicit strategy adopted in South Africa (and globally), and AWG, the focus of this special feature. The terms are not synonymous but are, or can be, closely aligned where governance provides the context within which IWRM can be implemented (GWP 2000). We suggest that, although not named as such at the time of policy reforms, South Africa has built a history of AWG that has been operationalized in some areas through the concept of IWRM. In tracking the progress of IWRM, the United Nations (UN; 2021) lists four key dimensions of IWRM: enabling environment, institutions and participation, management instruments, and financing. The enabling environment and the development of stakeholder-centered institutions were at the forefront of a transformative political shift to enable participation by those historically disadvantaged so as to create a new way of "doing" water governance. In South Africa, despite being state led, local-level organizations and associated institutions were given latitude for enacting water governance in contextually appropriate ways.

The term AWG represents the convergence of a number of concepts with different epistemological foundations. Governance refers to a social-political process to manage the relationships between people, rules, and norms (i.e., institutional arrangements), with water governance focusing on water resources and water services (see Rogers and Hall 2003, Chaffin et al. 2014). Folke et al. (2005) provide an extensive discussion on the transformative nature of adaptive governance that requires learning, flexibility, participation, and co-management at multiple scales. This reorientation was widely evident in the governance reforms of 1994 in South Africa, which, underpinned by principles of equity, sustainability, and efficiency of the new democracy, were deeply transformative (see Pollard and du Toit 2014). The reforms also highlight the importance of accountability and good governance, principles that are imbued in the South African constitution and policies. Water governance adopted a decentralized, integrated, catchment-based, pluralistic, and inclusive approach for coordinated, stakeholder-centered river basin management with a strong commitment to learning and adaptation as new governance arrangements unfold (Pollard and du Toit 2011, Rogers and Luton 2016).

We suggest that the hallmarks of AWG are all characteristics of water governance envisioned for South Africa from 1994; the term adaptive water governance may well have been applied if it had been common currency at that time. Water governance in South Africa was conceived as multi-scaled or polycentric, which refers to a form of governance with distributed leadership and citizenship and with multiple centers of decision making, each with a certain degree of autonomy, functioning to protect the integrity of the system (Ostrom 2010). It is administered by the Department of Water and Sanitation (DWS) and supported by regional offices. Inclusive water governance is largely enacted through progressive decentralization to catchment management agencies and forums under these, although their establishment is far behind schedule. The National Ministry retains oversight of some core functions, including allocations for strategic and international purposes and for the reserve (see later). As part of the new institutional arrangements, South Africa adopted IWRM, for which there are various definitions (Box 1), all of which emphasize holism, sustainability, equity, integration, and coordination. South Africa's description of IWRM as a process indicates the need for learning and adaptation (Pollard et al. 2007, Pollard and du Toit 2014). If they had been appreciated more widely, the South African adoption and enactment of its framings of IWRM may have avoided the constraints pointed to by Biswas (2008) in his critique of IWRM.

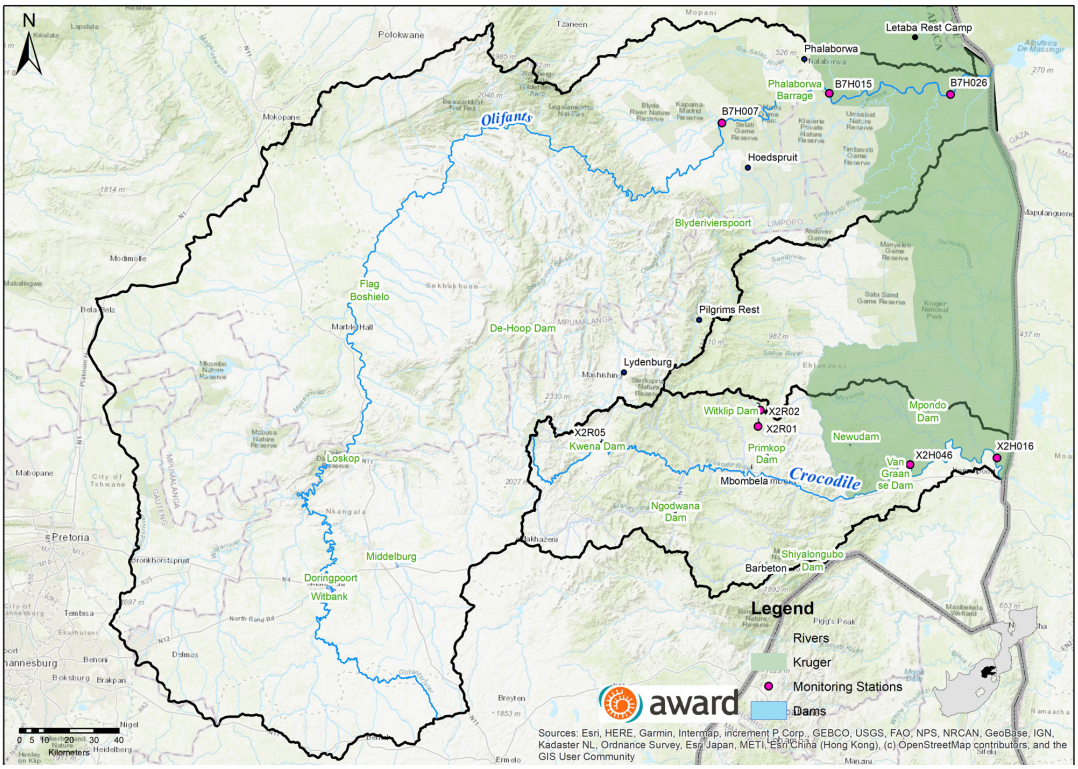
Box 1:

Definitions of IWRM

There are various definitions of IWRM, each of which has been critiqued by Biswas (2008). South Africa refers to "A philosophy, a process and a management strategy to achieve sustainable use of resources by all stakeholders at catchment, regional, national and international levels, while maintaining the characteristics and integrity of water resources at the catchment scale within agreed limits" (Republic of South Africa 1998).

South Africa also embraces the GWP (2000) definition: "A process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP 2000).

Fig. 1. Map of the case study sites showing the Crocodile and Olifants River Catchments in South Africa.



As a management process, IWRM is nested within a broader AWG system. Given their underlying transformative value propositions (see, for example, Melo Zurita et al. 2018), we suggest that water governance, AWG, and IWRM are closely aligned terms in the South African context, although there are differences; AWG focuses on social-political processes for the management of relationships and institutional arrangements whereas IWRM focuses on decision making and enactment at a catchment scale. Even so, there are overlaps, because in the "doing" relationships are being managed and rules and practices are being established, especially within an adaptive and learning paradigm. Both recognize the need for learning and adaptation.

A central idea informing our approach is that water governance is concerned with management of complex, dynamic, and hence often unpredictable situations (Pollard and du Toit 2011, Pollard et al. 2014), for which systemic social learning praxes are key (see Ison et al. 2007, Wals 2007). These concepts have been reviewed elsewhere (Ison 2010, Pollard et al. 2014) but in essence they seek to move from a normative paradigm of linear, reductionist approaches to ones that embrace transparency, accountability, holism, and inclusivity and that build more sustainable and equitable (resilient) futures. This is because dynamic drivers of change, such as water use, declining water quality, and climate change, often lead to emergence and surprise in the system (e.g., the basin). Accepting this requires a certain mode and quality of governance that is strategically and operationally adaptive and for which flexibility, reflexivity, and learning are needed (Ison 2010). In other words, while charting a course toward a common purpose, adaptive governance responds to feedbacks in the social-ecological system as learning happens (Biggs and Rogers 2003); this became a normative framing for the praxis of IWRM that expanded to include systemic governance driven by feedback dynamics (Ison 2010, Roux and Foxcroft 2011, Pollard et al. 2014). Given the cycle of action and learning, feedbacks are essential for adaptation, and in many cases the ability to self-organize around these feedbacks builds a collective water governance practice (see later). This is not to suggest that they are the only features of AWG, but rather that they entrain various other factors that may vary depending on systemic context and dynamics.

METHODOLOGICAL APPROACH

As pointed out by Chafin et al. (2014), the scholarship of AWG covers many fields and theoretical framings. One important aspect involves understanding the evolution of institutional arrangements (Hatfield-Dodds et al. 2007) for the management and use of water and, in particular, those that foster experimentation and learning (i.e., adaptation; Ison 2010, Pollard and du Toit 2011). Pollard and du Toit (2011) proposed that systemic feedbacks, which emerge through cycles of action and learning, are enabled by certain conditions, such as trust, leadership, the presence of champions or watchdogs, and the ability to self-organize around a collective vision. Over time, these feedbacks may become institutionalized as new or strengthened

institutional arrangements (rules, protocols, practices, and even organizations). In this way, evolving institutional arrangements that foster learning are central to AWG.

One set of evolving institutional arrangements in South Africa is aimed at the implementation of the reserve as a benchmark for sustainability and equity (Box 2). In their study of progress on this front a decade ago, Pollard and du Toit (2011) discussed at length emerging institutional arrangements for compliance with the reserve, specifically highlighting the role of feedbacks and self-organization as key to learning and hence adaptation. Meeting the reserve (compliance) requires a range of strategies and institutional arrangements, such as water use authorization, regulation, protection, and restoration as well as stakeholder inclusion, financing, and cooperative governance. Thus, tracking compliance with the reserve can reveal a great deal about the evolution of this bundle of institutional arrangements: in other words, about AWG.

Box 2:

The reserve: an important institutional device

The reserve makes provision for an amount of water that must remain in a water resource, such as a river, prior to any water allocation to maintain ecological integrity and function and to satisfy basic human needs. It is a legally binding (prior right), dynamic benchmark, and is therefore an important institutional device for achieving sustainability and equity in South Africa. In international terms, the reserve would be more commonly referred to as environmental water requirements, environmental flows, or E-flows, although these fail to capture the social element imbued in the concept of the reserve.

This paper critically examines the progressive evolution of institutional arrangements for compliance with the reserve since that reported by Pollard and du Toit (2011). Our approach constitutes a meta- or second-order inquiry building on work between 2004 and 2009; meta, or second-order, processes involve boundary expansion and recursion, such as an inquiry into an inquiry (thus, second order). It is thus a longitudinal study of unfolding AWG arrangements based on three long-term case studies (2013–2019) in two basins, the Crocodile and Olifants River Catchments. Work in each case aimed to build capacity to comply with the reserve and water quality standards, thereby strengthening IWRM sensu South Africa. The two river basins represent positions on a continuum of decentralized water governance. In the Crocodile River Catchment, emerging robust governance arrangements were already evident, whereas in the Olifants River Catchment, which is regarded as highly stressed, new governance arrangements were just emerging.

Methodologically, we employed a combined soft systems methodology (SSM) and grounded theory approach, which share some important philosophical underpinnings. Both are situated not just in the data but also in the context in which data are collected (see Checkland and Howell 1998, Gasson 2003). Both recognize the limitations of using a priori, deductive theories to human transactions (such as adaptive governance) that are embedded in a social context. Both methods surface and value data from the participants and researchers' perspectives, although grounded theory leans toward the theoretical developments from researchers and SSM values participants' perspectives (Durrant-Law 2005). Although these research methods can be used for both quantitative- and qualitative-interpretive data analysis, we focus on the latter as a means to generate, and in this case to build on, a grounded theory (or substantive theory) from earlier work. In this sense the work is interpretive and evaluative. This is consistent with a systemic approach that proposes that substantive theories and actions emerge out of a systemic understanding in context. Building on the soft systems approach for action-research (Checkland and Howell 1998), we adopted a systemic co-inquiry with practitioners and within the team (see Ison 2010).

The meta-inquiry was led by the authors who engaged in, or facilitated, a collective co-inquiry over six years. We drew on data from first-order action-research by R & D staff, which were systematically documented through an in-house M & E system known as MERL (monitoring, evaluating, reporting, and reflecting; Rosenberg et al. 2017). All staff were trained in the approach until it became part of the organizational practice (Pollard et al., *unpublished manuscript*). This is critical because, as Gasson (2003) points out, a grounded theory approach takes time and requires researchers who are capable of reflexive theoretical abstraction. We focused on the need for trust, stakeholder support (compliance), monitoring, and regulation as key action-learning cycles named by stakeholders. As a meta-inquiry, we do not detail the methodological approaches for each case study that are reported elsewhere and for which the researcher-practitioners drew on a range of different traditions and praxes in the context in which they were working, all features of the systemic and action-research praxis used (Greenwood and Levin 1998, Ison and Straw 2020; Pollard et al., *unpublished manuscript*).

RESULTS

Maintaining flow dynamics in the Crocodile River (Case 1)

The highly utilized Crocodile River experiences periodic water deficits and water quality challenges. As part of the transboundary Incomati basin, flow-sharing arrangements are in place with Eswatini and Mozambique. In South Africa, governance of water resources is effected through the Inkomati-Usuthu Catchment Management Agency, or IUCMA, established in 2004, which adopted an IWRM approach. The early 2000s saw improved institutional arrangements. Pollard and du Toit (2011) described a number of enablers and constraints, including emerging governance and institutional arrangements through the IUCMA and the gradual development of systemic, multi-scale feedbacks for achieving a shared vision and associated benchmarks (Box 3). In this process, champions, watchdogs, partnerships, and leadership were key, whereas the lack of delegations from the National Ministry was a major constraint. These authors pointed to consistent non-compliance with the reserve; Riddell et al. (2014) provided a detailed account of this.

Box 3:

The reserve and flow agreements as benchmarks for sustainability

In terms of water resources protection, the reserve and other water quality benchmarks were gazetted in 2019. Prior to this, a present-day hydrology-based reserve flow agreement to maintain the status quo was in place. A water-sharing agreement (IIMA) was signed in 2002 between the Republics of Mozambique and South Africa and the Kingdom of Swaziland (now Eswatini). The minimum cross-border flow of 2.6 m^3/s (1.2 m^3/s contribution from the Crocodile Catchment) is intended to contribute to sustainability downstream.

The past decade has seen a general improvement in river management and consequently in compliance with various benchmarks (Harwood et al. 2017, Tickner et al. 2020). Key to this has been improved institutional arrangements and collective action toward a common vision with established benchmarks (Box 3). Major progress was seen after 2010 with the development of a catchment management strategy, progressive delegation of authority to the IUCMA to implement strategic functions, the establishment of a river system operations committee known as CROCOC (Crocodile River Operations Committee), the inclusion of the reserve as a metric for the CROCOC's river operations, and the development of a rapid-response-system for compliance management (McLoughlin et al. 2011). At the same time, major challenges were evident with a revised hydrology suggesting increased deficits, increased demands for riparian land reform from beneficiaries, domestic and agricultural needs, as well as the need to plan for climate change impacts.

The establishment and strengthening of tenable and trusted local institutional arrangements, notably CROCOC, have been major enablers for this progress. The committee's role in meeting mutual interests, though initially contested, was eventually recognized, and a loose community-of-practice emerged. The ability to self-organize and proactively develop locally adapted management strategies while communicating and negotiating with national and international stakeholders has fostered a transparent and inclusive approach focusing on meeting the full user requirements (at various levels of assurance) along the Crocodile River while maintaining reserve compliance (see Pollard and du Toit 2014; Fig. 2). A number of key institutional arrangements that foster adaptation have emerged, including the use of a decision-making framework associated with a robust short-term (operations) and long-term (planning) hydrological model used for determining accepted operating rules. In terms of learning, adaptation, and decision making, the establishment of regular, well-documented meetings, chaired by a champion of IWRM, and the establishment of ad hoc task teams provide the means to foster and strengthen feedbacks. For example, during the drought in 2015, the IUCMA, the irrigation board, and the Kruger National Park (or Kruger Park) collaborated on options for sustainable irrigation abstractions along the lower Crocodile River, giving effect to intricate flow management down to the Mozambique border. Notably, there was a shared purpose to maintain water security for the local economy and into Mozambique. The Crocodile Catchment's geography (Fig. 1) effectively fosters three watchdogs (the Kruger Park, the irrigation boards, and the multi-lateral Komati Basin Water Authority [KOBWA]) that oversee flow management upstream of the Mozambique border.

As pointed out by various authors, progressive realization of a shared vision through flexible, learning-based collaboration and decision-making processes involving both state and non-state actors are all features of AWG (Jackson 2015, Riddell and Jewitt 2020, McLoughlin et al. 2021). Indeed, with the aim to adaptively negotiate and coordinate management, we suggest that these institutional arrangements have been sufficiently robust to overcome a number of governance challenges, the first being the delegations of authority to the IUCMA being revoked by the state in 2016, effectively curtailing its ability to perform adaptive river operations. This happened at a critical time (during the worst drought on record), making the catchment extremely vulnerable. The users decided to support the IUCMA and the CROCOC carried on with its operations regardless. The second challenge, soon after, was changes in staff at higher levels within the IUCMA. However, they actively valued and supported the CROCOC, providing further impetus for its success. During this time, with drought as the driver, the mandate of the CROCOC expanded to include irrigation boards from smaller tributaries, effectively extending the community-of-practice. Significant, also, is that the IUCMA and its networks have withstood political uncertainty that has prevailed following moves by the National Ministry in 2017 to dissolve CMAs and establish one national CMA.

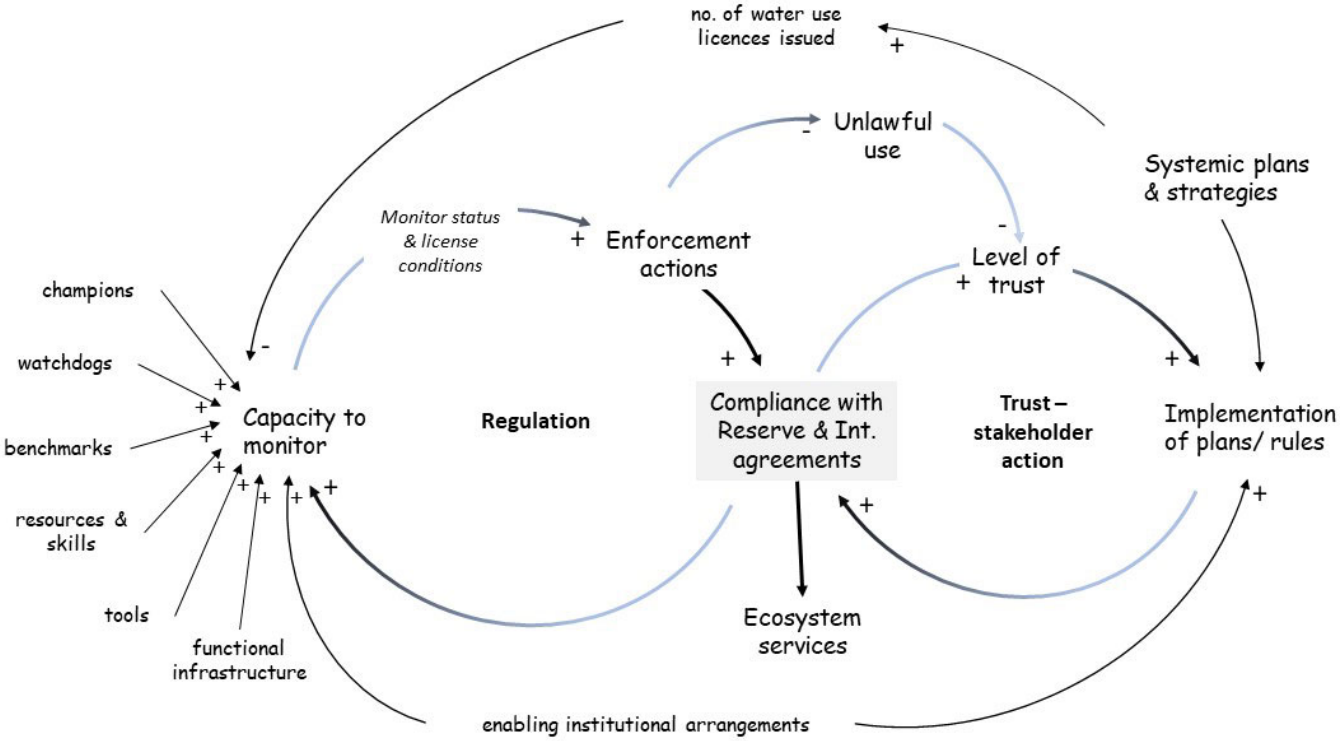
Despite progress in realizing a vision of compliance with the reserve (Harwood et al. 2017, Tickner et al. 2020), full compliance is still elusive, but there are promising signs with, for example, the ecological status quo of the river being maintained through stressed times (e.g., Roux et al. 2018).

Securing flows in the lower Olifants throughout the worst drought on record (Case 2)

The Olifants Basin, the major river within the greater Limpopo River Basin, is the most stressed of all transboundary basins in eastern South Africa (Fig. 1). Like the Crocodile, baseline research a decade ago pointed to the urgent need to support IWRM in order to mitigate increasing water insecurity in the face of growing uncertainty (Pollard and du Toit 2011, Pollard et al. 2011). The availability and quality of water resources were deteriorating rapidly, and flow cessations in a wet cycle revealed management and governance failures (Pollard et al., *unpublished manuscript*). Climate change, now projected to drive a 30% to 50% reduction in stream flow and similar reductions in dam yield (Pollard and Retief 2019, Schulze and Davis 2019), also poses a significant challenge for human well-being and adaptation across the Limpopo Basin into Mozambique.

At the outset of the 2015–2020 drought it was already clear that systemic failure in catchment governance was highly likely. Downstream users (the Kruger Park, regional water utilities, and Mozambique) increasingly voiced concerns as the drought deepened, and discontent over perceived lack of management increased. The town of Phalaborwa regularly experienced no water supply, and pollution spills from mines and wastewater treatment works severely affected what little flow remained in a tributary of the Olifants (see Case 3).

Fig. 2. Simplified causal-loop schematic indicating two key adaptive water governance (AWG) feedbacks that contributed to the maintenance of flows in the lower Olifants and Crocodile rivers during the protracted drought. Key enablers, both state- and stakeholder-led, for learning and adaptation supported improved compliance with various benchmarks or goals. Int., international.



The drought provided a window into a potential future and opportunity to further transition IWRM toward enacting the core features of AWG. Against this background, the seven-year RESILIM-Olifants program, led by a research-based non-profit AWARD (Association for Water & Rural Development), was initiated to support strategic adaptive management through systemic social learning approaches, again using the statutory reserve and water-sharing agreement as benchmarks. Through a process of systemic co-inquiry, three leverage points were identified (Pollard et al., *unpublished manuscript*), including support for emerging governance arrangements, development of tools and protocols and training in their use, and mobilizing capacitated networks for water resources custodianship. Importantly, the establishment of an incoming proto-CMA offered a key institutional platform for engagement.

Box 4:

A vision and benchmarks for sustainability and equity

The reserve and other water quality benchmarks for the Olifants were gazetted in 2016 following a collective visioning exercise. Water quality planning limits were set in 2018. Although there is no bilateral agreement between South Africa and Mozambique for the Olifants, both countries are signatories to the Southern African Development Community (SADC) Protocol on Shared Watercourses promulgated by the SADC in 2000.

The extreme five-year drought posed major challenges for water security, livelihoods, and well-being. Starting conditions were such that flow and water quality management were already severely compromised. In particular, regulation of unlawful water use by the state became increasingly contentious and the inability to track flows in real time not only hampered the state's ability to monitor and respond but also allowed stakeholders to engage in an unsubstantiated blame game, undermining trust between sectors (Pollard and du Toit 2011). These problems were compounded in the lower Olifants (a region of high water demand by commercial agriculture) by notions of sufficient water availability upstream, and a lack of understanding of downstream needs and rights (including those of Mozambique) and of legal requirements to comply with the reserve and how climate change might impact it. Trust in the state's abilities to manage had worsened with inadequate planning and growing institutional, including political, uncertainty (see below).

In response to the requirement to track flows and compliance, the need for real-time monitoring tools and an integrated decision-support system became apparent. Consequently, AWARD developed the FlowTracker app and the INWARDS DSS (see http://award.org.za/ for details), which allowed stakeholders to track flow against the reserve in near–real time. As a first in the region, FlowTracker is significant for users in that it enables transparency and responsive action.

In 2017, institutional uncertainty compounded the deepening crisis in the water sector in South Africa. Not only were localized structures called into question, but the overarching governance

body, the Olifants proto-CMA (as per the IUCMA model), was put on hold as the then-minister announced plans to create a single, national "one-CMA." AWARD had invested significant effort in supporting the capacity and emerging practices of the Olifants proto-Catchment Management Agency, which was then effectively halted. With the lack of institutional oversight, and as the drought worsened, it became apparent that swift action was needed to avert a complete cessation of flow in the lower Olifants. A core group of stakeholders turned their efforts to supporting an emerging network in the lower Olifants, composed of the Kruger Park, water users, regional and national Water Affairs staff, the water services authority, dam operators, non-governmental organizations, and representatives from Mozambique (i.e., a self-organizing governance network).

Through this network and its use of the FlowTracker app and the INWARDS DSS tools as mediating devices, together with good evidence and the ability to model river operations, AWARD was able to demonstrate that flows could be maintained and demands met (albeit at reduced levels of assurance) if dam releases could be temporarily switched from the small local dam to a new, larger dam farther upstream in the catchment. Key government stakeholders secured permission for this, and the first flows were released in 2016. For operational purposes, flows were monitored using INWARDS, whereas stakeholders were able to track these using FlowTracker, with Kruger Park acting as a watchdog. Adjustments had to be made and, as each release was communicated, operational staff within government and water users became increasingly confident in the evolving disaster mitigation system. In the initial stages, additional flows were taken up by some farmers, resulting in near-zero flows farther downstream. With evidence clearly available through FlowTracker, errant farmers were taken to task internally through the local water user association. Ultimately, flows in the lower Olifants Catchment were maintained through the worst drought on record. A number of important feedbacks, as enablers, were identified, catalyzed, and strengthened through the work, and are discussed below.

Managing wastewater effluent in the lower Olifants (Case 3)

Persistent pollution problems caused by mining and wastewater effluent affect the Selati River (a tributary of the lower Olifants), which supplies water to the town of Phalaborwa, the Kruger Park, and Mozambique (Fig. 1). In recognition of this, the Kruger Park and AWARD worked with stakeholders from mining and water services authorities to develop long-term adaptive strategies and practices to mitigate systemic impacts, particularly under climate change (see Carnohan et al. 2020).

Box 5:

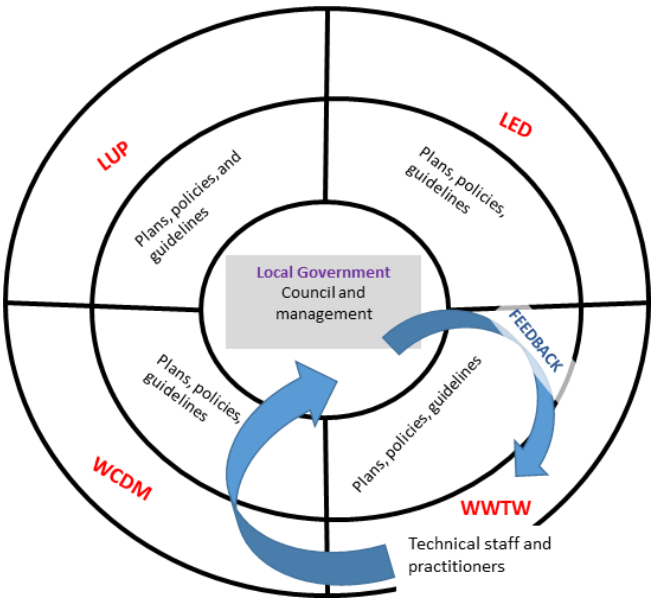
A vision and benchmarks for water quality

The vision for the AWARD-facilitated network was to achieve better effluent outcomes, based on the conditions set out in the water use license. Furthermore, awareness building of the impacts on the receiving environment (water resource) was paramount, and guided by the legislated resource quality objectives. The case exemplifies institutional innovation as well as building systemic relations between institutions enacted with effective practices.

In terms of mitigating poor effluent water quality due to a breakdown in wastewater management, support was given to the Ba-Phalaborwa local municipality as the water services provider for improved strategies and transformative practices for wastewater management. This process embodied more than training; it aimed at effecting a systemic approach by providing workplace support for practitioners and decision makers while simultaneously improving municipal management systems. For practitioners it involved technical support, training, tool development, and application within the context of wastewater management. For decision makers (management and councils), it involved priority setting, budget allocation, institutional reorientation, compliance monitoring and reporting, stakeholder engagement, familiarization with consequences of non-compliance, and the need for complying with conditions for effluent discharge.

Key innovations included the development of an internal and external communication feedback system for adaptive governance and seeing practitioners and practices as an integrated system rather than as a linear hierarchy frequently adopted in an organization. The basis for these innovations was the conceptualization of the municipal system as a "wagon wheel" that connects practitioners with politically elected council members of local government through continuous feedbacks (Fig. 3). An important foundation of the wagon wheel model is that feedbacks between technical staff and political leadership are mediated by an enabling environment of legislation, guidelines, tools, and instruments for wastewater management (namely, effluent monitoring, infrastructure and maintenance budgets, and performance assessments).

Fig. 3. The conceptualization of local government as a non-hierarchical system for integrating decision making and practices. LUP, land use planning; LED, local economic development; WCDM, water conservation and demand management; WWTW, waste water treatment works.



Placing feedbacks for communication, learning, and adaptation at the center of a revised wastewater governance system allowed organizational stakeholders to review priorities, refine decisions, and move the organization toward more sustainable practices. Ongoing adaptive practices circumvented the wait for annual performance reviews, external assessments, target setting, and budgeting. The introduction of communication through feedback within the local government resulted in a higher profile for wastewater management within the council, leading to greater support for practitioners and technical staff formerly perceived as further down the line.

A number of important feedbacks, as enablers, were identified, catalyzed, and strengthened through the work. The first emerged regarding resources and budget. With the engagement of the district municipality more directly in the business of wastewater management (where finances for wastewater infrastructure are sourced), an understanding of the legal requirements for monitoring, and with increasing trust, resource allocations became more coherent and efficient. The second was in engagements with the broader water resources activities that are critical for furthering the aims of wastewater management and contributing to increased compliance in the catchment. In this case, the Kruger Park played an important watchdog role in monitoring and reporting effluent spills and non-compliance. Unfortunately, despite progress in enabling polycentric managing and governing by bringing the municipality into the governance system, anecdotal but emerging evidence suggests that inadequate resources and capacity as well as political interference and corruption may significantly constrain some of the positive gains made.

Table 1. Summary of enablers for adaptive water governance (AWG) identified in three case studies. In all cases the qualifiers of quality and mode need to be considered to avoid drawing simplistic conclusions.

	Enablers
Institutional arrangements	Systemic understanding Overarching governance praxis (quality and mode) Shared vision / purpose Strategy to achieve purpose Processes that enable collective, ongoing learning Collaboration of stakeholders (relationship networks) Multi-scale networks (polycentric governance) Tools (technical, conceptual) Rules: benchmarks (collectively endorsed) Operating systems and processes Regular, transparent communication Resources
Socio-political enablers (enablers of adaptive capacity)	Inclusive processes Trust Leadership (quality and mode of engagement) Active role of champions and watchdogs Ability to self-organize

DISCUSSION

Our meta-inquiry, conducted through a systemic, social learning framing, reveals multiple and interconnected factors that influence compliance with statutory benchmarks and feedbacks for collaborative learning. The key feedbacks of interest from this work focused on those of monitoring regulation and of stakeholder trust compliance (Fig. 2), both of which resulted in the emergence of a new set of institutional and governance arrangements for adapting to a new normal. Of interest are the factors that enable or constrain these feedbacks and what new institutional arrangements emerge, either by chance or through purposeful design, to support them. In keeping with earlier findings (Pollard and du Toit 2011), the role of champions and watchdogs, the introduction of statutory benchmarks against which to monitor and act, the ability to self-organize around a shared purpose, the quality of leadership and communication, and the central role of trust were all important (Table 1).

Recent innovations have highlighted a number of additional enabling factors. Both the shared vision and the use of benchmarks for achieving this, together with the availability of systemic tools (e.g., tracking flow in real time) and shared protocols (e.g., systems operations and integrated wastewater management systems), act as important mediating devices in contested landscapes by affording transparency and objectivity. Additionally, regular, formalized communication and the existence of a safe collaborative space for trial and error all enabled learning. In all cases, a nested, networked governance system emerged with roles and functions being assumed at different scales, either informally or formally, and where each was able to self-organize around risk (see Berardo and Lubell 2016). Learning and adaptation were demonstrated through the progressive strengthening of multi-scale feedbacks supported by emerging institutional arrangements. For example, the rapid-response systems that were established in both the Crocodile and Olifants during the drought involved multi-stakeholder networks that catalyzed new feedbacks and fostered those in existence.

The case findings indicate positive outcomes that can be achieved as IWRM transitions toward AWG, but they also highlight the fragility of governance arrangements unless gains are secured by institutions and practitioners committed to situated systemic practices in the face of localized uncertainty and surprise: i.e., committed to institutionalized social learning as process as well as governance model, rather than governance models driven by hierarchy and command and control (Ison et al. 2007, Colvin et al. 2014). As described here, the legitimacy created through stakeholder-driven processes is well documented (Rogers and Luton 2016, Pahl-Wostl and Patterson 2021). These provide sound examples of an emerging transformative governance process where an overarching policy that has initially been set by government ("implement the reserve") is taken forward through inclusive multi-level actions. Importantly, local actors are able to secure a level of requisite adaptive capacity (Pahl-Wostl 2009, Rogers and Luton 2016); that is, unless politically driven command and control destroy this new repository of relational capital (Steyaert and Jiggins 2007).

There were many dissimilarities between the case studies, which emphasize the need for situated, adaptive praxis. In the Crocodile, a number of networked organizations have convened around a

shared purpose over nearly a decade and are supported by well-developed relationships that have formed through an active process of learning and trust building (McLoughlin et al. 2021). Within the CMA, as a leadership organization, the quality of governance is such that learning, reflexivity, and partnerships are seen as key to building adaptive capacity. The staff, dedicated to their basin, have developed strong partnerships and systemic knowledge of the area so that, although there are constraints, the polycentric governance and institutional arrangements, under enabling leadership, have fostered feedbacks around trust, monitoring, regulation, and compliance. As stated by one stakeholder, "It is a system which - although not necessarily liked by all- is trusted by all." In contrast, these important institutional arrangements were just unfolding in the Olifants when they were put on hold by the state, effectively annulling the CMA leadership role. This role reverted to the under-capacitated regional DWS office that inherited a vast portfolio of additional IWRM and service-delivery related responsibilities. Although leadership still exists in pockets, and stakeholders could be drawn together to avert a crisis during the drought, the long-term sustainability of such a network is far less certain without the continuous basin-level oversight of a dedicated CMA functioning in ways open to local conditions. Equally, the quality of oversight for wastewater management has also constrained positive, long-term outcomes. This means that despite policy commitments to decentralized governance, there is no institutional home in the Olifants Catchment in which to embed learning and adaptation nor are there institutional arrangements to support these as part of an organizational norm. This has been compounded by a growing sense of distrust in the role of the state, marred by allegations of increasing unlawful use and corruption (Muller 2020), which have also undermined AWG elsewhere (Lopez et al. 2019).

LESSONS AND RECOMMENDATIONS

We have made the case that in South Africa, given the framing and ensuing praxis, IWRM and AWG have become closely aligned concepts, with IWRM nested within an adaptive water governance approach. Water resource governance is held at multiple levels, but most notably at the catchment or basin scale. As an emerging and evolving praxis, the experience of decentralized water governance, enacted through IWRM, has to direct attention to learning and the practices and institutional arrangements that strengthen resilience. These would be critical components of successful transformations to AWG, as called for by Chafin et al. (2014). The progress on these fronts is highly variable, as is shown in these three case studies. All cases involved a systemic conceptualization of the catchment (see Pollard et al. 2014) and overarching governance and institutional arrangements that endorsed experimentation, learning, and adaptation, for which feedbacks are key. In all cases, the evolution of networks (as part of polycentric governance) enabled multi-scale feedbacks for learning and hence played an important role in transitioning toward inclusivity, transparency, and responsivity in the face of stress. Strong learning networks also provide the basis for effecting the new institutional arrangements that were envisaged and partially enacted in response to the Water Act. For instance, in the case of the Crocodile River, adaptation and responsivity are being institutionalized through the ongoing development of protocols and practices that are understood by most, if not all, stakeholders; so much so, that they have proved resilient in times of stress and uncertainty, supported by the functioning of the Inkomati-Usuthu Catchment Management Agency. Networks can also provide a stopgap, mitigating governance inadequacies at other scales (in other words, through maintaining redundancy in the resilience context).

However, networks alone do not appear to be sufficiently robust without the critical role of a meta-governor or meta-governance function (such as the CMA), which, under a certain quality of leadership, offers an institutional home for embedding learning and adaptation. In terms of governance, our findings are commensurate with the notion of meta-governance (Bell and Park 2006, Pahl-Wostl 2019), a strong feature of the Crocodile but one that has all but collapsed in the Olifants. In the Crocodile River Catchment, the quality of leadership of the IUCMA aligns with the notion of meta-governance that has opened and sustained the space for emergent, polycentric (systemic) forms of governance and management arrangements, including both state-led and stakeholder-led platforms. This blended mix is best understood conceptually as a layered system, i.e., a system nested within a sub- and supra-system, inhabited by heterogeneous actors. This means that government is not the only candidate for leadership, thus precluding predispositions by the state to slip into command and control.

As emphasized by Melo Zurita et al. (2018), as the world becomes more networked and the emergence of systemic drivers such as climate change render greater complexity and uncertainty, the state will find it increasingly challenging to manage water resources alone, not just in South Africa but globally. Moreover, aside from issues of capacity, the impacts of corruption in particular (especially state-led corruption) undermine trust and enable unlawful practices (Lopez et al. 2019, Muller 2020). Whereas a normative view is one of the state playing a major leadership role, the exploration of alternative institutional arrangements, in which competent collectives can support or assume certain functions (and foster feedbacks) through good governance and enabling institutional arrangements, offers an innovative direction for research and practice. Various authors (Melo Zurita et al. 2015, Ison and Straw 2020) suggest that the seemingly messy, convoluted systems that have emerged out of this complexity and connectedness offer potential insights into crafting new global water governance futures.

We have emphasized that multi-scale feedbacks for experimentation, action, and learning, and the factors that enable them, are key for adaptation in a model of decentralized, polycentric governance such as that envisaged in South Africa. For embedding (or institutionalizing) the continued praxis of learning-and-action as the social-ecological system changes, attention must be paid to the multiple scales of governance that comprise the overall governance system and the feedbacks between them. Whereas challenges or weaknesses at one scale can be mitigated for some time, our work suggests that feedbacks at multiple scales, supported by enabling overarching governance (or meta-governance) are needed for long-term resilience. However, meta-governance is likely to be effective as long as command-and-control or hierarchy displaces localized social learning (Ison et al. 2007, Ison and Straw 2020). Indeed, the experience of governance conditions for strategic adaptive management (SAM) within Kruger Park over a 20-year period

(Biggs and Rogers 2003) suggests that for meta-governance to be effective it must be of a facilitatory nature so as to support the emergence of localized innovation.

Finally, in the face of multiple challenges, purposeful attention to elements that foster resilience is needed (Ison 2010, Pollard and du Toit 2011, Pahl-Wostl 2019). Pelling et al. (2015) make the case for deploying "reflexive monitoring for promising configurations," and we suggest that with AWG, as an evolving practice, the incorporation of explicit recognition of systemic feedbacks that enable learning at multiple scales (and where and how these are to be institutionalized) is essential if the vision of ongoing adaptation is to be realized.

Acknowledgments:

The work was supported by a USAid grant and funds through SANParks, which are gratefully acknowledged. The authors would like to thank the reference group: Prof. Ison, Dr. Biggs, and Prof. Rosenberg for their support over the length of the research, as well as Doreen Robinson, our USAid agreement officer, who enabled the work on governance. The valuable inputs of multiple partners and collaborators are gratefully acknowledged, in particular staff of the IUCMA, SANParks, and the staff of AWARD. Shane Carnohan is acknowledged for his support of systems diagrams.

Data Availability:

Data/code sharing is not applicable to this article because no data/code were analyzed in this study.

LITERATURE CITED

Bell, S., and A. Park. 2006. The problematic metagovernance of networks: water reform in New South Wales. Journal of Public Policy 26(1):63-83. https://doi.org/10.1017/S0143814X06000432

Berardo, R., and M. Lubell. 2016. Understanding what shapes a polycentric governance system. Public Administration Review 76 (5):738-751. https://doi.org/10.1111/puar.12532

Berkes, F., and C. Folke, editors. 1998. Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press, Cambridge, UK.

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

Biswas, A. K. 2008. Integrated water resources management: is it working? International Journal of Water Resources Development 24(1) 5-22. https://doi.org/10.1080/07900620701871718

Carnohan, S. A., J. K. Clifford-Holmes, H. Retief, U. S. McKnight, and S. Pollard. 2020. Climate change adaptation in rural South Africa: using stakeholder narratives to build system dynamics models in data-scarce environments. Journal of Simulation 15(1-2):5-22. https://doi.org/10.1080/17477778.2020.1762516

Chaffin, B. C., H. Gosnell, and B. A. Cosens. 2014. A decade of adaptive governance scholarship: synthesis and future directions. Ecology and Society 19(3):56. https://doi.org/10.5751/ES-06824-190356

Checkland, P., and S. Holwell. 1998. Action research: its nature and validity. Systemic Practice and Action Research 11:9-21. https://doi.org/10.1023/A:1022908820784

Colvin, J., C. Blackmore, S. Chimbuya, K. Collins, M. Dent, J. Goss, R. Ison, P. P. Roggero, and G. Seddaiu. 2014. In search of systemic innovation for sustainable development: a design praxis emerging from a decade of social learning inquiry. Research Policy 43(4):760-771. https://doi.org/10.1016/j.respol.2013.12.010

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

Durrant-Law, G. 2005. Soft systems methodology and grounded theory combined: a knowledge management research approach. actKM Online Journal of Knowledge Management 2(1):13-23.

Folke, C., T. Hahn, P. Olsson, and J. Norberg. 2005. Adaptive governance of social-ecological systems. Annual Review of Environment and Resources 30:441-473. http://dx.doi.org/10.1146/annurev.energy.30.050504.144511

Gasson, S. 2003. Rigor in grounded theory research: an interpretive perspective on generating theory from qualitative field studies. Pages 79-102 in M. Whitman and A. Woszczynski, editors. Handbook for information systems research. IGI Global, Hershey, Pennsylvania, USA. https://doi.org/10.4018/978-1-59140-144-5.ch006

Global Water Partnership. 2000. Integrated water resources management. Global Water Partnership, Stockholm, Sweden.

Greenwood, D. J., and M. Levin, M. 1998. Introduction to action research: social research for social change. Sage, London, UK.

Harwood, A., S. Johnson, B. Richter, A. Locke, X. Yu, and D. Tickner. 2017. Listen to the river: lessons from a global review of environmental flow success stories. WWF-UK, Woking, UK.

Hatfield-Dodds, S., R. Nelson, and D. Cook. 2007. Adaptive governance: an introduction and implications for public policy. Australian Agricultural and Resource Economics Society Conference, 13-16 February 2007. Queenstown, New Zealand.

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

Ison, R. 2010. Systems practice: how to act in a climate change world. Springer, London, UK. https://doi.org/10.1007/978-1-84996-125-7

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(6):499-511. https://doi.org/10.1016/j.envsci.2007.02.008

Ison, R., and E. Straw. 2020. The hidden power of systems thinking: governance in a climate emergency. Routledge, London, UK. https://doi.org/10.4324/9781351026901

Jackson, B. 2015. An adaptive operational water resources management framework for the Crocodile River Catchment,

South Africa. Thesis. University of KwaZulu-Natal, Pietermaritzburg, South Africa.

Lopez Porras, G., L. C. Stringer, and C. H. Quinn. 2019. Corruption and conflicts as barriers to adaptive governance: water governance in dryland systems in the Rio del Carmen watershed. Science of the Total Environment 660:519-530. https://doi.org/10.1016/j.scitotenv.2019.01.030

McLoughlin, C. A., A. Deacon, H. Sithole, and T. Gyedu-Ababio. 2011. History, rationale, and lessons learned: thresholds of potential concern in Kruger National Park river adaptive management. Koedoe 53(2):a996. https://doi.org/10.4102/koedoe.v53i2.996

McLoughlin, C. A., E. S. Riddell, R. M. Petersen, and J. Venter. 2021. Adaptive and transformative learning in environmental water management: implementing the Crocodile River's Ecological Reserve in Kruger National Park, South Africa. Koedoe 63(1):a1663. https://doi.org/10.4102/koedoe.v63i1.1663

Melo Zurita, M. D. L., D. C. Thomsen, N. J. Holbrook, T. F. Smith, A. Lyth, P. G. Munro, A. De Bruin, G. Seddaiu, P. P. Roggero, J. Baird, et al. 2018. Global water governance and climate change: identifying innovative arrangements for adaptive transformation. Water 10(1):29. https://doi.org/10.3390/w10010029

Movik, S., L. Mehta, B. van Koppen, and K. Denby. 2016. Emergence, interpretations and translations of IWRM in South Africa. Water Alternatives 9(3):456-472.

Muller, M. 2020. Money down the drain: corruption in South Africa's water sector. Corruption Watch and the Water Integrity Network, Johannesburg, South Africa.

Ostrom, E. 2005. Understanding institutional diversity. Princeton University Press, Princeton, New Jersey, USA. https://doi.org/10.1515/9781400831739

Ostrom, E. 2010. Beyond markets and states: polycentric governance of complex economic systems. American Economic Review 100(3):641-672. https://doi.org/10.1257/aer.100.3.641

Pahl-Wostl, C. 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Global Environmental Change 19 (3):354-365. http://dx.doi.org/10.1016/j.gloenvcha.2009.06.001

Pahl-Wostl, C. 2019. The role of governance modes and meta-governance in the transformation towards sustainable water governance. Environmental Science & Policy 91:6-16. https://doi.org/10.1016/j.envsci.2018.10.008

Pahl-Wostl, C., and J. Patterson. 2021. Commentary: transformative change in governance systems: a conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Global Environmental Change 71:102405. https://doi.org/10.1016/j.gloenvcha.2021.102405

Pelling, M., K. O'Brien, and D. Matyas. 2015. Adaptation and transformation. Climate Change 133:113-127. https://doi.org/10.1007/s10584-014-1303-0

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. https://doi.org/10.5751/ES-06312-190263

Pollard, S., and D. du Toit. 2011. 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. https://doi.org/10.1007/s11269-011-9904-0

Pollard, S. R., and D. du Toit. 2014. Meeting the challenges of equity and sustainability in complex and uncertain worlds: the emergence of integrated water resources management in the eastern rivers of South Africa. Pages 195-212 in D. E. Garrick, G. R. M. Anderson, D. Connell, and J. Pittock, editors. Federal rivers: managing water in multi-layered political systems. Edward Elgar, London, UK. https://doi.org/10.4337/9781781955055.00024

Pollard, S., D. du Toit, and H. Biggs. 2011. River management under transformation: the emergence of strategic adaptive management of river systems in the Kruger National Park. Koedoe 53(2). https://doi.org/10.4102/koedoe.v53i2.1011

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

Pollard, S., and H. Retief, editors. 2019. Predicted impacts on climate change of the water resources of the Olifants River Catchment. https://award.org.za/wp/wp-content/uploads/2020/05/AWARD-BOOKLET-Predicted-Impacts-of-Climate-Change-on-Water-Olifants-Catchment-2020-v1.pdf

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

Riddell, E. S., and G. P. W. Jewitt, editors. 2020. A management tool for the Inkomati Basin with focus on improved hydrological understanding for risk-based operational water management. Water Research Commission, Pretoria, South Africa. http://wrcwebsite.azurewebsites.net/wp-content/uploads/mdocs/1935_final.pdf

Riddell, E., S. Pollard, S. Mallory, and T. Sawunyama. 2014. A methodology for historical assessment of compliance with environmental water allocations: lessons from the Crocodile (East) River, South Africa. Hydrological Sciences Journal 59 (3-4):831-843. http://doi.org/10.1080/02626667.2013.853123

Rogers, K. H., and R. Luton. 2016. Building an adaptive and stakeholder-centred catchment management agency in the Inkomati/Usuthu River catchment. WRC report No. 2072/1/16. Water Research Commission, Gezina, South Africa.

Rogers, P., and A. W. Hall. 2003. Effective water governance. Global Water Partnership, Stockholm, Sweden.

Rosenberg, E., K. Kotschy, J. Burt, V. Mudau, D. du Toit, and S. Pollard. 2017. Monitoring, evaluation, reporting and learning for the USAID RESILIM-O program: MERL framework. http://award.org.za/wp/wp-content/uploads/2021/04/AWARD-TECH-REPORT-18-RESILIM-O-Monitoring-Evaluation-Reporting-Learning-MERL-Framework-2017.pdf

Roux, D. J., and L. C. Foxcroft. 2011. The development and application of strategic adaptive management within South African National Parks. Koedoe 53(2). https://doi.org/10.4102/koedoe.v53i2.1049

Roux, F., G. Diedericks, A. C. Hoffmann, M. Selepe, P. Scherman, and E. Riddell. 2018. Ecostatus of the Crocodile River catchment, Inkomati River system, phase II. Inkomati-Usuthu Catchment Management Agency, Mbombela, South Africa.

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. https://doi.org/10.1007/978-90-481-9367-7

Schulze, R. E., and N. S. Davis. 2019. Development of a framework and methodology for undertaking a risk and vulnerability assessment in all nine water management areas of South Africa. Practitioners' handbook for undertaking current and projected future climate related risk and vulnerability modelling assessments. Schulze and Associates, Pietermaritzburg, Report to GIZ, Pretoria, South Africa.

Steyaert, P., and J. Jiggins. 2007. Governance of complex environmental situations through social learning: a synthesis of SLIM's lessons for research, policy and practice. Environmental Science & Policy 10(6):575-586). https://doi.org/10.1016/j.envsci.2007.01.011

Tickner, D., J. J. Opperman, R. Abell, M. Acreman, A. H. Arthington, S. E. Bunn, S. J. Cooke, J. Dalton, W. Darwall, G. Edwards, et al. 2020. Bending the curve of global freshwater biodiversity loss: an emergency recovery plan. BioScience 70 (4):330-342. https://doi.org/10.1093/biosci/biaa002

United Nations (UN) Water. 2021. Progress on integrated water resources management - 2021 update. https://www.unwater.org/publications/progress-on-integrated-water-resources-management-651-2021-update/

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