REFLEXIVE LEARNING IN THE PRACTICE OF ADAPTIVE FRESHWATER MANAGEMENT

Craig Anthony McLoughlin

Master of Science (Resource Conservation Biology)

Bachelor of Science Honours (Geography)

University of the Witwatersrand, Johannesburg, South Africa

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I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree or qualification.

I certify that any help received in preparing this thesis and all resources used have been acknowledged in this thesis.

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This thesis is dedicated to the memory of Kevin McLoughlin, an amazing brother.

Preface

This research thesis is by publications. The structure of this thesis follows the guidelines as set out by the University of New England document entitled "Higher Degrees Research Thesis by Publication".

Chapters (manuscripts) associated with peer-review article publication are presented in the pertinent format of the targeted journal. However, in order to standardise presentation of this thesis and its table of contents, section headings, figures and tables of the manuscripts (chapters) have been formatted and numbered accordingly.

In addition, the term adaptive resource management (ARM), as used in the Ecology and Society published paper, has been changed to adaptive natural resource management (ANRM) in the corresponding thesis chapter three. This change is needed in order to standardise terminology throughout the thesis.

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Chapter 3

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Chapter 2

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Chapter 4

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Chapter 5

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List of Abbreviations

ACCC	Australian Competition and Consumer Commission
AFM	Adaptive Freshwater Management
ANRM	Adaptive Natural Resource Management
CEWO	Commonwealth Environmental Water Office
CMA	Catchment Management Agency
CMS	Catchment Management Strategy
COAG	Council of Australian Governments
CROCOC	Crocodile River Operations Committee
DEA	Department of Environmental Affairs
DLA	Department of Land Affairs
DMR	Department of Mineral Resources
DoA	Department of Agriculture
DWA	Department of Water Affairs
EMC	Ecological Management Class
FEPAs	Freshwater Ecosystem Priority Areas
IBs	Irrigation Boards
IWRM	Integrated Water Resources Management
KNP	Kruger National Park
MDB	Murray-Darling Basin
MDBA	Murray-Darling Basin Authority
MDBP	Murray-Darling Basin Plan
NWA	National Water Act (South Africa)
NWRS	National Water Resources Strategy
PES	Present Ecological Status
RDM	Resource Directed Measures
RHP	River Health Programme
RRS	Rapid Response System
SAM	Strategic Adaptive Management
SRLF	Strategic Adaptive Management Reflexive Learning Framework
SDC	Source Directed Controls
SDLs	Sustainable Diversion Limits
TPC	Threshold of Potential Concern

WMA	Water Management Area
WRPA	Water Resource Plan Area
WUA	Water User Association

Abstract

Learning-by-doing strategies allow for inherent uncertainty in the management of complex social-ecological systems. Adaptive management epitomises learning-by-doing, an iterative process based on incremental, experiential learning within adaptive management cycles. This learning is supported by strategic monitoring of, and feedback from the impacts and outcomes of decisions. Adaptive management of freshwater ecosystems facilitates a greater social context within freshwater management. This is achieved through an increased emphasis on flexible, open institutions and multi governance-level systems that allow for critical thinking and learning. Adaptive management of freshwater ecosystems is an important approach for practicing resilience because it addresses uncertainty in a complex world.

Lack of an effective natural resource management practice is frequently confounded by the requirement for complex social and technical (environmental) components to learning. Integrating societal learning based on increasing time-scales for social and technical change through the modes of single-, double-, and triple-loop learning, into adaptive natural resource management is intricate. This is because of many “enabling conditions” and facilitators associated with practicing this learning. Key “enabling conditions” for societal learning include stakeholder participation, learning-centred organizations, social learning capacities, and adaptive governance arrangements. In addition, reflexive learning (adaptive feedback systems) must be explicitly used and incorporated within adaptive management cycles in order to facilitate the three modes of societal learning. This thesis proposes that for efficient adaptive freshwater management single-, double-, and triple-loop learning must be exercised more deliberately within any adaptive freshwater management system, by the explicit facilitation of adaptive feedback systems.

The thesis employs an inductive approach to the research undertaken. It is comprised of two phases. The first phase involves the development of the frameworks, and aims to advance knowledge about the complex relationship between societal learning and the practice of adaptive natural resource management. The conceptual framework is hierarchical in nature and its design enhances understanding about how to integrate societal learning (the central learning construct) into adaptive natural resource management. Learning-centred organisations, which foster social learning capacities and achieve adaptive institutional

arrangements within natural resource management have a place in adaptive natural resource management as critical enabling conditions for societal learning. However, development and use of a reflexive learning foundation of stakeholder networks and adaptive feedback systems is needed as a core mechanism for practicing single-, double-, and triple-loop learning. These feedbacks facilitate societal learning within adaptive natural resource management.

The development of the Strategic adaptive management Reflexive Learning Framework (SRLF) within this thesis uses a multi governance-level adaptive feedback system that works to enhance the facilitation of single-, double-, and triple-loop learning within adaptive natural resource management. The SRLF emphasizes the types, roles, and transfer of information within a reflexive learning context. The SRLF is a key enabler for implementing the adaptive management cycle, and thereby translating the theory of adaptive natural resource management into practice. It promotes the heuristics of adaptive management within a cohesive framework and its deployment guides adaptive natural resource management within and beyond typical single-loop learning, across all governance levels.

Under thesis phase two, application of the SRLF's adaptive feedback system to Ecological Reserve implementation in the Crocodile River Catchment of South Africa demonstrates the importance of the SRLF adaptive feedback system for societal learning and achieving ecosystem objectives. Adaptive feedbacks for lower grade single-loop learning are mandatory because frequent adjustment to Ecological Reserve operations is required due to uncertainty about implementing the required river flows. Upper grade single-loop learning is often neglected within the Crocodile River Catchment with too much attention focused on operations to implement the Ecological Reserve. However, these river flows are hypotheses about maintaining an agreed upon ecological condition in the rivers, and therefore must be assessed against end-point goal achievement, to adjust operations as required. The skill with incorporating double-loop learning is avoiding the trap of "learning for the sake of learning" because resources for this learning are scarce in the Crocodile River Catchment. However, reframing of interventions and end-point goals is required based on new knowledge becoming available and/or changing human values. Triple-loop learning is compulsory and deliberately imposed over longer time intervals because objectives require revision over time and stakeholder values also change. Triple-loop learning is required for completion and then regeneration of the adaptive management cycle.

Achieving societal learning within and across multiple governance levels within the Murray-Darling Basin is needed in order to practice an effective adaptive freshwater management. Societal learning is fostered via an explicit recognition of practitioner mandates across governance levels. In addition, by adopting a flexible objectives hierarchy and seeking stakeholder participation and finding adaptive management champions to steer the learning requirements. Achieving an effective balance between the modes of societal learning is key, while working toward implementing adaptive freshwater management in water resource plan areas of the Murray-Darling Basin is needed for stimulating learning in the upper governance levels.

Thesis chapters two to five are presented as manuscripts for journal publication. Each provide an original research contribution. Chapter Two advances our understanding about the complexity of learning within the practice of adaptive natural resource management (ANRM). Chapter Three demonstrates a unique way for deploying an adaptive feedback system within adaptive management cycles, for facilitating single-, double- and triple-loop learning within and across governance levels. Chapter Four sets an important precedent for implementing adaptive freshwater management in the real-world, using single-, double-, and triple-loop learning explicitly and deliberately within the adaptive management cycle. Lastly, Chapter Five advances our knowledge about how to implement adaptive freshwater management in the real-world, within and across governance levels. This adaptive freshwater management uses societal learning to embrace uncertainty under complex water reforms.

The thesis proposes that a complex adaptive feedback system must replace the typical linear interpretations of feedbacks within the adaptive management cycle, and therefore learning. In addition, a mind-set change is required for the translation of natural resource management theory into practice. The research (theory) mind-set, with its “idealism” frame-of-mind (“enhancing angle to learning”) emphasises an enhanced version of societal learning within adaptive freshwater management, i.e. with full double-, and triple-loop learning occurring. However, in the real-world practice of adaptive freshwater management a “pragmatism” frame-of-mind (“requisite angle to learning”) is needed. This mind-set focuses on getting single-loop and some initial form of double-loop learning going, within any given adaptive freshwater management system using current resources/structures available. Implementation of a complex nested and overlapping set of adaptive feedbacks is required to activate the more immediate responses, and adaptive assessment and reflection routines within the adaptive management cycle, and this bequeaths a critical foundation of "facilitating processes" for both learning angles. In addition, for assessing potential success or effectiveness of any given adaptive freshwater management system, taking a hierarchical, scaled perspective to implementation of the adaptive management cycle, across all governance levels, bestows a better gauging method for the practice of adaptive freshwater management. This is because societal learning is more achievable at the lower governance levels.

The SRLF and its principles developed in this thesis promote the practice of resilience. This is achieved via several emergent themes; thinking in multiple scales, paying attention to thresholds, celebrating/embracing change and uncertainty/surprise, fostering innovation, and remembering adaptive governance. Hence, the SRLF has implications for further research to advance knowledge about harnessing adaptive capacity within natural resource management (e.g. integrating with panarchy theory). In addition, research exploring application of the SRLF Environment theme with the other SRLF themes, i.e. Economic and Community/Social themes, is needed due to the integrated nature of freshwater legislation and management. Testing implementation of the SRLF principles at the upper governance levels of adaptive freshwater management is another area requiring further research, within a multiple governance-level practice of adaptive freshwater management.

CHAPTER 1. INTRODUCTION

1.1 Adaptive freshwater management

Major paradigm shifts are occurring in the field of natural resource management (Stankey *et al.*, 2005; Pahl-Wostl *et al.*, 2011a; Walker and Salt, 2012). Natural resource management has traditionally been mechanistic and technocratic in nature, with its command-and-control strategies characterised by a limited appreciation of complexity and the human dimension of managing natural resources (Holling and Meffe, 1996; Gleick, 2003; Pahl-Wostl *et al.*, 2007a; Pahl-Wostl, 2009; Herrfahrdt-Pahle, 2013). Traditional natural resource management also views nature and natural resource systems as being stable and near equilibrium (Holling and Meffe, 1996; Pahl-Wostl *et al*. 2011a). However, natural resource systems are inherently complex, with multiple components, numerous process interactions and feedbacks between the many human and biophysical sub systems (Holling, 2001; Walker and Salt, 2012; Biggs *et al*., 2015). In recognition of this complexity, natural resource management is developing approaches to manage natural resources within the context of social-ecological systems. Social-ecological systems are inherently dynamic, complex, integrated systems (Cilliers, 2008; Holling, 2001) that behave in a nonlinear manner with the presence of marked thresholds (Folke *et al.*, 2002; Folke *et al.*, 2005; Walker and Salt, 2012). As a result of these system characteristics multiple outcomes can arise from similar natural resource management interventions in social-ecological systems (Folke *et al.*, 2002). Therefore, management interventions for social-ecological systems must embrace complexity (Pahl-Wostl, 2006; Walker *et al.*, 2006; Cilliers, 2008; Biggs *et al*., 2015).

Learning-by-doing strategies are more able to address the complexity of managing social-ecological systems, compared to traditional command-and-control strategies (Rogers *et al.*, 2000; Biggs *et al*, 2015). Complex systems are dynamic and characterized by self-organization, which results in systems operating far from equilibrium conditions (Folke *et al.*, 2005; Walker and Salt, 2012; Biggs *et al*., 2015). Learning-by-doing strategies respond better to complex environments by speeding up learning cycles, allowing for the quicker assessment and execution of new understandings. Within natural resource management, learning is key in the transformation toward adaptive natural resource management (Pahl-Wostl *et al*., 2007a). Conventional natural resource management tools of risk management, planning and design are inadequate to manage complex social-ecological systems because of limited attention given to learning (Jiggins and Röling, 2002). Learning-by-doing strategies assume that social-ecological systems are in a state of flux, that the understanding of complex systems is always imperfect and, managing social-ecological involves much uncertainty. Hence, managing complex natural resource systems necessitates the strategy of learning-by-doing (Rogers, 2003; Stankey *et al.*, 2005).

The management of freshwater systems has a history of being managed by command-and-control strategies (Gleick, 2003; Pahl-Wostl, 2009). Command-and-control freshwater management focuses on technical solutions to problems, such as mitigation schemes to alleviate flood impacts on cities and the construction of dams to improve the reliability and efficiency of water supply to agricultural systems. Increasingly, freshwater management includes aspects of social and environmental quality. This has arisen because many freshwater resource crises are being recognised as issues of resource governance and not the resources themselves (Pahl-Wostl *et al*., 2011a). Influences from external factors, such as climate change, exacerbates uncertainty associated with managing freshwater resources. This uncertainty reduces the ability to predict the state of freshwater resources which in turn aggravates the inadequacies of technically focused command-and-control management strategies (Biggs *et al*., 2015). Thus, the effectiveness of command-and-control strategies for achieving social and environmental quality objectives within freshwater management has been questioned (Larsen and Gujer, 1997; Gleick, 2003).

Adaptive natural resource management and integrated water resource management (IWRM) are alternative approaches to the management of freshwater ecosystems (Medema *et al*., 2008; Pahl-Wostl *et al*., 2011a). These newer approaches challenge assumptions upon which command-and-control freshwater management is based, including viewing water resources as linear or predictable systems, and managing without consideration of human and social aspects (Pahl-Wostl *et al.*, 2011b). Wallace *et al.* (2003) point out that IWRM mandates clearer and stronger links between human and ecosystem requirements. Ultimately, this mandate allows for managing people's activities in a manner that promotes sustainable development. However, case studies have not clearly demonstrated the achievement of the human and ecosystem mandate associated with IWRM (Wallace *et al.*, 2003; Medema *et al.*, 2008) and institutional integration required by IWRM may not be possible (Biswas, 2004; Marshall *et al*., 2013; Giordano and Shah, 2014). Furthermore, there is doubt about the ability of IWRM to address the impacts of climate change on freshwater resources (Medema *et al.*, 2008; Pahl-Wostl, 2009). While IWRM has been a guiding principle of freshwater management and good natural resource governance since the 1990s, there is increasing interest in adaptive natural resource management to counteract the shortcomings of IWRM (Herrfahrdt-Pahle, 2013).

Adaptive natural resource management (ANRM) epitomises learning-by-doing strategies. It has been described as learning to manage by managing to learn (Bormann *et al.*, 1994). From its early beginnings ANRM suggested that scientific understanding emanates from the experience of management as an on-going, adaptive and experimental process (Walters and Hilborn, 1978; Holling, 1978; Walters, 1986). Continued or ongoing learning is important for increasing our understanding of systems, structures and organisations, in addition to basic research or the generation of ecological theory. There have been many contributions to the development of the field of ANRM, including but not restricted to: Rogers and Bestbier (1997); Rogers and Biggs (1999); Jiggins and Röling (2002); Edwards (2002); Biggs and Rogers (2003); Stankey *et al*. (2005); Pahl-Wostl *et al*. (2007b); Medema *et al*. (2008); Allan and Stankey (2009); van Wilgen and Biggs (2011), Susskind *et al*. (2012), Greig *et al*. (2013), and Scarlett (2013). Adaptive natural resource management has been broadly defined as a series of actions and feedbacks with the intent to modify goals, hypotheses and objectives in order to influence outputs and actions of management (Edwards, 2002; Stankey *et al*., 2005). It is an iterative process based on incremental, experiential learning and decision making, supported by strategic monitoring of and feedback from the impacts and outcomes of decisions (Jiggins and Röling, 2002). Adaptive natural resource management supports adaptable governance, where participants within the system adopt an on-going approach of rethinking and negotiating their assumptions (Pahl-Wostl *et al*., 2007b).

1.1.1 The human factor for learning in adaptive freshwater management

Humans play a decisive role in the management of natural resources (Pahl-Wostl, 2002). This is because utilization of natural resources involves biophysical and social dynamics (Lescuyer, 2002), that arise from the coevolution of natural and social systems (Wiersum and de Hoogh, 2002). Learning within the ANRM context initially focused on the dynamics of biophysical systems. Over time the importance of the human dimension has been included to ANRM (Pahl-Wostl *et al.*, 2007a). This relatively recent inclusion of the human dimension demonstrated that social-ecological systems are more complex and unpredictable than previously recognised, arising from uncertainties and lack of complete understanding about both the biophysical and human dimensions of these systems (Pahl-Wostl and Hare, 2004).

Application and testing of adaptive management within the context of natural resources arose from the recognition that although interaction between people and ecosystems is inherently unpredictable there is a need to take management actions even though complete knowledge about social-ecological systems is rarely available and attainable (Rogers, 2003). Hence, effective ANRM does not seek once-off optimum solutions to problems, but is a process of on-going learning with continual participant negotiation (Huxham and Vangen, 2000; Pahl-Wostl, 2002; Pahl-Wostl and Hare, 2004; Pagan and Crase, 2005). Adaptive natural resource management actions are designed to promote explicit learning about the processes governing the natural resource system and also aids with the management of uncertainty when dealing with social-ecological systems (Shea, 1998).

Technical solutions alone are not sufficient to tackle the complex problems natural resource managers face (Pahl-Wostl and Hare, 2004; Pahl-Wostl *et al.*, 2007a). There is mounting recognition of "soft" problems, which focus on attitudes and institutions or rules and arrangements within the process of natural resource management. Natural resource governance has been defined as the range of social, economic, political, and managerial systems and activities required to develop, provide and manage natural resources at different levels of social organisation (Rogers and Hall, 2003). The roles performed by individuals, their social relations and social networks are essential within natural resource governance as they serve as the web that binds adaptive governance systems (Folke *et al.*, 2005). The notion of adaptation implies a capacity to respond to change, and potential to convert social-ecological systems into improved states (Folke *et al.*, 2005). This is necessitated with active adaptive management approaches, where policy and its implementation are used as tools for accelerated learning in order to further structure a range of alternative management responses. Passive adaptive management contrasts to this active version of adaptive management because it is defined as improving a single best policy from lessons learned over time (Pagan and Crase, 2005). To enhance learning opportunities and potentials that promote ANRM, adaptability of governance structures must accompany adaptability via the technical solutions (Herrfahrdt-Pahle, 2013).

Adaptive management of freshwater ecosystems facilitates a greater social context through an increased emphasis on flexible and open institutions and multi-level governance systems that allow for continual learning (Folke *et al.*, 2002; Pahl-Wostl, 2008). Adaptive freshwater management also addresses organizational learning by taking a multi-organization guise to management and governance (McDaniels and Gregory, 2004; Pahl-Wostl, 2008). There are a number of key adaptive management benefits for freshwater management (McLain and Lee, 1996; Wondolleck and Yaffee, 2000; McDaniels and Gregory, 2004). Adaptive management increases the pace and frequency at which policy makers and freshwater managers acquire knowledge about ecological relationships. It also improves the effectiveness of management decisions through the use of iterative hypothesis testing, via feedbacks which enhance information flows among stakeholders. The creation of a shared understanding among scientists, policy makers, managers and stakeholders within the freshwater management system is important (Rogers *et al.*, 2000; Rogers and Breen, 2003). Thus, adaptive freshwater management is better equipped to deal with the inherent systems complexity of these freshwater systems (Folke *et al.*, 2005).

1.1.2 Emergence of adaptive natural resource management with resilience thinking

The emergence of ANRM has paralleled the development of resilience thinking (Holling, 1978; Walker and Salt, 2012). Collectively, the need for sustainable natural resource management regimes that promote resilient systems has been recognised (by many cf. Walker and Salt, 2006). This is in part because global change has been associated with increasingly unpredictable natural resource states (Pahl-Wostl, 2009); unpredictability that has been shown to influence the supply of ecosystem goods and services from natural resource systems (Stankey *et al*., 2005; Biggs *et al*., 2015). Adaptive natural resource management has, therefore, arisen to become an important management approach within resilience thinking because it addresses uncertainty in a complex world (Rogers *et al.*, 2000; Folke *et al.*, 2005; Cilliers, 2008; Biggs *et al*., 2015). Resilience is the capacity of a system to recover from shocks or disturbances while retaining essentially the same function, structure, feedbacks, and therefore system identity (Walker *et al.*, 2006). According to Walker and Salt (2006) a resilient world would incorporate three key elements: the sustainability of diversity in all forms; maintenance of a degree of modularity; and, a stronger emphasis on learning for resilience. Overall, natural resource management must embrace uncertainty within complex social-ecological systems (Biggs *et al*., 2015), rather than attempting to control or eliminate it, and resilience thinking and practice is the way to achieve this (Folke *et al.*, 2005; Walker and Salt, 2006; Pahl-Wostl, 2009; Walker and Salt, 2012).

There are three essential components for practicing resilience (Walker and Slat, 2012). These are (cf. Fig. 1.1):

(1) Describing the system. This this includes understanding the scales that bound a system; the people and governance of the system including the players, power issues and the rules involved; the resilience of systems to what, in terms of values and issues contained within the system; and the pertinent drivers and trends within the system.

(2) Assessing a system's resilience. This includes defining resilience as an emergent property that applies differently in various aspects of a system, and depends on the context of the particular system and which part of it is being examined. This component of resilience practice deals with specified resilience, which is resilience of some section of the system to certain kinds of disturbance. The idea of thresholds is a key aspect of assessing specified resilience, and may include using known thresholds, thresholds of potential concern, conceptual models, and/or analytical models. In contrast to specified resilience, general resilience is the capacity within a system for absorbing any kind of disturbance, particularly if these disturbances are unexpected. General resilience includes attributes such as diversity, modularity, the tightness of feedbacks, openness, and high levels of financial, human, natural, built, and social capital. Another important part of assessing resilience is transformability, or the capacity to effect transformational change within a system.

(3) Managing a system's resilience. This includes the tools and options for management; and considering where the focal scale of the system fits into the adaptive cycle, i.e. the four phases of exploitation, conservation, release and reorganization (Holling, 2001; Gunderson and Holling, 2002). Knowing how to sequence interventions is critical, as is knowing when transformation is needed. Adaptive governance is key for resilience practice, and occurs when governance changes in anticipation of or in response to new circumstances, issues or problems and different opportunities that may crop up. In addition, adaptive natural resource management is a critical management approach to adopt for resilience practice. Accordingly, Walker and Salt (2012) pose a key question about the relationship between adaptive management and resilience: how can natural resource management interventions be implemented within an adaptive management framework?

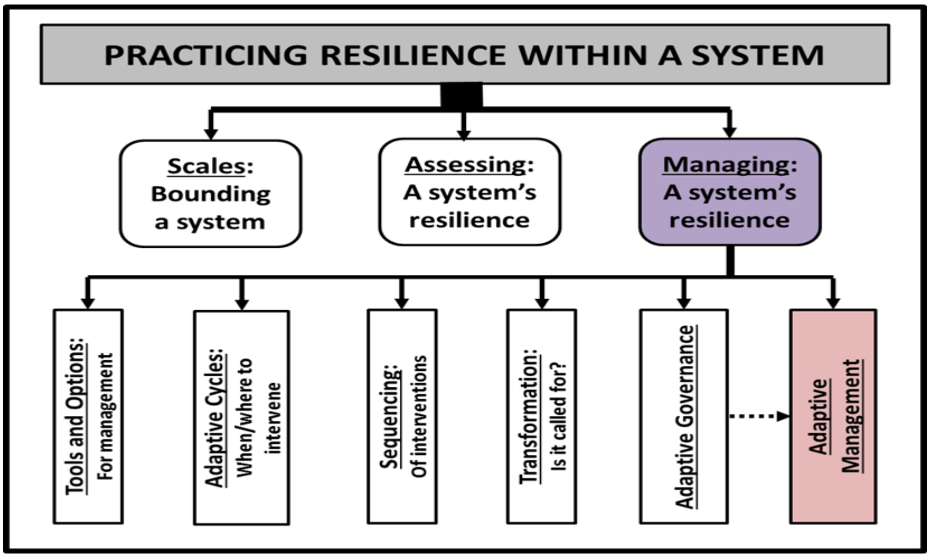

Figure 1.1. The resilience practice context for adaptive freshwater management, highlighting the main emphasis on managing system resilience, and the thesis focus on adaptive management (with consideration of adaptive governance).

1.1.3 Two broad constructs for practicing adaptive freshwater management

Two broad constructs are identified as providing the context for this thesis. The first construct is a paradigm shift in adaptive natural resource management from command-and-control to a learning-by-doing strategy. The second is a focus on resilience practice and especially the management of a system's resilience using adaptive management (Fig. 1.1). Adaptive natural resource management and the improvement of its practice for freshwater systems is the focus, with more detailed work on resilience out of the scope of this thesis.

1.2 Translating adaptive freshwater management theory into practice

The practice of ANRM has been generically depicted as an "adaptive management cycle" (Greig *et al*., 2013; Pratt Miles, 2013). The adaptive management cycle consists of a series of actions and feedback loops, with the intent of achieving a set of goals through the modification and refinement of hypotheses and objectives, with intent to improve outputs/outcomes and management actions (Edwards, 2002; Stankey *et al*., 2005). This iterative process is supported by strategic monitoring and identification of feedbacks from the outcome(s) of any decisions (Jiggins and Röling, 2002; Allan and Stankey, 2009). Thus, the adaptive management cycle is a process based on incremental, experiential learning. While intuitively appealing, ANRM is more complex than most traditional natural resource management approaches and therefore, it is perceived to be difficult to put into practice

(Stankey *et al.*, 2005; Smith, 2009). Evidence for the effective implementation of adaptive management within natural resource management is limited (Allan and Curtis, 2005; Stankey *et al.*, 2005; Medema *et al.*, 2008; Stankey and Allan, 2009; Pahl-Wostl *et al.*, 2011a). Successful applications of adaptive management of natural resources remain elusive (Susskind *et al.*, 2012; Greig *et al.*, 2013; Westgate, 2013).

The proposed advantages of ANRM have not been realised in freshwater management (McLain and Lee, 1996; Walters, 1997; Pahl-Wostl, 2008). Many initiatives that purport to use adaptive management often fail, with no visible products or outcomes, and become confined to a process of model development and modification (Walters, 1997; Susskind *et al.*, 2012). This is not surprising given that there are major barriers to implementing adaptive freshwater management (Medema *et al.*, 2008). Social dynamics with its associated institutional inflexibility can stall implementation of adaptive management. Participation of many stakeholders is required in the learning process, and these stakeholders must maintain a commitment to the learning process within organisations that embrace change. It is also not easy to report back or demonstrate results, they are often not quantitative in nature. Failure to define exactly what adaptive management is, and how managers should implement it, also contributes to confusion of adaptive management. The complexity, cost and risk involved means that stakeholders are often unwilling to accept the unknown consequences (risk) inherent within adaptive management projects (Stankey *et al.*, 2005). Risk aversion is exacerbated when management interventions are applied experimentally, with associated high input costs and the long time-scales for achieving meaningful results. Thus, adaptive freshwater management projects are not practiced on a wide scale because they are difficult to initiate and sustain, and struggle to live up to their full potential (Jeffrey and Geary, 2006; Medema *et al.*, 2008).

1.2.1 Practicing learning as a critical aspect for implementation of adaptive freshwater management in the real world

The contemporary dilemma of translating ANRM theory into practice is confounded by the need for learning. Learning is a vital construct for the successful practice of any ANRM system (Bormann *et al.*, 1994; Pahl-Wostl, 2009; Pahl-Wostl *et al.*, 2013; Fabricius and Cundill, 2014). An overarching lesson from many studies demonstrating implementation of ANRM (e.g. Table 1.1) concerns the application of an adaptive management cycle and a need for learning. Development of an adaptive management cycle is an important initial requirement in the ANRM process. This includes an explicit outlining of components such as objectives to be achieved, interventions to meet objectives and monitoring programs to evaluate and learn from past interventions. To achieve learning as a desirable outcome within the adaptive management cycle requires that appropriate processes be practiced more effectively. Appropriate learning requires effective participation between all stakeholders, real collaboration and adaptive governance arrangements, and pertinent adaptive feedback systems for information flows. However, identifying the types of learning and understanding the conditions upon which to execute different types of learning is a major stumbling block for implementing any ANRM system (Allan and Stankey, 2009; Pahl-Wostl, 2009; Pahl-Wostl *et al*., 2011b).

Learning can be a complex and confusing process to put into practice because of the requirement for both the social and environmental components to be included in the learning process (Daniel and Walker, 1996; Mackay *et al*., 2002; Wiersum and de Hoogh, 2002; Pahl-Wostl *et al*., 2007a; Pahl-Wostl *et al*., 2007b; Medema *et al*., 2008; Pahl-Wostl, 2009; Herrfahrdt-Pahle, 2013). Adaptive natural resource management not only aims to improve the state of the environment per se, by adapting management actions over time, but also it strives to improve social processes that are critical for sustaining ANRM systems (Stankey *et al.*, 2005; Pahl-Wostl *et al*., 2007a). These processes include consideration of how new understanding may be better formulated, enhanced and eventually communicated and incorporated into organisational policies, management and governance arrangements. Societal learning is a prominent theoretical model that has recently emerged in relation to both the technical and social requirements for learning within ANRM (Pahl-Wostl, 2009).

Societal learning (Pahl-Wostl *et al*., 2011b) encompasses processes of "the doing" (single-loop learning), "changing practice" (double-loop learning), and "altering governance arrangements" (triple-loop learning) (Pahl-Wostl, 2009; Fabricius and Cundill, 2014). Single-loop learning results in incremental advances from action strategies within ANRM, without questioning underlying assumptions (Pahl-Wostl, 2009). It involves a continuation of, with concurrent improvements to, established practices and routines and targets the achievement of goals. Double-loop learning refers to a change in the actual frame of reference within

Table 1.1. Lessons learned from examples of adaptive natural resource management practice.

Example adaptive natural resource management case	Main lessons	Reference
Lessons learned from adaptive management in British Columbia, Canada. Coast Forestry Strategy, the Forest and Range Evaluation Program, the Pine-Lichen Woodlands and Northern Caribou Adaptive Management Project, and the Ospika Mountain Goat Trial.	• Good leadership, partnerships and organisational commitment are required. • An adequate amount of resources is vital for the process of "closing the adaptive loop" to adaptive natural resource management.	Smith (2009)
Adaptive management for the Tasmanian Wilderness World Heritage Site. 30-year perspective on linking management planning with effectiveness evaluation.	• Need to integrate monitoring, evaluation and reporting within the adaptive management plan to establish an on-going adaptive management cycle. • Monitoring approaches must test effectiveness of management performance. • All stakeholders involved to assess the management process. • Recognition of factors to sustain long-term strategic programs, in the context of ongoing institutional change.	Jones (2009)
Assessment of adaptive ecosystem management in a large savannah protected area in South Africa, associated with biodiversity conservation.	• Difficult to implement an active adaptive management system, in the contemporaneous experimental sense. • More feasible to adopt consecutive experiments than to manage several large-scale adaptive management experiments at any one time. • Adaptive natural resource management must be an iterative learning process. • Adaptive natural resource management initially should not be too rapidly or wholly measured by outcomes.	van Wilgen and Biggs, (2011)
Ten year evaluation of adaptive management of environmental flows in rivers of south eastern Australia.	• Major constraint is uncertainty about decisions on the appropriateness of environmental objectives. • Objectives must link into need for implementing flow releases from	Ladson (2009)

Example adaptive natural resource management case	Main lessons	Reference
	impoundments, for legitimacy of environmental flows. • Without societal consensus and learning about how much water must remain in the rivers for environmental purposes, the processes of adaptive management remains fruitless.	
Assessment of adaptive management in practice. The Glen Canyon Dam Adaptive Management Program (AMP) in the United States. With no clear water resource protection goals, the AMP was established in order to improve conditions associated with the Colorado River ecosystems.	• An adaptive management cycle aimed to reduce conflict between stakeholders. • A lack of procedures for learning (harvesting new knowledge emanating from experimentation) for adapting management practices, negatively impacted species and habitats that the AMP was set up to protect. The adaptive management cycle required: • First, the setting of clear overarching goals with explicit and measurable objectives. • Second, employment of tools and incentives to facilitate participation. • Third, stakeholders to commit to monitoring and adapting management regimes over time, even in complex and contentious resource management contexts. • Overall, fostering of collaboration, via implementation of well-defined joint fact-finding protocols to promote a shared learning process is vital.	Susskind *et al*. (2012)
Insight into enabling adaptive management for the forest sector under the United States Northwest Forest Plan. Associated with biological diversity management.	• Working with people to understand their concerns and to develop a common understanding about systems. • Build up an environment of trust to allow adaptive management to proceed. • Closing the adaptive management cycle is the most commonly neglected component of ANRM. • Often, the initial focus of the ANRM system is not conducive to what was actually needed. • Depends on effective communication and engagement early on, establishing the learning focus.	Greig *et al*. (2013)

Example adaptive natural resource management case	Main lessons	Reference
Synthesis of lessons. In: *Adaptive Environmental Management: A Practitioner's Guide*. A synthesis of many global experiences in ANRM with key lessons learned.	• Practitioners of adaptive natural resource management must be aware of context. This provides a critical source of information about processes previously undertaken, the types of participation, issues and concerns, and existing knowledge and experience. - Understanding adaptive management approaches is key. It must be seen as more than just making something up as we go. • There is a critical need to support the right people, who are enthusiastic, are established with respect and trust among stakeholders. • Adaptive management people have a commitment to change and a capacity to cope with ambiguity and uncertainty. • Overall, there must be a purpose with deliberate and careful documentation processes, designed to promote learning that can be transferred into action.	Allan and Stankey (2009)
Learning in adaptive management: Insights from published practice. A systematic review of 22 papers (2011 – 2013) focusing on the practical implementation of adaptive management within natural resource management.	• During learning, there is a need for scientists and academics to include external stakeholders. • Adaptive natural resource management is dominated by direct assessment and single-loop learning, aimed at improving existing practices. • Half of the reviewed papers reviewed included some double-loop learning. • Fewer cases combined double- and single-loop learning. • Most reviewed papers reporting on actual conservation achievements. • Adaptive natural resource management is an evolutionary process; the majority of reviewed papers reporting on governance issues. • Most programs of adaptive natural resource management remain in the early pioneering stage, which may be explained by participant's lack of learning capacity.	Fabricius and Cundill (2014)

ANRM and requires a revisitation of the initial underlying assumptions of any action (Pahl-Wostl, 2009). Triple-loop learning is a transformation of the factors that determine the frame of reference, and may include a transformation of the entire governance regime itself (Pahl-Wostl, 2009). The emergence of societal learning has increased understanding about the practice of single-, double- and triple-loop learning within adaptive freshwater management (Pahl-Wostl, 2009). Societal learning is based on increasing time scales for change and must integrate into the adaptive management cycle to promote appropriate change while managing freshwater resources adaptively (vis-à-vis Pahl-Wostl, 2009).

1.2.2 Knowledge gap

The freshwater management sector is in transition, with theory ahead of practice, and even further ahead of the capacities (e.g. skills, knowledge, and competencies) needed to implement adaptive regimes (Pahl-Wostl *et al*., 2011a). This research proposes that for adaptive natural resource management to be practiced more effectively in freshwater management, single-, double-, and triple-loop learning must be employed more explicitly and deliberately. Management regimes of freshwater resources are to a large degree trapped in the single-loop mode of maintaining established routines to achieve goals (see Pahl-Wostl, 2009; Pahl-Wostl *et al.*, 2011b), although such routines are being improved over time. A deliberate movement beyond this single-loop learning is required to practice adaptive freshwater management more effectively. Further investigation is required about how societal learning can be integrated more explicitly into the adaptive management cycle, however, achieving this integration is intricate.

Key “enabling conditions” are being identified for practicing societal learning within ANRM (Fig. 1.2). Enabling conditions are synchronous situations which provide the means and possibilities for societal learning to take place within ANRM. It is widely accepted that stakeholder participation and cross-sector stakeholder engagement is paramount for learning within the context of ANRM (e.g. du Toit and Pollard, 2008). Learning-centred organizations (e.g. Stankey *et al*., 2005; Roux *et al.*, 2006; Roux *et al*., 2010; Fazey and Schultz, 2009; Stirzaker *et al*., 2011) that build and foster social learning capacities (e.g. Mostert *et al*., 2007; Ison and Watson, 2007; Pahl-Wostl, 2009; Cundill *et al*., 2011) are key proponents specifically for double-loop learning. Social learning is defined as achieving concerted action in complex and uncertain contexts (Ison and Watson, 2007). Social learning takes place within a process of on-going learning and negotiation, with communication, perspective sharing and development of adaptive group strategies being important (Huxham and Vangen, 2000; Pahl-Wostl and Hare, 2004). Adaptive governance with flexible arrangements (e.g. Folke *et al*., 2005; Gunderson and Light, 2006; Herrfahrdt-Pahle, 2013) promotes triple-loop learning (e.g. Pahl-Wostl, 2009). Decision-making strategies that incorporate complexity thinking are also beneficial within the practice of societal learning (Rogers *et al*., 2013). They are important enabling conditions. Identifying enabling conditions for societal learning has increased our understanding about implementing double-, and triple-loop learning modes of societal learning. This understanding is an important element for practicing adaptive freshwater management effectively (Fig. 1.2).

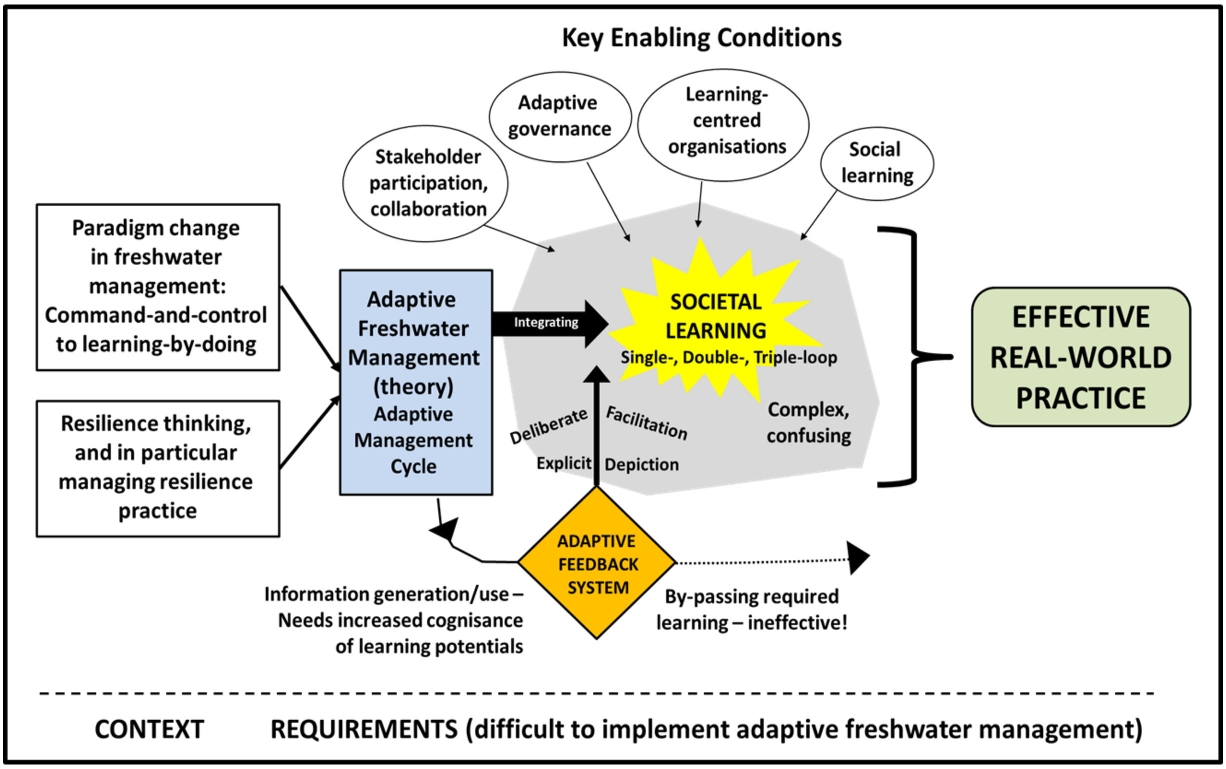

Figure 1.2. Conceptual diagram indicating important elements required for practicing adaptive freshwater management more effectively in the real world. It shows the main context and the integration requirement with societal learning, which is reliant on key enabling conditions and an explicit adaptive feedback system. A knowledge gap is indicated, i.e. the need for more understanding about explicit design and use of an adaptive feedback system to facilitate (by guiding) the three modes of societal learning more deliberately, in conjunction with seeking the enabling conditions for this learning.

Adaptive feedback systems is another key element associated with the effective practicing of adaptive freshwater management (Pollard *et al*., 2011) (Fig. 1.2). Adaptive feedbacks improve data and information dissemination within governance networks (formal and informal), and forms one critical step in executing shared learning experiences under adaptive freshwater management (Pahl-Wostl *et al*., 2007a; Pollard *et al*., 2011). Adaptive feedback systems are required for integrating societal learning more explicitly into the adaptive management cycle (Fig. 1.2). In progressing toward achieving a set of agreed management objectives, the adaptive management cycle must deliberately harness all three modes of societal learning, to strategically modify inputs, outputs, assumptions and hypotheses, to improve management and to transform governance. However, most scholarly attention remains focused on the "enabling conditions" for societal learning and furthering understanding about these conditions (Fabricius and Cundill, 2014), particularly within and across different governance levels of freshwater management (Pahl-Wostl *et al*., 2013). Using adaptive feedbacks within an adaptive management cycle is often assumed and/or implied (e.g. Pahl-Wostl, 2009), or these feedbacks are neglected within many real-world practices of adaptive freshwater management (Pollard *et al*., 2011). According to Stankey *et al*. (2005), adaptive feedbacks within ANRM are inadequate because of three issues. First, there is a lack of data and information being generated within the system. Second, despite some information being available, this is not always made available for decision-making within ANRM. Third, often the information that is available is not suitable and is presented in a manner that is not conducive to learning. A lack of an explicitly derived adaptive feedback system that deliberately directs information flows to facilitate societal learning increases the probability that societal learning will be bypassed during adaptive freshwater management (Fig. 1.2). This by-passing of societal learning compromises any effective practice of adaptive freshwater management.

Understanding of the explicit design of an adaptive feedback system for deployment within the adaptive management cycle must increase. Adaptive feedback systems must act to deliberately guide and facilitate societal learning within the practice of adaptive freshwater management (Fig. 1.2). Single-, double-, and triple-loop learning modes of societal learning have been considered within adaptive freshwater management (e.g. Pahl-Wostl, 2009; Biggs *et al*., 2011; Kingsford *et al*., 2011; Kingsford and Biggs, 2012; Roux *et al*., 2013). However, less attention is given to an explicit and strategically placed adaptive feedback system within the adaptive management cycle, and how this system is deliberately deployed to facilitate societal learning. Using adaptive feedback systems within the adaptive management cycle more explicitly will promote an effective facilitation and guidance of societal learning in the practice of adaptive freshwater management (Fig. 1.2).

1.3 Aim and objectives of the thesis research

This thesis proposes the translation of adaptive natural resource management theory into the practice of adaptive freshwater management requires effective reflexive learning (Fig. 1.3). Reflexive learning is "learning from action," with the deliberate intent to enhance the practice of management (Kolb, 1984). Reflexive learning can be portrayed as a "feedback loop," whereby actions are manipulated and/or modified via feedback from the context within which they were executed (Pollard and du Toit 2007). An appropriate use of an adaptive feedback system within the reflexive learning process is to facilitate societal learning, this being the central learning construct in adaptive freshwater management. Deploying this reflexive learning process is additional to enabling conditions for societal learning, i.e. stakeholder participation and collaboration, learning-centred organisations, social learning, and adaptive governance (Fig. 1.3). Reflexive learning promotes the activation, completion, and regeneration components of the adaptive management cycle to achieve goals, and is applicable to any governance level of natural resource management.

There are two aims to the research presented in this thesis.

(1) To integrate societal learning (single-, double-, and triple-loop learning) into ANRM, via the explicit design and inclusion of an adaptive feedback system within the adaptive management cycle.

(2) To assess the use of this adaptive feedback system for deliberately facilitating and guiding societal learning in the actual practice of adaptive freshwater management; and in the process generate lessons learned for supporting a more effective practice of the adaptive feedback system, and ultimately adaptive freshwater management.

To achieve these aims an inductive approach is adopted whereby the research is divided into two phases, which correspond to the two aims of the thesis research (Fig. 1.3). There are four objectives in the thesis (two per phase). Importantly, the four objectives build on each other sequentially, for progression through the thesis (Fig. 1.4).

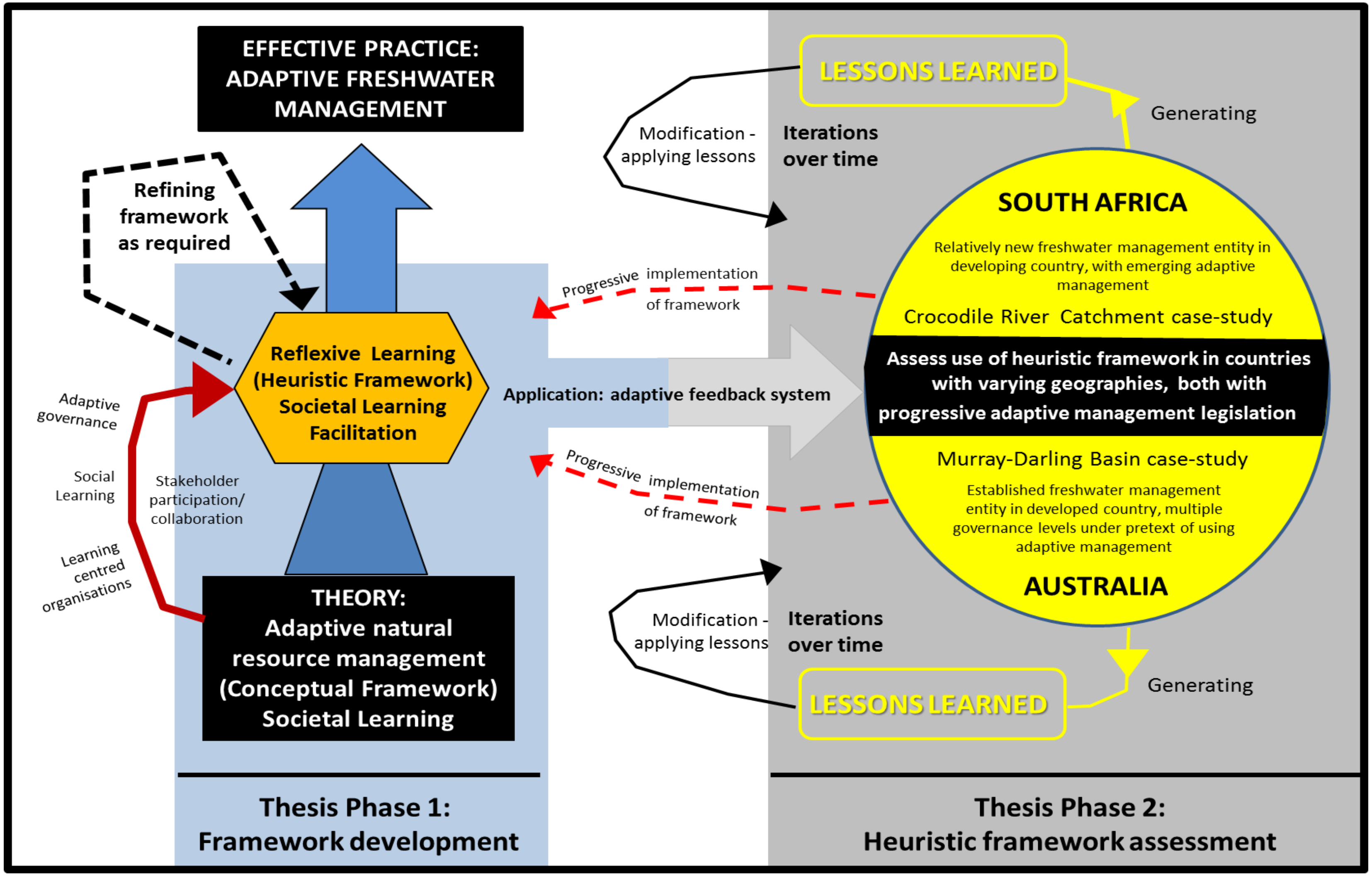

Figure 1.3. The two research phases of the thesis. It is envisaged that over the longer term (not in the scope of this thesis research) that these lessons be applied back into the adaptive freshwater management system. Using these lessons will assist in deployment of the adaptive feedback system, and over longer time scales for improved adaptive freshwater management practice. Refining the actual framework itself is also needed over time.

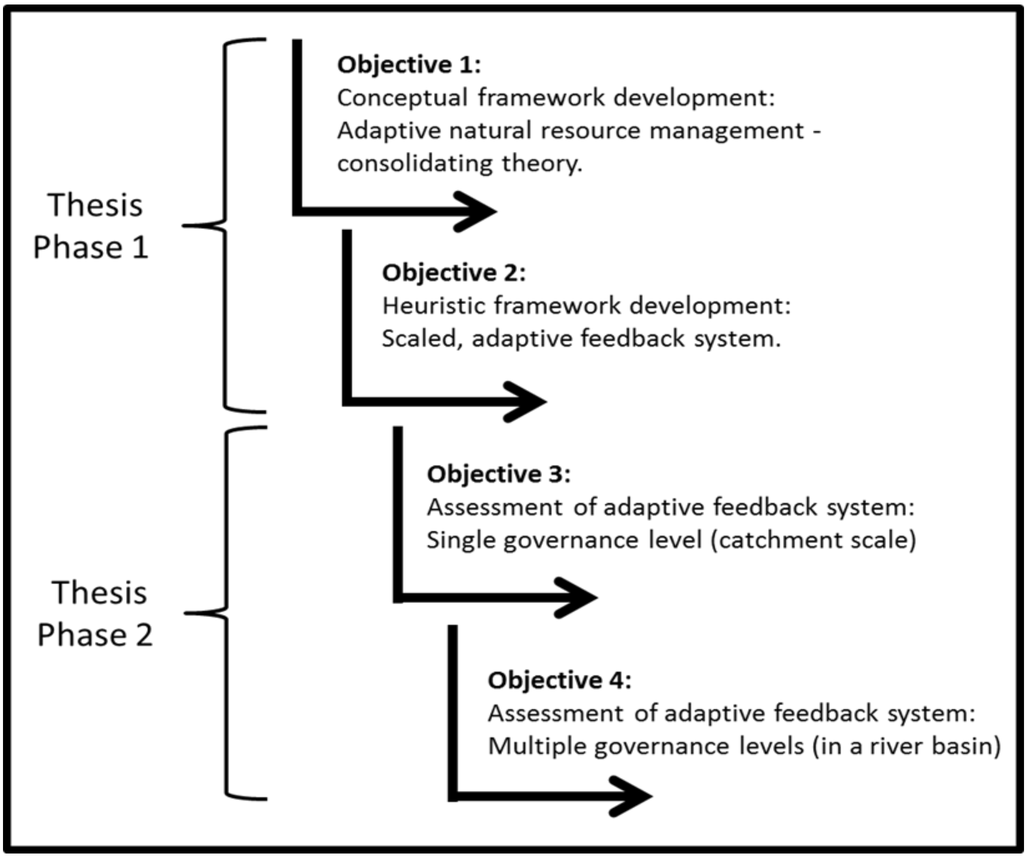

Figure 1.4. The sequential design of the thesis research through four objectives. The output and findings of one objective become an input into successive objectives, i.e. the second objective builds on the first, the third objective on the second, and the fourth objective on the third.

Phase 1: Framework development (Aim 1)

The first objective of phase one focuses on increasing our knowledge about the complex system of enabling conditions and adaptive feedback systems for facilitating societal learning within ANRM. To achieve this, a conceptual framework of ANRM is developed (Fig. 1.3) from consolidating the available literature. Conceptual frameworks are effective tools for integrating components of complex systems, defined as a network of interlinked concepts that together provide a comprehensive understanding of a phenomenon or phenomena. The concepts that constitute a conceptual framework support one another, articulate their respective phenomena, and therefore establish a framework-specific philosophy (Jabareen, 2009). Attempts are frequently made to simplify complex systems by identifying and then examining their individual components. However, oversimplification and loss of explanatory power is often the outcome (Jabareen, 2009). A reductionist approach, that teases apart learning into its constituent components for further examination, results in loss of understanding about the broader complexity of this learning within ANRM.

Objective 1 demonstrates the important place for societal learning within ANRM, and its complex relationship with its facilitators (adaptive feedback system) and key enablers (learning centred organisations, social learning capacities and adaptable governance arrangements). This will be achieved by developing a single, coherent conceptual framework that consolidates important adaptive management philosophies of ANRM and the key learning components (Fig. 1.3; 1.4). Enhanced understanding about the place for reflexive learning (adaptive feedback system) within ANRM, developed in the conceptual framework allows for the second part of thesis phase one, which is development of the reflexive learning heuristic framework (Fig. 1.4).

The focus of the second objective of phase one is on building a foundation of reflexive learning (adaptive feedback system) for the deliberate facilitation of, and appropriate balance between, single-, double-, and triple-loop learning within the adaptive management cycle (Fig. 1.3). The framework is heuristic because it serves to promote further learning or discovery, and enables identification of common problems and solutions as well as appropriate variables and their descriptors (Jabareen, 2009). A heuristic framework guides the search for information and in doing so allows for modifications in order to facilitate solutions. Heuristic frameworks are seen as indispensable for integrative thinking and solving problems, especially when logic and probability theory cannot provide solutions (Pickett *et al*., 1999).

Objective 2 develops a heuristic framework to guide the practice of ANRM across multiple levels of governance within natural resource management (Fig. 1.4). It will consist of a detailed generic, explicit and pragmatic adaptive feedback system designed to deliberately facilitate the three modes of societal learning – single-, double-, and triple-loop learning – within and across multiple governance levels of natural resource management. The heuristic framework is then used in phase two of the thesis research (Fig 1.4).

Phase 2: Assessment of the heuristic framework in real-world practice (Aim 2)

Phase two of the thesis is about assessing the use of the heuristic framework's adaptive feedback system for the practice of adaptive freshwater management (Fig. 1.3). This is by applying elements of real-world freshwater management (the observed) to components of the adaptive feedback system (the expected). The third objective of the thesis research focuses therefore, on applying the adaptive feedback system to elements of environmental watering under the South African National Water Act (Act N^o 36 of 1998), known as the Ecological Reserve. This application of the heuristic framework is at the catchment scale in South Africa (Fig. 1.3). The Crocodile River Catchment and its catchment management agency are implementing elements of the environmental flow requirements of the Ecological Reserve.

Objective 3 applies the adaptive feedback system of the heuristic framework in a case study of adaptive freshwater management associated with implementation of environmental watering at a single governance level (Fig. 1.4). This is to explore real-world facilitation of the three modes of societal learning using an explicitly placed and deliberately used adaptive feedback system (reflexive learning) within the adaptive management cycle. The importance of the developed adaptive feedback system for facilitation of single-, double-, and triple-loop learning will be assessed, for working toward achievement of freshwater-related management objectives of the Crocodile River Catchment, and South Africa more broadly. Key lessons will be derived for implementing the Ecological Reserve adaptively within river catchments of South Africa (Fig 1.3).

Increased understanding about facilitation of societal learning within the adaptive management cycle, at a single governance level, prepares the study for the fourth objective of the thesis research under phase two (Fig 1.4). The fourth objective is an assessment of the application of the adaptive feedback system of the heuristic framework to freshwater management in Australia's Murray-Darling Basin (Fig. 1.3). The adaptive feedback system is deployed for integration of societal learning within and across governance levels of the Basin, associated with elements of the Basin's environmental watering. This case-study is to explore potential for building capacity to deal with uncertainty under complex water reforms.

Objective 4 assesses the adaptive feedback system of the heuristic framework across multiple governance levels of freshwater management associated with environmental watering in the Murray-Darling Basin (Fig. 1.4). Key lessons learned will be derived about the facilitation of single-, double-, and triple-loop learning at different governance levels, but also concerning the important "top-down" and "bottom-up" links between these levels and the factors making this system work. Key lessons will be derived about embracing uncertainty in complex water reforms, for effective environmental watering in the Murray-Darling Basin (Fig 1.3).

This thesis follows the "New Philosophy" of doing science (Bissonette, 1997; Pickett *et al.*, 2007). The new philosophy of science is based on the four key elements of: developing a framework and/or model; the testing (hypothesis building) and/or application (demonstration) of the framework or model; the evaluation of the framework/model from the testing of set hypotheses to the framework/model (with possible falsification), or the identification of lessons learned from applying the framework/model; and feedbacks or lessons from the evaluation of the application of the framework/model. Under this philosophy of doing science, the lessons are then employed to improve the initial framework and/or model. In this thesis, developing, applying and then assessing the application of the heuristic framework within real-world cases of adaptive freshwater management, a number of key lessons learned are identified (Fig. 1.3). Although not within the scope of this thesis the broader benefit of these lessons will be for improving application of the adaptive feedback system, thus for a more effective adaptive freshwater management practice. In addition, lessons learned can be used to modify the actual heuristic framework itself, for re-application back into the adaptive freshwater management systems (Fig. 1.3).

1.4 Structure of the research thesis

Including chapter one, this thesis consists of six chapters:

Chapters two to five target the specific objectives of the thesis in line with its two phases, and are manuscripts prepared in publication format for selected journals (Table 1.2). Chapter Two is entitled "Understanding the complexity of learning in adaptive natural resource management". It critically evaluates learning within an ANRM system. It has the specific intention of consolidating this learning by building a coherent conceptual framework that is hierarchically based and comprises the different components necessary for an effective learning-by-doing strategy. Therefore, it promotes awareness about what is required in terms of learning during the practice of ANRM.

Chapter Three is entitled "Integrative learning for practicing adaptive natural resource management". It outlines a heuristic framework for the practice of ANRM. The adaptive feedback system of the heuristic framework is designed within and across three governance levels of natural resource management. It acts as an important reflexive learning foundation to facilitate an appropriate balance among the three modes of single-, double-, and triple-loop learning within each of the governance levels, with linkages between levels. The reflexive learning foundation is presented as a critical need for promoting the activation, completion, and regeneration components of the "adaptive management cycle" to achieve goals under ANRM.

Both chapters four and five are associated with actual application of the heuristic framework given in Chapter Three, i.e. testing its key reflexive learning principles for practicing societal learning in the real world of adaptive freshwater management. Chapter Four is entitled "Societal learning in adaptive freshwater management: a case-study of the Ecological Reserve in South Africa". Using the Crocodile River Catchment of the Inkomati Water Management Area as a case-study, it provides a real-world precedent for getting the Ecological Reserve implemented adaptively at the river catchment scale in South Africa. This is by assessing application of the adaptive feedback system to facilitate an appropriate balance between and use of single-, double-, and triple-loop learning, for meeting Ecological Reserve and freshwater protection goals in South Africa. Chapter Four discusses lessons learned, as well as providing a number of real-world worked examples associated with implementation of an adaptive management cycle for Ecological Reserve management at the river catchment scale in South Africa.

Chapter Five is entitled "Embracing uncertainty across three levels of governance in complex water reforms: a case-study of adaptive freshwater management in Australia's Murray-Darling Basin". This chapter assesses the heuristic framework's potential to build relevant know-how to deal with uncertainty due to much complexity inherent within environmental watering programs implemented across multiple governance levels under water reforms. It demonstrates that to achieve an effective practice of adaptive freshwater management an efficient societal learning strategy is needed within and across governance levels. Societal learning is facilitated by adopting an ongoing set of overlapping adaptive feedbacks, at each governance level of the Basin with intelligent links between levels. Chapter Five discusses lessons learned, as well as providing a number of real-world worked examples associated with implementation of an adaptive management cycle at the water resource area scale (lower governance level) of the Murray-Darling Basin.

Table 1.2. The arrangement of thesis chapters and objectives as journal papers.

Thesis chapter	**Thesis phase**	**Target objective**	**Journal**	**Submission status**
Chapter 2: Understanding the complexity of learning in adaptive natural resource management.	1	Objective 1: Developing the adaptive natural resource management conceptual framework.	*Annals of the Association of American Geographers*	Submitted
Chapter 3: Integrative learning for practicing adaptive natural resource management.	1	Objective 2: Developing the heuristic framework to guide the practice of adaptive natural resource management.	*Ecology and Society*	Published
Chapter 4: Societal learning in adaptive freshwater management: a case-study of the Ecological Reserve in South Africa.	2	Objective 3: Assessing facilitation of the three modes of societal learning in freshwater management, using the adaptive feedback system.	*Ecology and Society*	Submitted
Chapter 5: Embracing uncertainty across three levels of governance in complex water reforms: a case-study of adaptive freshwater management in Australia's Murray-Darling Basin.	2	Objective 4: Assessing an adaptive feedback system within and across governance levels, to deal with uncertainty under complex water reforms.	*River Research and Applications*	Submitted

Chapter six synthesises the thinking emanating from undertaking this research thesis, associated with the practice of learning within adaptive freshwater management. First, it presents the main contributions of the four manuscripts that have been submitted and/or published within a peer reviewed journal. The main philosophy of the thesis research is then discussed, associated with initiating societal learning and deliberately guiding this in the real world of adaptive freshwater management. Such guidance of societal learning works toward overcoming the implementation dilemma of any given adaptive freshwater management system. Further ideas emanating from the thesis are then provided, concerning ANRM practice and its integration with resilience practice. The chapter concludes by outlining implications of the heuristic framework and its application for further research. This involves increasing understanding about how to get ANRM implemented by translating its theory into practice.

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CHAPTER 2. UNDERSTANDING THE COMPLEXITY OF LEARNING IN ADAPTIVE NATURAL RESOURCE MANAGEMENT

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Name of Candidate: **Craig Anthony McLoughlin**

Name/title of Principal Supervisor: **Professor Martin Thoms**

[redacted]

12/11/2015

Candidate Date

[redacted]

12/11/2015

Principal Supervisor Date

ABSTRACT. The learning-by-doing strategy of adaptive natural resource management deals with uncertainty in managing complex social-ecological systems. Societal learning, which incorporates the modes of single-, double-, and triple-loop learning, achieves both technical and social learning. The effective practice of societal learning is dependent however on many factors. Adaptive feedback systems, stakeholder participation and engagement are required for encouraging shared learning experiences for the effective practice of natural resource management. There is increasing evidence that organizational structures must become learning-centered organizations, and building of social learning capacities enable the double-, and triple-loop modes of societal learning. Achieving adaptable governance regimes is also recognized, and this promotes triple-loop learning. Hence, putting societal learning into practice within adaptive natural resource management is becoming a complex process and moving beyond typical single-loop learning is intricate to achieve in practice. This manuscript presents a coherent conceptual framework that consolidates the learning within adaptive natural resource management. It is built hierarchically in stages to enhance understanding about the complex learning requirements under adaptive natural resource management; commencing with key philosophies, i.e. recognition of wicked problems, embracing complexity by expecting uncertainty and harnessing experiential learning processes with stakeholder collaboration. Societal learning is the central learning construct of any learning-by-doing strategy. Although building learning-centered organizations; fostering social learning capacities, and achieving adaptive institutional arrangements is needed for progressively realizing societal learning, a reflexive learning foundation of stakeholder networks and adaptive feedback systems is paramount for the facilitation of its three modes of single-, double-, and triple-loop learning. Within any adaptive natural resource management system this reflexive learning component must not be taken for granted, otherwise effective implementation of societal learning is compromised.

Key Words: *Adaptive management, governance; adaptive feedbacks; complexity; learning organizations*; *societal, social, reflexive learning*

2.1 Introduction

Learning-by-doing is a strategy frequently employed within adaptive natural resource management (ANRM) to deal with uncertainty in managing complex systems (Rogers et al. 2000; Folke et al. 2005; Pahl-Wostl 2009; Walker and Salt 2012). Complex systems are characterized by a diversity of system components (both the number and type of components), component organization, and multiple non-linear feedbacks between components (Walker and Salt 2012; Biggs et al. 2015). Many potential outcomes can occur as a consequence of similar management interventions, therefore generating uncertainty in managing complex systems (Folke et al. 2002; Cilliers 2008; Walker and Salt 2012). Development, application and testing of learning-by-doing strategies within natural resource management arose because of the recognition that interactions between people and ecosystems are intrinsically complex, hence highly unpredictable (Gunderson et al. 1995). Moreover, management interventions are commonly implemented in the absence of complete knowledge of social-ecological systems (Rogers 2003). Learning-by-doing strategies are iterative, where management interventions are treated as potential learning opportunities that provide feedback which leads to an improvement in future decision making (Rogers and Biggs 1999; Allan and Stankey 2009). Learning-by-doing builds system resilience and should become the focus for longer term sustainable management of complex natural resource systems (Rogers et al. 2000; Cilliers 2008; Pahl-Wostl et al. 2011a; Walker and Salt 2012).

Learning-by-doing is a complex strategy to put into practice (Pahl-Wostl 2009; Fabricius and Cundill 2014) because it requires both technical and social learnings within ANRM (Lee 1993; Stankey et al. 2005; Mostert et al. 2007; Pahl-Wostl et al. 2011b). Societal learning drives both the technical and social components of learning within natural resource management (Pahl-Wostl 2009; Pahl-Wostl et al. 2013; Rogers et al. 2013). It also occurs over increasing time-scales for change and is associated with processes of single-, double-, and triple-loop learning (see Pahl-Wostl 2009; Fabricius and Cundill 2014). Single-loop learning results in incremental advances from action strategies within ANRM, without questioning underlying assumptions of management interventions (Pahl-Wostl 2009). It involves a continuation of established practices and routines in targeting the achievement of goals with minimal improvement to management interventions. Double-loop learning refers to a change in the actual frame of reference within ANRM and includes a visitation of the initial underlying assumptions of any action (Pahl-Wostl 2009). Triple-loop learning is the transforming of the factors that determine the frame of reference, and may include a transformation of the entire governance regime itself (Pahl-Wostl 2009). Hence, societal learning is a key component of any learning-by-doing strategy in ANRM.

Shared learning experiences are a feature of societal learning and this is promoted by adaptive feedbacks (Pollard et al. 2011). Adaptive feedbacks determine the dissemination of data and information within stakeholder networks (Pahl-Wostl et al. 2007a). Stakeholder participation and engagement within networks provide the means for achieving societal learning (Pahl-Wostl et al. 2011b). The development of learning-centered organizations is another key enabling condition for societal learning, because these act to encourage and foster this learning (du Toit and Pollard 2008; Fazey and Schultz 2009). In addition, social learning capacities are needed for effective debate during double-loop learning (Ison and Watson 2007; Pahl-Wostl 2009). Social learning is concerned with social change, defined as achieving collective action resulting from the negotiation among individuals and groups as they proceed toward critically questioning underlying norms, values, institutions and interests when attaining desirable outcomes (Pahl-Wostl and Hare 2004; Mostert et al. 2007; Ison and Watson 2007; Cundill et al. 2011). Social learning is promoted within flexible, open institutions with multi-level adaptive governance arrangements enhance stakeholder debate for societal learning (Folke et al. 2005; Gunderson and Light 2006; Pahl-Wostl 2009; Herrfahrdt-Pahle 2013). Achieving adaptable governance regimes improve particularly the triple-loop mode of societal learning (e.g. Pahl-Wostl 2009). Hence, achieving societal learning in practice requires many different components and frequently there is uncertainty about how to implement these components within the learning-by-doing strategy, i.e. who should be learning, what they need to be learning and the processes that support learning (Fabricius and Cundill 2014). Evidence for successful implementation of learning in ANRM is, therefore, limited (Medema et al. 2008; Stankey and Allan 2009; Susskind et al. 2012; Rist et al. 2013; Scarlett 2013; Westgate 2013) despite decades of research and ANRM experience (Fabricius and Cundill 2014).

A holistic scholarship approach to learning-by-doing in ANRM would include all societal learning components and their interrelationships, for a better understanding about the complex process of implementing learning in ANRM. Complex systems are frequently made simple by identifying and then individually examining system components. This type of reductionist approach that teases apart the learning-by-doing strategy into its constituent components for further examination results in loss of understanding about the broader complexity of learning for practicing ANRM. However, conceptual frameworks can be effective tools to link concepts together and thus provide a comprehensive understanding of complex systems (Jabareen 2009). The concepts that constitute a conceptual framework support one another, articulate their respective phenomena, and therefore establish a framework-specific philosophy (Jabareen 2009). Incorporating societal learning and all its components under a coherent conceptual framework of ANRM acts to re-direct focus to the complexity of the learning-by-doing strategy within ANRM. A grasp of this complexity is important because awareness about the ANRM method, which critically includes learning, is necessary for the practice of ANRM (Allan and Stankey 2009).

The aim of this manuscript is to develop a conceptual framework that consolidates the constituent components of the learning-by-doing strategy of ANRM. The framework employs a hierarchical approach to improve the interpretation of learning requirements, and as a basis to merge the many components of complex learning systems. First, the key philosophies of ANRM are outlined as they are critical for the understanding and practice of learning-by-doing. Second, societal learning as the central learning component within the learning-by-doing strategy is defined. Third, stakeholder driven adaptive feedback systems – termed reflexive learning – as a core technical learning component of learning-by-doing is emphasized. Reflexive learning performs an essential role in facilitating societal learning, and therefore for achieving objectives within an ANRM context. Fourth, enabling conditions that are critical for the realization of societal learning are discussed. Here we focus on: organizational structures – building learning centered institutes; human interfacing – fostering the social learning component; and governance systems – achieving adaptive institutional arrangements. An understanding is provided for each enabling condition, and the associated attributes essential for achieving single-, double-, and triple-loop learning are then mapped out. Finally, we conclude by highlighting the value of the conceptual framework for practicing learning within ANRM, directed at practitioners who have the arduous task of implementing the learning-by-doing strategy.

2.2 Underlying philosophies for the practice of adaptive natural resource management

Understanding the philosophies underlying the practice of ANRM is fundamental for understanding learning-by-doing strategies. Thus, we commence construction of the conceptual framework with four underlying philosophies (Figure 2.1A).

2.2.1 Acknowledgement of "wicked problems"

Problems characterized by social concerns often cannot be tackled using traditional scientific approaches, because scientific approaches are best suited to deal with "tame" problems (Rittel and Webber 1973). "Wicked problems" are problems which cannot ultimately be defined, and furthermore any policies to counter such problems cannot be objectively tested as correct or false (Rittel and Webber (1973). Hence, wicked problems go beyond the capacity of any one organization to understand and manage (APSC 2007). In tackling wicked problems there is often disagreement about the cause(s) of the problem(s), which introduces intricacies in how to efficiently tackle them because there is no one method or approach to solve wicked problems (Allan and Wilson 2009). To solve or manage wicked problems requires an ability to work across internal and external organizational boundaries. This involves engaging all stakeholders in selecting, developing and implementing management interventions (Ison and Watson 2007; Ison 2010).

Managing complex social-ecological systems requires the ability to deal with wicked problems. This is can only be achieved by embracing uncertainty and working with complexity, rather than attempting to control or eliminate them (Holling 2001; Pahl-Wostl 2006; Walker et al. 2006; Walker and Salt 2012).

2.2.2 Embracing complexity

A complexity "frame of reference" for decision making is advocated for the practice of ANRM (Rogers et al. 2013). It is increasingly recognized that natural and social systems behave in nonlinear ways, exhibit thresholds in their dynamics and act as strongly coupled, complex and evolving integrated systems (Folke et al. 2002; Folke et al. 2005; Cilliers 2008). Within this context, stakeholders of social-ecological systems strive to internalize not only "intellectual complexity" (knowing) but also "lived complexity" (being and practicing), and Rogers et al. (2013) describe a framework for complexity thinking. First, an explicit/tacit knowledge framework in which formal knowledge (reports, publications) is augmented with less formal knowledge that becomes available through stakeholder negotiation and the build-up of trust. Second is unlearning selective exposure, to overcome the issue that the more someone knows the harder it becomes to change one's world view. Third is the conscious/competence learning matrix, which includes the stages that people go through in gaining and using new knowledge (Howell 1982). This includes "unconscious incompetence" (don't know that they don't know); "conscious incompetence" (know they don't know); "conscious competence" (they know they know); "unconscious competence" (they don't know that they know) and "reflective competence" (they continually challenge their conscious incompetence to improve their knowledge). These learning modes all superimpose on the single-, double-, and triple-loop modes of societal learning, within the composite complexity "frame of reference" framework (see Rogers et al. 2013).

With the framework of Rogers et al. (2013), deep reflection is a prerequisite to transformational learning, ultimately fostering change in mind-sets and behaviors that are conducive for building a complexity "frame of reference". Furthermore, three broad frames of mind work together to produce different "habits of mind" that allow one to unlearn reductionist habits while adopting and embedding those mind-sets more favorable for working in complex systems (see Rogers et al. 2013). These frames of mind are openness or a willingness to accept, connect with and internalize peoples varying perspectives; situational awareness, of the complex context in which adaptive challenges occur; and a healthy respect for the restraint/action paradox, that allows ideas, opportunities and trust to emerge. These frames of mind guide stakeholders through the processes of participative planning and adaptive decision-making in complex social-ecological systems (Rogers et al. 2013).

2.2.3 Expect uncertainty and a need for ongoing change

A key concept associated with complex social-ecological systems is that our understanding of them is always imperfect, and therefore managers must continually deal with system uncertainty. The conventional tools of risk management, planning and design are inadequate to manage social-ecological systems (Jiggins and Röling 2002), because of the on-going state of flux and surprise which is characteristic of coupled systems. Thus, uncertainty is a characteristic trait of social-ecological systems and why surprises must be formally assimilated into ANRM (Stankey et al. 2005). Learning-by-doing strategies are necessitated under these situations, especially where uncertainty cannot be minimized (Hendriksen and Barlebo 2008). Thus, effective ANRM should not be seeking one-off optimum solutions to problems but rather, engage in an on-going learning process with relevant participants (Huxham and Vangen 2000; Pahl-Wostl 2002; Pahl-Wostl and Hare 2004). Within this context, society must strive to turn command-and-control strategies into adaptive, learning-by-doing strategies (Rogers 2003; Stankey et al. 2005) that can enhance and speed up the learning cycle that allows for quicker assessment and execution of the consequences of new understandings (Pahl-Wostl et al. 2007a).

2.2.4 Harness experiential learning, stakeholder participation and collaboration

Experiential learning is fundamental for complexity thinking (Rogers et al. 2013). It is a process that relates to or results from reflections on experiences. The experimental-inquiry technique or reductionist scientific method of learning is a traditional model for generating understanding about phenomena. It involves the generation and testing of hypotheses (often via controlled experimentation using statistical techniques) which leads to explicit factual knowledge of phenomena. However, there are limits to this reductionist approach for resolving complex problems that challenge society (Stankey at al. 2005; Roux et al. 2006; Fazey and Schultz 2009; Stirzaker et al. 2011). For example, new knowledge is valid only when other factors are excluded via the constraining of problems. Also, complete understanding of ecological systems is elusive due to much uncertainty in these systems, but reductionist approaches seek to eliminate uncertainty by constraining problems (Stirzaker et al. 2011). Hence, experiential learning is required because it deals with uncertainty more effectively.

There are five characteristics of experiential learning (Kolb 1984) pertinent to the practice of ANRM. First, learning is conceived as a holistic process, and not in terms of outcomes only. Second, learning is a continuous process with individual experience as its basis. Third, knowledge is generated as a consequence of transactions between social knowledge and personal knowledge. Fourth, learning involves an adaptation between people and the environment. Fifth, the learning process must resolve conflict between divergent modes of adaptation to the world. It is this type of learning and the knowledge gained from it that is more appropriate for many analyses under ANRM rather than the traditional reductionist model of learning (Stirzaker et al. 2011). It allows the development of functional predictions and selecting the best management approaches for achieving predefined goals (Stankey et al. 2005).

There are two main styles associated with practicing experiential learning (Kolb 1984; Pahl-Wostl 2002). The first dialect relates to the task of "grasping information", involving our emotional responses - whether we prefer learning by feeling or by thinking (a "perception continuum" dialect). Information is grasped either by an external first-hand experience (concrete experience mode) or by an internal mental process of calling up a stored memory (abstract conceptualization mode). The second dialect relates to the task of actually "transforming information", and is dependent on whether we prefer to learn by doing something or by watching something (a "processing continuum" dialect). Information is transformed either by an external mode of active experimentation or by the internalized mode of reflective observation. Kolb (1984) considers the experiential learning process as a context of people moving through, on the one hand, the modes of concrete experience and abstract conceptualization; and on the other-hand the modes of reflective observation and active experimentation. Effective experiential learning relies on attaining an appropriate balance between these opposite modes of the two dialects. Overall, learning is an active process whereby information is transformed into a form of subjective perception and this is also vital for the generation of knowledge in the practice of ANRM (Pahl-Wostl 2002).

Learning within ANRM must embrace different components that are crucial for decision-making. This includes subjective perception of individuals, emanating from experiential learning (tacit knowledge) and scientific factual-knowledge (Pahl-Wostl 2002). To embrace all components, all stakeholders must participate from the beginning; otherwise the problem definitions can miss crucial aspects and/or include aspects that are not relevant (Funtowicz and Ravetz 1990, Pahl-Wostl et al. 2008). Stakeholder participation is paramount because multiple views and perspectives can be aligned, with common values and problem frames established (Bettini et al. 2015). Thus, participatory approaches within ANRM are critical for addressing conflicts and achieving co-evolved stakeholder preferences (Rammel et al. 2007). This leads to the generation of shared goals and compromises vital for effective decision-making under ANRM (Sherwill and Rogers 2001).

There are four categories of stakeholder participation that can be employed within ANRM (du Toit and Pollard 2008). “Inform” is the first category and provides stakeholders with a balanced set of information in order for them to gain an understanding of the problems, opportunities, solutions and alternatives available, for example, via press releases and fact sheets. The second category is “Consult,” in which stakeholders are given the opportunity to provide feedback on various analysis, alternatives and decisions, for example, within focus groups and public meetings. “Involve” is the third category that ensures working directly with stakeholders throughout the management process to ensure that stakeholder concerns are received, understood and also considered, for example, within processes of workshops and/or meetings. The final category is “Collaborate”. This includes partnering with stakeholders in each component of the decision-making process, where development of alternatives and identification of preferred solutions is achieved, for example, as part of citizen advisory committees and participatory decision-making forums.

All four categories of stakeholder participation can occur within ANRM. However, the collaborative approach to stakeholder participation is the most beneficial for an inclusive process within ANRM whereby multiple stakeholders are brought together strategically within networks (du Toit and Pollard 2008). Stakeholder networks are important under ANRM because this is where trust and ownership are nurtured, allowing for consensus building and voluntary compliance that is important for effective adaptive decision-making (Ananda and Proctor 2013; Armitage et al. 2015). Effective decision-making processes are necessary for achieving societal learning within ANRM (Pahl-Wostl et al. 2011b).

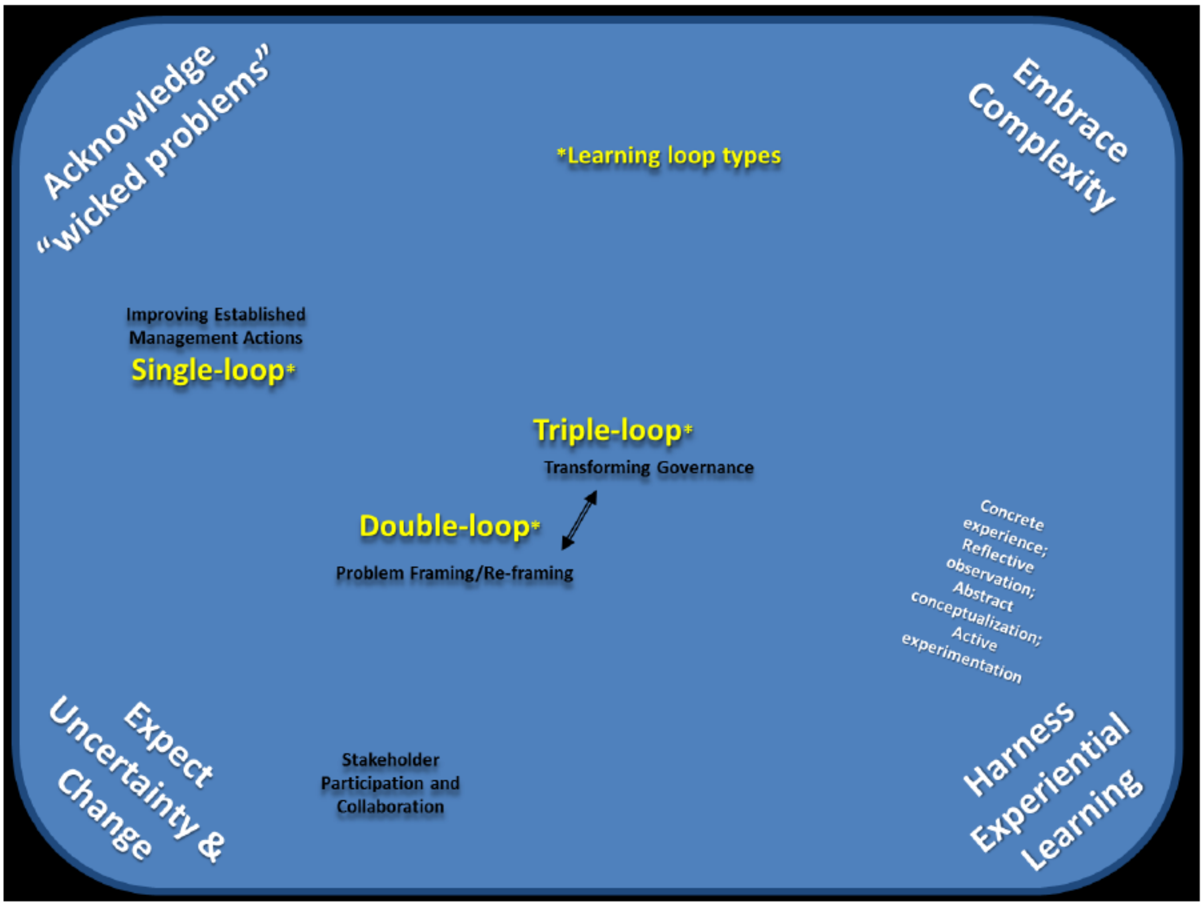

Figure 2.1A. Underlying philosophies of adaptive natural resource management, including the central societal learning construct (single-, double-, and triple-loop learning) required for its effective practice.

2.3 Societal learning – central learning construct in learning-by-doing

Societal learning is necessitated within ANRM because it promotes and deals with change (Pahl-Wostl 2009). Increasing uncertainties, resulting from changing climates or political regimes, require adaptive regimes for the management and governance of natural resources (Pahl-Wostl et al. 2011a). Societal learning fosters an ability to change management and governance systems making them resilient to unpredictable changes in the natural and/or social environments (Pahl-Wostl 2009). Societal learning is not achieved within bureaucratic hierarchies, but rather by processes of network governance and it is these networks that promote social learning outcomes (Pahl-Wostl and Hare 2004). Societal learning builds capacity to achieve joint solutions, which makes stakeholder participation effective in decision-making (Pahl-Wostl 2009). This decision-making is necessary for working toward objective achievement within ANRM, and the promotion of sustainable natural resource management (Walker and Salt 2012).

Societal learning is made up of three different modes of learning, i.e. single-, double-, and triple-loop learning. The concept of triple-loop learning has its origins within management theory (Hargrove 2002). It essentially builds upon double-loop learning by increasing time scales and the different management and governance levels that provide direction and stability in social contexts (Pahl-Wostl 2009). It differs from single-loop learning, which occurs when individuals realize that there is a mismatch between their specific intentions and what actual events took place (Stankey et al. 2005). Single-loop learning involves the actual doing (Fabricius and Cundill 2014), and results in incremental advances from action strategies without questioning the underlying assumptions (Pahl-Wostl 2009) (Figure 2.1A). It is a continuation of (with concurrent improvements to) established practices and routines in targeting the achievement of goals. By comparison, double-loop learning refers to "changing practice" (Fabricius and Cundill 2014), and it involves changing the actual 'frame' of reference by re-visiting the initial underlying assumptions of any action (Pahl-Wostl 2009) (Figure 2.1A). Double-loop learning addresses issues of why certain problems exist and whether the current management solutions are correct, and if not then how to correct these (Stankey et al. 2005). The reframing process of double loop learning commonly occurs within stakeholder networks by characterizing the resource governance regime and experimenting with innovative approaches to achieve improvements in management. Double-loop learning has important implications for ANRM as it re-emphasizes the importance of sound problem-framing processes. Processes of double-loop learning often reveal short-comings within organizations that make them vulnerable to the risk of inaction (Stankey et al. 2005). Stakeholders involved in double-loop learning normally explore reframing in the context of structural constrains of governance systems, such as regulatory frameworks.

Changes in structural constraints within natural resource management are the focus of triple-loop learning (Pahl-Wostl 2009). Triple-loop learning includes transformation of the factors that determine the frame of reference, and may include transformation of the entire governance regime itself (Pahl-Wostl 2009) (Figure 2.1A). This style of transformation necessitates an acknowledgment that paradigms and structural constraints inhibit effective reframing of resource governance and management practices. Hence, triple-loop learning implies a paradigm shift as well as changes in the norms and values underlying the processes of governance (Pahl-Wostl 2009). Importantly, double-loop learning should be accompanied by triple-loop learning because the dominating "frame" of reference (associated with double-loop learning) is regularly affected by the "structural context" linked to triple-loop learning (double-arrow Figure 2.1A). This suggests that if the structural context within resource governance regimes remains too rigid it can impede the “reframing” component critical within double-loop learning (Pahl-Wostl 2009).

2.4 A learning foundation to facilitate societal learning

Development of a core adaptive feedback system is essential for facilitating societal learning within ANRM (Figure 2.1B). Reflexive learning defines this feedback related system, and reflexive learning is a mechanism driven by participating and collaborating stakeholders.

2.4.1 Stakeholder-driven adaptive feedback systems

Knowledge production through policy and management actions and its dissemination to and use by all stakeholders via feedback systems are integral to ANRM (Stankey et al. 2005). Explicit (objective facts) and tacit (experiential) knowledge are both important in the learning process within ANRM. Individuals acquire tacit knowledge about their world, which is shared by common practice. Tacit knowledge is valuable because it contributes to innovation in ANRM (Pahl-Wostl et al. 2007a). The ability of stakeholder networks to use new information within shared social learning experiences creates opportunities to facilitate collective action that emerges from the process of incorporating and synthesizing new knowledge (Pahl-Wostl et al. 2007a; Pahl-Wostl et al. 2008). However, processes of sharing of new information and derived knowledge must be cognizant of the quality and types of communication systems in networks rather than just undertaking a synthesis of this information and knowledge. This can be aided by considering the appropriateness of institutional settings for processing information and subsequent knowledge (Pahl-Wostl et al. 2007a). For example, using tools such as computer simulation programs ensure complex problems are explained in understandable ways to multiple stakeholders. An ANRM system requires that all knowledge is enacted, whether it is skill based or attitudinal, as a result from shared experiences (Pahl-Wostl et al. 2007a; Rogers et al. 2013).

Unbiased information generation and dissemination is also critical for ANRM. Information must not be filtered or selectively searched and processed based on confirming beliefs, but also include knowledge that may contradict dominating assumptions. Thus, requirements for change can be recognized where and when appropriate within ANRM (Pahl-Wostl 2009).

2.4.2 Building the reflexive learning foundation

Practicing ANRM involves sharing experiences between stakeholders. This shared experience improves information which leads to better communication via a series of adaptive feedbacks (see Stankey et al. 2005) (Figure 2.1B). The reflexive learning process among stakeholders can be characterized as a "feedback loop", whereby actions are manipulated and or modified via "feedback(s)" from the context within which they were executed (Pollard and du Toit 2007). Thus, reflexive learning is "learning from action", with the deliberate intent to enhance the practice of management (Kolb 1984). Reflexive learning is incorporated into ANRM via development and application of an adaptive management cycle (Greig et al. 2013; Prat Miles 2013). The adaptive management cycle consists of a series of actions, characterized by feedback loops with the intent of achieving a set of goals, through the modification and refinement of hypotheses, objectives, outputs/outcomes, and management actions (Edwards 2002; Stankey et al. 2005). This iterative process is supported by strategic monitoring and identifying feedbacks from the outcome of any decisions (Jiggins and Röling 2002; Allan and Stankey 2009). Thus, the adaptive management cycle is a process based on incremental, experiential learning.

The deployment of adaptive feedback loops within a foundation of reflexive learning drives the core adaptive assessment and adaptive reflection routines of ANRM (Figure 2.1B). Collectively, adaptive assessment and reflection are important as they generate a shared understanding among stakeholders, thus shaping deliberations under ANRM (Biggs et al. 2011). Adaptive assessment means to 'evaluate or estimate the nature, quality, ability, extent, or significance of' something (Biggs et al. 2011) and this is a minimum requirement for driving single-loop learning under adaptive management. Meanwhile, adaptive reflection routines are seen more as 'a calm, lengthy, intent driven consideration' (Biggs et al. 2011), and this deeper deliberation is necessary for executing double-loop learning and triple-loop learning in ANRM. (Figure 2.1B).

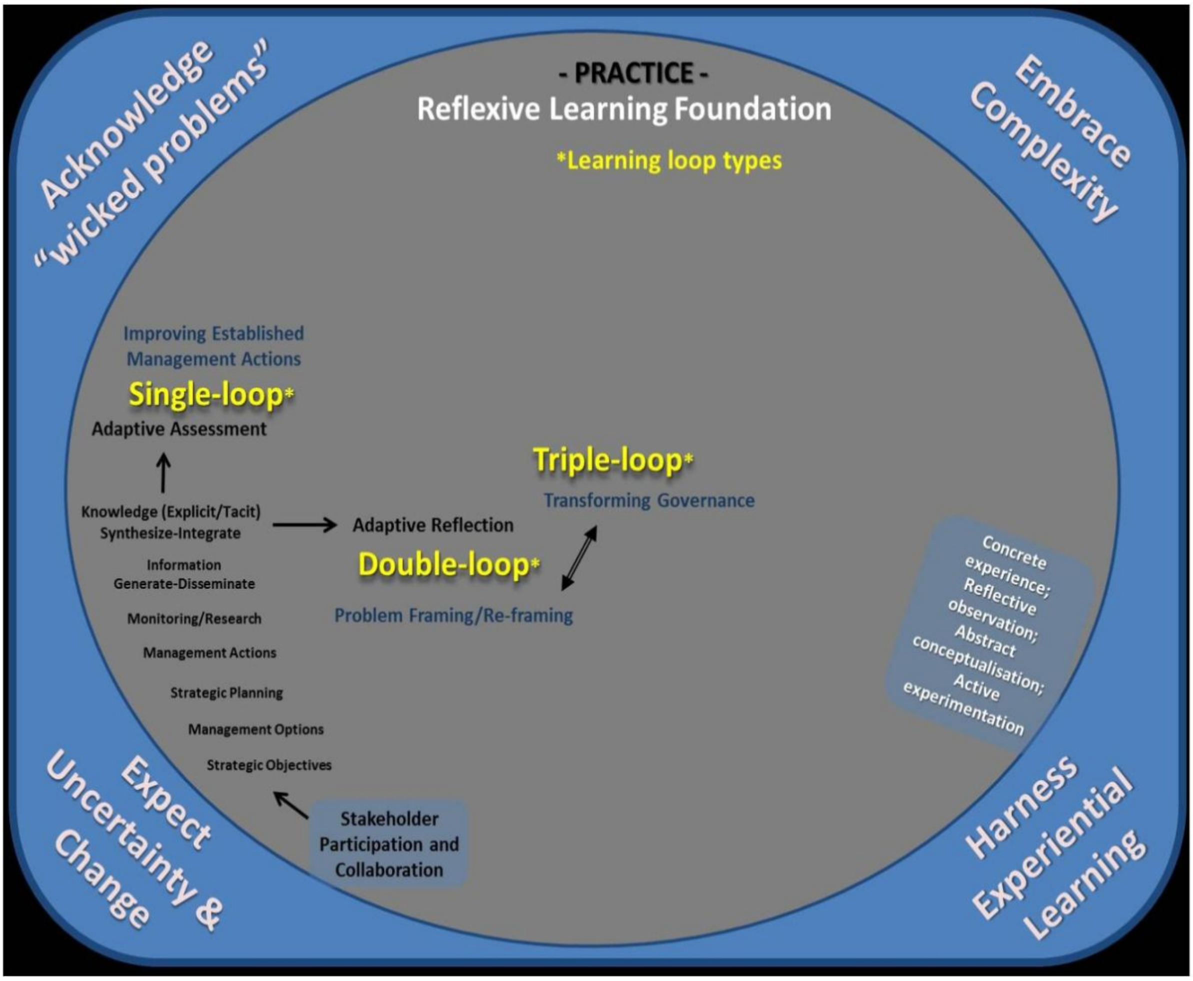

Figure 2.1B. The reflexive learning foundation requirement of adaptive natural resource management. An adaptive feedback system using adaptive assessment and reflection is a critical component to facilitate the modes of single- and double-loop learning, and potentially triple-loop learning in conjunction with double-loop learning.

2.5 Key enabling conditions for societal learning

Although reflexive learning is needed to facilitate "when and how to" use the modes of single-, double-, and triple-loop learning of societal learning, there are a number of key enabling conditions for effective societal learning. Enabling conditions are defined here as situations which when occurring synchronously within ANRM provide the means for societal learning and the possibilities that this learning can take place. There are three enabling conditions that are key for societal learning presented in the conceptual framework: organizational structure; human interfacing; and governance systems. Over longer time-scales, these enabling conditions increase likelihoods of achieving the societal learning components of the learning-by-doing strategy used within ANRM.

2.5.1 Organizational structures

Learning-centered institutes are organizations in which individuals come together to actively manage the ANRM system and its learning processes (Roux et al. 2006; Roux et al. 2010; Stirzaker et al. 2011). There are two predominant views related to the idea of learning-centered organizations (Stankey et al. 2005). First, organizational learning is the sum of all learning individuals. Organizations do not learn themselves. Individual learning can be institutionalized into organizational components when pertinent structures exist to sanction individual learning. Second, organizations as entities can and do learn but it is an emergent quality that is greater than the sum of individual learning. Individual learning is necessary but is an insufficient condition for organizational learning, where learning is acquired and emerges via interaction between organizational members. New knowledge is generated through a collective process, and this is not attributable to one individual. Thus, this type of emergent organizational learning is inextricably tied to the human interfacing enabling condition for societal learning (see section 2.5.2 below).

An organization is classified as a learning organization if it is ultimately competent at creating, acquiring, and transferring knowledge (Roux et al. 2006; Biggs et al. 2011). Learning organizations have the ability to modify behavior (Garvin 1993), so that measurable improvements in results or outcomes of performance can be realized. The process of modifying behavior is difficult, and involves three overlapping phases (Stirzaker et al. 2011). First, is the cognitive phase where members within an organization get exposed to new ideas and broaden their knowledge base and this allows them to think in different types of ways. Second, is the behavioral phase where individuals commence internalizing the new knowledge, resulting in an alteration in behavior. Third, is the performance improvement phase where change in behavior leads to measurable improvements in results and/or outcomes. All phases are needed for progressing through the three modes of societal learning.

Building learning centered institutes

Learning-centered institutes are knowledge-orientated organizations with a risk-tolerant culture, with human capital that is highly motivated, flexible and adaptive (Figure 2.1C). These organizations do not operate in silos, hence benefiting from cross-sector collaboration which allows access to larger repertoires of knowledge (Wenger 2005). Importantly, learning centered institutes are promote the practice of the three modes of societal learning under adaptive management, i.e. in the doing (single-loop learning), changing practice (double-loop learning) and transforming governance (triple-loop learning).

Organizations are becoming learning-centered institutes if the following key criteria within the organization emerge (Fazey and Schultz 2009). First, there are people with ability to learn flexibility and become adaptive. Second, the personal beliefs that people hold about the nature of knowledge are interrogated, with probing of how individuals come to know something (a focus of educational psychology research). Third, people's learning is focused on the organization as a whole, and they have a strong desire to continuously learn from their experiences, and therefore improve their performance. Fourth, people in the organization have the ability to learn flexibility in various circumstances. Fifth, people in the organization are given responsibility for their own learning, and have the incentive and space to do so. Sixth, there is an appropriate culture and structure for people to develop adaptability. With this, learning-centered organizations must become risk-tolerant institutions, meaning that they embrace risk and its associated uncertainty. An inability to handle risk is a major obstacle to practicing ANRM using societal learning (Stankey et al. 2005).

Functioning learning-centered institutes have learning as the mechanism through which individuals and their collective understanding about the world is changed (Stirzaker et al. 2011). There are a number of key aspects to these organizations. To accommodate any new knowledge "unlearning" is sometimes required, where previous learning and beliefs are left behind (Roux et al. 2006; Rogers et al. 2013). Organizations must be prepared for multi stakeholder situations with collaborative and ongoing learning scenarios, acknowledging that learning is undertaken in combination with other parties who may hold very different world views (Stirzaker et al. 2011). With this, empathy and humility are necessitated, where empathy is an ability to suspend one's own perspectives and assumptions by considering those of others (Stirzaker et al. 2011). An awareness that the knowledge base is too vast for any one person to master is a sign of humility (Stirzaker et al. 2011).

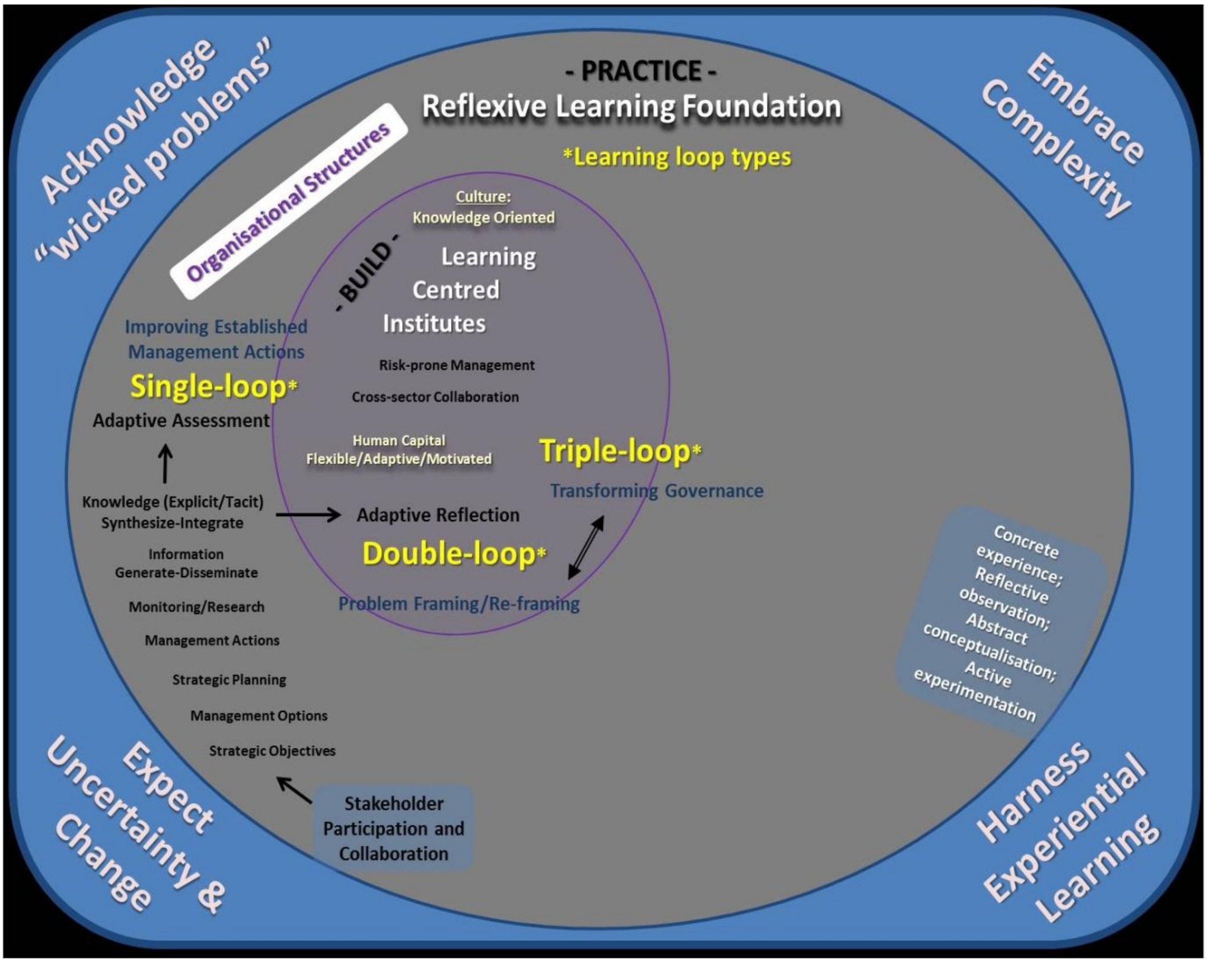

Figure 2.1C. Conceptual framework of adaptive natural resource management indicating organizational structures of learning-centered institutes, aiding single-loop learning but built chiefly for effective double- and triple-loop learning processes.

2.5.2 Human interfacing

Human interfacing plays a decisive role in the management of natural resources (Pahl-Wostl 2002) because the utilization of natural resources results from both bio-physical and social dynamics (Lescuyer 2002). Moreover, natural and social systems co-evolve (Wiersum and de Hoogh, 2002). Adaptive natural resource management initially focused on ecosystems and over time they included human dimensions (Pahl-Wostl et al. 2007a). This transition has been the result of problems being more complex, with limited prediction-making abilities because of high uncertainties and the lack of complete knowledge and understanding about systems (Pahl-Wostl and Hare 2004). Human interaction within natural resource management is epitomized by social learning, defined broadly as achieving concerted action in complex and uncertain contexts (Ison and Watson 2007). Social learning involves an iterative learning and negotiation process with communication comprising many feedback loops for adaptation to on-going change (Pahl-Wostl and Hare 2004). Social learning is important for societal learning because it supports perspective sharing and development of adaptive group strategies (Huxham 2000; Pahl-Wostl and Hare 2004). This human interfacing assists management in finding solutions to the complex and "wicked problems" often presented within ANRM.

There are two prominent aspects to the concept of social learning (Pahl-Wostl and Hare 2004; Pahl-Wostl et al. 2007a; Pahl-Wostl et al. 2008; Pahl-Wostl et al. 2007b). First, processing of factual information is required, involving a problem/task or content management about a specific problem. Second, an engagement in social exchange or relational processes emphasizes that social relations are inextricably connected to management problems, because managers have to take into account whose problems to solve, and how these problems are framed. Integration of social and content issues is facilitated by relational practices, for example, the quality of interaction, the shared ownership of tasks, transparency for mutual testing of options and contradiction, and making suitable opportunities for reflexive sessions in problem solving activities. Importantly, active involvement of stakeholders and the building of a sense of ownership of the decision-making process, results in stakeholders showing more commitment to outcomes, and this promotes consensus.

Social learning therefore assists the management of complex problem situations of ANRM (Daniel and Walker 1996; Jiggins and Röling 2002; Cundill et al. 2011). The social learning processes direct shared collaboration rooted in a specific context. It implies that natural resource management processes are not only composed of technical qualities, for example, improvement to the condition of the environment, but also relational qualities, for example, improved capacity of stakeholders to solve conflicts by achieving consensus through cooperation. Social learning is therefore a key enabling condition for societal learning, and must be fostered within the learning-by-doing strategy of ANRM.

Fostering a social learning ethos

Fostering an ethos of social learning promotes collective action by addressing conflict management among stakeholders, and this strengthens cooperative agreements and consensus building for learning-by-doing (Figure 2.1D). Achieving consensus assists in moving beyond wicked problems and in so doing fosters shared values that then guide decision-making (Rogers 2006). This decision-making ability is critical for achieving the double-, and triple-loop learning modes of societal learning within ANRM.

Institutional settings that support informal discourse and social learning are required for achieving double-loop learning within ANRM (Pahl-Wostl 2009; Pahl-Wostl et al. 2011b). The "reframing" component of double-loop learning would be difficult to achieve without occurrence of social learning. Social learning happens within and between all stakeholders involved in an ANRM system, and this stakeholder base may be determined by asking a number of key questions (Pahl-Wostl and Hare 2004): Who may be contributing to the decision making process? Who is needed or who may block implementation of adaptive management? and, Who is directly or indirectly affected by or have issues at stake within the management process? Social learning is promoted if these types of issues are resolved early on within the ANRM process.

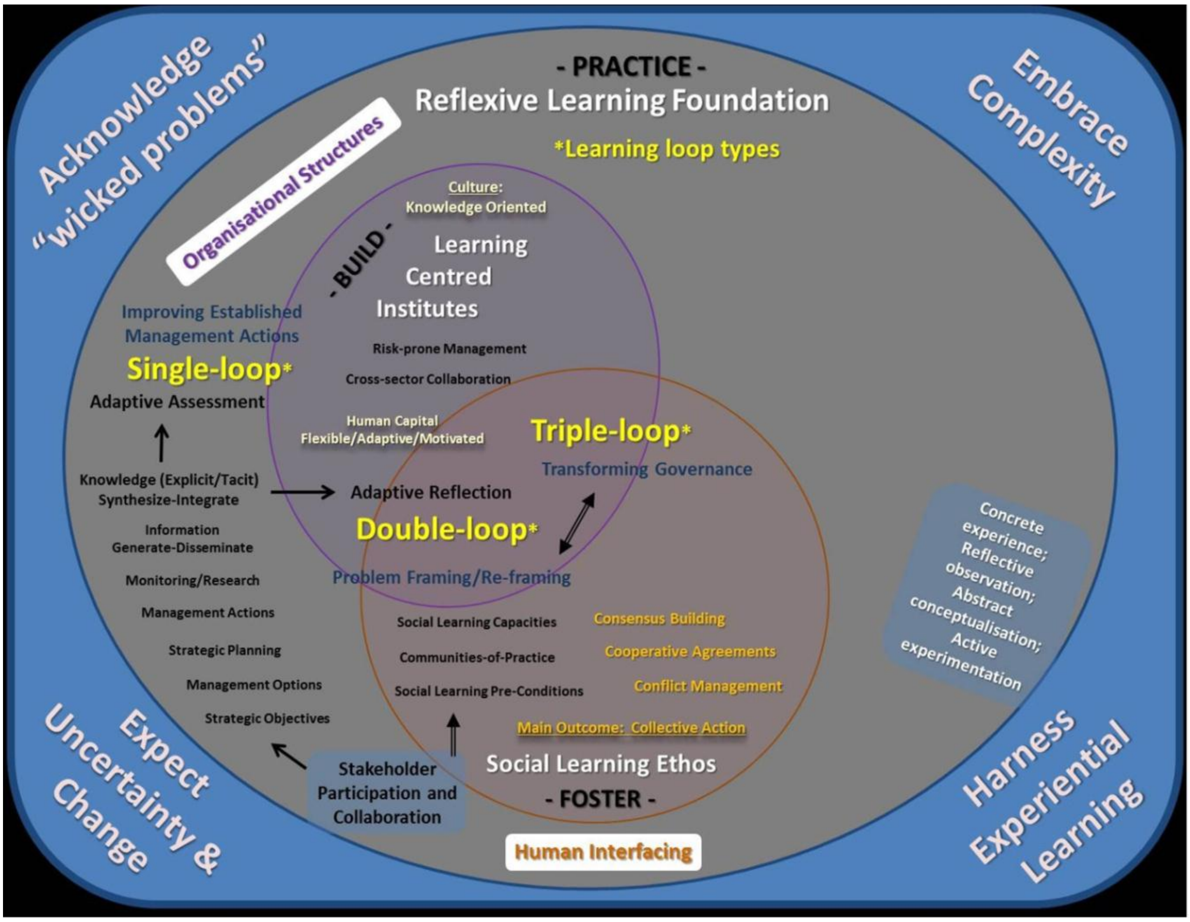

Figure 2.1D. Conceptual framework of adaptive natural resource management indicating the three steps for fostering a social learning ethos, i.e. pre-conditions, communities of practice and social learning capacities. Social learning capacities are needed for effective double-loop learning, and linked triple-loop learning.

Importantly, to foster social learning a sequence of three main outcomes is needed within ANRM (Figure 2.1D). The first outcome is a set of pre-conditions for social learning (see Table 2.1; Mostert et al. 2007). The second outcome is the emergence of "communities-of-practice" (sensu Wenger 1998), which is the main mechanism driving social learning. Realization of communities-of-practice depends on a number of criteria, described in Table 2.1 (Pahl-Wostl et al. 2008; Iaquinto et al. 2011). The third outcome relates to key capacities (see Table 2.1) that allow social learning to occur (Pahl-Wostl and Hare 2004; Pahl-Wostl 2008; Cundill et al. 2011), and these capacities emerge from within the communities-of-practice. Notably, this sequence of outcomes for social learning is best achieved under ANRM using the "Collaborative" stakeholder participatory approach (see section 2.2.4).

Table 2.1. Three steps and their key criteria for fostering a social learning ethic within adaptive natural resource management.

Key step for social learning	Key criteria for social learning	Description of key criteria for social learning
Development of pre-conditions for social learning (Mostert et al. 2007)	1. Role of stakeholder involvement	There is clarity on the purpose for stakeholder involvement, and status of the initiative whereby different stakeholders could become involved.
	2. Institutional setup	Strong institutions with legal authority over the area under management, cognizant of the different scales of the system, with relationships among the key authorities. Arrangements are made for interactions among different stakeholders, recognizing the types, number and quality of meetings between stakeholders.
	3. Type of facilitation	A neutral facilitator, with independent facilitation of the stakeholder process, thus having no bias in any way. Facilitator must have personal qualities that invoke trust within the social learning process, allowing differences of opinion to be overcome.
	4. Transparency of the approach	Legitimacy of the program must be established, achieved by developing a system of ongoing feedbacks with joint planning, and setting of clear ground rules.
	5. Representativeness	Inclusivity of pertinent stakeholders in the program, and organizations that have adequate representation of their members. Too many stakeholders may lead to difficulties for executing large group discussions, requiring special meeting formats.
	6. Framing of problems	Need to account for different stakeholder perspectives within the program. Identifying different problem perceptions leads to increased ownership of the process, including of the many issues and solutions. The quality of communication must not be too complex, thus conducive to problem solving.
	7. Resources	The commitment of all stakeholders is important and depends on their opportunity to say how they want to be involved. Demands on stakeholder time and finances play a role.

Key step for social learning	Key criteria for social learning	Description of key criteria for social learning
Building communities-of-practice (CoP)	1. Joint enterprise	Build a sense of joint enterprise by bringing different stakeholder groups together, with shared roles, responsibilities and practices. Stakeholders must address clear-cut issues.
(Pahl-Wostl et al. 2007; Iaquinto et al. 2011)	2. Stakeholder interaction	Stakeholders within the group must have ongoing mutual engagement, interacting with one another and learning from each other.
	3. Capability of practice	There is a shared repertoire of resources developed amongst the stakeholder group, for example, lessons learned, rules of thumb, and standards. Stakeholders accumulate a set of shared knowledge.
	4. Identity of the stakeholder group	Stakeholders have shared practices and tangible products in order to generate an identity for itself, including a history and a body of shared knowledge that is different to that of individuals within the network.
	5. Limitations of the group	Stakeholders must have capacity to identify pertinent limitations, and be willing to make improvements.
	6. Recognition of coordinator	The coordinator of the stakeholder group must be well networked, and accepted within these networks. Pre-exiting networks can be used, with communication across teams and offices. Acceptance of any new stakeholders to the group is important, to broaden the network.
	7. Management support	Acquisition of high level management support is important, at pertinent levels within the adaptive process.
	8. Evaluation	There is a predetermined want to evaluate and learn during the networking process, where opportunities are openly presented and discussed, and there is accountability to various options chosen.
Social learning capacities	1. Understanding complexity	Stakeholders have a good understanding that the system under management is complex.
(Pahl-Wostl and Hare 2004; Pahl-Wostl et al. 2007, Cundill et al. 2011)	2. Awareness	Stakeholders have an awareness of each other's different goals and perspectives, and are willing to overcome these.
	3. Shared problems	Stakeholders have a common interest and vision. They jointly identify and agree on solutions to problems, and reflect on assumptions about the dynamics of the system.

Key step for social learning	Key criteria for social learning	Description of key criteria for social learning
	4. Interdependence	Stakeholders understand that they are interdependent. They recognize the value of sharing information, and respect one another by listening to each other's point of view.
	5. Cooperation	Stakeholders learn how to work together, and engage in collaborative decision making. They are willing to exchange ideas and are open to new ways of doing things. Initiatives are viewed as a new learning process by all involved.
	6. Trust and collective actions	There is engagement in a collective decision-making within a process of learning, for example within the development of new management strategies. Stakeholders perceive the decision-making process as open and fair.
	7. Informal interactions	An informal network of participants is required, who conduct regular meetings, where rules and arrangements of the network are not formally imposed. There is increased potential for self-organization, innovation and creative thinking if the networks are more autonomous and informal.
	8. Connections between institutions	The stakeholder networks established connect with all pertinent organizations, so that all organizations are included in the decision-making process. Good communication between all stakeholders involved is paramount, and stakeholders are informed about the issues, and their views and opinions are listened to.

2.5.3 Governance systems

To enhance societal learning potentials and opportunities within ANRM adaptability of governance structures must accompany the adaptability gained via the technical learning components (Herrfahrdt-Pahle 2013). Essentially, the technical solutions alone in natural resource management are often insufficient to tackle the complex problems managers face (Pahl-Wostl and Hare 2004; Pahl-Wostl 2007a). There must be recognition of the so-called “soft problems”, these include attitudes and institutions (rules and arrangements) within the process of natural resource management. Natural resource governance has been defined as the range of social, economic, political, and managerial systems in place to develop, provide and manage natural resources at diverse levels of social organization (Rogers and Hall 2003). There is an essential role performed by individuals and their social relations, with these social networks serving as the web that binds the adaptive governance system together (Folke et al. 2005). The notion of adaptation implies capacity to respond to change, and potential to convert, when applicable, social-ecological systems into improved states (Folke et al. 2005). Fundamentally, it is necessitated under an active adaptive management approach, where policy and its implementation are used as tools for accelerated learning in order to further structure a range of alternate management responses. This is in contrast to passive adaptive management defined as improving a single best policy from lessons learned over time (Pagan and Crase 2005).

Achieving adaptive institutional arrangements

To establish an ANRM system that can support double and/or triple-loop learning, four adaptive governance criteria are needed (Pahl-Wostl 2009; Pahl-Wostl et al. 2013) (Figure 2.1E) (Table 2.1). First, there must be an informal network of participants that conduct regular meetings, where the rules and arrangements (for example, who is included; the operational requirements; leadership) of the network are not formally imposed. Second, the mandate of this network must be open ended, and the results not formally binding straightaway. Third, the network of participants must deal with specific problems, and is open to experimentation involving different approaches (allowing for innovation). Fourth, the network has joint and shared practices (communities of practice, sensu Wenger 1998) and tangible products, in order to generate an identity for itself, that includes a history and a body of shared knowledge which is different to that of individuals within the network. Notably, there is increased ability

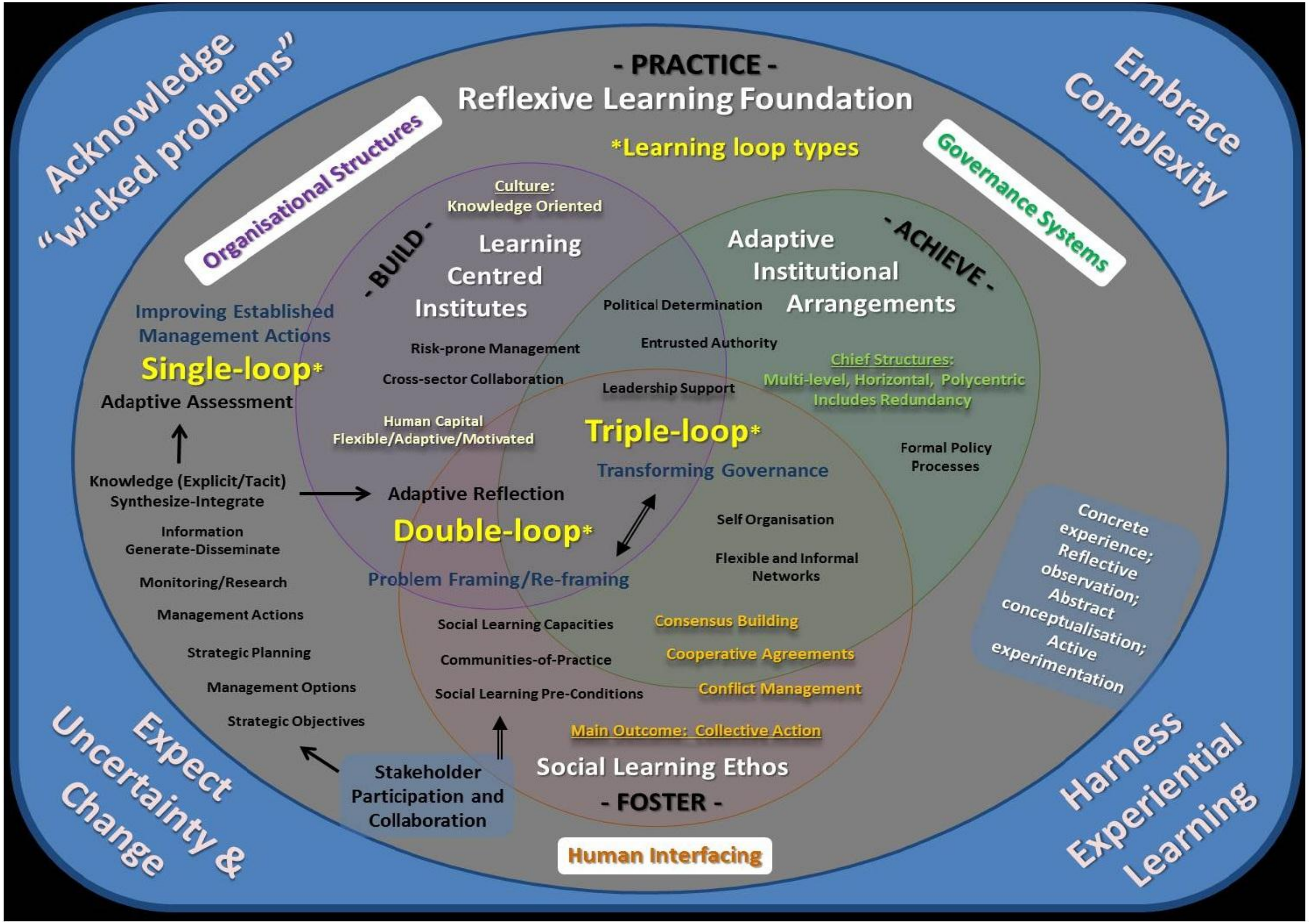

Figure 2.1E. The full and completed conceptual framework of adaptive natural resource management and its learning, indicating the place for adaptive institutional arrangements required for effective triple-loop learning, in combination with double-loop learning.

for self-organization if the social networks are more autonomous and informal. This self-organization promotes creative thinking and therefore, innovation within ANRM (Pahl-Wostl 2009).

The existence of multi-level, horizontal and polycentric governance structures (Ison 2010) within ANRM promotes achievement of the four criteria given above (Pahl-Wostl 2009) (Figure 2.1E). Here, decision making authority is distributed in a nested hierarchical form, rather than existing at one single governance level. These polycentric governance structures incorporate a higher ability to adapt to changing environments, because they are characterized by increased potential for individuals and groups to self-organize. In addition, the degree of redundancy within the polycentric and adaptive governance systems is key to maintain functionality in changing environments, which is similar to the role of diversity within ecological systems (Folke et al. 2005). Flexible network structures with informal networks are needed (Herrfahrdt-Pahle 2013) because these promote informal learning environments in which participants are more enthusiastic to leave any entrenched situation. However, Pahl-Wostl (2009) warn that the influence of these informal groups on policy and real implementation may be weak, therefore some closer links to formal policy processes is desirable to increase the effectiveness of learning.

2.6 Value of the coherent conceptual framework to practitioners of adaptive natural resource management

The value of the constructed conceptual framework (see Figure 2.1E) lies in its role as an integrator of the components required for learning-by-doing. It acts as a "one-stop-shop" for enhancing understanding about the learning-by-doing strategy for the practice of ANRM. Understanding is promoted via the method of framework development deployed in this manuscript, i.e. building in stages, hierarchically. Practicing effective ANRM using learning-by-doing is often compromised because under the pretense of practicing societal learning many practitioners remain trapped in the single-loop mode of learning (Pahl-Wostl 2009; Pahl-Wostl et al. 2011a). It is widely accepted that applying single-, double-, and triple-loop learning is difficult to achieve in practice (Pahl-Wostl et al. 2013; Fabricius and Cundill 2014), but this difficulty is exacerbated if reflexive (adaptive feedback system) learning is discounted because societal learning then lacks an efficient learning foundation to facilitate it. In addition, greater recognition by practitioners of the key enabling conditions for achieving societal learning is needed, to generate a healthier awareness about the intricacies involved with implementing societal learning within the learning-by-doing strategy. Notably, the conceptual framework’s main intention is to generate greater respect for the immense challenges involved in implementing ANRM, rather than offering a hasty solution to its practice. Within ANRM, more focus and effort is required in relation to moving beyond typical single-loop learning, but this requires recognition of the full repertoire of learning components associated with societal learning, for application within the learning-by-doing strategy.

The main strength of the conceptual framework developed in this manuscript lies in its exposure of important linkages between different societal learning components, thus demonstrating the complex strategy that is learning-by-doing. It is emphasized that societal learning is the central learning construct of the learning-by-doing strategy. Building a reflexive learning foundation of stakeholder networks and adaptive feedback systems is vital for facilitating societal learning and therefore must not be taken for granted within any ANRM system. However, a focus on pursuing further knowledge about the enabling conditions for societal learning in the context of ANRM practice (learning-centered institutes, social learning, and adaptive governance arrangements) means scholarly attention has inadvertently forsaken the core adaptive machinery of ANRM. This core machinery is the reflexive learning component. Although generating such knowledge is important for understanding problems with practicing societal learning, these enabling conditions are too often seen as the “end result” within ANRM rather than an important “means to an end” (Fabricius and Cundill 2014) of enabling societal learning for the achievement of objectives derived within ANRM.

The conceptual framework is not a manual for practicing ANRM. It deals with the “what” and “why” type questions associated with ANRM practice, rather than the more detailed “how-to” questions. The more detailed scholarship associated with the four learning components, as described in the conceptual framework, is available in the academic literature. Rogers et al. (2013) and Biggs et al. (2015) describe complexity and uncertainty within systems and how best to deal with this. Societal learning is adequately defined by Pahl-Wostl (2009), and the social learning component is covered extensively by Mostert et al. (2007); Ison and Watson (2007); Pahl-Wostl (2009) and Cundill et al. (2011). In addition, adaptive governance arrangements are explored by Folke et al. (2005), Gunderson and Light (2006), Pahl-Wostl

(2009) and Herrfahrdt-Pahle (2012). Stankey et al. (2005), Roux et al (2006), Fazey and Schultz (2009), Roux et al. (2010) and Stirzaker et al. (2011) provide details of learning centered organizations.

In conclusion, enabling conditions for societal learning are progressively realized over time and therefore must not be seen as an obstacle to commencing ANRM. The reflexive learning component of ANRM with its critical foundation role in facilitating societal learning, is an area of the learning-by doing strategy requiring further and more explicit research.

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	Author's Name (please print clearly)	**% of contribution**
Candidate	Craig A. McLoughlin	95 %
Other Authors	Martin C. Thoms	5 %

Name of Candidate: **Craig Anthony McLoughlin**

Name/title of Principal Supervisor: **Professor Martin Thoms**

[redacted]

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Candidate

Date

[redacted]

12/11/2015

Principal Supervisor

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Name of Candidate: **Craig Anthony McLoughlin**

Name/title of Principal Supervisor: **Professor Martin Thoms**

[redacted]

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Candidate Date

[redacted]

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Principal Supervisor Date

CHAPTER 3. INTEGRATIVE LEARNING FOR PRACTICING ADAPTIVE NATURAL RESOURCE MANAGEMENT

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Name of Candidate: **Craig Anthony McLoughlin**

Name/title of Principal Supervisor: **Professor Martin Thoms**

[redacted]

12/11/2015

Candidate

Date

[redacted]

12/11/2015

Principal Supervisor

Date

ABSTRACT. Adaptive natural resource management is a learning-by-doing approach to natural resource management. Its effective practice involves the activation, completion, and regeneration of the "adaptive management cycle" while working toward achieving a flexible set of collaboratively identified objectives. This iterative process requires application of single-, double-, and triple-loop learning, to strategically modify inputs, outputs, assumptions, and hypotheses linked to improving policies, management strategies, and actions, along with transforming governance. Obtaining an appropriate balance between these three modes of learning has been difficult to achieve in practice and building capacity in this area can be achieved through an emphasis on reflexive learning, by employing adaptive feedback systems. A heuristic reflexive learning framework for adaptive natural resource management is presented in this manuscript. It is built on the conceptual pillars of the following: stakeholder driven adaptive feedback systems; strategic adaptive management (SAM); and hierarchy theory. The SAM Reflexive Learning Framework (SRLF) emphasizes the types, roles, and transfer of information within a reflexive learning context. Its adaptive feedback systems enhance the facilitation of single-, double-, and triple-loop learning. Focus on the reflexive learning process is further fostered by streamlining objectives within and across all governance levels; incorporating multiple interlinked adaptive management cycles; having learning as an ongoing, nested process; recognizing when and where to employ the three-modes of learning; distinguishing initiating conditions for this learning; and contemplating practitioner mandates for this learning across governance levels. The SRLF is a key enabler for implementing the "adaptive management cycle," and thereby translating the theory of adaptive natural resource management into practice. It promotes the heuristics of adaptive management within a cohesive framework and its deployment guides adaptive natural resource management within and beyond typical single-loop learning, across all governance levels.

Key words: *Adaptive feedbacks, assessment, reflection; adaptive management cycle; objectives, targets, thresholds of potential concern; reflexive, single-, double-, triple-loop learning*

3.1 Introduction

Adaptive natural resource management (ANRM) is a learning-by-doing approach to managing natural resources (Allan and Stankey 2009, Walker and Salt 2012, Fabricius and Cundill 2014). It is heuristic in nature with continual updating. The practice of ANRM involves an “adaptive management cycle” (Greig et al. 2013, Pratt Miles 2013) consisting of a series of actions, characterized by feedback loops, with the deliberate intent of achieving a set of goals; through the modification and refinement of hypotheses, objectives, outputs/outcomes, and of management actions (Edwards 2002, Stankey et al. 2005). This iterative process is supported by strategic monitoring and feedbacks from the outcome of any decisions (Jiggins and Röling 2002, Allan and Stankey 2009). Thus, the adaptive management cycle is a process based on incremental, experiential learning. However, the effective translation of ANRM theory into practice is relatively elusive (Susskind et al. 2012, Rist et al. 2013*a*, Scarlett 2013, Westgate 2013, Williams and Brown 2014). Adaptive natural resource management has been described as confusing (Rist et al. 2013*b*), and protracted periods of transition in natural resource management exacerbate this confusion. In water resource management, for example, the theory of sustainable water resource management is relatively more advanced than its practice and capacities (skills, knowledge, and competencies) required to implement actual integrated and adaptive water management regimes (Pahl-Wostl 2008, Pahl-Wostl et al. 2011*a*). Nonetheless, traditional command-and-control styles of natural resource exploitation need to be replaced by ANRM to respond effectively and efficiently to ensure sustainable management in complex, uncertain, and changing environments (Rogers et al. 2000, Walker and Salt 2012).

The adaptive management cycle has three components: activation, completion, and regeneration. Effectively applying these components and promoting the linkages between them is critical for effective ANRM practice. The probability of successfully implementing this adaptive management cycle is greatly enhanced via three different modes of learning (Pahl-Wostl et al. 2013, Fabricius and Cundill 2014). This encompasses processes of “the doing” (single-loop), “changing practice” (double-loop), and “altering governance arrangements” (triple-loop), which is based on increasing time-scales for change (Pahl-Wostl 2009). The challenge for applying this collective three-mode learning is attaining an appropriate balance between the single-loop and double-loop learning modes and therefore avoiding the trap of “learning for the sake of learning” (Fabricius and Cundill 2014). In particular, the triple-loop mode of learning is important because if the structural contexts within resource governance regimes are too rigid, this can impede the “reframing” requirements of double-loop learning (Pahl-Wostl 2009). Critical enabling conditions associated with applying this collective three-mode learning have been considered within the broader context of ANRM. Adaptive governance arrangements have been explored by Folke et al. (2005), Gunderson and Light (2006), Pahl-Wostl (2009), and Herrfahrdt-Pahle (2013), knowledge sharing is highlighted by Roux et al. (2006) while Fazey and Schultz (2009) and Roux et al (2010) define the requirements for learning centered organizations. In addition, the importance of social learning processes have been emphasized by Mostert et al. (2007), Ison and Watson (2007), Pahl-Wostl (2009), and Cundill et al. (2012), and Rogers et al. (2013) highlight a complexity “frame of reference” for adaptive decision making. In practice, applying three-mode learning has been difficult to achieve (Pahl-Wostl et al. 2013, Fabricius and Cundill 2014) despite much research and identification of enabling conditions. As a result, many natural resource management regimes remain trapped in the single-loop mode of learning, by maintaining and improving established routines (Pahl-Wostl 2009, Pahl-Wostl et al. 2011*b*).

Achieving an appropriate balance between single-, double-, and triple-loop learning (termed here as three-mode learning) within an ANRM context is challenging. Reflexive learning can assist in building capacity in this area (Pahl-Wostl et al. 2007, Pollard and du Toit 2007, Fabricius and Cundill 2014). Reflexive learning is “learning from action,” with the deliberate intent to enhance the practice of management (Kolb 1984). According to Pollard and du Toit (2007), reflexive learning can be portrayed as a “feedback loop,” whereby actions are manipulated and/or modified via feedback from the context within which they were executed. Effective feedback systems have adaptive assessment and reflection routines (Biggs et al. 2011*a*), which require debate between all stakeholders. Strategic transfers of information aid this process within and between flexible, informal, and adaptive network systems (Pahl-Wostl 2009). Fundamentally, reflexive learning processes execute feedbacks for more immediate responses in ANRM, but also for the adaptive assessment and reflection routines. It is these responses and routines that facilitate three-mode learning. ANRM is an evolutionary process with many contemporary programs in the early pioneering phase (Fabricius and Cundill 2014), and because reflexive learning receives little explicit attention in adaptive management cycle frameworks/models, application of three-mode learning is often compromised. Thus, a greater emphasis and focus on reflexive learning is required to facilitate an appropriate balance between and use of single-, double-, and triple-loop learning. Achieving this balance would increase the feasibility of reflexive learning thus supporting and enhancing the ANRM adaptive management cycle.

Our aim is to outline a heuristic framework for the practice of ANRM, heuristic because it serves to promote further learning or discovery, and a framework that enables identification of common problems and solutions as well as appropriate variables and their descriptors (Jabareen 2009). A heuristic framework is a strategy that guides the search for information and in doing so allows for modifications to facilitate solutions. They are seen as being indispensable for integrative thinking and solving problems especially when logic and probability theory cannot provide solutions (Pickett et al. 1999). We focus on building a foundation of reflexive learning to facilitate an appropriate balance within three-mode learning that promotes the activation, completion, and regeneration components of the ANRM adaptive management cycle to achieve goals.

3.2 Three-mode learning

The three-mode learning process advocated here refines the concept of triple-loop learning, which influences governing variables in relation to initial assumptions and values (Pahl-Wostl 2009). Originating from management theory (Hargrove 2002) triple-loop learning builds on double-loop learning developed by Argyris and Schon (1978), increasing the time scales for change by considering the different management and governance levels that provide direction and stability in social contexts (Pahl-Wostl 2009). It differs from single-loop learning, which results in the incremental advances from action strategies, without questioning underlying assumptions (Pahl-Wostl 2009). Single-loop learning involves a continuation of, with concurrent improvements to, established practices and routines, in targeting the achievement of goals. In comparison, double-loop learning refers to a change in the actual frame of reference and includes a revisitation of the initial underlying assumptions of any action (Pahl-Wostl 2009). Social learning processes, building trust through cooperation and buy-in between stakeholders for example, are vital in double-loop learning (Pahl-Wostl 2009). The reframing process commonly occurs within stakeholder networks characterizing the resource governance regime and improvements are achieved by experimenting with innovative approaches. Stakeholders involved in double-loop learning normally explore reframing in the context of structural constraints of governance systems, such as regulatory frameworks.

Change in structural constraints is however, associated with triple-loop learning (Pahl-Wostl 2009). Triple-loop learning includes a transforming of the factors that determine the frame of reference, transformation of the entire governance regime itself (Pahl-Wostl 2009). This style of transformation necessitates an acknowledgment that paradigms and structural constraints inhibit effective reframing of resource governance and management practices. Hence, triple-loop learning implies a paradigm shift as well as changes in the norms and values underlying the processes of governance (Pahl-Wostl 2009). Here we view the three-mode learning process as incorporating single-loop, double-loop, and triple-loop learning.

Four criteria are required to establish a learning cycle that can support double- and/or triple-loop learning (Pahl-Wostl 2009, Pahl-Wostl et al. 2013). First, there must be an informal network of participants who conduct regular meetings. The rules and arrangements (for example, who is included, the operational requirements, leadership) of the network must not be formally imposed. Second, the mandate of this network must be open ended, and the results not formally binding straightaway. Third, the network of participants must deal with specific problems, and is open to experimentation involving different approaches (allowing for innovation). Fourth, the network has joint and shared practices (communities of practice, sensu Wenger 1998) and tangible products to generate an identity for itself, including a history and a body of shared knowledge that is different to that of individuals within the network. Notably, there is increased ability for self-organization, innovation, and creative thinking if the social networks are more autonomous and informal.

3.3 Conceptual pillars for building reflexive learning

Three conceptual pillars central to reflexive learning, are recognized in the Strategic adaptive management (SAM) Reflexive Learning Framework (SRLF).

3.3.1 Stakeholder driven adaptive feedback systems

The production of knowledge through policy and management actions, its dissemination to all stakeholders via feedback systems, and its actual use, are integral parts of adaptive management (Stankey et al. 2005). Both explicit (objective facts) and tacit knowledge (experiential) are important in the learning process of adaptive management. Individuals acquire their own tacit knowledge about the world, which can only be shared by common practice. Tacit knowledge is valuable because it contributes to innovation in adaptive management systems (Pahl-Wostl et al. 2007). The ability of stakeholder networks to use new information within shared social learning experiences is critical because it creates opportunities to facilitate collective action that emerges from the process of incorporating and synthesizing new knowledge (Pahl-Wostl et al. 2007, Pahl-Wostl et al. 2008). However, processes of sharing of new information and derived knowledge must be cognizant of the quality and types of communication systems in networks rather than just undertaking a synthesis of this information and knowledge. This can be aided by considering the appropriateness of institutional settings for processing information and subsequent knowledge (Pahl-Wostl et al. 2007). For example, using tools such as computer simulation programs ensure complex problems are explained in understandable ways to multiple stakeholders. Adaptive management requires that all knowledge is enacted, whether it is skill-based or attitudinal, as a result from shared experiences (Pahl-Wostl et al. 2007, Rogers et al. 2013).

The practice of ANRM involves sharing experiences, by improving the flow of information and ultimately better communication via feedbacks (see Stankey et al. 2005). Along with the more immediate responses in ANRM, deployments of feedback loops are required to drive the core routines of adaptive assessment and reflection. Assessment differs from reflection, with the former being to evaluate or estimate the nature, quality, ability, extent, or significance of something, whereas reflection is seen more as a calm, lengthy, intent-driven consideration (Biggs et al. 2011*a*). Both are important within ANRM, and when adaptive assessment and reflection operate together they generate a shared understanding among stakeholders (Biggs et al. 2011*a*). Implementing adaptive assessment and reflection routines help shape deliberations under adaptive management (Biggs et al. 2011*a*), which is also an important basis for facilitating three-mode learning under ANRM.

3.3.2 Strategic adaptive management (SAM)

SAM builds on ANRM by strengthening collaboration between stakeholders and enhancing feedback systems. The SAM framework provides the reflexive learning structure for the SRLF.

The SAM framework

The SAM framework consists of three adaptive phases (Pollard and du Toit 2007, Roux and Foxcroft 2011, Kingsford and Biggs 2012). First, the Adaptive Planning Phase commences with the development of a vision, formulated on the basis of an understanding about context and values of the system under management. The vision is achieved, ensuring stakeholder consensus, using the criteria of VSTEEP (values; social; technical; environmental; economic; political), through a process of identifying vital attributes of the system with their key determinants. The vision and vital attributes of the system informs the setting of objectives, the outcome of which is a cascading set of objectives and subobjectives known as the Objectives Hierarchy. The vision statement at the pinnacle of the Objectives Hierarchy is broken down into higher-level objectives that are essentially value-laden statements about the "desired future state" of the system under management. The systematic break down of these higher-level objectives into subobjectives, with increasing focus and rigor, culminates in developing Thresholds of Potential Concern (TPC). These are the explicit, measureable end-points that guide management and are used for assessing the achievement of the interlinked higher-level objectives. The Objectives Hierarchy is central to SAM focusing the research and management agenda within a set of agreed stakeholder objectives (van Wilgen and Biggs 2011), thus facilitating and guiding the Adaptive Implementation Phase of the SAM process.

The Adaptive Implementation Phase has several key components. These include scoping of management options to meet objectives, planning and operationalization of selected options, as well as developing and implementing monitoring to provide the necessary information for use within the Adaptive Evaluation Phase. Learning and adapting over time within the Adaptive Evaluation Phase occurs throughout the SAM process via a series of feedback loops (see Roux and Foxcroft 2011). In doing so it determines how well management interventions have worked in line with the objectives and ultimately the vision. Overall, the Adaptive Planning Phase of SAM sets up the Adaptive Implementation Phase (van Wilgen and Biggs 2011) and this is pivotal for executing feedback processes of the Adaptive Evaluation Phase. Experience of implementing SAM in various settings, has shown that progress is typically quicker within the Adaptive Planning Phase because it is relatively easier to get agreement on a desired future state across a range of value systems, than it is to implement the measures required to achieve this desired future state (van Wilgen and Biggs 2011). Hence, application of TPCs is critical for operationalizing the Adaptive Implementation Phase of SAM, and concurrently the Adaptive Evaluation Phase.

Thresholds of potential concern and feedbacks

Within the SAM framework, TPCs are typically "decision thresholds," seen as an optimization of both ecological (scientific/model-based) and utility (value/objectives-based) thresholds (see Fig. 3.1; Martin et al. 2009), rather than specific predicted ecosystem thresholds (Biggs et al. 2011*b*). The process of constructing TPCs identifies all pertinent drivers within a system as well as measurable response indicators of change related to these drivers. They also recognize the natural variability of these response indicators by incorporating upper and lower levels (thresholds) of acceptable change. Often, there are many TPCs required (and developed) when the SAM process commences, but the idea is to narrow this set down to have as few TPCs as possible, to monitor against for guiding management. This idea epitomizes a resilience style of thinking, and is based on the "requisite simplicity" principle, i.e., as simple as possible, but not too simple (Walker and Salt 2012). This is important because resources are typically scarce under adaptive management programs.

Implementing TPCs in SAM requires an existing understanding of the dynamics of the system under management. This understanding does not have to be complete. Development of TPCs lies along a continuum, from empirically well or fairly well understood, through an intermediate position informed by expert opinion, to an intelligent early guesswork or from a conceptual understanding of the system (Biggs et al. 2011*b*). When determining TPCs, there is often uncertainty as to whether a real threshold even exists, and if so where it lies exactly. Thus, TPC developers often become hesitant because they expect TPCs to deliver this certainty (Biggs et al. 2011*b*). Further hesitation is generated with an expectation that the process is linear, or believed not to have a clear threshold. Although detection of abrupt change is useful, within the TPC process it makes little practical difference if some TPCs happen to describe a linear process (Biggs et al. 2011*b*). Thus, TPCs are viewed as hypotheses of acceptable change and open to challenge and refinement, forming an inductive approach to adaptive management (Rogers and Biggs 1999, Biggs and Rogers 2003; see Fig. 3.1).

By using best available information to determine TPCs, SAM monitors trends and then mandates reflection on collaboratively identified goals before mutually agreed action is taken

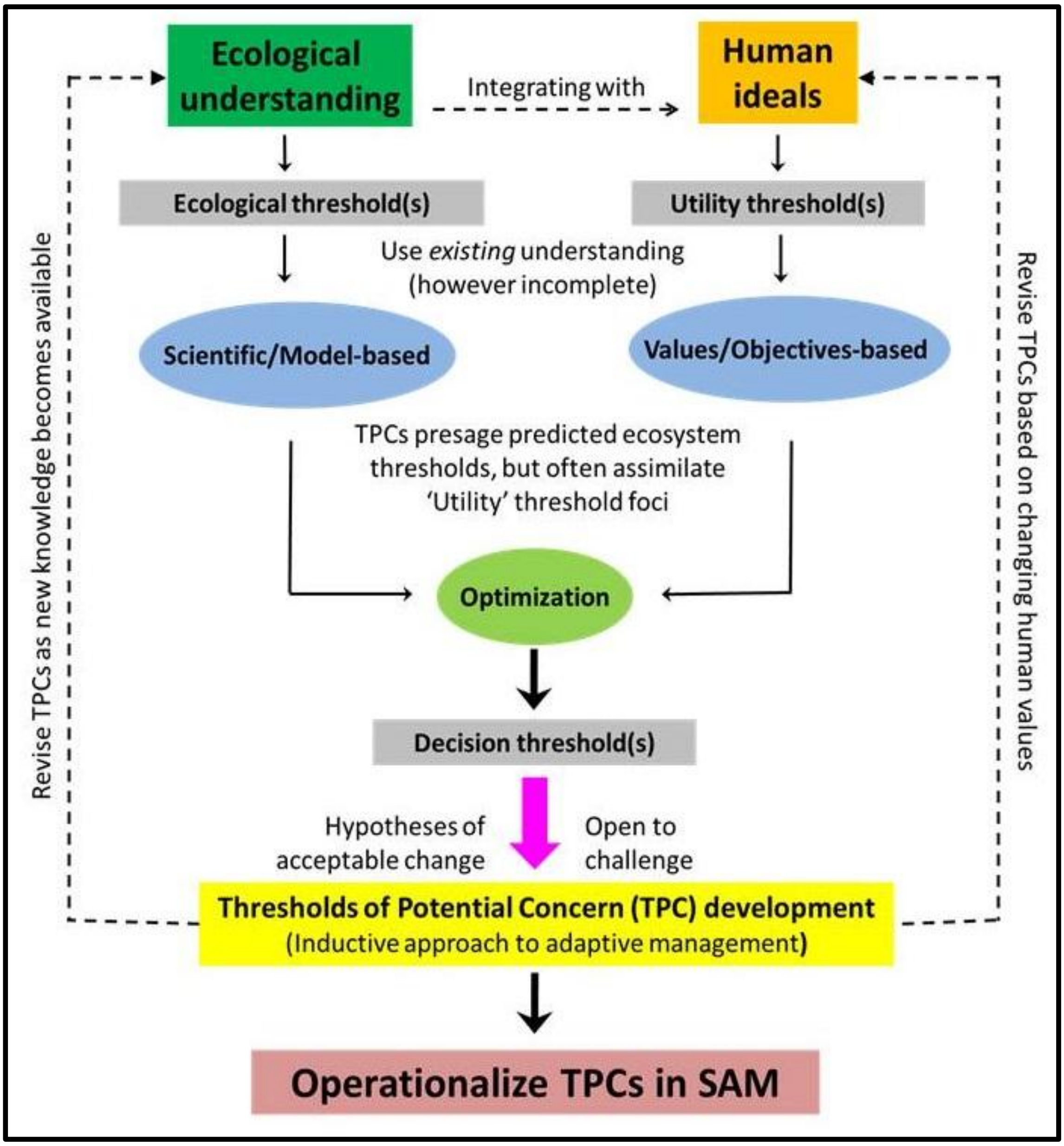

Figure. 3.1. Development of Thresholds of Potential Concern (TPCs) in strategic adaptive management (SAM) is an inductive approach to adaptive management. TPCs are hypotheses of acceptable change (in an indicator of interest) and open to challenge. Therefore, to implement the TPCs in SAM one only requires an existing understanding, however incomplete at the time, of the dynamics within a system under management. TPCs are often developed as "first generation TPCs," which then require revision over time as new knowledge becomes available, and/or based on changing human values. Although TPCs often presage predicted ecological thresholds (scientific/model based understanding in ecology), they often integrate with utility thresholds (values, objectives-based understanding associated with human ideals). Typically, developing TPCs in SAM involves an optimization of ecological and utility type thresholds, becoming decision thresholds. Adapted from Martin et al. (2009). *Ecological Applications:* A publication of the Ecological Society of America. Reproduced with permission of Ecological Society of America, in the format republish in a journal/magazine via Copyright Clearance Center.

(Pollard et al. 2011). Collectively, TPCs define the measurable component of the "desired future state" under SAM. This desired future state falls within the "tent boundary," formed by the collective of TPCs (or "targets" if system state is already outside the tent boundary; cf. Biggs et al. 2011*b*). The notion of TPCs under SAM is a "red-flag" concept, because TPCs are intended as an early warning system prior to the actual threshold (often theoretical) boundaries being reached. If and when TPCs are exceeded (known from monitoring, and/or modelling), this sets in motion a stakeholder driven process of investigation as to the reasons why, and possible management action necessary, or TPC revision. Importantly, without a monitoring program to allow auditing of the TPCs, the SAM process remains academic and un-implementable, because evaluating the outcomes of proposed management actions cannot be achieved (McLoughlin et al. 2011*a*). Monitoring can be resource expensive hence monitoring requirements of TPCs must be practicable, fast, affordable, and effective. As scientific understanding improves, and/or human values change, TPCs should be refined, if and when appropriate (see Fig. 3.1; McLoughlin et al. 2011*b*). However, management intervention may be required to avoid the system moving out of the tent boundary, or if the system is already outside of this boundary then for rehabilitation back. Therefore, development, use, and auditing of TPCs in SAM are important for providing feedback into research and management within an iterative, adaptive process. This functions to keep management strategically adaptive, rather than reactive (Rogers and Biggs 1999). Although the TPC concept, within the context of SAM, evolved within an ecological domain its principles have wider application especially in the economic and social domains (see Swemmer and Taljaard 2011).

3.3.3 Hierarchy theory

Hierarchy theory allows for the decomposition of a system into levels of organization, thereby forming a hierarchical structure (Ahl and Allen 1996). Each level of organization or holon is a separate entity whose character is constrained by those holons immediately above and influenced by those emerging from the level immediately below. Thus, levels within a hierarchy are not strictly independent of each other (Parsons and Thoms 2007). Hierarchical systems have three main properties. First, each level of organization has its own distinct spatial and temporal scales, so that higher levels have larger spatial and longer temporal scales and those at lower levels have smaller spatial and shorter temporal scales. Second, the frequency or rate of operation differs between each level of organization so that higher levels in a hierarchy have lower frequencies of behavior compared to lower levels. Third, higher levels of organization constrain lower levels because their larger entities have slower rates of processing information or frequency rates and therefore react more slowly than lower levels. Conversely, lower levels of organization are faster but smaller entities providing initiating conditions to upper levels. Lower levels within an organization influence those at higher levels through their faster rate flow of information and emerging properties. Hierarchy theory is applicable to systems with natural hierarchical structures and is appropriate for use in natural, public, and societal systems problems (Dollar et al. 2007), dealing with complexity.

Hierarchical concepts are common in many disciplines of study, with each organizing their subject of study into distinct hierarchical levels of organization. Fundamental to ecological understanding is the familiar hierarchical levels of organism, species, community, and ecosystem (Barrett et al. 1997). Although levels of organization are not scales (Petersen and Parker 1998), they operate in characteristic spatial and temporal domains and are used to stratify components within any system. For example, physiology and behavior are generally studied at the level of the individual, whereas species richness and diversity are studied at the community level and energy and nutrient fluxes are studied at the ecosystem level. Scale defines the physical dimension of an entity and Quinn and Keogh (2002) characterize scale in terms of grain and extent. Grain refers to the smallest spatial or temporal interval in an observation set and has also been referred as the smallest scale or pattern to which an organism may respond (O'Neill et al. 1989) or the smallest scale of influence of an ecosystem disturbance or process driver (Rogers 2003). Extent is the total area or duration over which observations are made, the largest pattern to which an organism responds (that is, the habitats used by a fish or the time over which a given habitat is used), or the largest scale at which a disturbance or process driver exerts influence on the system. Therefore, grain and extent define the upper and lower limits of resolution in the description of a level of organization of an ecosystem. Assigning a scale to a hierarchical level of organization provides contextual meaning and more importantly it determines the variables and units of measure that can be associated with each level of a particular hierarchy.

Hierarchical translations within interdisciplinary areas of study are becoming more common (Thoms and Parsons 2002). The frameworks of Thoms and Parsons (2002) and Dollar et al. (2007) provide examples of how individual disciplinary (or subsystem) hierarchical structures use scale as the currency for linking between disciplines. Recognition of spatial and temporal scales inherent to the levels of organization of a disciplinary hierarchy makes integration of multiple subsystems possible (Dollar et al. 2007). Integration of scales allows researchers and managers to ask appropriate questions through recognition that there are causal linkages across different disciplines or organizations. There are four steps in the application of the frameworks put forward by Thoms and Parsons (2002) and Dollar et al. (2007). The first step requires identification of various subsystems and the second focuses on describing the relevant levels of organization that characterize the different subsystems in the context of the issue/problem being addressed. The third step involves the identification of appropriate scales and variables within the different organizational levels and step four describes the process interactions between appropriately identified subsystem components. Overall, hierarchy theory provides a valuable mechanism for investigators to disentangle system complexity, improving our understanding and thinking through complex problems. Hierarchy theory is important in building the SRLF because it allows the “multiscale” requisites of reflexive learning across all governance levels that are coupled with three-mode learning.

3.4 The SAM Reflexive Learning Framework

The SRLF has a nested hierarchical structure with three levels of organization within the ANRM governance (Fig. 3.2). Adaptive water resource management in South Africa for example, may recognize the national boundary as the SRLF Level-1, and nested within this are a number of water management areas, the SRLF Level-2, of which there are 19 demarcated water management areas. Nested within each water management area are individual river catchments for ANRM implementation at SRLF Level-3. The SRLF is designed to facilitate three-mode learning within each level of organization as well as providing the linkages between these levels. It is also dependent on relative rather than absolute scales (Kotliar and Wiens 1990) of governance thereby making the SRLF applicable for any hierarchical structure, from global, national, or basin levels of organization and from regional to local levels of organization. At any given spatial scale of application, more than three levels of ANRM governance may be utilized through the nominated scale, if deemed necessary.

3.4.1 SAM reflexive learning framework structure and function

A strategic trait of SRLF is the development of a multilayered set of objectives that cascades through all three SRLF governance levels (see Fig. 3.2). Learning adaptively, toward achieving these scaled objectives is the main focus of SRLF. Objectives setting commences with a visioning process at Level-1, resulting in development of an overall Vision statement. The relevant content derived in the Vision statement is decomposed into a series of higher-level objectives specific to Level-1 that are differentiated according to themes (Fig. 3.2). Themes depend on the Vision statement and may include Environment, Economic, and Community/Social. There are a set of "policy targets" for each theme, for example, increase biodiversity in freshwater systems of South Africa, emanating from the higher-objectives and these depict the end-point goals at Level-1 (Fig. 3.2). Within the SRLF, policy targets are then decomposed into a set of subobjectives at Level-2 that are characterized by increasing focus and rigor. Specification of "management targets," for example, restore percentages of river habitat types in the Inkomati Water Management Area, represents the end-point goals of the subobjectives at Level-2; and this is also done for each theme (Fig. 3.2). Subsequently, management targets are further decomposed into the subobjectives at Level-3. At this level of organization they culminate in the Thresholds of Potential Concern (TPC), for example, bedrock-influenced river habitat type coverage is 20 percent or less in rivers of the Crocodile River Catchment, as the explicit end-point goals of the subobjectives at this level of organization (Fig. 3.2). This hierarchical approach to the setting of objectives within the SRLF has the advantage of providing practitioners, operating at different SRLF levels, the opportunity to pinpoint pertinent end-point goals and the appropriate scales in which to implement ANRM processes that are feasible to achieve these end-point goals, and associated objectives.

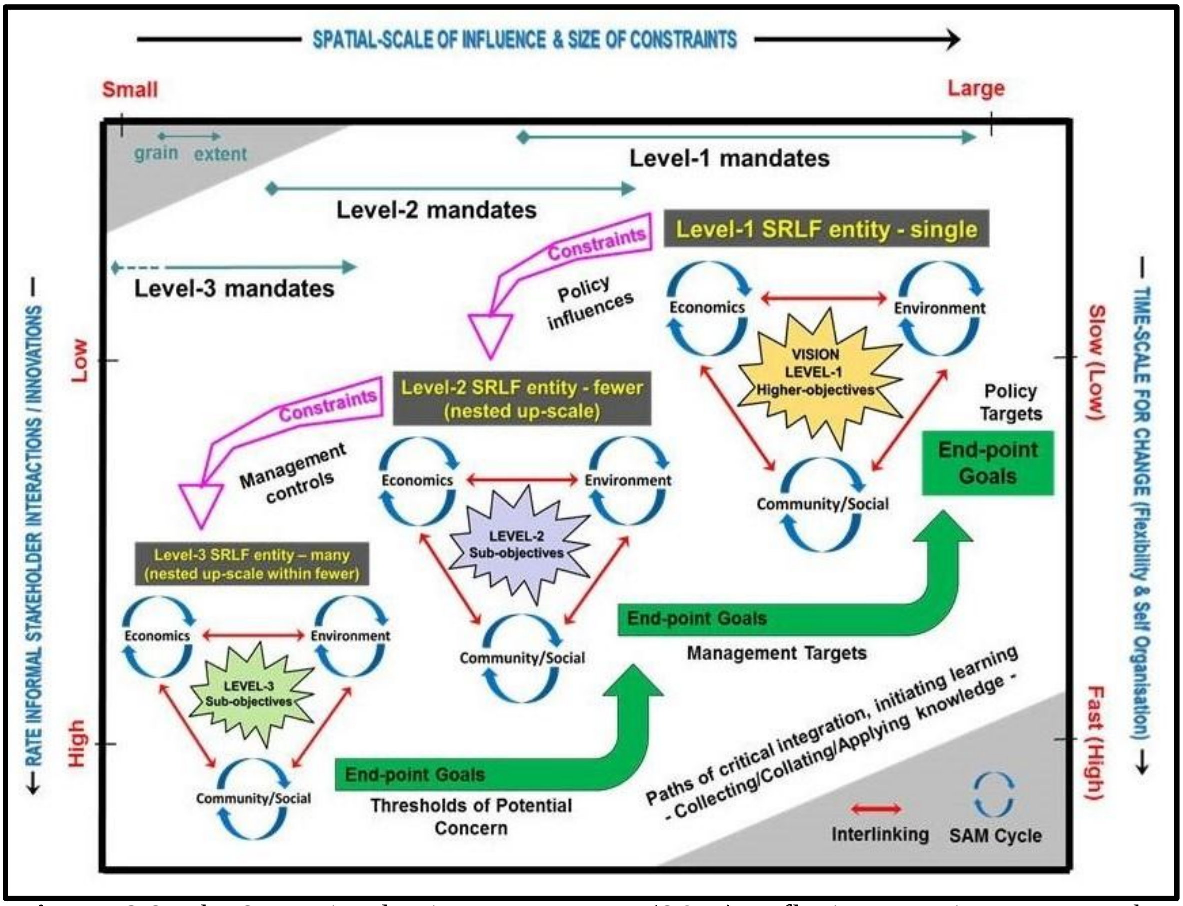

Figure. 3.2. The Strategic adaptive management (SAM) Reflexive Learning Framework (SRLF) exhibits a nested, hierarchical structure, across three levels of governance. A SRLF entity comprises interlinked SAM cycles for the Environment, Economic, and Community/Social themes. Typically, there are many Level-3 entities nested within fewer parent Level-2 entities, and these all nest within the single Level-1 entity. The Vision statement, derived at Level-1, is broken down into the Higher-objectives (per theme) at Level-1. These Higher-objectives culminate in Policy Targets at Level-1. Policy Targets cascade down into more detailed Level-2 Subobjectives, culminating in Management Targets at Level-2. Management Targets cascade down into finer detailed Level-3 Subobjectives, culminating in Thresholds of Potential Concern (TPCs) at Level-3. “Top-down” processes in SRLF include policy influences that constrain the types of Level-2 management approaches allowed. In turn, management approaches selected control the types of Level-3 actions required. The main “bottom-up” process involves learning. Learning is initiated primarily during the TPC feedback processes occurring within Level-3 entities. Information/knowledge is collated up to parent Level-2 entities to inform the Management Targets; similarly information and knowledge is collated up to the parent Level-1 entity to inform Policy Targets. Functional attributes pertaining to SRLF entities vary dependent on governance level. This is demonstrated along three axes: the spatial scale of influence and size of constraints imposed on SRLF practitioners and stakeholders; the rate of stakeholder interaction, including development of critical innovations for change; and the time-scale for change, related to the degree of flexibility and self-organization inherent in the stakeholder forums. Additionally, practitioner mandates are defined across the governance levels, represented conceptually by hierarchy “grain” and “extent.” This differentiates practitioner responsibilities and accountabilities (spatially) for applying SAM cycle processes, per level of SRLF.

The SRLF entity

The SRLF entity is defined as a group of interlinked SAM cycles; one for each theme, Environment, Economic, and Community/Social (Fig. 3.2). SRLF entities occur at each level of organization and work collectively toward achieving their determined objectives at the particular SRLF level. With the hierarchical structure of SRLF there will be many small-scale Level-3 SRLF entities that nest under a parent Level-2 SRLF entity, and the fewer number of Level-2 SRLF entities all nest under one large-scale Level-1 SRLF entity (Fig. 3.2). Information flows, through adaptive feedbacks facilitating three-mode learning potentials, must be executed within all SAM cycles to activate, complete, and then regenerate the SAM cycles within SRLF entities. SAM cycles contained within the SRLF entities are required to be interlinked (see Fig. 3.2) because it is widely accepted that ecological, economic, and social systems are inextricably bound (Folke et al. 2005, Walker and Salt 2012). Thus, when considering intervention strategies to meet the agreed objectives and end-point goals for each theme the intervention paths chosen for a particular SAM cycle must be formulated in conjunction with any potential impacts on SAM cycles of the other themes. Therefore, to meet the full range of objectives at each level of organization in the SRLF it is crucial that SAM cycles comprising a SRLF entity are both interdependent and are operating in tandem with each other (Fig. 3.2). Overall, these SAM cycles give effect to the practice of ANRM under SRLF.

SRLF entity: attributes across SRLF levels

SRLF entities vary across the three SRLF levels of organization, defined along three axes according to specific functional attributes (Fig. 3.2). First, the Spatial-scale of Influence and Size of Constraints, the Level-1 SRLF entity, has the largest jurisdiction and influence over ANRM implementation. However, the largest constraints are imposed on implementing ANRM at Level-1, relative to the other levels. For example, more rigid governance arrangements will negatively impact change potentials at Level-1. Second, the Rate of Informal Stakeholder Interactions / Innovations, the scale of informal relationships and stakeholder interactions, is highest within Level-3 SRLF entities, diminishing through Level-2 to Level-1 SRLF entities. Thus, elevated potentials for learning occur at Level-3, compared to the two higher SRLF levels, because learning is fostered in the less formal structures (Pahl-Wostl et al. 2013) where social learning is nurtured (Pahl-Wostl 2009). Third, the Time-scale for Change (Flexibility and Self-Organization), faster scales of adaptability, occur within Level-3 SRLF entities. This results from quicker stakeholder response times due to higher flexibility and self-organization of ANRM stakeholders at Level-3, enhancing learning potentials (Pahl-Wostl et al. 2013). Thus, there is increasing potential for ANRM realization, because of escalating amounts of flexibility in governance arrangements associated with Level-2 going into Level-3 SRLF entities, which is more conducive to change. A decreasing scale of flexibility in governance arrangements, occurring within SRLF entities of Level-2 up to the Level-1 entity, produces slower response times in these entities, thus increasingly longer time steps are required for change.

ARM practitioner "grain" and "extent" across SRLF levels

Adaptive natural resource management practitioners, for example, agricultural and environmental consortia, and civil society, operating at the SRLF Level-1 assume the largest scale of geographical influence (extent) over ANRM implementation (Fig. 3.2). These practitioners deal primarily with policy development and implementation, which is linked to meeting the predetermined policy targets. They oversee adaptive processes occurring within the Level-1 SRLF entity and in order to evaluate policy targets they must also administer and collate information emanating from all SRLF entities at Level-2. Thus, Level-2 is effectively the grain for these ANRM practitioners, who have no direct mandate at lower levels (Fig. 3.2). Adaptive natural resource management practitioners operating at Level-2, for example, catchment management agencies, and Level-3, for example, catchment forums including local authorities, communities, and researchers, have diminishing scales of geographical influence (extent) under ANRM (Fig. 3.2). Level-2 ANRM practitioners are primarily responsible for determining and achieving management targets linked to higher-level policy, by implementing suitable management approaches and they must oversee adaptive processes occurring within the Level-2 SRLF entities. To evaluate management targets they must also administer and collate information emanating from all nested SRLF entities at Level-3. Thus, Level-3 is effectively the grain for these ANRM practitioners, who have no direct mandate at lower sublevels (Fig. 3.2). Level-3 ANRM practitioners are responsible for action on-the-ground, to achieve the TPCs linked to higher level management, and must implement detailed adaptive management processes within the Level-3 SRLF entities, but at pertinent nested sublevels too. Thus, detailed sub-Level-3 areas become the grain for these ANRM practitioners (Fig. 3.2), who may not distinguish any further ANRM mandate, although smaller areas may exist, under SRLF.

Vertical linkages across SRLF levels

There is a top-down link in SRLF, and this is molded by societal values that emerge during the visioning process at SRLF Level-1. Policy targets, as the detailed end-point goals at Level-1 shape policies derived at Level-1. Ultimately, this influences and constrains management within nested Level-2 entities because management targets as end-point goals at Level-2 are ultimately derivatives of specific policy targets determined, and policies impact the types of Level-2 management approaches allowed (Fig. 3.2). Management targets at SRLF Level-2 determine types of TPCs required at Level-3, and management approaches selected at Level-2 then control and constrain actions pertinent for the nested Level-3 entities (Fig. 3.2). There is also a bottom-up link that ensures a critical path characterized by integration and learning (Fig. 3.2). Here, information and derived knowledge from Level-3 SRLF entities, where learning potentials are highest, acquired within the TPC process, are collated at higher levels of organization through feedback loops into parent SRLF Level-2 entities. This occurs in order for consolidation and learning at this level to meet the management targets, and is done so in all Level-2 SRLF entities consolidating into the one Level-1 SRLF entity to inform policy implementation outcomes. This bottom-up process facilitates decision making and learning across all SRLF levels to meet the complete hierarchy of objectives in SRLF, and ultimately the derived Vision at Level-1.

The generic vertical structure of SRLF exhibits a nested pattern of SAM cycles distributed across the three levels of organization, and these levels differentiate the types of interventions required to meet different end-point goal types (see Fig. 3.3). For pragmatic implementation considerations, this nested distribution of SAM cycles is applied separately to each theme, Environment, Economic, Community/Social. The Environment theme, for example, has many Level-3 SAM cycles nested within and overseen by fewer Level-2 SAM cycles (Fig. 3.3). Similarly, these Level-2 SAM cycles are nested within and are overseen by the single Level-1 SAM cycle (Fig. 3.3). The objectives applicable to the Environment theme are cascaded downward through all levels of the SRLF with increased focus and rigor (Fig. 3.3), for application within these SAM cycles.

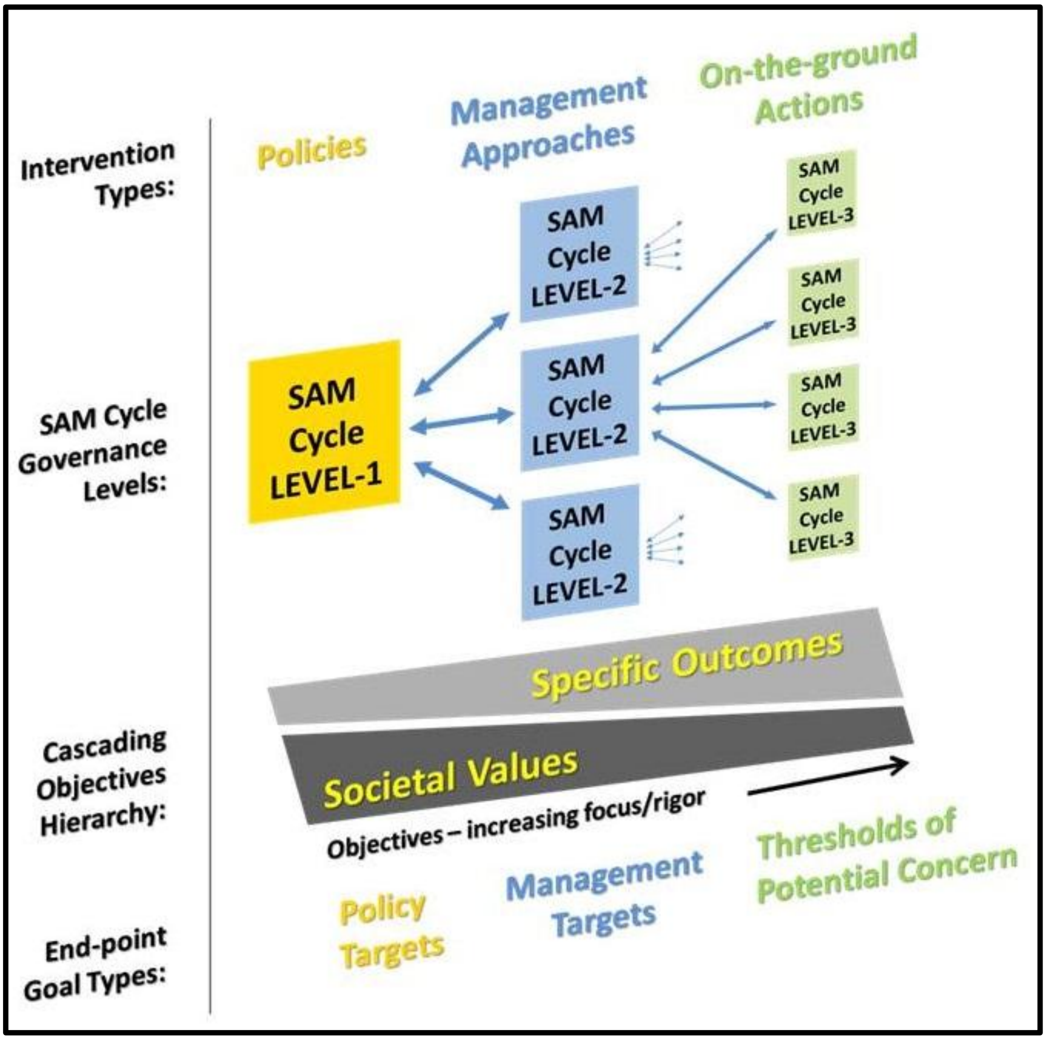

Figure. 3.3. The nested distribution pattern of strategic adaptive management (SAM) cycles across governance Level-1, Level-2, and Level-3 of the SAM Reflexive Learning Framework (SRLF), applicable to each SRLF entity theme (Environment, Economic, and Community/Social). Intervention type, governance level, spread of Objectives, and End-point Goal types are also indicated. Notably, there is increasing focus and rigor of the Objectives from Level-1, through Level-2 into Level-3, characterized by a decrease in societal values and an increase in detail of the end-point goal outcomes. Arrows (blue) between governance levels represent critical vertical feedbacks required in SRLF ("top-down" and "bottom-up").

SAM cycle: horizontal structure per SRLF level

The SAM cycle of the SRLF entity is based on the model developed by McLoughlin et al. (2011*a*). The SAM cycle is iterative, with a distinct arrangement of adaptive phases and components applied to each theme of the SRLF entity. The SAM cycle horizontal structure is applicable at each level of organization within the SRLF, and consists of two phases: (1) Adaptive Planning, composed of two adaptive components (represented in the black boxes in Fig. 3.4); the first represents development of the objectives, corresponding to the particular level; the second represents development of the detailed end-point goals culminating at the base of these objectives; and (2) Adaptive Implementation, composed of five adaptive components (represented in the grey boxes in Fig. 3.4). This includes processes of selecting the best intervention options to meet the developed end-point goals; determining inputs for planning, associated with meeting end-point goals; operationalizing inputs via implementation of the plans; checking adequacy of plan implementation by swift response to operational outputs; assessing suitability of the operational outputs by auditing strategic outcomes, against end-point goals; and testing achievement of the broader objectives applicable at each SRLF level.

The starting position and direction of the SAM cycle is given in Figure 3.4 and is applicable to subsequent iterations of the SAM cycle. Details relevant to each adaptive component of the Adaptive Planning Phase and Adaptive Implementation Phase of the SAM cycle, across SRLF levels, are given in Table 3.1. SAM cycle phases and components are standard across all SRLF levels, although key differences are dictated by objective and end-point goal determination at each level. Additionally, the type of intervention to achieve the objectives and end-point goals varies according to the particular SRLF level, for instance policy, management, and action related interventions at Level-1, Level-2, and Level-3, respectively (see Table 3.1). The adaptive phases and components of the SAM cycle at each SRLF level sanction strategic feedbacks for guiding three-mode learning, by facilitating an appropriate balance between the modes of single-, double-, and triple-loop learning.

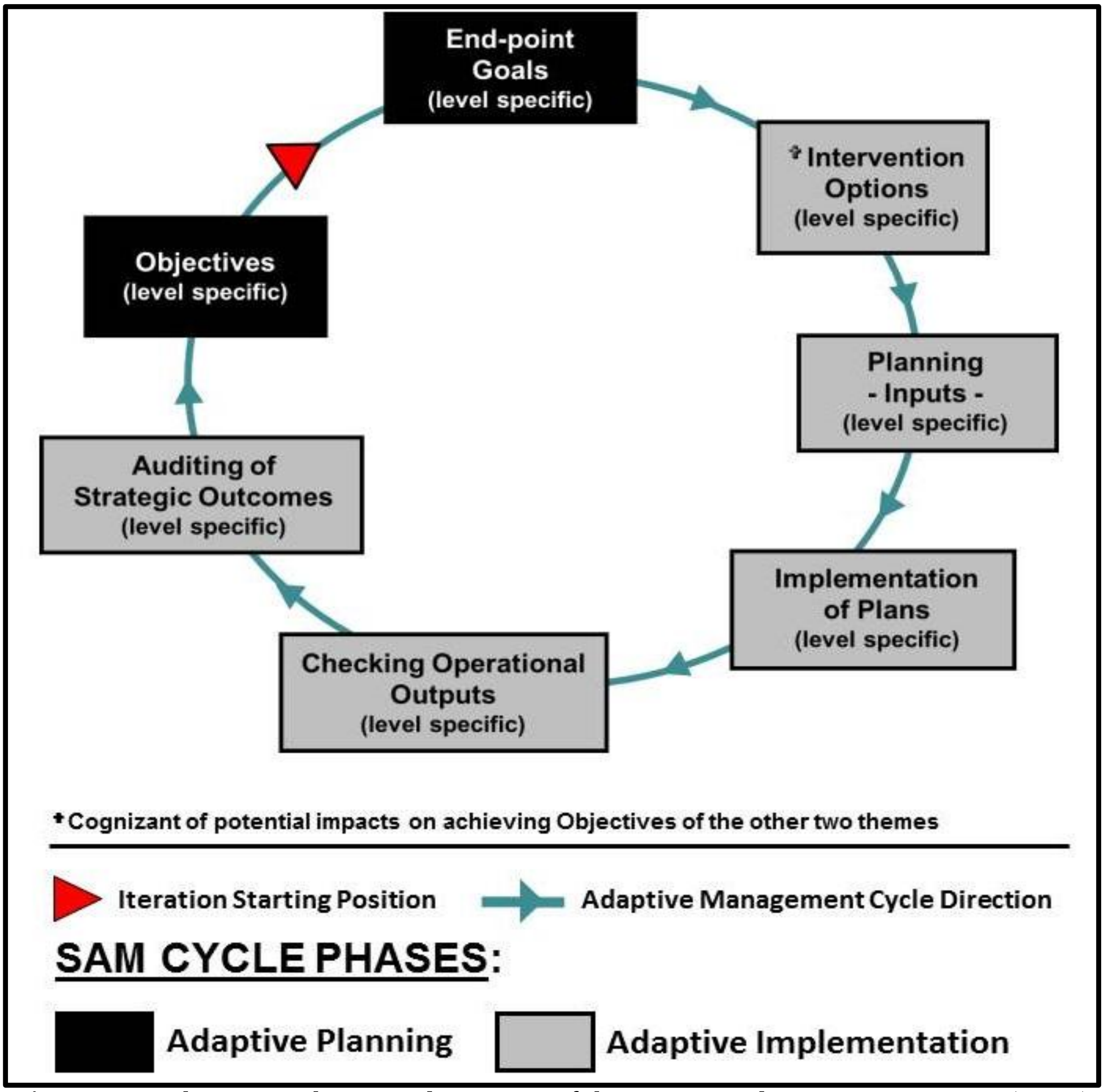

Figure. 3.4. The generic horizontal structure of the strategic adaptive management (SAM) cycle used within the SAM Reflexive Learning Framework (SRLF) entities. Two components of the SAM Adaptive Planning Phase and five components of the Adaptive Implementation Phase are given. Determining the Objectives and associated End-point Goals commences the SAM cycle process, in the clock-wise direction. Importantly, in determining "Intervention Options" for one particular theme, there must be cognizance of potential impacts on achieving objectives linked to the other two themes. This generic SAM cycle horizontal structure is used at SRLF Level-1, Level-2, and Level-3 as detailed in Table 3.1.

Table 3.1. Processes associated with components of the Adaptive Planning and Adaptive Implementation phases of the strategic adaptive management (SAM) cycle used in the SAM Reflexive Learning Framework (SRLF), applicable to SRLF Level-1, Level-2, and Level-3.

Adaptive Planning Phase		Adaptive Implementation Phase				
Objectives	End-point Goals	Intervention Options	Planning - Inputs -	Implementation of Plans	Checking Operational Outputs	Auditing of Strategic Outcomes
Governance Level-1: Higher-objectives within the SAM Reflexive Learning Framework, emanating from the overall Vision statement.	Governance Level-1: Policy Targets, as broader end-points of the Level-1 Higher-objectives.	Governance Level-1: Best Policies, expected to allow for meeting of the Policy Targets.	Governance Level-1: Broad Planning documents, incorporating inputs necessary for implementation of Policies across nested Level-2 entities.	Governance Level-1: Operationalizing inputs given in the planning documents at Level-1.	Governance Level-1: Checking implementation of Level-1 plans. Collating operational information from across nested Level-2 entities.	Governance Level-1: Collation/synthesis of all monitoring data/information, emanating from across nested Level-2 entities, associated with auditing against the Policy Targets.
Governance Level-2: Sub-objectives, increasing focus and rigor, cascaded down from Level-1.	Governance Level-2: Management Targets, as more detailed end-points of the Level-2 Sub-objectives.	Governance Level-2: Appropriate Management approaches, expected to allow for meeting of the Management	Governance Level-2: Detailed Planning documents, incorporating inputs necessary for implementation of Management approaches across	Governance Level-2: Operationalizing inputs given in the planning documents at Level-2.	Governance Level-2: Checking implementation of Level-2 plans. Collating operational information from across	Governance Level-2: Collation/synthesis of all monitoring data/information, emanating from across nested Level-3 entities, associated with auditing against

Adaptive Planning Phase		Adaptive Implementation Phase				
Objectives	End-point Goals	Intervention Options	Planning - Inputs -	Implementation of Plans	Checking Operational Outputs	Auditing of Strategic Outcomes
		Targets.	nested Level-3 entities.		nested Level-3 entities.	the Management Targets.
Governance Level-3: Detailed Sub-objectives, well-developed focus, cascaded down from Level-2.	Governance Level-3: Thresholds of Potential Concern (TPC), as finely detailed, explicit end-points of the Level-3 Sub-objectives.	Governance Level-3: Pertinent Actions 'on the ground', expected to allow for meeting of the TPCs.	Governance Level-3: Highly detailed Planning documents, incorporating inputs necessary for implementation of Actions, within Level-3 entities.	Governance Level-3: Operationalizing inputs given in the planning documents at Level-3.	Governance Level-3: Checking implementation of Level-3 plans. Collating operational information from within Level-3 entities.	Governance Level-3: Collation/synthesis of all monitoring data/information, emanating from within Level-3 entities, associated with auditing against the TPCs.

3.4.2 SAM cycle feedbacks facilitating three-mode learning

Horizontal adaptive feedbacks within SRLF levels

There are two kinds of nested learning potentials facilitated by reflexive learning within the generic SAM cycle, namely Adaptive Learning and Transformational Learning (Pahl-Wostl et al. 2013; see Fig. 3.5). The Adaptive Learning component includes both single- and double-loop learning. There are two grades of feedbacks to facilitate single-loop learning, including "lower" (red, thin/solid arrows) that give rise to the more immediate responses in ARM, to check if the operational inputs are being implemented correctly, that is achieving the intended output results; and "upper" (blue, hashed arrows) that give rise to adaptive assessment routines, auditing strategic outcomes against the end-point goal benchmarks. Feedbacks for double-loop learning (green, dotted arrows) give rise to adaptive reflection routines, which evaluate achievement of the broader objectives within the SAM cycle (with consideration of any surprises), and there is potential for reframing end-point goals and existing planning inputs. Feedbacks for triple-loop learning (pink, thick/solid arrows) allow adaptive reflection into a holistic review process of all objectives and end-point goals. This reflection and review process promotes Transformational Learning and is combined with a reconsideration of underlying values, for adapting governance systems and the effective regeneration of the SAM cycle.

Three-mode learning within each SAM cycle is an ongoing process, nested over increasing time-scales for change (Table 3.2). Key attributes and processes particular to the single-, double-, and triple-loop modes of learning are defined in Table 3.2, for each SRLF level.

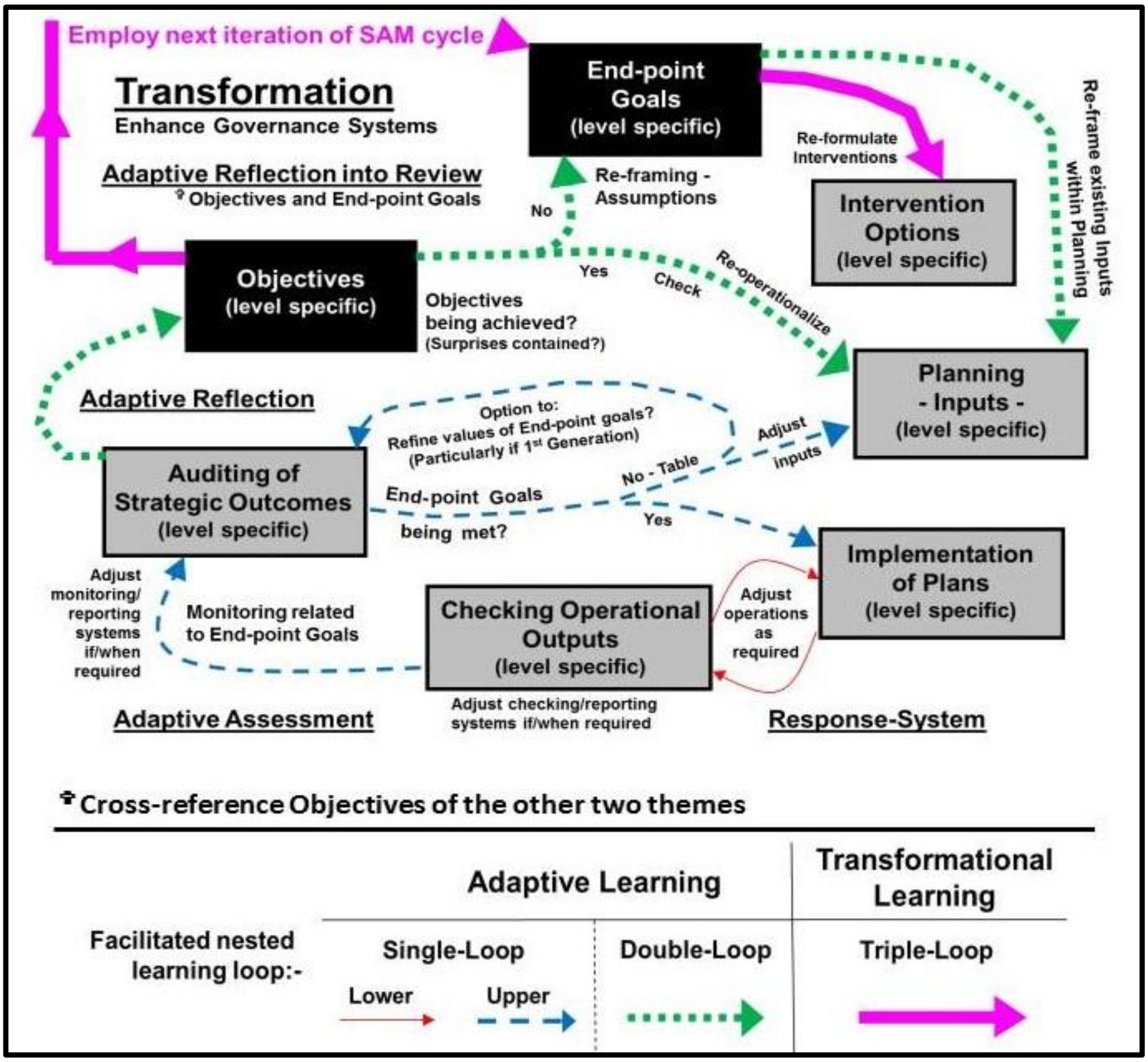

Figure. 3.5. The learning process is not linear in the Strategic adaptive management (SAM) Reflexive Learning Framework (SRLF). SRLF uses a nested set of generic adaptive feedbacks within each SAM cycle, and this is applied at SRLF Level-1, Level-2, and Level-3 as described in Table 3.2. These feedbacks occur simultaneously but over increasing time-scales for change, by providing potential for both Adaptive and Transformational learning (vis-à-vis Pahl-Wostl et al. 2013). This is given effect by facilitation of three-mode learning, in relation to meeting Objectives and associated End-point Goals, which allows for activation, completion, and regeneration of the SAM cycle. Specifically, by allowing for more immediate responses to check operational outputs (red, solid arrows); adaptive assessment, to audit strategic outcomes against End-point Goals (blue, hashed arrows); adaptive reflection, to test achievement of the Objectives (considering any surprises; green, dotted arrows); and review, a holistic revision of the Objectives and associated End-point Goals, with transformation of governance arrangements to improve application of the SAM cycle (pink, thick solid arrows). It is important that when reviewing Objectives and associated End-point-Goals for one particular theme, there is cross-reference to the other two themes where pertinent. For comparison, hypothetical time-scales for learning loop types within the SAM cycle, at different governance levels in SRLF, are: Level-1 > 3-5 years (single-loop, lower), 5-8 years (single-loop, upper), 8-10 years (double-loop), and 10-15 years (triple-loop); Level-2 > 1-3 years (single-loop, lower), 3-6 years (single-loop, upper), 6-8 years (double-loop), and 8-10 years (triple-loop); Level-3 > daily/weekly (single-loop, lower), 1-3 years (single-loop, upper), 3-5 years (double-loop), and 5-6 years (triple-loop).

Table 3.2. Learning potentials in the Strategic adaptive management (SAM) Reflexive Learning Framework (SRLF). A functional description of the SAM cycle nested feedback system, demonstrating explicitly where and when to implement more immediate responses, adaptive assessment, adaptive reflection, and review with governance transformation. These feedbacks facilitate and guide single-, double-, and triple-loop learning in the SRLF, ultimately for activating, completing, and then regenerating the SAM cycles.

Adaptive Learning Potential			**Transformational Learning Potential**
Single-loop Learning Facilitation		**Double-loop Learning Facilitation**	**Triple-loop Learning Facilitation**
Lower Sub-loop	**Upper Sub-loop**		
Response-System Feedbacks	**Adaptive Assessment Feedbacks**	**Adaptive Reflection Feedbacks**	**Adaptive Reflection into Review, with Governance Transformation**
<u>At all governance levels</u>: Implementation of planning ‘inputs’, linked to intervention options selected, must be tested to check if (a) the planning ‘inputs’ were implemented as intended, and (b) the desired ‘output’ results did actually occur.	<u>At all governance levels</u>: ‘Strategic outcomes’ are audited against End-point Goals to test if these are being met. If not, then this is tabled. Adjusting existing planning ‘inputs’ must be considered, and or an option to revise specific values of End-point Goals.	<u>At all governance levels</u>: Auditing of ‘strategic outcomes’ is not an end in itself. A lengthy intent driven consideration (reflection) of Objectives is necessary. If these Objectives are not being met, then re-framing of End-point Goals is necessary,	<u>At all governance levels</u>: Reviewing all Objectives, including End-point Goals is necessitated because human values change over time. New knowledge acquired must also be incorporated back into the SAM cycle process. Re-consideration of governance at each level is important. This

Adaptive Learning Potential			Transformational Learning Potential
A Response-System is employed during operationalization of the 'inputs'. To adjust operations timeously in order to achieve the intended 'outputs' Adjustment of checking/reporting systems is done if/when required.	Re-implementation of the adjusted inputs is required. Adjustment of monitoring/reporting systems is done if/when required.	using acquired knowledge. Occurrence of surprises (i.e. unexpected outcomes) must be evaluated, in order to learn from these events (e.g. a related, but unexpected decline in a species of concern other than the indicator species). Re-framing, involving an in-depth re-thinking of planning 'inputs', is also necessitated. The revised 'inputs' must be implemented, in order to achieve the newly developed End-point Goals.	facilitates 'institutional arrangement' transformation, in order to improve application of the SAM cycle. Re-thinking options for intervention is necessary, in working towards achieving all revised Objectives and related End-point Goals.

Adaptive Learning Potential			Transformational Learning Potential
<u>Governance Level-1</u>: Time-interval: Stakeholder meetings every 3-5 years. Response-System concerning testing of 'outputs': Collation of results from nested Level-2 entities, to decide if intended 'outputs' at level-1 are actually transpiring. If Level-1 planning 'inputs' are not being implemented as intended, with expected 'outputs' not occurring at Level-1, then adjustment to implementation is required,	<u>Governance Level-1</u>: Time-interval: Stakeholder meetings and workshops every 5-8 years. Adaptive Assessment within the Level-1 entity auditing strategic 'outcomes': Collation of monitored results from nested Level-2 entities, to decide if Policy Targets at Level-1 are being met. Auditing Policy Targets spawns feedbacks for further decision making. If Policy Targets are not met then this is tabled. Decisions required - existing policy planning 'inputs' at Level-1 require	<u>Governance Level-1</u>: Time-interval: Stakeholder workshops every 8-10 years. Adaptive Reflection within the Level-1 entity, to decide if higher (more value-laden) Objectives at Level-1 are being achieved. If not, then assumptions associated with Policy Targets require re-framing, with potential for re-developing these targets. Re-framing of policy planning 'inputs' is also required based on new knowledge, in order to	<u>Governance Level-1</u>: Time-interval: Stakeholder workshops every 10-15 years. Adaptive Reflection within the Level-1 entity, to review the Higher-(value-laden) objectives and Policy Targets. There is evaluation of existing paradigms, with deliberation of structural context. Involves altering regulatory frameworks (e.g. rules) that may be stalling application of the SAM cycle. Key challenges exist due to prohibitive rigidity of governance systems at Level-1.

Adaptive Learning Potential			Transformational Learning Potential
of the planning 'inputs' at Level-1, to obtain intended output results over the long-term.	adjustment and re-implementation across nested Level-2 entities, and or specific target values can be revised (particularly if first generation targets).	achieve the revised Policy Targets, with implementation of the re-framed planning 'inputs'.	With this, the SAM cycle of the Level-1 entity is completed. Regeneration, allowing for the next iteration of the SAM cycle, commences with re-formulation of Policies, to meet newly devised Higher-objectives and associated Policy Targets at Level-1.
Governance Level-2: Time-interval: Stakeholder meetings every 1-3 years. Response-System concerning testing of 'outputs': Collation of results from nested Level-3 entities, to decide if	Governance Level-2: Time-interval: Stakeholder meetings and workshops every 3-6 years. Adaptive Assessment within each Level-2 entity, auditing strategic 'outcomes': Collation of monitored results from nested Level-3 entities,	Governance Level-2: Time-interval: Stakeholder workshops every 6-8 years. Adaptive Reflection within each Level-2 entity, to decide if Sub-objectives at Level-2 are being met. If not, then assumptions associated with	Governance Level-2: Time-interval: Stakeholder workshops every 8-10 years. Adaptive Reflection within each Level-2 entity, to review the Sub-objectives and Management Targets. Includes evaluation of current

Adaptive Learning Potential			Transformational Learning Potential
intended 'outputs' at level-2 are actually transpiring. If Level-2 planning 'inputs' are not being implemented as intended, with expected 'outputs' not occurring at Level-2, then adjustment to implementation is required, of the planning 'inputs' at Level-2, to obtain intended output results over the medium-term.	to decide if Management Targets are being met. Auditing Management Targets spawns feedbacks for further decision making. If Management Targets are not met then this is tabled. Decisions required - existing management planning 'inputs' at Level-2 require adjustment and re-implementation across nested Level-3 entities, and or specific target values can be revised (particularly if first generation targets).	Management Targets require re-framing, with potential for re-developing these targets. Re-framing of management planning 'inputs' is also required based on new knowledge, in order to achieve the revised Management Targets, with implementation of the re-framed planning 'inputs'.	institutional arrangements. Innovations must be identified and promoted; and associated constraints (e.g. lack of decision-making delegation) reduced. Working progressively towards achieving adaptable governance at Level-2 is paramount. With this, SAM cycles of Level-2 entities are completed. Regeneration, allowing for the next iteration of the SAM cycle, commences with re-formulation of Management approaches to meet newly devised Sub-objectives and associated Management Targets at Level-2.

Adaptive Learning Potential			Transformational Learning Potential
Governance Level-3: Time-interval: Daily, or weekly communication - via email and or phone. Monthly stakeholder meetings, to determine if operations and feedback systems are occurring adequately. Rapid-Response-System concerning testing of ‘outputs’: Collation of results from nested sites within Level-3 entities, to decide if intended ‘outputs’ at level-3 are actually transpiring.	Governance Level-3: Time-interval: Stakeholder meetings and workshops every 1-3 years. Adaptive Assessment within each Level-3 entity, auditing strategic ‘outcomes’: Collation of results from on-the-ground monitoring activities at sites. TPCs, the explicit and measurable end-points, are audited to evaluate if thresholds of specified indicators are exceeded, or not. TPC rationale and monitoring protocols guide and prioritize monitoring activities at Level-3	Governance Level-3: Time-interval: Stakeholder workshops every 3-5 years. Adaptive Reflection within each Level-3 entity, to decide if Sub-objectives at Level-3 are being met. If not, then re-framing of assumptions (hypotheses and or models) used in TPC development is required, using newly acquired knowledge. New TPCs may be developed if pertinent TPC challenges have been posed during the period.	Governance Level-3: Time-interval: Stakeholder workshops every 5-6 years. Adaptive Reflection within each Level-3 entity, to review the Sub-objectives and TPCs. Includes evaluation of stakeholder network systems. Increasing stakeholder participation is important. Encouragement of key innovations is required, and this is used to transform stakeholder networks into more adaptive networks, promoting flexible and informal interactions. With this, SAM cycles of Level-3

Adaptive Learning Potential			Transformational Learning Potential
If Level-3 planning 'inputs' are not being implemented as intended, with expected 'outputs' not occurring at Level-3, then adjustment to implementation is required, of the planning 'inputs' at Level-3, to obtain intended output results over the short-term.	sites. TPCs are tabled if or when exceeded, or close to being exceeded thus giving time for adjusting actions in order to avoid TPC exceedance. TPC reporting formats spawn feedbacks for further decision making, i.e., adjusting existing action planning 'inputs', and or revising existing thresholds of TPCs (particularly if first generation TPCs).	Re-framing of action planning 'inputs' is also required based on new knowledge, in order to achieve the revised and or new TPCs developed, with implementation of these re-framed planning 'inputs'.	entities are completed. Regeneration, allowing for the next iteration of the SAM cycle, commences with re-formulation of Actions to meet newly devised Sub-objectives and associated TPCs at Level-3.

Vertical adaptive feedbacks across SRLF levels

For each SRLF theme, Environment, Economic, and Community/Social, collating information from the Level-3 SAM cycles, through parent Level-2 SAM cycles into the Level-1 SAM cycle is essential. This allows for learning, initiated at Level-3, to bridge with policy decisions (vis-à-vis Pahl-Wostl et al. 2013) occurring at SRLF Level-1. Thus, potential to evaluate and link the end-point goals and associated objectives across SRLF levels is expedited, and ultimately with the overall Vision determined at SRLF Level-1.

It must be expected that advancement in ANRM will not occur uniformly across governance levels because of disparate rates in realizing critical enabling conditions for three-mode learning. Panarchy theory, with its complex adaptive cycles including the four phases of exploitation, conservation, release, and reorganization (Holling 2001, Gunderson and Holling 2002), has been useful in assessing processes of change across levels of organization within systems (Garmestani et al. 2009). Although not within the scope of this manuscript, integration of these concepts into SRLF development would be beneficial, because further understanding about change, and influences across ANRM governance levels, is needed.

3.5 Deploying the SAM Reflexive Learning Framework

The SRLF instigates integrative thinking associated with the contemporary problem of translating ANRM theory into practice. It achieves this by demonstrating a generic, explicit and pragmatic reflexive learning schema for facilitating three-mode learning under ARM. Specifically, SRLF promotes an appropriate balance and use of the single-, double-, and triple-loop modes of learning at different governance levels, and this is important for implementing the adaptive management cycle, at each SRLF level. It is acknowledged that deployment of the SRLF will occur in situations where real-world components and processes are already happening within programs of natural resource management. For instance, governance arrangements will be in place and policies determined with various monitoring activities implemented. The idea of SRLF is that is it seen as a pragmatic tool for guiding the practice of ANRM. The intention is that its principles be integrated into existing components and processes where pertinent, and this is the key challenge for deploying the SRLF. Examples are, explicitly considering the impact of multilevel governance arrangements for implementing the adaptive management cycle; or the need to reconsider older (entrenched) monitoring systems and formulate new strategic ones, such as at SRLF Level-3 with potential to measure progress against TPCs. Strategic interventions can then be actively tested against a measurable desired future state that has been agreed upon by all stakeholders; because stakeholder involvement is paramount in SRLF, particularly when determining objectives and related end-point goals.

Importantly, SRLF is not the remedy for achieving successful three-mode learning outcomes under ANRM, because in real-world situations three-mode learning is dependent on other factors too, for example, stakeholder participation rates and how these stakeholders are engaged; development of learning centered organizations that encourage three-mode learning; fostering critical capacities for social learning, specifically important for double-loop learning; and achieving adaptable governance regimes, which allows for triple-loop learning. Notably, financial and other managerial logistics, including risk, also impact implementation of ANRM. Nonetheless, the overarching benefit of applying the SRLF in ANRM programs is that it unpacks the reflexive learning process, clearly, to guide practitioners through three-mode learning and implementing the adaptive management cycle. The SRLF improves on existing ANRM adaptive management cycle frameworks by focusing, explicitly, on the types, roles, and transfers of information in adaptive feedback systems (reflexive learning) and this is fostered by several key elements:

Streamlining coupled sets of objectives across SRLF levels

Fragmentation of objectives commonly imposes a loss of collective purpose, momentum, and focus associated with implementation of the adaptive management cycle under ARM. This often occurs across different levels of implementation. Under SRLF, the scaled, cascaded set of objectives is the common currency of the ANRM venture. These objectives integrate organizational levels in SRLF by permitting a common purpose for ANRM, given effect via increasing focus and rigor down SRLF levels. Thus, the objectives determine the rationale for SRLF, but also unite practitioners in their different roles, responsibilities, and mandates.

Incorporation of multiple but interlinking SAM cycles

It can be overwhelming to conceptualize the what, when, and how-to implement the adaptive management cycle under ANRM, because of the wide range of objectives to be met. Under

SRLF, this is resolved by separate SAM cycles within individual themes, i.e., Environment, Economic, and Community/Social, or other, thereby making it easier to contemplate specific adaptive processes, for example, goal setting or monitoring, as related to each theme. This promotes learning efficiencies in the task of activating, completing, and then regenerating the SAM cycles. Importantly, thematic SAM cycles within the SRLF must be interlinking, because being cognizant of all intervention strategies is important to achieve the full range of objectives across SRLF themes.

Applying three-mode learning as an ongoing, nested process

Nested feedbacks occur over a broad range of time-scales in SRLF, from days/weeks (minimum time-step at SRLF Level-3) to decades (maximum time-step at SRLF Level-1). The evaluation (learning) phase is not depicted as a separate step along the SAM cycle, as is given in many ANRM models. Often, these models begin with objectives and problem formulation, which then flow into implementation and monitoring, then an evaluation step implying subsequent feedback back into problem formulation (Gregory et al. 2012, Williams and Brown 2014). This suggests that processes of evaluation occur at discrete intervals toward the end of the adaptive management cycle. Under SRLF, this evaluation step is deliberately excluded from the SAM cycle, because feedback processes for the more immediate responses in ANRM, along with adaptive assessment and adaptive reflection are nested and ongoing; this is conveyed explicitly within the SAM cycles (see Fig. 3.5).

Explicitly recognizing when and where to apply three-mode learning

In the SRLF, at each governance level, the nested feedbacks for single-loop learning (both lower and upper) are mandatory and ongoing, because these incorporate the actual doing (improving established practices to meet end-point goals) and this is where progress is made within ANRM (Fabricius and Cundill 2014). Notably, double-loop learning feedbacks are invoked only if and when required, that is after deeper reflection has examined achievement of the objectives, at each SRLF level. If the objectives are not being met (considering any surprises) then changing practices becomes pertinent. For example, at SRLF Level-3 devising alternate TPCs (end-point goals) via redefining assumptions (hypotheses and models), along with updating monitoring systems and existing planning inputs, may be necessary. Over longer time-scales, triple-loop learning is required, i.e., a holistic review of the objectives based on changing human values, including revision of the end-point goals. A deliberate attempt to adapt governance systems at each particular SRLF level is also required. With this, the SAM cycle (per theme) contained within SRLF entities (across levels) is completed, and set for regeneration by applying all newly available knowledge to achieve a revised hierarchy of objectives.

Distinguishing initiating conditions for three-mode learning and time-scales for change

Slower response times of entities at higher levels in a hierarchy must be seen as standard practice, not failure. Relative to SRLF Level-3 entities, the longer time frames for change within the SRLF Level-1 entity (and to a lesser degree SRLF Level-2) must be conceded when inferring achievements under SRLF. Hence, outcomes for three-mode learning are initially pursued within the Level-3 entities (within constraints from higher levels) because these exhibit quicker learning potentials. Increased capacities for social learning and the development, use, and auditing of TPCs at Level-3 supports this learning. Subsequently, and over longer time-scales, SRLF Level-3 entities influence learning in the upper SRLF levels, via vertical feedbacks.

Explicitly contemplating practitioner mandates across SRLF levels

Practitioners at lower governance levels often become overwhelmed by higher level factors that constrain processes throughout ANRM, thereby stunting their motivation because such factors are out of their direct control. These factors include policy processes, formal and inflexible governance arrangements, exacerbated by diminished capacities for social learning. Meanwhile, practitioners operating at the policy level may not receive satisfactory feedback from the lower levels; becoming bogged down by too much detail. Their capacity to evaluate policy outcomes is, therefore, diminished. Under SRLF, explicitly defining practitioner mandates across SRLF levels is required, to clarify (feasible) implementation roles and responsibilities in the practice of ANRM. Here, panarchy theory is useful for furthering understanding.

Four criteria will increase effectiveness of SRLF deployment. First, champions at each SRLF level are required; these operators are the glue that binds the ANRM process together, without which it is more likely to fail. Principal champions are those practitioners operating at SRLF

Level-2 because their mandates coincide with both SRLF Level-1 and Level-3 practitioner mandates. These practitioners coordinate information flows, vertically across SRLF levels for learning to result throughout SRLF. Second, applying the SRLF is not organization specific, but a collaborative venture comprising all stakeholders, and these stakeholders cover all the themes under SRLF (within one social-ecological and economic system). Here, adaptive network systems are built across all organizational sectors, and these ideally become "communities of practice" (sensu Wenger 1998) that then oversee SRLF deployment. Third, achieving adaptable governance regimes across SRLF levels is expedient, particularly the establishment of polycentric and decentralized governance arrangements. With this, decision-making powers are devolved to the lower SRLF levels, thus SRLF Level-3 practitioners (and at Level-2) exhibit the freedom to oversee and implement their ANRM mandates as necessary. Fourth, it is astute to include a research component as part of the objectives strategically developed within SRLF (all levels, for each theme). Research objectives define research priorities associated with implementation of the SAM cycle, broken down into applied and basic research subobjectives. Applied research may be concerned with developing new TPCs at SRLF Level-3 (as these are required). New TPCs are developed using new knowledge emanating from basic research, which has the primary role of soliciting and overseeing research to enhance understanding about systems in ANRM.

Overall, the heuristic SRLF serves as an exploratory map for integrative learning in the practice of ANRM. This is beneficial because subsequent modifications to the SRLF will provide a measure of progress in integrative thinking (Pickett et al. 1999) associated with this learning.

3.6 Conclusion

Effective ANRM practice requires activation, completion, and then regeneration of the adaptive management cycle, which works toward achieving a flexible set of collaboratively identified objectives. This iterative process, at all governance levels, requires an appropriate balance and use of single-, double-, and triple-loop learning, to strategically modify inputs, outputs, assumptions, and hypotheses linked to improving policies, management approaches and actions, along with transforming governance. The SRLF consolidates essential reflexive learning heuristics of adaptive management explicitly under one framework and its deployment guides ANRM purposely within and beyond the single-loop learning, across three governance levels. Hence, the SRLF is a key enabler for implementing the ANRM adaptive management cycle, thereby rendering increased know-how for the practice of ANRM. Consequently, real-world examples demonstrating SRLF deployment across governance levels will be beneficial to test application of this heuristic framework to develop it further. Currently, principles of the SRLF are being applied in two ANRM case-study areas: South Africa, associated with implementation of the ecological Reserve, and in Australia, associated with environmental watering in the Murray-Darling Basin.

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Other Authors	Martin C. Thoms	10 %

Name of Candidate: **Craig Anthony McLoughlin**

Name/title of Principal Supervisor: **Professor Martin Thoms**

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Name/title of Principal Supervisor: **Professor Martin Thoms**

[redacted]

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Candidate Date

[redacted]

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Principal Supervisor Date

CHAPTER 4. SOCIETAL LEARNING IN ADAPTIVE FRESHWATER MANAGEMENT: A CASE-STUDY OF THE ECOLOGICAL RESERVE IN SOUTH AFRICA

McLoughlin, C.A., Thoms, M.C., Parsons, M. and Jackson, B. (submitted). Societal learning in adaptive freshwater management: a case-study of the Ecological Reserve in South Africa. *Ecology and Society*.

Name of Candidate: **Craig Anthony McLoughlin**
Name/title of Principal Supervisor: **Professor Martin Thoms**

[redacted] 12/11/2015

Candidate Date

[redacted] 12/11/2015

Principal Supervisor Date

ABSTRACT. Societal learning (single-, double-, and triple-loop learning) enhances learning-by-doing within adaptive freshwater management, however limited examples exist demonstrating this learning. Reflexive learning is a system of adaptive feedbacks for deliberately instigating single-, double-, and triple-loop learning within the adaptive management cycle. In this manuscript, an adaptive feedback system is applied to Ecological Reserve implementation in the Crocodile River of South Africa, providing a resolution for implementing the adaptive management cycle using societal learning, and working toward achievement of ecosystem objectives. Adaptive feedbacks for lower grade single-loop learning are mandatory because frequent adjustment to Ecological Reserve operations is required due to uncertainty about implementing the required river flows. Upper grade single-loop learning is often neglected within the Crocodile River Catchment with too much attention focused on operations to implement the Ecological Reserve. However, these river flows are hypotheses about maintaining an agreed upon ecological condition in the rivers, and therefore must be assessed against end-point goal achievement, to adjust operations as required. The skill with incorporating double-loop learning is avoiding the trap of "learning for the sake of learning" because resources for this learning are scarce in the Crocodile River Catchment. However, reframing of interventions and end-point goals is required based on new knowledge becoming available and/or changing human values. Triple-loop learning is compulsory and deliberately imposed over longer time intervals because objectives require revision over time and stakeholder values also change. Triple-loop learning is required for completion and then regeneration of the adaptive management cycle. Lessons learned, iteratively over time, will allow for a progressive implementation of the adaptive feedback system using societal learning, thus for working toward Ecological Reserve realization in South African rivers and the sustainable use of freshwater ecosystems.

Key Words: *Adaptive feedback system; adaptive management cycle; Ecological Reserve; freshwater ecosystems, management; lessons learned; single-, double-, triple-loop learning*

4.1 Introduction

Adaptive natural resource management (ANRM) is a learning-by-doing strategy for managing natural resources (Allan and Stankey 2009, Fabricius and Cundill 2014). The practice of ANRM involves an “adaptive management cycle” comprising three interconnecting components of activation, completion, and regeneration (McLoughlin and Thoms 2015). Applying each component and promoting linkages between them is essential for achieving stakeholder objectives (Pahl-Wostl et al. 2013). The adaptive management cycle is an iterative process that is enhanced by societal learning of which there are three different modes at increasing time-scales (Pahl-Wostl 2009). These three modes are “the doing” or single-loop learning, “changing practice” which is double-loop learning and “altering governance arrangements” or triple-loop learning (Fabricius and Cundill 2014). The adaptive management cycle harnesses all three learning modes to strategically modify inputs, assumptions and hypotheses, which are designed to improve policies, management approaches and actions, and the transformation of governance (Pahl-Wostl et al. 2013, McLoughlin and Thoms 2015). The three learning modes also assist with the achievement of collaborative objectives. Learning is an essential component of managing natural resources (Rogers et al. 2000, Walker and Salt 2012).

There is limited evidence for the successful application of learning in the adaptive management cycle (cf. Medema et al. 2008, Stankey and Allan 2009, Pahl-Wostl et al. 2011a, Susskind et al. 2012, Rist et al. 2013, Scarlett 2013, Westgate 2013). For example, the Glen Canyon Dam ANRM project in the USA negatively impacted species and habitats that it was established to protect because of a lack of procedures for learning within the adaptive management cycle (Susskind et al. 2012). It was suggested that collaboration and the promotion of shared learning will be required for better management of species and habitat in this river (Susskind et al. 2012). This example suggests that employing the three modes of societal learning within adaptive management cycles is intricate (Pahl-Wostl et al. 2013, Fabricius and Cundill 2014). This intricacy of societal learning in adaptive management cycles can be improved through understanding of the enabling conditions for this learning. In learning centered organizations that attempt to build and foster social learning capacities it is recognized that debate is essential for double-loop learning (Fazey and Schultz 2009, Roux et al. 2010, Cundill et al. 2011, Stirzaker et al. 2011, Mostert et al. 2007, Ison and Watson 2007) but more flexible governance arrangements are necessary to achieve triple-loop learning

(Pahl-Wostl 2009, Rogers et al. 2013). Achieving societal learning in ANRM is needed for the activation, completion and regeneration of the adaptive management cycle (McLoughlin and Thoms 2015).

Adaptive feedback systems are fundamental for learning in ANRM (Stankey et al. 2005, Pahl-Wostl et al. 2007, Pollard et al. 2011). Reflexive learning is a system of adaptive feedbacks whereby actions are manipulated and/or modified via feedback from the context within which they were executed (Pollard and du Toit 2007). Without reflexive learning the facilitation of societal learning in which single-, double-, and triple-loop learning occurs is diminished (McLoughlin and Thoms 2015). A lack of adaptive feedback systems results in adaptive management cycles that often remain trapped within single-loop learning (Pahl-Wostl et al. 2011). Inability to move beyond single-loop learning is an obstacle to effective ANRM practice because maintaining and/or improving established management practices negates full adaptive management potentials (Pahl-Wostl 2009). Deployment of reflexive learning within ANRM requires further evaluation of examples where the facilitation of single-, double-, and triple-loop learning has been employed in an explicit adaptive feedback system.

The process of setting the Ecological Reserve for freshwater ecosystems in South Africa presents an opportunity to explore reflexive learning within an adaptive management cycle. The National Water Act of South Africa (Act No. 36 of 1998), with its adaptive management philosophy, governs the establishment of the Ecological Reserve to protect freshwater linked ecosystems (O'Keeffe & Rogers 2003, Pollard and du Toit 2011). In addition, systematically defined Freshwater Ecosystem Priority Areas (FEPAs) identified across South African river catchments (Nel et al. 2011) are reliant on realization of the Ecological Reserve (Roux et al. 2006, Driver et al. 2011). However, there are currently major lags occurring in South Africa with implementing the Ecological Reserve. This is due largely to highly water stressed and stakeholder contested river catchment scenarios countrywide (van Wyke et al. 2006, McLoughlin et al. 2011*a*, Pollard and du Toit 2011). Implementation of the Ecological Reserve demands effective societal learning within an ANRM approach (Roux et al. 2013). The Strategic adaptive management Reflexive Learning Framework of McLoughlin and Thoms (2015) outlines an adaptive feedback system for facilitation of societal learning within the adaptive management cycle of ANRM. Improving the process of Ecological Reserve implementation within South African catchments would be strengthened by the facilitation of single-, double, and triple-loop learning using reflexive learning.

In this manuscript, the Strategic adaptive management Reflexive Learning Framework (SRLF) is applied to Ecological Reserve implementation within the Crocodile River Catchment of South Africa. The SRLF stresses the importance of adaptive feedback systems for facilitating single-, double-, and triple-loop learning within the adaptive management cycle of implementing the Ecological Reserve and highlights this style of learning for achieving FEPA related objectives. The Crocodile River was selected for this study as it is currently a catchment which is undergoing continual activation, completion and regeneration of an adaptive management cycle associated with implementation of the Ecological Reserve process in South Africa.

4.2 Case-study background

4.2.1 Basis for adaptive freshwater management in South Africa

The current water policy of South Africa was developed following a political regime change in 1994. This resulted in the Water Services Act (Act No. 108 of 1997) and the National Water Act (Act No. 36 of 1998) (de Coning and Sherwill 2004, Herrfahrdt-Pahle 2013). The National Water Act, from here on referred to as the NWA, embraced adaptive management of South Africa's freshwater resources (Biggs et al. 2008).

There are six key attributes which seek to increase the NWA's adaptive capacity (Herrfahrdt-Pahle 2013). These are: 1) Flexible water legislation with a phased implementation within South Africa over time, thereby recognizing the existence of limited resources and future adjustments to the legislation; 2) increased transparency, accountability and decentralization of freshwater management with the establishment of Catchment Management Agencies (CMA); 3) overlapping of institutions that manage water resources, such as the co-existence of CMAs with regional offices of the Department of Water Affairs, in order to promote functional management at the different levels of governance; 4) equal access to water through the "basic-human-needs" Reserve and the prioritization of domestic requirements for water, thus, contributing to improved social equity and increased adaptive capacity of large segments of the population; 5) public participation in freshwater management at all governance levels; and, 6) there is no ownership of water but only a right or an authorization for its use, the only right to priority of use is that of the Reserve, comprised of the "basic-human-needs" and Ecological Reserve components (DWAF 1997).

4.2.2 Freshwater Ecosystem Priority Areas (FEPAs)

Freshwater Ecosystem Priority Areas are strategic priorities for conserving South Africa's freshwater ecosystems. The national FEPA program identified critical catchments that were deemed important for meeting the national biodiversity objectives that were linked to freshwater ecosystems (Nel et al. 2011). The FEPAs were developed in expert review workshops using certain key criteria (Table 1), in response to high levels of threat prevalent in river, wetland and estuary ecosystems of South Africa (Driver et al. 2005). This involved many different stakeholders including The Department of Water Affairs, Department of Environmental Affairs, South African National Parks and the Department of Agriculture; all of which agreed upon a vision for managing and conserving freshwater ecosystems. This vision guided the development of a range of policy objectives and recommendations that could ultimately be shared across departments (Roux et al. 2006).

The derived FEPA maps (see Nel et al. 2011) demarcate rivers, wetlands and estuaries that are required to stay in a "good" condition in order to conserve freshwater ecosystems but also to protect water resources for human consumption. Hence, it is envisaged that FEPAs must not be fenced off from human use, but must be supported by good planning, decision-making and management in order to ensure that human use does not detrimentally impact the condition of the ecosystem (Nel et al. 2011).

Table 4.1. The key criteria used to determine the Freshwater Ecosystem Priority Areas (FEPAs) in South Africa (based on the 2006 national cross-sector policy process, see Roux et al. (2006)).

Key criteria	Description of key criteria
1	FEPAs are representative of pertinent ecosystem types and flagship free-flowing rivers.
2	FEPAs act to maintain water supply in areas with high water yield.
3	FEPAs include consideration of any identified connected ecosystem.
4	FEPAs include representation of threatened and near-threatened fish species and associated migration corridors.
5	FEPAs overlap with free-flowing rivers and priority estuaries identified in the National Biodiversity Assessment of 2011, and existing protected areas for protected area expansion as identified in the National Protected Area Expansion Strategy.

4.3 Governance and FEPA context for Ecological Reserve implementation

The case-study of the Crocodile River Catchment recognizes higher level constraints to Ecological Reserve implementation in the Crocodile River from the national, water management area (WMA) and river catchment scales (Fig. 4.1). There are 19 demarcated WMAs in South Africa (Fig. 4.1). Within each WMA, catchments are grouped into larger river catchment areas, for example the three major river catchments of the Inkomati WMA in the north eastern corner of South Africa (Fig. 4.1). In addition, FEPA related objectives are defined for the national and water management area levels in South Africa. The FEPA related objectives at the WMA governance level provide context for development of pertinent Ecological Reserve related objectives at the river catchment scale, i.e. to achieve the FEPAs objectives.

4.3.1 South African national scale

The NWA is the principal legal instrument for water resource management in South Africa. As the public trustee of the nation’s freshwater resources the national government, acting through the Minister of Water Affairs, must ensure that freshwater resources are protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner. This is for the benefit of all persons and in accordance with its constitutional mandate and is reinforced at the national level via societal values inherent within the broader vision of the NWA, i.e. “some, for all, forever”. This vision sets a top-down link for integrated and adaptive freshwater management in South Africa. The National Water Resource Strategy (NWRS) is the implementation mechanism for the NWA. The NWRS sets out policies, strategies, objectives, plans, guidelines, procedures and institutional arrangements for the protection, use, development, conservation, management and control of the country's water resources.

Integrated Water Resources Management (IWRM) is defined in the NWRS as a process promoting the co-ordination, development and management of water, land, and related resources in order to maximize the resultant economic and social welfare in an equitable manner, but without compromising the sustainability of ecosystems. Two important tool sets included in the IWRM are the Resource Directed Measures (RDM) and the Source Directed Controls (SDC). The RDM consists of the water resource Classification System; the Reserve, and monitoring to ensure compliance to specified Resource Quality Objectives (see Kleynhans and Louw 2007). The Minister of Water Affairs determines the Class and Reserve for every significant freshwater resource in South Africa. The SDC include water licensing, authorization, enforcement, water allocation and restrictions, among others.

RDM – freshwater classification component

Ecological Management Classes (EMC) are determined for all significant freshwater resources as part of the RDM Classification process. Stakeholders who benefit from the resource, must agree on a EMC level for a particular freshwater resource. The EMC ranges from I to IV (Fig. 4.2), and represents an order with decreasing levels of protection for (or increasing levels of risk to) freshwater aquatic species and habitats. It is intended that the EMC creates a balance between the environmental, economic and social benefits emanating from the resource.

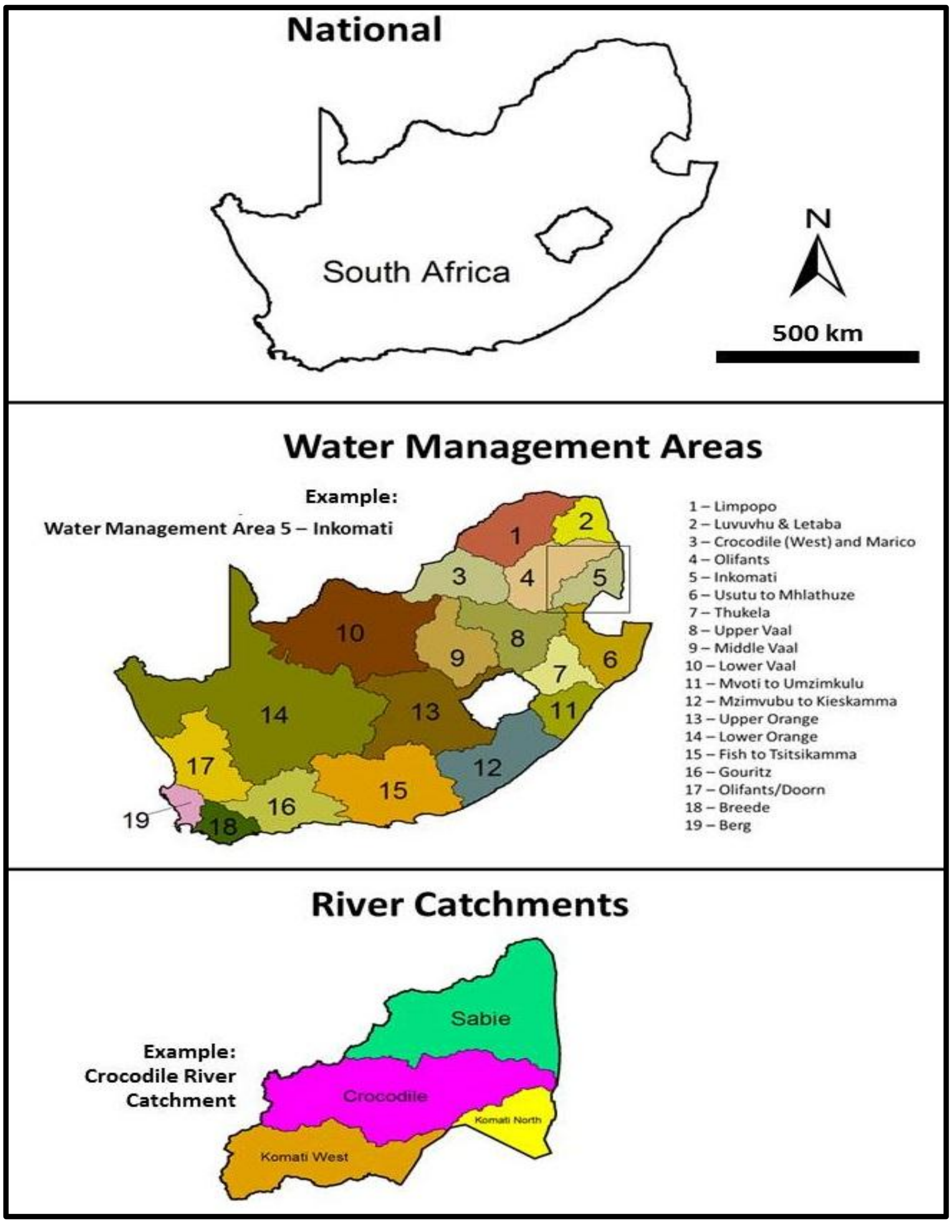

Figure 4.1. Three governance levels related to freshwater management in South Africa, pertinent for application of the Strategic adaptive management Reflexive Learning Framework to Ecological Reserve implementation. The national scale is divided into 19 water management areas which in turn are demarcated into catchments associated with river systems contained with the water management areas.

Eco-classification is the procedure to determine and categorize the ecological state of various biological and physical attributes of freshwater resources. This ecological state is then compared to a specified Reference state to describe the health of a freshwater resource. Management targets, objectives and specifications for the freshwater resource, called Resource Quality Objectives, are then derived per water resource (see Kleynhans and Louw 2007). Eco-classification outputs are known as Ecological Categories, ranging from A (natural) to F (highly impacted) (see Fig. 4.2) similar to the EMCs. Ecological Categories are then integrated into EMCs (Fig. 4.2) and utilized for planning linked to Ecological Reserve implementation within river catchments.

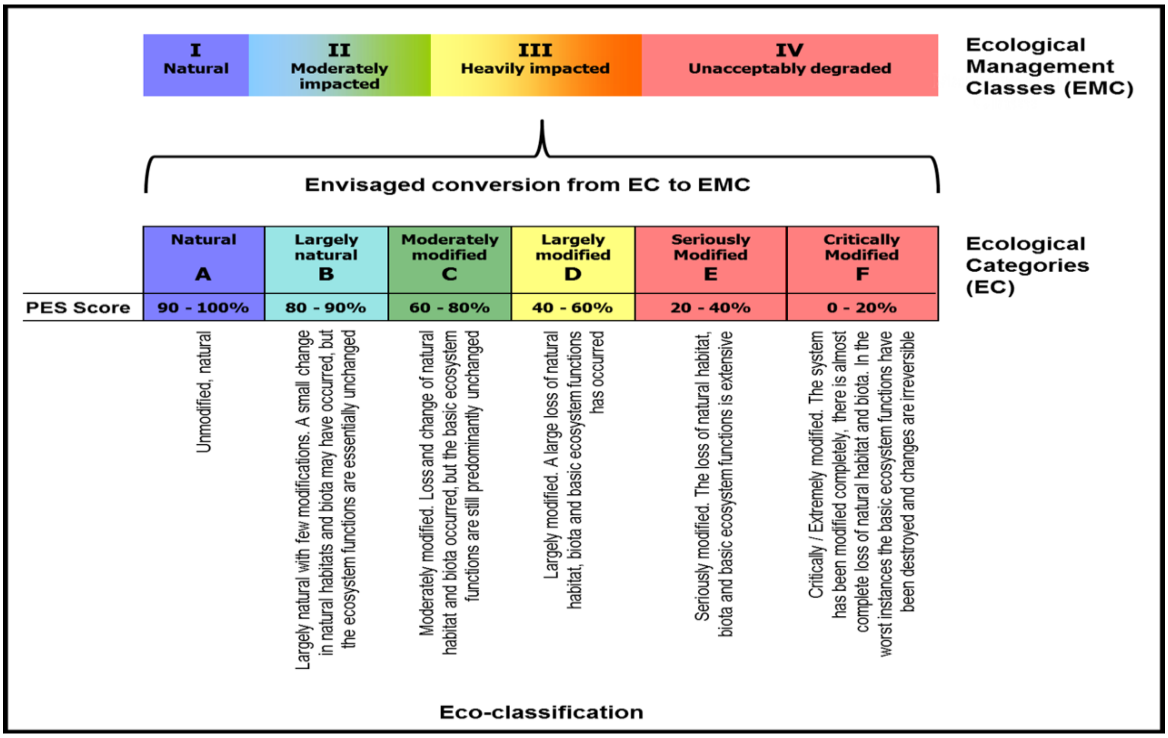

Figure 4.2. Definition of the Ecological Categories (A, natural to F), representing an order with decreasing levels of protection for (or increasing levels of risk to) freshwater aquatic species and habitats. Indicated is the envisaged conversion of the Ecological Category into the Ecological Management Class used for selecting Ecological Reserves for river systems within catchments.
PES: present ecological state.

RDM – Ecological Reserve component

The quantity and quality of water required to protect the ecological functions on which humans depend is defined as the Ecological Reserve, and this must be determined and maintained in natural freshwater resources (O'Keeffe & Rogers 2003). The intention of the Ecological Reserve is to maintain the ecological functions on which humans depend (DWAF 1997), rather than reinstating pristine conditions in all rivers. It is thus determined according to the desired EMC for a particular river, with a larger component of the flows required to manage for an 'I' class river compared to an 'IV' class river (Fig. 4.2). However, the Ecological Reserve or any river system is a recommended flow regime (water quality aspects important too, although not a focus in this case-study) based on current understanding and it is expected to maintain a specific river EMC. Using monitoring the generally precautionary estimates of required flows can be tested against the real ecological conditions which result and so enabling a vastly improved understanding of the relationship between flow patterns and resultant ecological conditions.

Monitoring of South African river systems is achieved under the National Aquatic Ecosystem Health Monitoring Program, of which the River Health Program is a significant component (see Kleynhans and Louw 2007, DWAF 2008*a*). Setting up pertinent monitoring programs in South Africa is the mandate of the Directorate of Resource Quality Services within DWA. A number of tools and methods have been developed to enable consistent and reliable assessment and classification of the ecological condition of a variety of component attributes of rivers, such as fish, riparian vegetation, aquatic invertebrates and geomorphology (see Kleynhans and Louw 2007).

National FEPA objectives and related policy targets

At the national level, higher objectives linked to the FEPAs may include giving effect to the ratified international agreements associated with freshwater, and to provide for cooperative governance in freshwater biodiversity management and conservation (Roux et al. 2006). There must also be fair and equitable sharing among all stakeholders of the benefits arising from freshwater resources in South Africa. A cross-sectoral policy process played an important role in deriving a politically-accepted national policy target for South Africa's freshwater ecosystems (Roux et al. 2006). The departments and organizations agreed to maintain at least 20 percent of each major freshwater ecosystem type (223 identified) in a "good" condition, but subject to refinement as new knowledge arises (Nel et al. 2011).

4.3.2 Water management area scale

At the WMA level, the Minister of Water Affairs promotes the management of freshwater resources by assigning powers and duties to CMAs (section 73(4) of the NWA). The CMA for each WMA, which comprises all key stakeholders, has responsibility for freshwater management functions within their domain. An initial responsibility of CMAs under the NWA is development of a Catchment Management Strategy (CMS) (see DWAF 2007 for a full treatise). The CMA for each WMA will need to make strategic decisions regarding adequate selection, planning and implementation of the RDM tools to develop the "water resource protection" component of their CMS.

FEPA related management targets for water management areas

The 20 percent FEPA policy target agreed to at the national scale is given effect in South Africa by the FEPAs within each WMA. The percentage of each WMA that has been demarcated as a FEPA is given in Table 4.2 (Nel et al. 2011). For purposes of this manuscript, these percentages per WMAs are considered as "management targets" at the scale of the WMA in South Africa.

Table 4.2. Distribution of Freshwater Ecosystem Priority Areas (FEPAs) throughout South Africa, defined by the percentage of each water management area required to be protected as a FEPA.

Water management area	Percentage of water management area selected as Freshwater Ecosystem Priority Area
1. Limpopo	21
2. Luvuvhu and Letaba	30
3. Crocodile (West) and Marico	12
4. Olifants	14
5. Inkomati	33
6. Usutu to Mhlathuze	37
7. Thukela	38
8. Upper Vaal	23
9. Middle Vaal	13
10. Lower Vaal	20
11. Mvoti to Umzimkulu	33
12. Mzimvubu to Kieskamma	18
13. Upper Orange	24
14. Lower Orange	23
15. Fish to Tsitsikamma	20
16. Gouritz	18
17. Olifants/Doorn	21
18. Breede	22
19. Berg	10

4.3.3 River catchment scale

The high demand for water relative to supply in South Africa adds to the complexity of the management of freshwater resources in catchments of the country (Nel et al. 2011). A key factor in most catchments is the high water-stress situation (see DWAF 2004*a*, DWAF 2004*b*, DWAF 2004*c*). In addition, the establishment of the Ecological Reserve and the "basic-human-needs" component has increased uncertainty about water allocations between competing water users (Pollard and du Toit 2011). This added level of complexity is further exacerbated by the amount of water that must remain in river systems for sustaining freshwater ecosystems. Determining water requirements for freshwater ecosystems remains imperfect because of limited knowledge on ecosystem water requirements (Rogers and Bestbier 1997) which can result in the loss of trust concerning the practicalities of the Ecological Reserve (Pollard and du Toit 2011). In South Africa it has been suggested that this loss of trust has contributed to the delay in the implementation the Ecological Reserve, almost two decades since the introduction of the NWA (Pollard and du Toit 2011). This is despite an ANRM approach being expected to assist in the implementation of the Ecological Reserve within river catchments, leading to the sustainable development of South Africa's riverine freshwater resources (Rogers et al. 2000, McLoughlin et al. 2011*a*, Pollard and du Toit 2011). The SRLF with its adaptive feedback system can assist with the societal learning requirements for realization of the Ecological Reserve in South Africa, and this is important for working toward achievement of the FEPA related objectives associated with catchments.

4.4 Case-study area

4.4.1 Inkomati Water Management Area

The Inkomati WMA, located in the north-eastern region of South Africa (Fig. 4.1) has a catchment area of 28,757 km^2. Rainfall across the catchment is strongly influenced by topography, it varies from over 1,200mm per annum in the Drakensberg Escarpment in the west to as low as 400mm per annum in the lowland plains in the east. Mean annual runoff from the Inkomati WMA is estimated at 3,022 million m^3 per annum (DWAF 2004a). There are three main river catchments in the Inkomati WMA; the Sabie-Sand River Catchment; the

Crocodile River Catchment; and, the Komati River Catchment. Each of these river systems flows eastward through Mozambique to the Indian Ocean (Fig. 4.1).

The Inkomati WMA is dominated by extensive afforestation and irrigated commercial agriculture is the biggest water user (DWA 2010). The population of the Inkomati WMA is estimated at 1,511,343 (DWAF 2004*a*) and it is mainly rural. Poverty is a major problem, highlighting the urgent requirement for further development and hence increasing demand for water. Significant urban, rural and industrial users of water exist, and conservation areas cover around 35% of the WMA. Some mining occurs in the upper reaches of the Komati River Catchment. Important sectors in terms of gross domestic product are: manufacturing (24. 6%); agriculture (18. 6%); government (16. 4%); trade (13. 4%) and other (27. 0%) (Pollard and du Toit 2011). Several major dams exist in the WMA in order to meet water demand of these sectors. The Komati River is highly regulated, while the Crocodile River and Sabie and Sand Rivers are less regulated by dams (DWA 2010).

The Inkomati-Usuthu CMA was established over a decade ago. It has led the development of a draft CMS (2010) which provides guidance with adaptive planning associated with the Inkomati WMA. In addition, committed leadership from the Inkomati-Usuthu CMA and ongoing support from its key stakeholders include potential for cooperation, connectedness, buy-in around shared objectives, while building up key partnerships and responsibilities for information generation and use (Fig. 4.3). These WMA-scale components provide key enabling conditions for implementing the Ecological Reserve within the Crocodile River Catchment using an ANRM approach. With implementation of Ecological Reserve the Inkomati WMA is mandated to protect all river FEPAs within the WMA. The current required management target for the Inkomati WMA is to maintain 33 percent of catchments as river FEPAs, i.e. as A or B Ecological Categories (Table 4.2). In addition, the fish support areas and upstream river reaches associated with these river FEPAs must be maintained (see Fig. 4.4, Nel et al. 2011).

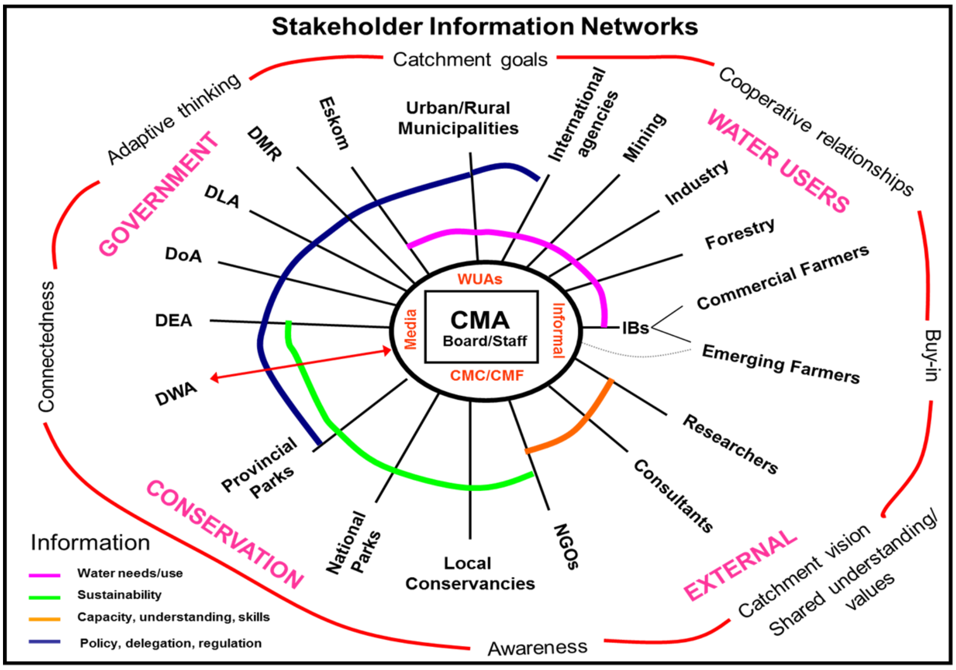

Figure 4.3. Potential stakeholder information networks in adaptive freshwater management related to the Inkomati Water Management Area; partnership with and facilitated by the Inkomati-Usuthu Catchment Management Agency.
DLA: Department of Land Affairs; DoA: Department of Agriculture; DEA: Department of Environmental Affairs; DWA: Department of Water Affairs; NGOs: Non-governmental organizations; IBs; Irrigation boards; WUA: Water User Association; CMC: Catchment Management Committee and CMF: Catchment Management Forum.

4.4.2 Crocodile River Catchment

The Crocodile River Catchment (Fig. 4.5) is one of three major river catchments of the Inkomati WMA (see Fig. 4.1). Consumptive water uses in the catchment include industry, irrigation, domestic and plantation forestry and non-consumptive uses include environmental water requirements and the international obligation of a minimum flow requirement to Mozambique. The Kruger National Park (KNP) overlaps with the north-eastern section of the Crocodile River Catchment. The Crocodile River forms the southern boundary of the park and is an important contributor to ecological integrity within the park. The freshwater resources of the Crocodile River are dominated by unregulated river reaches but a regulated reach occurs where flows are controlled by the Kwena Dam in the upper catchment. The Kwena Dam (Fig. 4.5) has a gross storage capacity of 158 million cubic meters and is used primarily to supplement water supplies for irrigated agriculture occurring adjacent to the river (DWA 2010). There are also a number of smaller sized dams, weirs and water supply schemes

[redacted]

Figure 4.4. Spatial distribution of the Freshwater Ecosystem Priority Areas of the Inkomati Water Management Area, with their associated management and support areas. Source Nel et al. (2011).

throughout the catchment which transfer water to towns. There are several flow gauging stations (e.g. Ten Bosch) along the Crocodile River (Fig. 4.5), which provide real-time river flow data that can be accessed remotely. In addition, there are several Ecological Water Requirement (EWR) sites; these are used to complete the Ecological Reserve determination studies (Fig. 4.5). River Health Program monitoring is implemented at demarcated biophysical sites along the Crocodile River in KNP (Fig. 4.5), and outside the park.

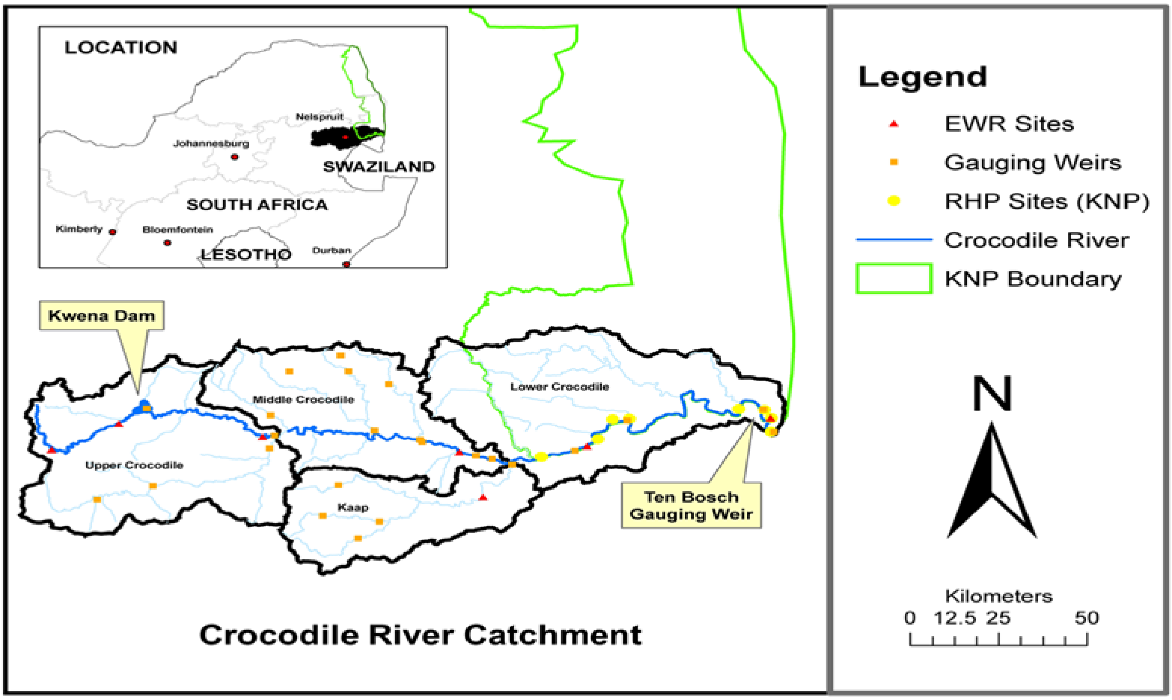

Figure 4.5. The Crocodile River Catchment, indicating Ecological Reserve determination sites (EWR), gauging weirs, River Health Program (RHP) monitoring sites, and its position in relation to the Kruger National Park (KNP).

Crocodile River and the Ecological Reserve

A comprehensive Ecological Reserve determination study has been undertaken for the Crocodile River and it provides recommendations for environmental water allocations to meet desired ecological conditions (DWA 2010). This has been achieved in part through the use of hydrological models with the aim to mimic natural flow variability as much as possible. This is to be achieved through dam releases and/or water restrictions, calculated and applied to meet both the Ecological Reserve requirements with adequate water supply to the various water user sectors. However, the current water deficit in the Crocodile River, without the Ecological Reserve, requires a continuing adaptive realization of the Ecological Reserve. A key requirement for this is that all water stakeholders must become more efficient in their water use and work together to implement the Ecological Reserve.

Institutional arrangements for managing the Crocodile River

The Crocodile River Operations Committee (CROCOC) is the key institutional arrangement for managing the Crocodile River. Set up by the Inkomati-Usuthu CMA, in addition to the Crocodile River Forum, the CROCOC oversees management of the Crocodile River. Stakeholders of CROCOC include: The Inkomati-Usuthu CMA - Water Resources Planning and Program Manager and CROCOC chairperson; DWA - several members from the Directorates National Water Resource Planning and Resource Directed Measures, and Regional Office and Infrastructure Branch representatives; Crocodile River Main Irrigation Board - including chair, secretary, technical members; KNP - River Manager and Scientist; Mpumalanga Tourism and Parks Agency - two scientific personnel; Mbombela Municipality - one personnel; Nkomazi Municipality - one personnel. Additionally, there are several stakeholders acting in an observer capacity, including those from the Komati Basin Water Authority, Inkomati-Usuthu CMA, Ehlanzeni District Municipality, consultants and research-related personnel. The CROCOC plays an active role in the integrated planning and operations of the river system, advising decision making by providing improved information inputs and outputs associated with river management in conjunction with all key stakeholders.

4.5 Case-study design

The national FEPA policy targets, spread across WMAs and their respective river catchments, provide an important basis for application of the SRLF to management of the Ecological Reserve in the Crocodile River. The SRLF is described below.

4.5.1 The Strategic adaptive management Reflexive Learning Framework

The vertical structure of SRLF exhibits a nested pattern of Strategic adaptive management (SAM) cycles distributed across three different levels of governance organization in natural resource management (McLoughlin and Thoms 2015). The generic SAM cycle structure of the SRLF consists of two phases (McLoughlin and Thoms 2015): (1) Adaptive Planning - composed of two adaptive components (represented in the black boxes in Fig. 4.6). The first represents development of the objectives, corresponding to the particular level; the second represents development of the detailed end-point goals culminating at the base of these objectives; and (2) Adaptive Implementation - composed of five adaptive components (represented in the grey boxes in Fig. 4.6). This includes processes of selecting the best intervention options to meet the developed end-point goals; determining inputs for planning (associated with meeting end-point goals); operationalizing inputs via implementation of the plans; checking adequacy of plan implementation by swift response to operational outputs; assessing suitability of the operational outputs by auditing strategic outcomes (against end-point goals); and testing achievement of the broader objectives applicable at each SRLF level.

Learning under the SRLF is an ongoing, nested process with two types of learning facilitated by reflexive learning - termed Adaptive Learning and Transformational Learning (Fig. 4.6). The Adaptive Learning component includes both single- and double-loop learning and there are two types of feedback to facilitate single-loop learning (Fig. 4.6). The "lower" type of feedback (thin/solid arrows) gives rise to the more immediate responses in ANRM, to check if the operational inputs are being implemented correctly and achieving intended outputs. The "upper" feedback (hashed arrows) promotes adaptive assessment routines, auditing strategic outcomes against end-point goals or benchmarks. Feedbacks for double-loop learning (dotted arrows) give rise to adaptive reflection routines, which evaluate achievement of the broader objectives within the SAM cycle (with consideration of any surprises), and there is potential for re-framing end-point goals and existing planning inputs. Feedbacks for triple-loop learning (thick/solid arrows) allow adaptive reflection into a holistic review process of all objectives and end-point goals. This reflection and review process is combined with a reconsideration of underlying values, for adapting governance systems (Transformational Learning) and the effective regeneration of the SAM cycle.

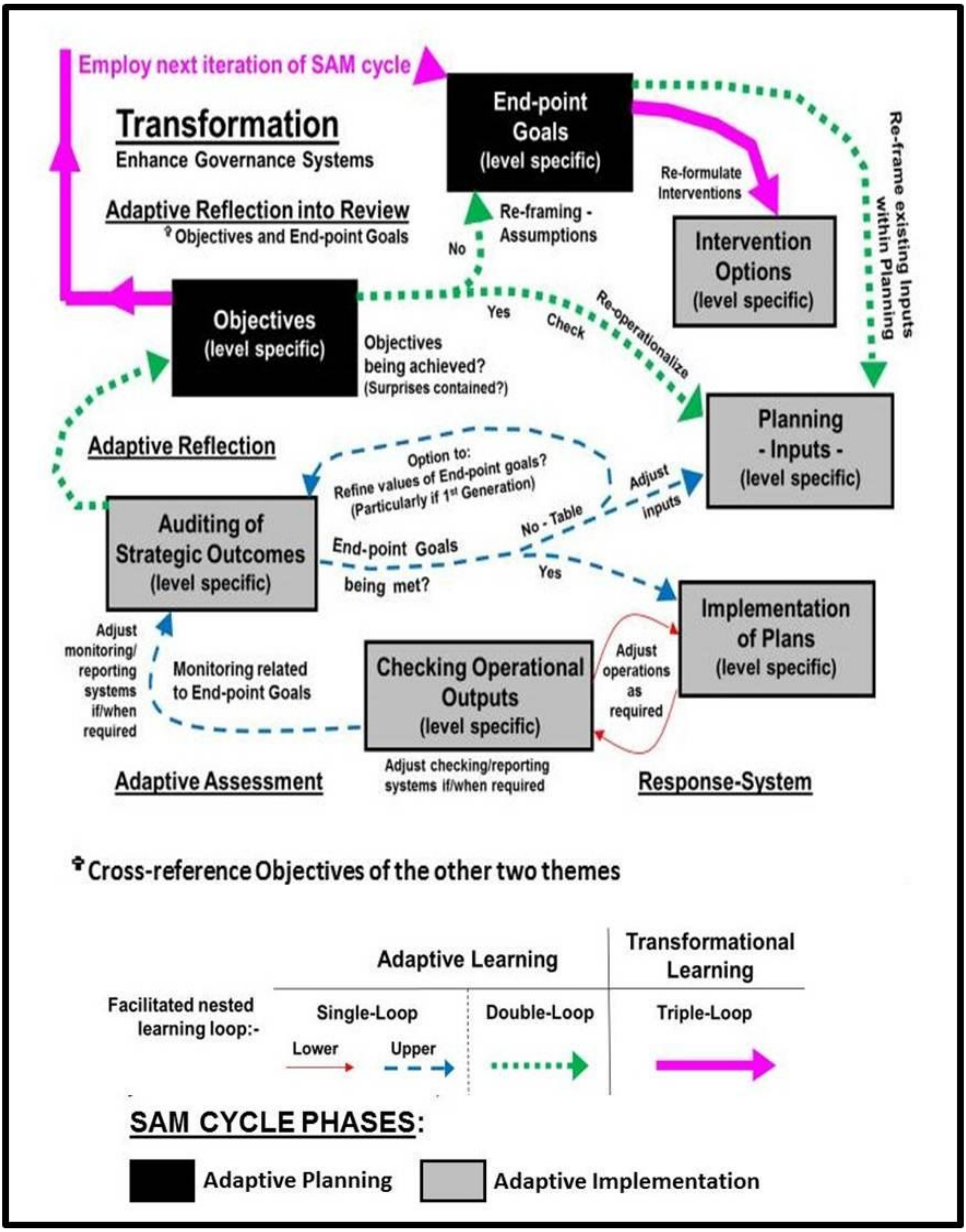

Figure 4.6. The generic Strategic adaptive management (SAM) Reflexive Learning Framework (SRLF) SAM cycle. The learning process is not linear in the SRLF, which uses a nested set of generic overlapping adaptive feedbacks within the SAM cycle. These feedbacks occur simultaneously but over increasing time-scales for change, by providing potential for both Adaptive and Transformational learning. This is given effect by facilitation of single-, double- and triple-loop learning for meeting Objectives and associated End-point Goals, and allows for activation, completion, and regeneration of the SAM cycle. Source: McLoughlin and Thoms (2015).

4.5.2 Formulating the SRLF SAM cycle for Ecological Reserve realization in the Crocodile River

Implementation of the SRLF SAM cycle is a continual process of collaboration with stakeholders of the Crocodile River Catchment (Fig. 4.7). An important enabler for initiating the SRLF SAM cycle was the Inkomati-Usuthu CMA gaining stakeholder support for maintaining the "C" Ecological Category for the FEPA related fish support river reaches traversing the KNP (see Appendix 1A). These river reaches are used in this case-study as examples for applying the SRLF SAM cycle to Ecological Reserve realization. Formulating the SRLF SAM cycle involved collating all elements associated with managing Ecological Reserve implementation in the Crocodile River. Examples of these elements were then added to the different phase components of the SRLF SAM cycle: the objectives and end-point goals (Adaptive Planning Phase); interventions options, planning, implementation of plans, checking operational outputs, and monitoring against strategic outcomes (Adaptive Implementation Phase). The resultant SRLF SAM cycle is described in Table 4.3.

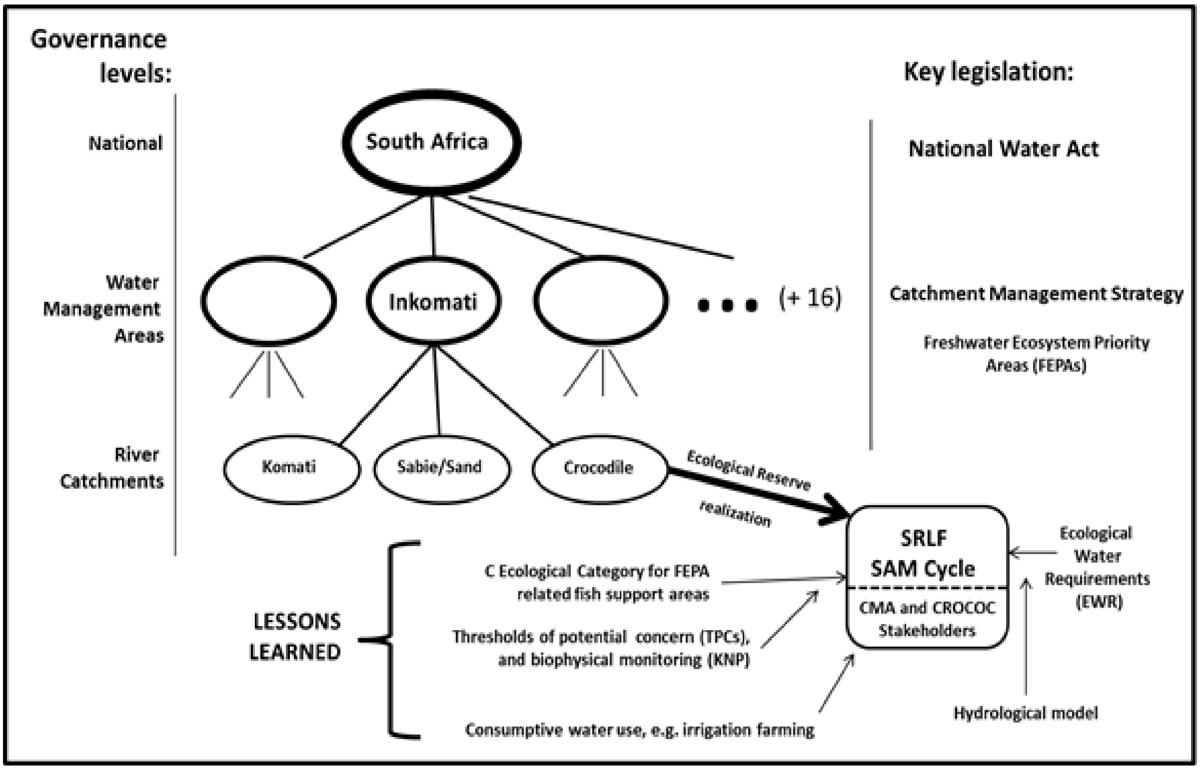

Figure 4.7. Case-study design for the Crocodile River Catchment involving the SRLF Level-3 SAM cycle and key Ecological Reserve elements.
CMA: Catchment management agency; CROCOC: Crocodile River Operations Committee; KNP: Kruger National Park.

All objectives given under the Adaptive Planning Phase of the SRLF SAM cycle (Table 4.3) are sub-objectives, hypothetically culminating down from a larger Objectives Hierarchy. This Objectives Hierarchy ideally commences at the national governance level and is developed through the WMA governance level. All objectives given within the SRLF SAM cycle (Table 4.3) thus have increased focus and rigor compared to the two upper governance levels, and these objectives become the main purpose for implementing the Ecological Reserve in the Crocodile River.

The main intervention option selected in this manuscript for achieving FEPA related objectives is the environmental flow requirements of the Ecological Reserve (Table 4.3); although other interventions are also considered, e.g. water quality controls. Elements used in the SRLF SAM cycle are only examples and do not represent an exhaustive set of all the Ecological Reserve elements under the NWA. In addition, actual outputs from applying the SRLF SAM cycle within the Crocodile River Catchment case-study are given in Appendix 1 (A-L). These worked examples are referenced against specific SRLF SAM cycle components in Table 4.3. All biophysical monitoring undertaken in this case-study related to end-point goals, or thresholds of potential concern (TPCs), is associated with the river reaches traversing the KNP (defined as FEPA related fish support areas; see Appendix 1A).

To initiate the SRLF SAM cycle the Inkomati-Usuthu CMA and its CROCOC stakeholders were engaged once the objectives and end-point goals were set up in the SRLF SAM cycle (Table 4.3). This was undertaken in order to gain their participation, support and involvement for deployment of the SRLF SAM cycle associated with Ecological Reserve implementation. The SAM cycle adaptive feedback system was then introduced to stakeholders and applied using its nested, overlapping set of adaptive feedbacks. These feedbacks are for facilitating single-, double- and triple-loop learning (Fig. 4.6). Ultimately, this is for the ongoing activation, completion and regeneration of this SRLF SAM cycle over time for achieving the FEPA related objectives. The CROCOC bi-monthly meetings were used as the main contact with catchment stakeholders for application of the SAM cycle. Cooperation and collective involvement among all CROCOC stakeholders was and remains essential for ongoing application of the SRLF SAM cycle, related to realization of the Ecological Reserve in the Crocodile River.

Table 4.3. Components of the Adaptive Planning and Adaptive Implementation phases of the Strategic adaptive management (SAM) cycle of the Crocodile River Catchment case-study. These phases of the SAM cycle are applicable to implementation of the Ecological Reserve in the Crocodile River, and for working toward achievement of Freshwater Ecosystem Priority Areas (FEPAs) related objectives (actual worked examples from this SAM cycle are given in Appendix 1).
EC: Ecological Category; WMA: water management area; TPC: thresholds of potential concern.

SAM Phase	SAM Component (Environment theme)	Real-world examples from the Crocodile River Catchment
Adaptive Planning	Sub-objectives with increased focus/rigor, emanating from higher level. Catalyst for broader objectives hierarchy. (cross-reference ‘Economic’ and ‘Social/Community’ themes)	• To achieve the Inkomati WMA 33 percent river Freshwater Ecosystem Priority Areas (FEPAs) target. • To work toward achievement of all FEPAs demarcated within the Crocodile River Catchment (Appendix 1A). • To maintain all fish support and upstream management areas in the river catchment associated with the FEPAs (Appendix 1A). • To give effect to Ecological Reserve implementation within the Crocodile River Catchment. • To oversee Ecological Reserve study outputs for rivers within the Crocodile River Catchment.
Adaptive Planning	End-point Goals (first generation examples) Thresholds of potential concern (TPC), culminating from the sub-objectives for this river catchment.	• Using available knowledge (Appendix 1B), with stakeholders develop thresholds of TPCs, the explicit/measurable end-points of the FEPA related objectives • TPCs represent the “tent boundary” (vis-à-vis Biggs et al. 2011) of the A or B ecological category (EC) associated with FEPA river reaches (Appendix 1C – macro-invertebrate TPCs for a B EC river reach). • TPCs developed for fish support and upstream management areas. Agreed upon ECs must be maintained (Appendix 1D – fish TPCs for a “C” EC river reach).
Adaptive Implement-ation	Intervention Options (examples pertinent at this governance level) Actions, for meeting the TPCs and ultimately the interlinked sub-objectives	• Develop pragmatic strategies for implementation of the Ecological Reserve. • Option to use hydrological models (e.g. Mike FLOOD WATCH and Water Resource Modelling Platform). • Enable stakeholder participation for implementation of the Ecological Reserve process.

SAM Phase	SAM Component (Environment theme)	Real-world examples from the Crocodile River Catchment
Adaptive Implement-ation	Planning inputs	Planning related to ecological Reserve operations: • Develop/roll-out methods for realization (progressively if necessary) of Ecological Reserves determined. • If Ecological Reserve studies not completed, then determine ad-hoc strategies for implementing environmental water in these rivers. • Develop hydrological modelling scenarios, river flow manipulation, dam operating rules to regulate water use and augmentation for implementing the Ecological Reserve. • Determine river flow monitoring potentials using existing gauging weirs with telemetry capability where possible. For river reaches where there are no gauging weirs, define alternate strategies for measuring river flow, such as using volunteers to make manual measurements as required. Operational planning related to monitoring of the ecological Reserve flows: • Design a Rapid-Response-System (RRS) for checking if the Ecological Reserve is being implemented appropriately (Appendix 1E). Strategic planning related to monitoring against achievement of the TPCs: • Design an effective strategic monitoring system for the river catchment, associated with the TPCs. • Framework must allow for efficient use of scarce resources available within the river catchment, e.g. Ecological Water Resource Monitoring (EWRM) framework (Appendix 1F). • Document TPCs, including rationale and definition of the TPC bundles, monitoring program allowing for available resources (Appendix 1G). • TPC protocols (Appendix 1H) guide and prioritize monitoring activities at Level-3 sites. • Compile a running list of all TPCs deployed, indicating their status, whether exceeded or not, and/or closed due to management action. Governance arrangements and critical information needs within the river catchment: • Produce a SAM cycle conceptual plan - components and processes (Appendix 1I). • Consider all stakeholders, their involvement, connections and feedbacks between stakeholders (Appendix 1J).

SAM Phase	SAM Component (Environment theme)	Real-world examples from the Crocodile River Catchment
		• Document stakeholder responsibilities. • Differentiate all information requirements (Appendix 1K).
Adaptive Implement-ation	Implementation of plans	<u>Implementation of operational planning inputs</u>: • Work toward maintaining required river flows as determined by the Ecological Reserve benchmarks calculated linked to the Ten Bosch gauging weir. • Release water from the Kwena Dam when required. • Implementing water user restrictions when required. <u>Implementation of monitoring programs</u>: • Operational monitoring – observe river flows (real-time if available using telemetry) at the Ten Bosch gauging weir. • Strategic monitoring - implementation of all fieldwork related to the TPC monitoring plan, i.e. at all pertinent sites within the river catchment.
Adaptive Implement-ation	Checking Operational Outputs	• Implementation of operational inputs (e.g. dam operating rules, water user restrictions). • Check if actions are appropriate in manipulating the required Ecological Reserve benchmarks.
Adaptive Implement-ation	Auditing of Strategic Outcomes (e.g. fish support river reaches traversing KNP)	<u>Collation of monitoring data for each TPC, auditing TPCs and reporting</u>: • With available data from TPC monitoring, start collating these data for auditing against TPCs. • Determine any TPC exceedances using audit reporting (Appendix 1L - Fish TPC audit). • Make all TPC audit information available to EWRM operations (Appendix 1F). • "Red-flag" TPC exceedances or close to exceedance. • Report areas at risk e.g. fish support reaches of the Crocodile River losing their "C" EC. • Direct EWRM resources to the most critical areas of the Crocodile River Catchment, for further monitoring and reporting if required.

4.6 Adaptive feedback system facilitating single-, double-, and triple-loop learning for Ecological Reserve realization in the Crocodile River

The SRLF SAM cycle adaptive feedback system was deployed to facilitate single-, double-, and triple-loop learning potentials during Ecological Reserve implementation in the Crocodile River. This deployment is described below and example applications of this adaptive feedback system are detailed in Table 4.4.

Lower grade single-loop learning adaptive feedbacks occur rapidly for the collation of results emanating from river-flow monitoring sites along the Crocodile River. The Rapid-Response-System determines if the planning "inputs" are being implemented as required. If not, and the planning "outputs" are not occurring, then adjustment to implementation of river flow operations is required, to obtain intended output results over the short-term. Bi-monthly stakeholder meetings, as informal gatherings to determine if operations and feedback systems are adequate, are also conducted to improve the Rapid-Response-System over time. Pragmatic solutions to problems are often needed in order to implement the ecological Reserve, and at the river catchment scale there is large potential for these innovations due to less formal arrangements between stakeholders.

Upper grade single-loop learning adaptive feedbacks can occur every one to three years within meetings and workshop environments, involving all stakeholders. Here, adaptive assessments are made concerning strategic outcomes associated with implementation of the Ecological Reserve. All tabled thresholds of potential concern (TPC) audit reports are evaluated, and this supports efficient decision making, such as by adjusting existing action planning 'inputs', and or revising the TPCs themselves, particularly if these are first generation TPCs.

Double-loop adaptive learning feedbacks occur every three to five years, and include a prolonged consideration (reflection) of the FEPA related objectives (even if TPCs are not exceeded). Occurrence of surprises (i.e. unexpected outcomes) must be evaluated, in order to learn from these events (e.g. a related, but unexpected decline in a fish species of concern other than the indicator species, and/or undue impacts on irrigation crop farmers due to water use restrictions applied).

Triple-loop learning adaptive feedbacks occur every five to six years, with reflection and a full review of the Environment theme related sub-objectives and TPCs. This ideally is in association with the Economic and Community/Social theme SRLF SAM cycles (see McLoughlin and Thoms 2015). In addition, an evaluation of stakeholder network systems is required where increasing stakeholder participation is important. There is encouragement of key innovations, and transformation of stakeholder networks into more adaptive networks is important, promoting flexible and informal interactions.

4.7 Lessons learned about using the adaptive feedback system

The Crocodile River case-study sets an ANRM precedent for realization of the Ecological Reserve in South African catchments and highlights constraints from the higher governance levels. To be effective the three modes of societal learning must be adequately balanced within the SAM cycle and this is facilitated and guided by reflexive learning. The reflexive learning nested and overlapping set of adaptive feedbacks is needed to facilitate single-, double-, and triple-loop learning within an adaptive management cycle. Decision-making from this societal learning allows stakeholders to appropriately adapt/transform management when required in order to meet the FEPA related objectives.

Implementation of the SRLF SAM cycle for realization of the Ecological Reserve is a work-in-progress; a common feature of many ANRM programs of this nature (Allan and Stankey 2009). In the future, stakeholder interactions will play an increasingly important role for completing and then regenerating the SRLF SAM cycle as the modes of single-, double-, and triple-loop learning proceed over time. To date, a number of key lessons about using the SRLF SAM cycle and its adaptive feedback system have emanated from this Crocodile River Catchment case-study. The lessons are outlined in the following sections.

4.7.1 Adaptive feedbacks facilitating single-loop learning

Adaptive feedbacks for single-loop learning are mandatory and ongoing within the SRLF

Table 4.4. Societal learning potentials within the Crocodile River Catchment case-study, as guided by the Strategic adaptive management (SAM) cycle of the SAM Reflexive Learning Framework (SRLF). The nested feedback system demonstrates explicitly where and when to implement more immediate responses, adaptive assessment, adaptive reflection, and review with governance transformation associated with management in the Crocodile River Catchment. The feedback system facilitates single-, double-, and triple-loop learning, ultimately activating, completing, and then regenerating the SAM cycles associated with Ecological Reserve implementation in the Crocodile River (actual worked examples from this adaptive feedback system are given in Appendix 2).

Learning Loop Type	Environment theme: Adaptive feedbacks facilitating single-, double-, and triple-loop learning (based on real-world examples associated with management of the Crocodile River)
Adaptive feedbacks – Response system Lower-grade Single-loop Learning Facilitation	Adaptive learning potential using feedbacks within an immediate response system: The Crocodile River Rapid Response System (RRS) operates daily and/or weekly via rapid communication between stakeholders, using pertinent techniques for example email and/or telephonic methods (Appendix 1E). The RRS incorporates different worry-levels, each linked to a specified management response. Increased urgency is required if and when the different worry levels (Appendix 2A) are breached, using river flows recorded at the Ten Bosch gauging weir. The RRS gets feedbacks working as quickly as possible before river flows decline to unacceptable levels, relative to Ecological Reserve benchmarks calculated (Appendix 2A). In reality, instances occur when river flows into the "Medium" and even "High" worry-levels, however these are accepted based on conditions within the river catchment, e.g. timing for irrigation crops and unusually high evaporation rates due to certain weather events. The bi-monthly meeting of the Crocodile River Operations Committee (CROCOC) allows recommendations to be made concerning the Ecological Reserve and the actual RRS. A management log is generated each month and relevant statistics are used (Appendix 2B) in order to decide on what is working or not working, thus providing opportunity to adapt and improve the RRS over time.
Adaptive feedbacks – Assessments Upper-grade Single-loop	Adaptive learning potential using feedbacks within adaptive assessment routines: Testing ecological outcomes related to implementation of the Ecological Reserve is achieved by consolidating TPC audit reports emanating from monitoring sites along the Crocodile River. For example, TPCs developed for the fish support reaches of the Crocodile River traversing the KNP are intended as a "red-flag" for management if exceeded. Thus, informing stakeholders if the "C" ecological category (EC) is lost, or close to being lost (Appendix 2C). Thus, supporting decisions about adjusting management actions, in order to prevent these river reaches moving out of the "C" EC (or rehabilitating back to the "C" EC).

Learning Loop Type	**Environment theme: Adaptive feedbacks facilitating single-, double-, and triple-loop learning (based on real-world examples associated with management of the Crocodile River)**
Learning Facilitation	Adjustments to planning inputs may include, first, changing the timing and duration of flow events during various seasons as based on the hydrological model used for calculating the Ecological Reserve benchmarks. Second, additional data from monitoring may be required to assess further macro-invertebrate trends over time. Third, the actual monitoring protocol itself, e.g. the frequency of monitoring and the number of sites used and the TPC monitoring methods may be updated.
Adaptive Feedbacks – Reflection Double-loop Learning Facilitation	Adaptive learning potential using feedbacks within adaptive reflection routines: There are three different types of reframing that may occur. First, re-framing of assumptions (hypotheses and or models) associated with the actual TPCs themselves, using all newly acquired knowledge. For example, there have been major changes made to the original geomorphology TPCs (using abiotic indicators of fish habitat suitability) as used by the KNP for bedrock influenced rivers (Appendix 2D). Subsequent to implementation of monitoring associated with the original geomorphology TPCs, for assessment of bedrock-influenced river conditions, major changes to these TPCs was deemed necessary. A key query during this double-loop learning is asking the question whether the monitoring program of TPCs is feasible and therefore sustainable. Subjectivity involved with measuring various geomorphic units along representative reaches, and expert input required proved this not to be the case, hence although based on extensive research these TPCs required re-framing. In addition, new thinking suggested that the geomorphology TPCs were inadequate because they assumed very gradual, incremental change in the morphology of the river channel over time. This aspect was not suitable for “red-flagging” problems before increased sedimentation problems arose; therefore reflection about meeting objectives was restricted. Notably, new TPCs may be developed if and when there are pertinent TPC challenges posed over the previous three to five years. Second, re-framing of the action planning “inputs”, based on new knowledge, in relation to the revised and/or new TPCs developed. Making changes to the developed EWRM framework may be required (see Appendix 1F), for example changing the timing of monitoring efforts and responsibilities for various levels of this monitoring framework. Third, the method used for implementation of the Ecological Reserve needs reconsideration too, e.g. the algorithms used within the hydrological model may require updating based on new technical knowledge. On completion of adaptive reflection with re-framing, there must be implementation of these re-framed planning “inputs”, as part of the ongoing SAM cycle process.

Learning Loop Type	Environment theme: Adaptive feedbacks facilitating single-, double-, and triple-loop learning (based on real-world examples associated with management of the Crocodile River)
Adaptive feedbacks – Reflection/ Review Triple-loop Learning Facilitation	Transformational learning potential using feedbacks within adaptive reflection into review: Even if the FEPA related sub-objectives are being met, via successful implementation of the Ecological Reserve, this may be at the expense of the other themes, e.g. the Economic and Community/Social themes and related sub-objectives. Thus, a full review is done of the Environment theme sub-objectives in conjunction with these themes, including evaluation of the current TPCs being used. Queries may relate to the actual feasibility of meeting the FEPAs (i.e. river reaches in the A or B EC), and/or ECs of the fish support and upstream management areas. For example, a "C" EC for the main stem of the Crocodile River that is traversing KNP may be deemed inappropriate to achieve, due to impacts on sugar cane farmers for instance. The RRS is one key innovation where partnerships between stakeholders are being built up. For example, between the Inkomati-Usuthu CMA, KNP and other key stakeholders of the Crocodile River Catchment, related to operational and strategic monitoring activities of the Ecological Reserve (Appendix 2E). Overall, this leads to transformation of the stakeholder networks within the Crocodile River Catchment. With this, the Environment theme SAM cycle operating for management of the Crocodile River is completed, and set for regeneration which allows for the next iteration of this SAM cycle. This commences with re-formulation of all actions in order to meet newly devised sub-objectives and associated TPCs within the river catchment. For example, investigating new hydrological models for implementing the ecological Reserve, that may be easier to apply with better data efficiencies. With each iteration of the SAM cycle the river management system becomes more informal, flexible and more adaptive, for sustainable management of the Crocodile River, in line with achieving the FEPA related objectives.

SAM cycle because this is where progress is made within ANRM, i.e. incorporating the actual doing (Fabricius and Cundill 2014). These adaptive feedbacks facilitate implementation and/or improvement of the established Ecological Reserve management practices in the Crocodile River.

Lower-grade single-loop learning is fostered by using the Rapid Response System (RRS), where quick learning assists decision-making for adapting operations as these are being implemented. This is important because there are many uncertainties with getting the Ecological Reserve implemented. An example relates to the hydrological models used which are based on assumptions and have insufficient data for making precise predictions about river flow behavior. In addition, there is little experience in applying these models in determining the Ecological Reserve, further increasing probabilities for uncertainty and error. Hence, the RRS is employed to extend existing knowledge while the planning inputs are being implemented. Generally, this learning improves understanding about the quantity and timing of water releases from the Kwena Dam and the resultant changes to river flows. Improving information and knowledge about impacts of water restrictions on end users is another important output.

Monthly CROCOC meetings provide an important platform allowing stakeholders to debate operational management of the Crocodile River, including that for the Ecological Reserve using the summary statistics produced (Appendix 2B). For example, Ten Bosch gauging weir data loggers maintained by DWA proved unreliable causing lost trust among stakeholders concerning daily hydrological data. Thus, stakeholders agreed to purchase and install more reliable data loggers and maintain these themselves. This adjustment promotes confidence in monitoring river flows and is particularly important for measurement of river flow against the worry-levels of the RRS. Importantly, any adjustments to planning inputs that occur as a result of single-loop (upper-grade) learning and re-framed/new planning inputs due to double- and/or triple-loop learning (see below), will require ongoing feedbacks within the RRS and CROCOC, about how to improve operationalization of these changed planning inputs. Both the RRS and the bi-monthly CROCOC meetings provide a key mechanism for rapid and continual learning associated with technical operations of the Ecological Reserve linked to the Crocodile River.

Upper-grade single-loop learning for management of the Crocodile River is fostered by adaptive feedbacks within the use and auditing processes of the TPCs. Often, this form of learning is overlooked because attention remains too highly focused on operations to implement the appropriate river flows in the Crocodile River. However, delivery of the Ecological Reserve is not an end in itself because it remains a hypothesis - the best available knowledge about how to maintain a particular river Ecological Category (and conversion to an EMC). Collation of all TPC audit reports via the TPC tabling system allows assessments to be made to interpret the adequacy of the implemented Ecological Reserve. Assessment of all tabled TPCs (TPCs that are exceeded or close to be exceeded) compels stakeholders to make decisions about whether to make adjustments to the current Ecological Reserve planning inputs. For example, the original three-month time interval for calculation of the Ecological Reserve benchmark was considered inadequate for checking river flows against the RRS worry-levels. The resultant adjustment now implemented includes a weekly calculation of this benchmark, and this higher temporal resolution within the RRS allows for timelier stakeholder responses to any undesirable river flow in the Crocodile River, as measured at the Ten Bosch gauging weir. Other adjustments may include altering the volume of water released relative to different RRS worry-levels. During this upper-grade single-loop learning, stakeholders also peruse all summary statistics emanating from the RRS (Appendix 2B/C) to check Ecological Reserve delivery success over a specified time period. If delivery proves inadequate, then more effort is directed into technicalities of implementing the Ecological Reserve.

4.7.2 Adaptive feedbacks facilitating double-loop learning

The skill with incorporating double-loop learning in the SRLF SAM cycle is to avoid “learning for the sake of learning” (Fabricius and Cundill 2014). This is achieved by promotion of an appropriate balance between the modes of single-loop and double-loop learning (McLoughlin and Thoms 2015). Re-framing does not occur too regularly and is only invoked if and when required, because re-framing is often resource expensive. Furthermore, if done at the expense of the actual “doing”, re-framing can result in demoralizing stakeholders, resulting in a loss of momentum for implementing the Ecological Reserve. This has major negative consequences for management of the Crocodile River and achieving the FEPA related objectives.

Adaptive feedbacks facilitating double-loop learning includes a deliberate and lengthy reflection on the FEPA related objectives for the river catchment, resulting in a re-framing of the TPCs if required. Importantly, construction of the TPCs uses existing knowledge however incomplete this is, and is also influenced by stakeholder values at the time of TPC development (McLoughlin et al. 2011*b*). This inductive approach to TPC development means that stakeholders never attempt to finalize indicators and associated thresholds of the TPCs (or the actual TPCs themselves) because this is unrealistic due to the uncertainty inherent within these complex systems. Hence, TPCs are often developed as “first generation” TPCs (Biggs et al. 2011) and open to challenge and refinement as new knowledge becomes available and/or based on changing stakeholder values (McLoughlin and Thoms 2015). For example, the original geomorphology TPCs as used within KNP were regarded as unsuitable end-point goals of the FEPA related objectives, because they do not associate with any particular river Ecological Category. The re-framed geomorphology TPCs (Appendix 2D) have this Ecological Category association and therefore are more effective and used in the SAM cycle.

In addition, key innovations are required for re-framing of planning inputs, and this may include changing the hydrological modelling parameters and/or the Kwena Dam operating rules. For example, acknowledgement that an approximate 10 percent error exists within the weekly Ecological Reserve benchmark calculations (Mallory pers. comm.) meant that low-flow fluctuations are allowed within an “envelope” of acceptability, as defined by the “Low-worry” and “Medium-worry” levels of the RRS (Appendix 2A). This change was agreed to by stakeholders; however, if and when the “Medium-worry” level is breached then more urgency in management response is mandatory. This situation contrasts to more rigid and formal legal governance arrangements of the Ecological Reserve which demands compliance with precise estimates (see Pollard and du Toit 2011). Rethinking ways to increase river flows during the critical part of the dry season (August – September) is another important re-framing exercise required, because in this period the Ecological Reserve is often not complied with due to low flows and high relative water demand from irrigators. Furthermore, to diminish impacts of higher water restrictions needed due to the Ecological Reserve irrigation farmers need to seek ways to increase their efficiency with using available water. Experimenting with the timing of Kwena Dam releases for delivery of the Ecological Reserve can also be considered, for example, releasing dam water in conjunction with the international flow requirements into Mozambique.

Operationalization of the RRS thus suggests emergent social learning capacities associated with management of the Crocodile River (see Appendix 2A/B) given the legal and practical difficulties with implementing the Ecological Reserve. This is fostered by the bi-monthly meetings of the CROCOC where stakeholders have opportunity to interact on a less formal basis, debating management of the catchment's river systems.

4.7.3 Adaptive feedbacks facilitating triple-loop learning

Triple-loop learning is compulsory within the SAM cycle, for stakeholders to review objectives and end-point goals and for transforming within the adaptive management cycle. Adaptive feedbacks facilitating triple-loop learning must be deliberately imposed over longer time intervals, because all FEPA related objectives and their end-points (TPCs) require revision over time. This review enables the harvesting of any new knowledge and importantly for applying it back into the regeneration component of the SAM cycle. In addition, stakeholder values can change over time (McLoughlin and Thoms 2015). Relevant to the catchment scale, triple-loop learning also involves transformation of existing governance arrangements. This transformation is necessary because if governance arrangements remain too rigid this can impede the re-framing requirements of double-loop learning (Pahl-Wostl 2009).

There is increased potential for transformation of governance arrangements at SRLF Level-3 therefore as applied within the SRLF SAM cycle at the catchment scale. This potential to transform is due to less formal and more flexible governance arrangements occurring at the catchment scale, relative to the WMA and national scales (McLoughlin and Thoms 2015). Transformation within the Crocodile River Catchment includes attempts to broaden stakeholder participation and involvement in the CROCOC. For example, the Inkomati-Usuthu CMA is conversing with the mining sector more closely as this sector does not at present participate in the CROCOC, although it is certainly an important interested and affected party. In addition, flexibility of networking between CROCOC stakeholders is promoted by incorporating more informal stakeholder gatherings. Organizing out-on-site meetings has been shown to be important where stakeholders informally discuss river management aspects, for instance ecological monitoring, water extraction and other farming operations adjacent to the Crocodile River. Furthermore, the fostering of strategic partnerships between CROCOC stakeholders increases feasibility of the SAM cycle by spreading the task load among stakeholders. Strategic partnerships, e.g. delegation of the ecological monitoring and reporting functions to the KNP (Appendix 2E), assists in using scarce resources more efficiently.

Future triple-loop learning for realization of the Ecological Reserve must involve reformulation of the current intervention actions, for achieving all reviewed objectives and their TPCs. For example, rethinking and changing the types of hydrological models used for Ecological Reserve implementation and/or altering the actual Ecological Category itself, if this is considered impracticable to meet. Importantly, any major transformational change at the national scale, for example a paradigm shift in freshwater management away from the current Ecological Reserve concept, will impact application of the SAM cycle as applied within the Crocodile River Catchment. All objectives and end-point goals at this scale will then need to be revised and redeveloped in line with this new paradigm. This is the nature of the SRLF SAM cycle and using the ANRM approach to freshwater management within river catchments of South Africa.

Overall, the lessons from the Crocodile River are readily transferable to the management of other rivers. Further research is needed focused at the higher governance levels, i.e. at the WMA scale and national scale, in particular for furthering understanding about “top-down” (constraints) and “bottom-up” (learning) influences across these levels (see McLoughlin and Thoms 2015). Within this broader three-tier governance system, it is envisaged that learning involving the TPCs within catchments would be the main instigator of “bottom-up” feedbacks within the SRLF (McLoughlin and Thoms 2015), initially involving evaluation of all FEPA management targets within WMAs. Subsequently, consolidation of learning across all WMAs is required in order to evaluate achievement of the FEPA policy targets at the national scale. Here all freshwater stakeholders, from the river catchment scale up through WMA and national scales are united in their roles, responsibilities and mandates associated with implementation of the Ecological Reserve. It is acknowledged that further research is needed in exploring linkages between the Environment theme SAM cycles and the Economic and Community/Social theme SAM cycles of the SRLF, which is important for maximum NWA implementation.

4.8 Conclusion

An adaptive feedback system (reflexive learning) operating within catchments of South Africa provides an important resolution for getting the ANRM process initiated for realization of the Ecological Reserve. However, this Ecological Reserve realization requires working within constraints emanating from the higher governance levels. To practice effective societal learning within the adaptive management cycle, stakeholders are not seeking an optimum "once-off solution" to implementing the Ecological Reserve. Rather, they are engaging within an ongoing process of rethinking and negotiating their options (vis-à-vis Pahl-Wostl et al. 2007, Huxum and Vangen 2000), about how to modify inputs, outputs, assumptions, and hypotheses, which are linked to improving actions along with transforming governance at the catchment level. Success in initiating the Ecological Reserve is increased by maintaining the set of overlapping adaptive feedbacks which work to lubricate the "cogs" of single-, double-, and triple-loop learning. Hence, supporting an ability to adapt and change when required which assists in the achievement of the freshwater ecosystem objectives. Lessons learned, iteratively over time, and then applied back into ANRM will allow for a progressive implementation of the adaptive feedback system, thus for working toward Ecological Reserve realization. Lessons learned within the Ecological Reserve ANRM system of the Crocodile River Catchment are transferrable to other environmental watering cases globally.

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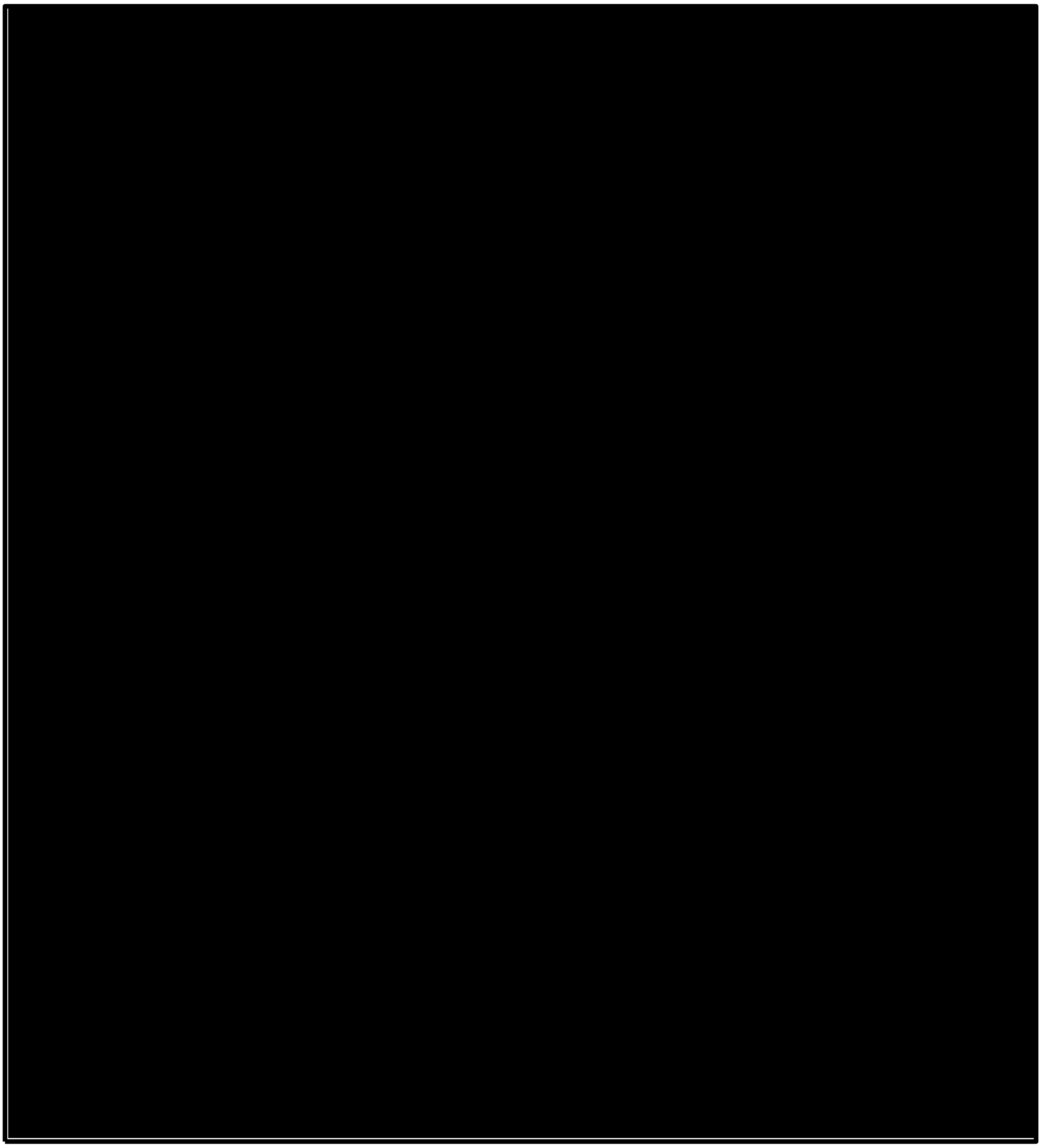
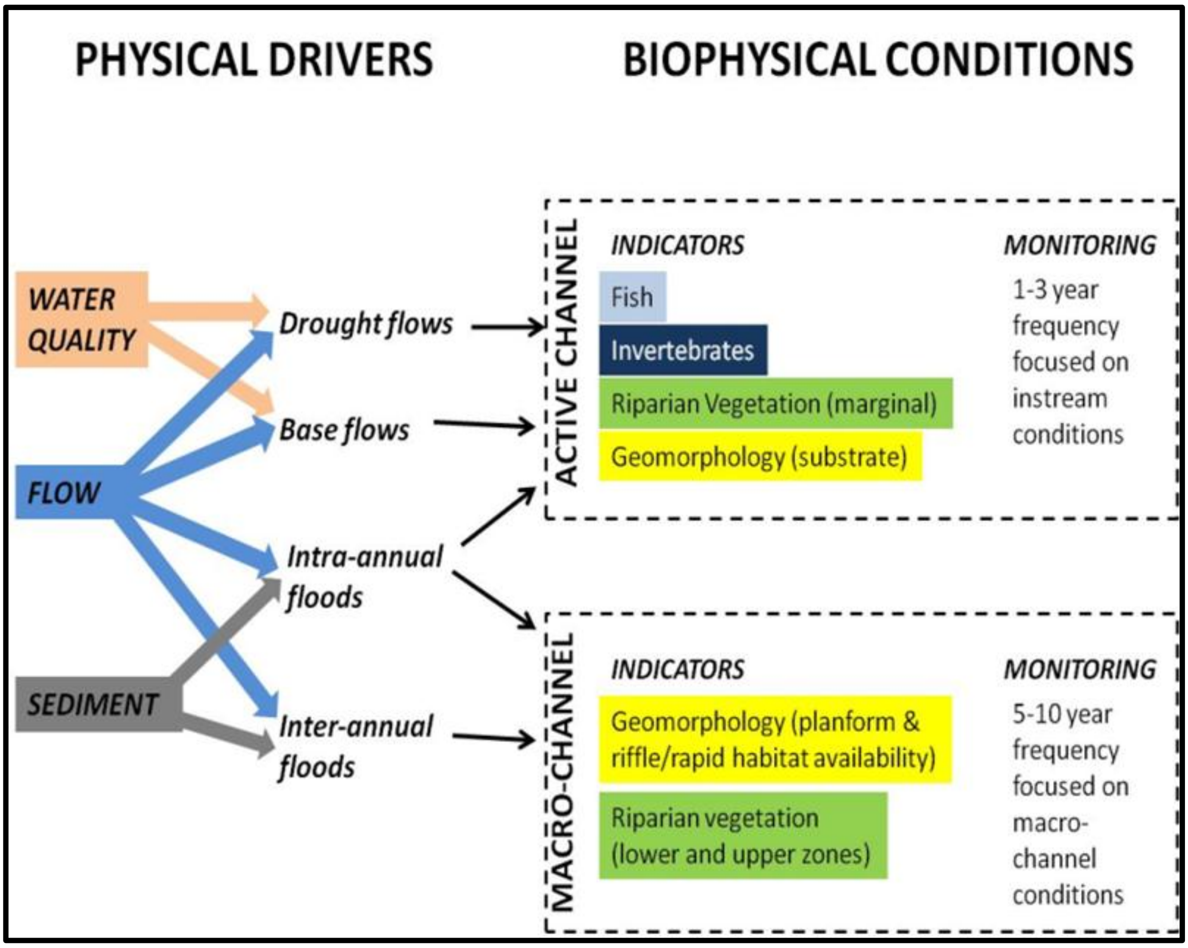
4.10 Appendices

Appendix 1A-L. Real-world examples - Crocodile River Catchment (Table 4.3).

Appendix 1A. FEPAs and associated support areas linked to the Crocodile River Catchment of the Inkomati Water Management Area. Source: Nel et al. (2011).



Appendix 1B. Pertinent river ecosystem related drivers and biophysical conditions associated with Thresholds of Potential Concern development. Source: McLoughlin et al. (2011a).



Appendix 1C. Macro-invertebrate related Thresholds of Potential Concern (TPC) associated with a river FEPA, Ecological Category "B" river reach of the Sabie River within the Kruger National Park. Source: Todd and Thirion (2010).

The following depicts an example (Sabie River reach 1) of the MI TPC output formats for all delineated river reaches along the Crocodile and Sabie Rivers (excerpt from the 2010 KNP Macro-invertebrate Project)

The Sabie River Catchment

Reach 1

Baseline description

Data included in the MIRAI is from KNP data from EWR3 2007, KNP data Sekuruwane 2009 and 2010, Lisbon 2009 and 2010 SASS biomonitoring surveys.

The SASS5 total score for the sites ranged from 164 to 203 and the ASPT ranged from 6.3 to 7.5. The Ecological Category determined is a B, corresponding to 84.7%.

The reference conditions used to derive the EcoStatus (MIRAI) were based on historical Rivers Database and KNP data for the reach, as well as taxa distributions from the same Ecoregions and Geomorphic zones, with similar altitudes (C. Thirion P*ers. Comm.*, September 2010). The reference total SASS5 score for the site is 220 with an ASPT of 7.8.

EcoSpecs and TPCs

The EC for this site is a B (84.7%).

The TPCs are set to alert managers that the PES of a B is in danger of not being maintained. The EcoSpecs are described for the PES.

Indicator taxa include: the flow-dependent cobble-dwelling macro-invertebrate taxa used for this site (Perlidae) which prefer velocities >0.6 m/s although they can also survive at other velocity categories and live on other substrates. Perlidae have a high sensitivity to water quality.

The flow-dependent cobble-dwelling macro-invertebrate taxa used for this site (Elmidae and Heptageniidae) both prefer velocities between 0.3 and 0.6 m/s although they can also survive at other velocity categories and live on other substrates. Elmidae are moderately sensitive to water quality whereas the Heptageniidae have a high sensitivity to water quality.

The vegetation-dwelling macro-invertebrate taxa used for this site are Coenagrionidae and Atyidae. Atyidae are moderately sensitive to water quality changes while Coenagrionidae have a low sensitivity to water quality changes.

Indicator Taxa

Overall preferences for the indicator taxa groups for Reach 1, Sabie River

Indicator Group	Families	Velocity (m/s)	Substratum	Water Quality
1	Perlidae	>0.6	Cobbles	High
2	Elmidae	0.3 – 0.6	Cobbles	Moderate
3	Heptageniidae	0.3 – 0.6	Cobbles	High
4	Atyidae	N/A	Vegetation	Moderate
5	Coenagrionidae	N/A	Vegetation	Low

Summary of TPCs and EcoSpecs for Reach 1, Sabie River

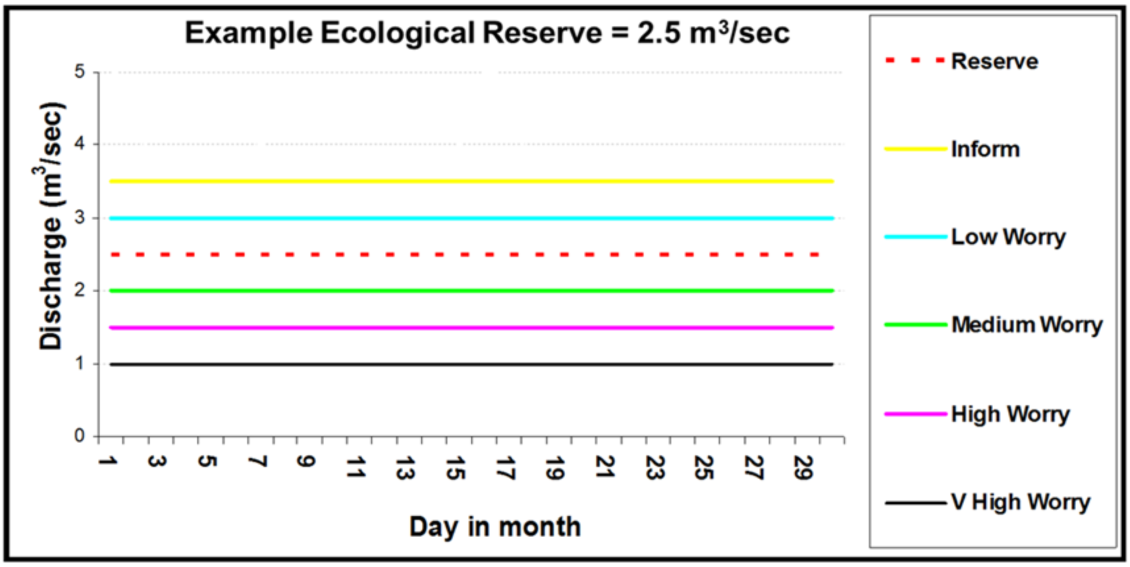
BIOLOGICAL ECOSPECS	BIOLOGICAL TPCs
To ensure that the SASS5 scores and ASPT values occur in the following range: SASS5 score: >160; ASPT value: >6.0.	SASS5 scores below 170 and ASPT below 6.2.
To ensure that the MIRAI score remains within the range of a B category (82% – 88%), using the same reference data used in this study.	A MIRAI score of 83 % or less.
To maintain suitable flow velocity (>0.6m/s) and to maintain clean, un-embedded surface area (cobbles) to support the following flow-dependent taxa: Perlidae (Abundance A)	If Perlidae is missing in two consecutive surveys or has a single individual present.
To maintain suitable flow velocity (0.3 – 0.6m/s) and to maintain clean, un-embedded surface area (cobbles) to support the following flow-dependent taxa: Elmidae (Abundance A) Heptageniidae (Abundance A)	Any one of these two taxa missing in two consecutive surveys or any one of these two taxa present as a single individual.
To maintain sufficient quantity and quality of inundated vegetation to support the following vegetation-dwelling taxa: Atyidae (A) Coenagrionidae (A)	Any one of these taxa missing in two consecutive surveys or any one of these two taxa present as a single individual.
To maintain suitable conditions for the following six key taxa: Perlidae Heptageniidae Elmidae Atyidae Coenagrionidae	Presence of less than four of the five key taxa listed in any survey.
To ensure that no group consistently dominates the fauna, defined as C abundance (>100) over more than two consecutive surveys.	Any taxon occurring in an abundance of >100 for two consecutive surveys.

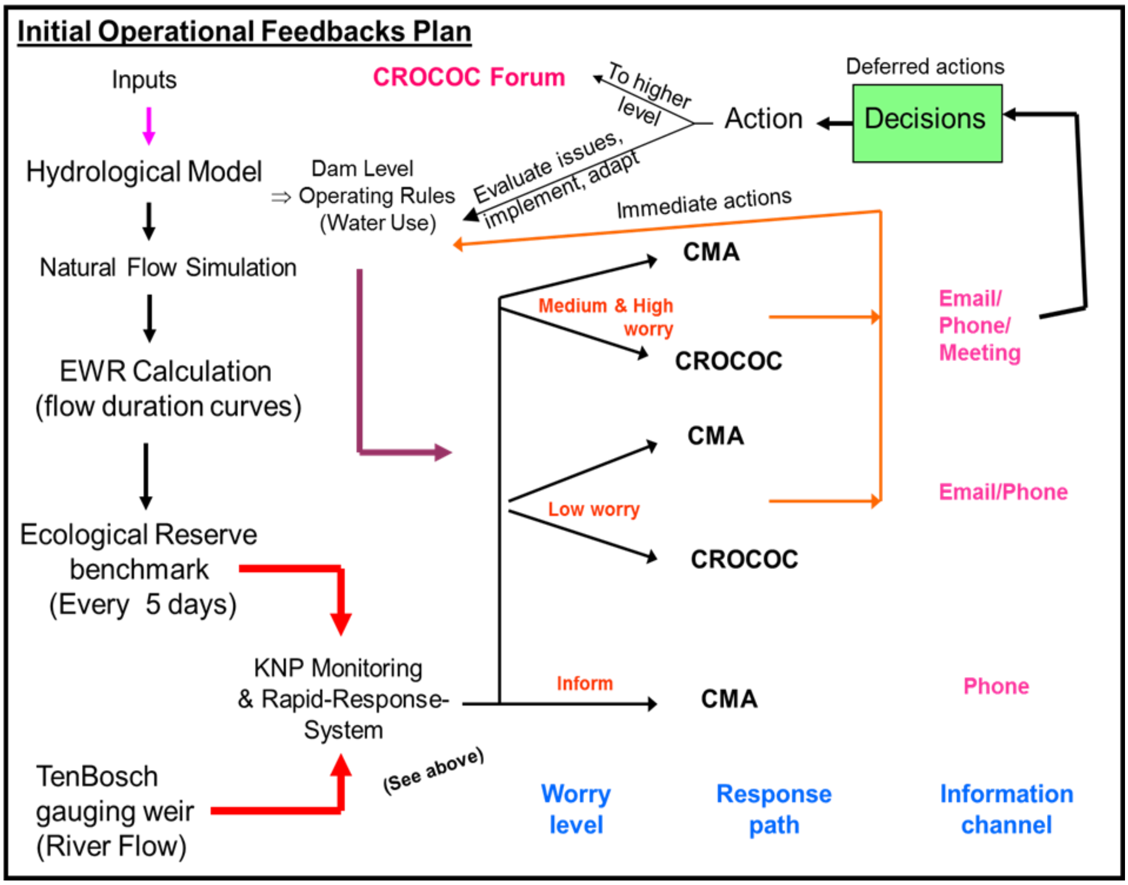
Appendix 1D. Fish related thresholds of potential concern for a "C" Ecological Category, linked to a FEPA fish support reach of the Crocodile River.

CROCODILE RIVER FISH TPCs: Reach 1

METRIC	INDICATOR SPP.	PES ECOSPECS	PES TPC (Biotic)
1. Species richness	all species	15 spp of the 34 expected indigenous fish species (for the reach) were sampled during the baseline (EWR) survey at EWR3.	Less than 13 fish species sampled during a survey when habitat can be sampled efficiently.
2. Alien fish species	any alien/introduced spp.	No alien fish species sampled at site during recent surveys	Presence of any alien/introduced fish species at site during any survey.
3. FD Habitats	BMAR & CANO (BEUT)	BMAR and CANO are expected to always be present at the site (conditions similar to baseline conditions).	BMAR and CANO present less than 100% of time (not sampled during any survey)
4. FS habitats Substrate	BMAR & LMOL	BMAR and LMOL are expected to always be present at the site (conditions similar to baseline conditions).	BMAR and LMOL present less than 100% of time (not sampled during any survey)
5. Flow dependant spp (flow teration)	OPER & CANO	CANO is expected to always be present at the site (conditions similar to baseline conditions) and OPER for 60% of the historical surveys.	OPER present less than 50% of time (not sampled for more than 2 consecutive surveys) and CANO absent during any survey
6. Water quality intolerance,	OPER & BEUT	Both species were sampled during baseline survey.	OPER and BEUT present less than 50% of time (not sampled for more than 2 consecutive surveys).
7. SD habitats	BMAR, TREN & OMOS	OMOS & TREN will be most appropriate indicators of SD habitats at the site.	BMAR absent during any survey (or with relative abundance <0.5 ind/min.) AND/OR both TREN and OMOS absent together during any survey.
8. Water column	BMAR, MBRE & OPER	Both species were sampled during baseline survey.	BMAR individuals of >150mm absent during any survey (both MBRE and OPER absent together during any survey.
9. SS habitats	BVIV	BVIV was present during baseline EWR survey	BVIV absent during any survey
10. Overhanging vegetation	BVIV & PPHI	Both species were sampled during baseline survey. BVIV is the best indicator of overhanging vegetation habitats	BVIV absent during any survey and PPHI present less than 50% of time (not sampled for more than 2 consecutive surveys)
11. Undercut banks	BEUT & PPHI	Both species were sampled during the baseline survey at relatively high numbers.	BEUT & PPHI absent during any survey
12. Instream vegetation	TREN & BVIV	TREN & BVIV will be most appropriate indicators of Instream vegetation habitats at the site.	BVIV absent during any survey

Appendix 1E. The Rapid-Response-System developed for the SAM cycle applied to the Crocodile River.





Appendix 1F. The Ecological Water Resource Monitoring Framework being implemented within the Crocodile River Catchment, for the strategic auditing of outcomes associated with the SRLF SAM cycle.

The following Ecological Water Resource Monitoring Framework (EWRMF) is designed for testing effectiveness of the Ecological Reserve (implemented or highlighting impacts of non-implementation) over time as part-and-parcel of the adaptive freshwater management system. It plays a critical role in ultimately assessing achievement of the broader adaptive management vision of the Inkomati Catchment Management Strategy, particularly associated with the water resource protection goals. The EWRMF is being piloted within reaches of the Crocodile East River systems of the Inkomati WMA contained within the Kruger National Park. The lessons - principles, methods and processes, linked to adaptive feedbacks and the broader SAM cycle, are applicable to river management at the catchment-scale, and must be applied at this scale, not just for those reaches of river within KNP itself.

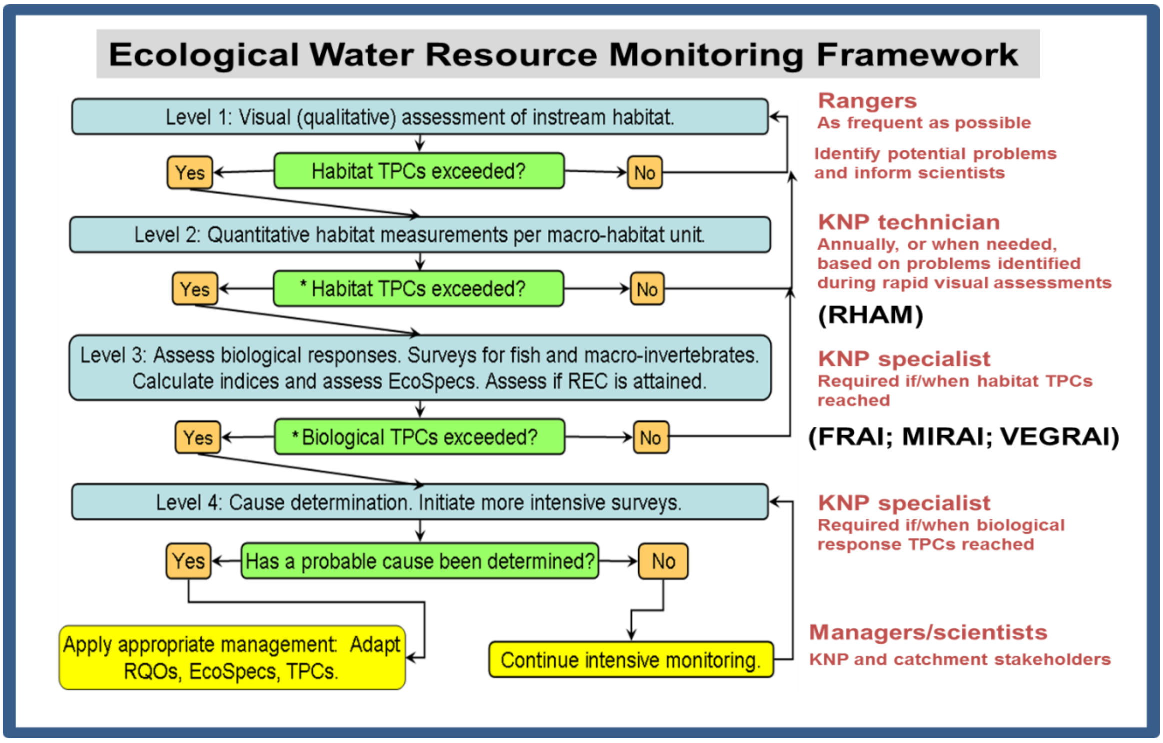


Figure F.1. The KNP modified Ecological Water Resource Monitoring Framework, to guide river biophysical monitoring and related decisions associated with the SAM cycle and assessing effectiveness of Ecological Reserve implementation. Source: adapted from Kleynhans et al. (2009).

There are four levels of monitoring intensity (Figure F.1). Simpler, more feasible monitoring is done more frequently, if or when thresholds of potential concern (TPC) are breached, then the next level of monitoring is considered, until pertinent management decisions can be made.

Appendix 1G.Threshold of potential concern documentation for the geomorphology associated indicators.

RIVER GEOMORPHOLOGICAL DIVERSITY
THRESHOLDS OF POTENTIAL CONCERN DOCUMENT

1. Motivational basis for these monitoring programs

Rivers form an important feature of any ecosystem and fulfil an even more important role in more arid regions. These life-supporting drainage lines are inseparable from their terrestrial surroundings; indeed, they are closely interconnected with and part of their catchment areas. It is partly changes outside river systems that affects and changes the latter, e.g. poor land-use practices resulting in higher sediment loads coming down the rivers. In addition to this, changed flows with lowered sediment carrying capacity cause all of the KNP rivers to undergo dramatic geomorphological changes. While past research contributed to improved and clearer understanding of aquatic and terrestrial ecosystems, more long- term information is required before one can create an even clearer picture of river dynamics. The importance of medium to long-term monitoring is emphasized by the 2000 flood which has caused considerable changes to the pre-flood river template. Understanding the effect of such large infrequent disturbances on river geomorphology and associated biota will have to be included in monitoring programs if better understanding of the functional role of river systems is to be achieved. This will provide many answers to the questions currently raised under the Water in the Landscape Objective, of which the Awareness Objective forms an important part. This latter objective will have to receive serious attention if the crises in which our rivers find themselves are to be resolved before it is too late.

2. Rationale for sampling plans and its balance with statistical considerations

In order to understand the dynamics of the KNP river systems, it is important to monitor the geomorphological diversity and dynamics, in other words, one need to know what kind of channel types are represented in each river and how these units change over certain time scales. The proposed technique involves the use of aerial photographs to delineate specified key units and determine their state changes. This has been tested and proves to be a robust and reliable technique.

The selection of sites along the rivers corresponds with key geomorphological units within representative reaches, regarded to be sensitive enough to act as indicators of changes in the broader river system. Any number of sites can be chosen within each of the five channel types, though time availability will dictate this. Number of grid blocks, the sizes of which are fixed at 20x20m, will be high enough to ensure an equally high degree of freedom to test for statistical significance. It must be stressed, though, that the emphasis is more on the amount (or percentage) of change within a certain reach and not so much on the sample size.

3. Geomorphology Thresholds of Potential Concern Monitoring

Sample intensity (time and space)	Sampling technique	Sampling sites	Sampling performed by
Temporal: every 5 years and events greater than 1 in 25 years (floods, etc). Spatial: 10^2-10^3m in identified representative reaches; currently only in Sabie and Letaba River (to be extended to other major rivers later).	Analyzing aerial photos by using an overlay grid and assigning geomorphological states per grid (20x20m ground grid size). Ground truth.	4 key units: - Bedrock core bar - Anastomosing bar - Bedrock pavement - Bedrock pool in 5 channel types: - Bedrock anastomosing - Alluvial anastomosing - Mixed anastomosing - Bedrock pool-rapid - Mixed pool-rapid	River scientist and technical staff to assist with ground truthing.

4. Monitoring program and persons responsible for or contributing to this program

The person being in charge of these programs is the Spatial Ecologist. Other people may be involved during different stages of the programs, especially when field surveys need to be done.

Alternative techniques for the geomorphological diversity monitoring are not yet available. High-resolution satellite and airborne LIDAR imagery are still too expensive or not available yet to replace aerial photography.

5. Questions expected to be answerable with these programs

The hypothesis states that the current alluviation trend suggests increased sediment storage in the rivers. This trend is directly related to decreases in sediment transport capacity and lower flows. This translates into loss of bedrock influence and associated biotic changes such as changes in plant composition and structure. The main question that can be answered is whether geomorphological diversity is decreasing or at least negatively affected in terms of loss of river characteristics or geomorphic units. Other related questions are whether terrestrial plant communities are replacing the riparian vegetation, whether species richness is declining and to what extent bedrock habitats are diminishing.

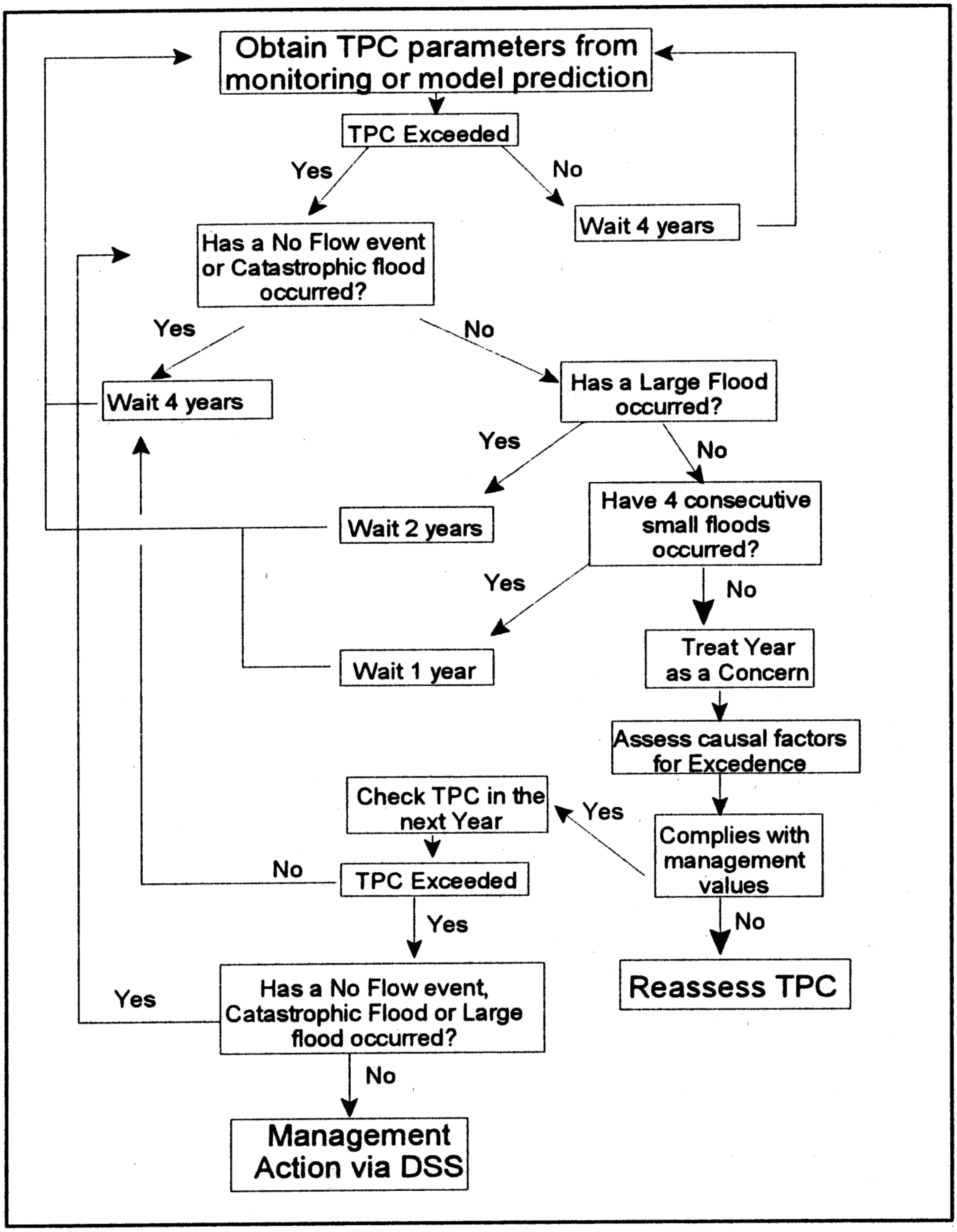
6. Expected consequences of TPC exceedances

Once a TPC has been reached, there are few options available as to how to respond. In the case of the geomorphological TPC’s, immediate action should be taken as the measured parameters are slow responders and by the time a TPC has been reached, considerable change has already occurred. No further time must be wasted but instead prompt action on the side of managers to address water usage upstream of the KNP. It is well-known by now, that alluviation of rivers is a direct result of changed flows, caused by water abstraction and reduced frequency of small floods. If these critical points can be addressed in a proper way, thus ensuring minimum base-flows (reserve) and simulate natural flows (especially different types of floods), this should lead to higher sediment transport capacity and thereby counter the alluviation process.

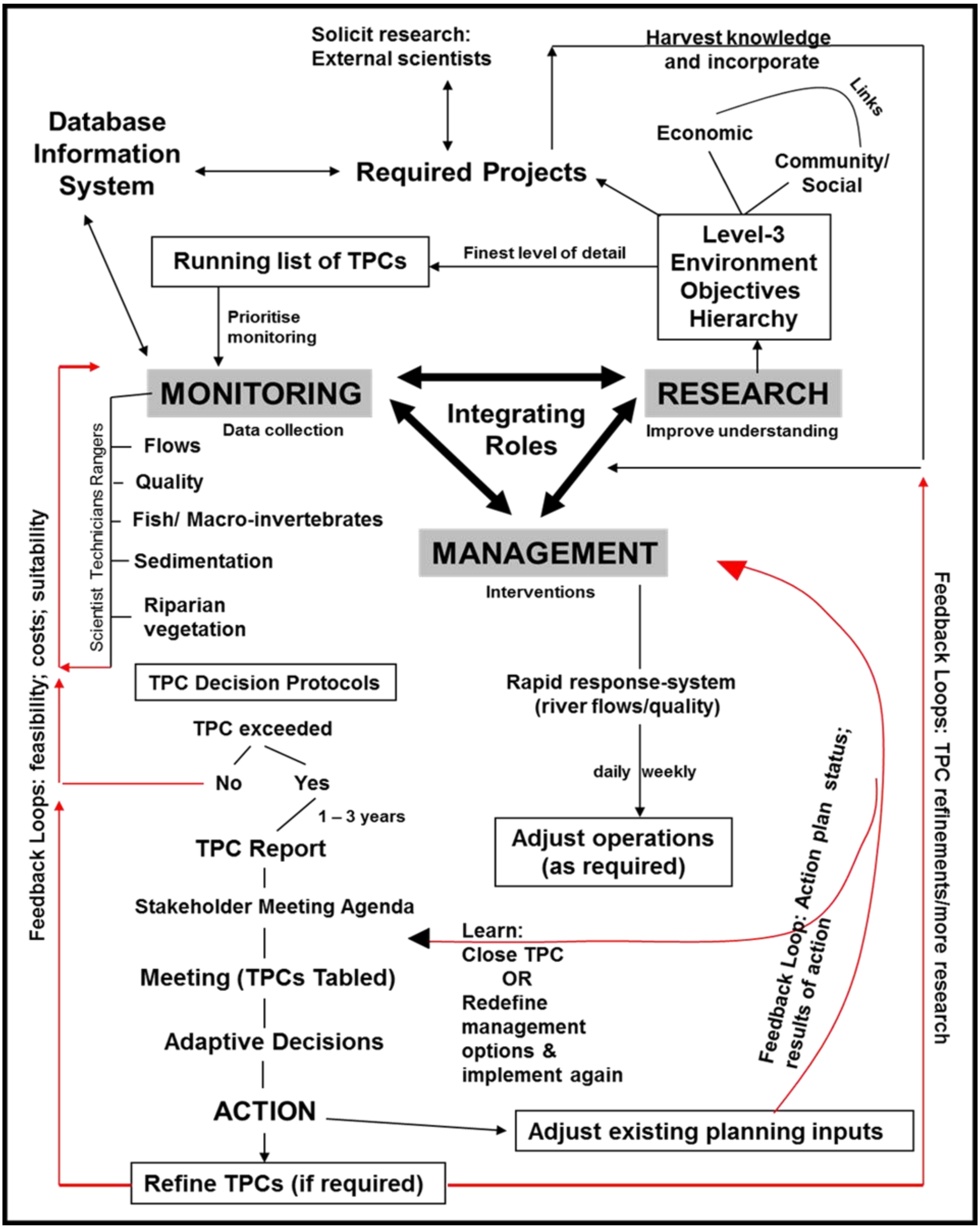
7. Costs of operationalizing the Geomorphology TPCs

Geomorphological diversity	**Fieldwork** costs are the following per river: Km = **R500** (R1/km rate using the Olifants River as average benchmark). - Subsistence and traveling = **R260** (4 days @R65/day). - Total **R760** (per river). - **Total ± R4000** (for all 5 main rivers	**Aerial photography** costs per river: **R1 800** (2 hours @ R900/hour flying costs). - **Total R9 000** (for all 5 main rivers).	**Analysis of aerial photographs** costs per river: - Probably around 3 days per river.
Grand Total	**R4 800**	**R9 000**	

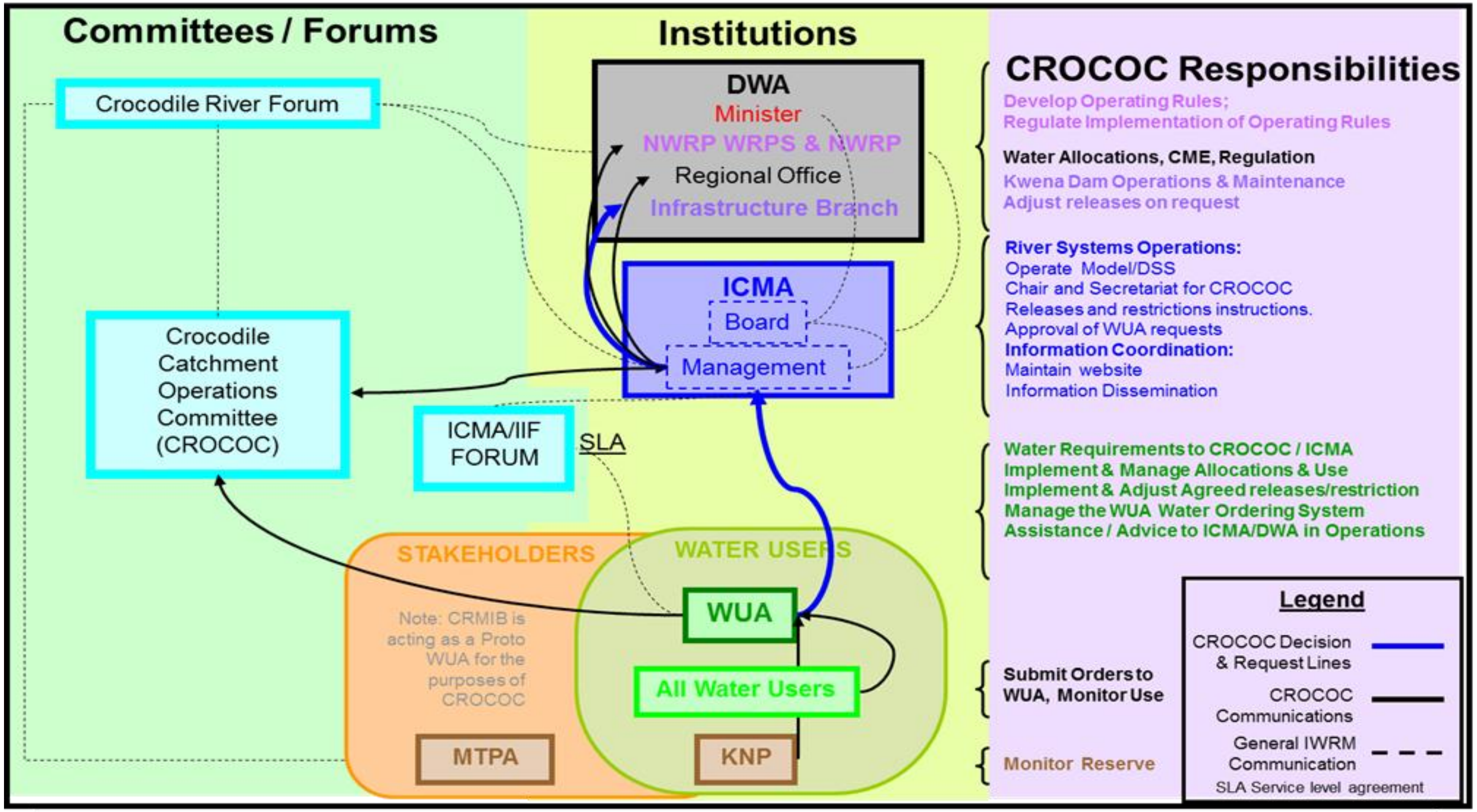
Appendix 1H. Example threshold of potential concern protocol, associated with the sedimentation management problem of mixed bedrock-alluvial controlled rivers, such as the Crocodile River. Source: Mackenzie et al. (1999).



Appendix 1I. Design of components and processes associated with the SAM cycle for adaptive implementation of the Ecological Reserve in river catchments of South Africa.



Appendix 1J. Governance arrangements for river adaptive management within the Crocodile River Catchment. Source: Inkomati Catchment Management Agency, Crocodile River Operations Committee Terms-of-Reference.



DWA = Department of Water Affairs; ICMA = Inkomati Catchment Management Agency; NWRP = National Water Resource Planning; WRPS = Water Resource Planning Systems; DSS = Decision Support System; IIF = Inkomati Irrigation Forum; WUA = Water User Association; KNP = Kruger National Park; MTPA = Mpumalanga Tourism and Parks Agency; IWRM = Integrated Water Resource Management; CRMIB = Crocodile River Major Irrigation Board

Appendix 1K. Information requirements and decisions needed for adaptive management of the Crocodile River. Source: Inkomati Catchment Management Agency, Crocodile River Operations Committee Terms-of-Reference.

ANNUALLY

INFORMATION NEEDS	DECISIONS REQUIRED
-Previous Year Water Use vs. Order	-Annual Water Allocations
-Water Orders & Distribution- current year	-Probability & Magnitude of Restrictions on Allocation
-Forecast of expected conditions	-History of Previous Decisions
-Dam, River & Rainfall Levels & compare to history	-Discuss / Review Operating Rules
-Scenarios (reserve, IIMA, new dams, WCDM, all towns strategies)	-Learning Strategy, reflection
-Bio Physical TPC info -Learning: Technical, social, sustainability, economic -Reflection/Evaluation of progress with new system -and change/adaptations required	-Impact of Reserve implementation on River Health -On track to longer-term plan/target for Reserve implementation

QUARTERLY

INFORMATION NEEDS	DECISIONS REQUIRED
-Water Orders and Use	-Review of Prevailing Catchment conditions
-Prevailing Catchment conditions	-Review Restriction Levels on allocations
-Dam, River & Rainfall Levels & compare to predictions	-Review Restriction Levels on dams
-Forecast of expected conditions	-Check implementation of annual decisions
-Dam, River & Rainfall Levels & compare to history	-Review monitoring, TPC refinements, -management action potential
-Scenarios -Check points on Bio-physical TPCs -Status of water quality and trends	

MONTHLY

INFORMATION NEEDS	DECISIONS REQUIRED
-Water Orders and Use (demands)	-Review of Prevailing Catchment conditions
-Report Back on Weekly operations, actions, decisions etc.	-Review Long term model output
-Prevailing Catchment Conditions	-Review year-to-date Water Use vs Order
-Dam Levels	-Review Demands
	-Possible Restriction Scenarios -Probable Dam releases
	-Data and information Exchange
	-International Obligation implementation
	-Reserve Status

WEEKLY / DAILY

INFORMATION NEEDS	DECISIONS REQUIRED
-Prevailing Conditions (flows, rainfall, releases, restrictions, levels, trajectories, reserve benchmark etc.)	-Dam Releases
-Short Term Forecast of expected conditions	-Short term restrictions on users
-Short term water demands -Communications regarding decisions and actions	-When to invoke the rapid response system within KNP: Worry levels

Appendix 1L. Fish related thresholds of potential concern - audit reporting.

Fish TPC Audit report

FEEDBACK ON FISH MONITORING WITHIN THE CROCODILE RIVER

1. Background

The Fish Response Assessment Index (FRAI) is used associated with fish sampled at RHP monitoring sites. However, although the data is different, there are similar outputs achieved – concerning the various metrics used in model calculations, indications of impacted (fish) indicators related to these drivers, and importantly the EcoStatus scores that are outputted. The SANParks Fish Specialist, has conducted the RHP monitoring in KNP, associated with fish and the FRAI, and has documented the processes involved.

2. Definition of the TPC

The current EcoSpecs and TPCs associated with fish indicators for reaches of the Crocodile River traversing the Kruger National Park were developed during the Comprehensive Ecological Reserve study conducted in 2010. The complete list of EcoSpecs and TPCs (sourced from the Ecological Reserve study), for 12 different ecosystem metrics, are given for the Crocodile River – Reach 1 (Figure 1) and reach 2 (Figure 2).

3. Data / information supporting the TPC

Fish monitoring, as part of the RHP, was conducted along the Sabie and Crocodile Rivers in KNP during 2008 and 2011 by the fish ecologist at all monitoring sites. The FRAI model was run for both river reaches of the Crocodile River, and the upstream reach of the Sabie River. To accomplish this, all data from RHP sites falling within a particular river reach were grouped and analyzed within the FRAI model per reach. Thus, FRAI outputs are given per river reach. TPC breaches in 2011 at specific sites instigated further fish monitoring in 2012, along the length of the Crocodile and Sabie Rivers.

4. Current Status/Results

Using results from the FRAI models determined and run per river reach the following sums up the TPC status subsequent to the 2012 fish sampling campaign within the Crocodile River of KNP:-

In connection with the EcoStatus and Ecological Category TPCs, associated with trajectory of change within Crocodile River Reach 1 and 2, the current river ecosystem condition remains within the system boundaries defined by the Ecological Category "C" (see Figure 3), and also within the set thresholds of concern for this Ecological Category.

Major Crocodile River concern is the Malelane site, which has the following TPCs flagged:-

1. Flow dependant spp (flow alteration) and water quality intolerance
TPC status: CPRE present at site; OPER not sampled, scarce:
TPC flagged – Review OPER as an indicator species.

2. FS habitats and substrate
CPAR present at site; LCYL but is expected:
TPC flagged – Review LCYL as an indicator species; review habitat.

4. Relative abundance
Relative abundance of 0.3 individual per minute sampled at the site is much less than the prescribed 1.5:
TPC flagged - Review habitat at Malalane and abundance of expected species.

5. Undercut banks
MMAC & PCAT absent at site; potential habitat in deep, fast flowing water:
TPC flagged - Review habitat at Malalane and abundance of expected species..

6. Water column
BMAR present at site; MBRE is absent and scarce:
TPC flagged - Review habitat at Malalane and abundance of expected species.

7. SS habitats
BVIV present, but BRAD absent:
TPC flagged - Review habitat at Malalane and abundance of expected species.

6. Water column
BMAR present at site; MBRE is absent and scarce:
TPC flagged - Review habitat at Malalane and abundance of expected species.

8. Overhanging vegetation
BVIV present, but BTRI absent:
TPC flagged - Review habitat at Malalane and abundance of expected species

10. In-stream vegetation
BMAR present; TREN absent.
TREN - the survey site did not have adequate habitat available since it is a rapid/riffle and run habitat:
TPC flagged - Review habitat at Malalane and abundance of expected species.

11. Species richness
Less than 10 fish species were sampled using electro-fishing during the current survey
Deep fast flowing habitat could not be sampled efficiently:
TPC flagged – Review habitat at Malalane and feasibility of site.

The Malelane site has the following TPCs exceeded:-

Crocodile River: Malelane Reach

2008 TPC	2012 Survey
Baseline (PES) FRAI score of 66.1 calculated for reach. Any decreased FROC in reach of especially CPAR, CPRE, BMAR, OPER, MMAC & PCAT or FRAI scores decreasing below 63% (low C).	Baseline (PES) FRAI score of 67.1 calculated for the reach (adjusted). A decreased in FROC in reach (a number of *Barbus* species, BFRI, BANN, BTOP and BUNI; other small fish: BIMB and MBRE). A decreased in FROC in reach of especially OPER, MMAC & PCAT. FRAI scores did not decrease below 63% (category C).
TPC status: FRAI score adequate, 67.1% (above 66.1%); OPER, MMAC & PCAT all absent; a decreased FROC – 6 fish species absence during 2010 to 2012 surveys, creating a worry level. **TPC breached – decreased FROC in reach** **Flagged!**	

1. Flow dependant spp (flow alteration) and water quality intolerance
CPRE present at site; OPER not sampled, scarce: TPC breached.

5. Undercut banks
MMAC & PCAT absent in reach: TPC breached.

6. Water column
BMAR present at site; MBRE is absent: TPC breached.

5. Proposed management actions for the Crocodile River

The main consideration along the Crocodile River is the Malelane site:
The EWR 5 (Malelane) site compromises TPC process because it was chosen for feasibility, and for ideal hydraulic measurements.

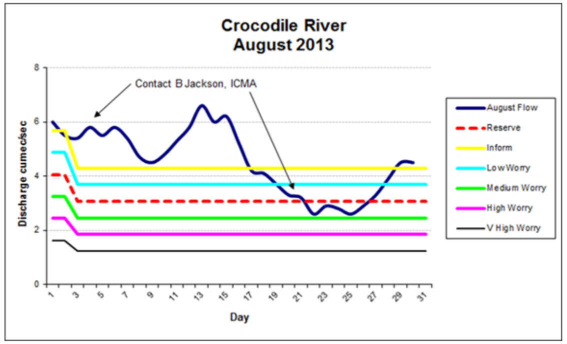
- Habitats at the site and immediately surrounds are not ideal for fish monitoring; the habitats are limited to riffles and the fast deep run is not accessible due to crocodiles.
- 6 of the 35 indigenous fish species were sampled during the baseline (EWR) survey. It is expected that around 21 species should be present at site. However, sampling conditions were not optimal because of high flows and crocodiles.

There are two possible management responses recommended:
1) Adapt the TPCs at the Malelane Site to reflect the low species presence and abundance; or
2) Move the fish survey site to the Ludwich's Lust site (5 km downstream of Malelane Site)

Overall, further intense monitoring is required at the Malelane site, as part of the EWRM framework, in order to identify the main drivers (water quality and/or river flow) impacting this site. The issue of low flows (falling under ecological Reserve benchmarks) and high levels of pollution entering the river, exacerbating the algae problem, requires further inputs and research.

Appendix 2A-E. Real-world examples - Crocodile River Catchment (Table 4.4).

Appendix 2A. Operation of the Rapid-Response-System associated with adaptive management of the Crocodile River.



SRLF Level-3

Activation of the Rapid-Response-System (22 August 2013)

CROCOC Stakeholder	Feedback Comments within the adopted Rapid-Response-System
KNP	Please note that the flow in the Crocodile River at Ten Bosh dropped to the high worry zone where action is needed so that river flow is maintained. In fact, the flow dropped from 3 cumec to 2 cumec this morning. Would you urgently look into this please, thanks?
CRMIB	We are monitoring the situation. As you can see there is huge variability in the flow on a daily and weekly basis. Normally this time of the week is the lowest flow of the week which should be taken into account. We are also not sure that the bottom measuring weirs readings are correct; we are visiting each weir and taking the physical readings. A lot of poor decisions have been made in the past based on wrong readings. We will re-assess the situation tomorrow morning, hopefully with verified information taking into account the current variability of flow in the river system.
Inkomati CMA	[To Inkomati technician] Please get inputs from all concerned. Are we happy our reported flows at Ten Bosch gauging weir are correct?
Inkomati CMA	Please note that out hydrologist and technician visited Komatipoort and Ten Bosch on Friday last week to calibrate our Inkomati CMA data loggers. They did not need much adjustment then. The CRMIB technician has just sent us a manual reading today and it correlates well with our current readings. The readings are thus OK this time for the ICMA loggers. However, we realise that none of you can see the ICMA data though. We are sorting that situation out tomorrow, and from Monday the flow rates on the ICMA http://riverops.inkomaticma.co.za website will be our own loggers with the flows shown. We suggest that these flows then get used for monitoring. The [KNP river technician] is basing his flows on DWA data and we do not know the state of that. However, the DWA flow being used appears to be similar to ours so we believe the flow is really that low. [To CRMIB] Please note that our recently calibrated Karino gauge is also showing just over 6 cumecs. This is rather low and does not bode well for the river recovering well over the next few days. We must keep a careful eye on the situation. Warm windy weather next week will probably affect the flow drastically and we must thus start considering some release. Let's look again tomorrow.
CRMIB	If the flow is actually correct, then we need to release some water out of the dam despite the fact that the flow will increase over the weekend. Let us look at tomorrow's flow and then we can recommend the flow needed from the dam.
KNP	Thanks for that, we are waiting for you then. Yes, this time of the year the flow at Ten Bosh gauging weir does vary a lot, even in one day. Can't be too good for the ecology I guess.

KNP: Kruger National Park;

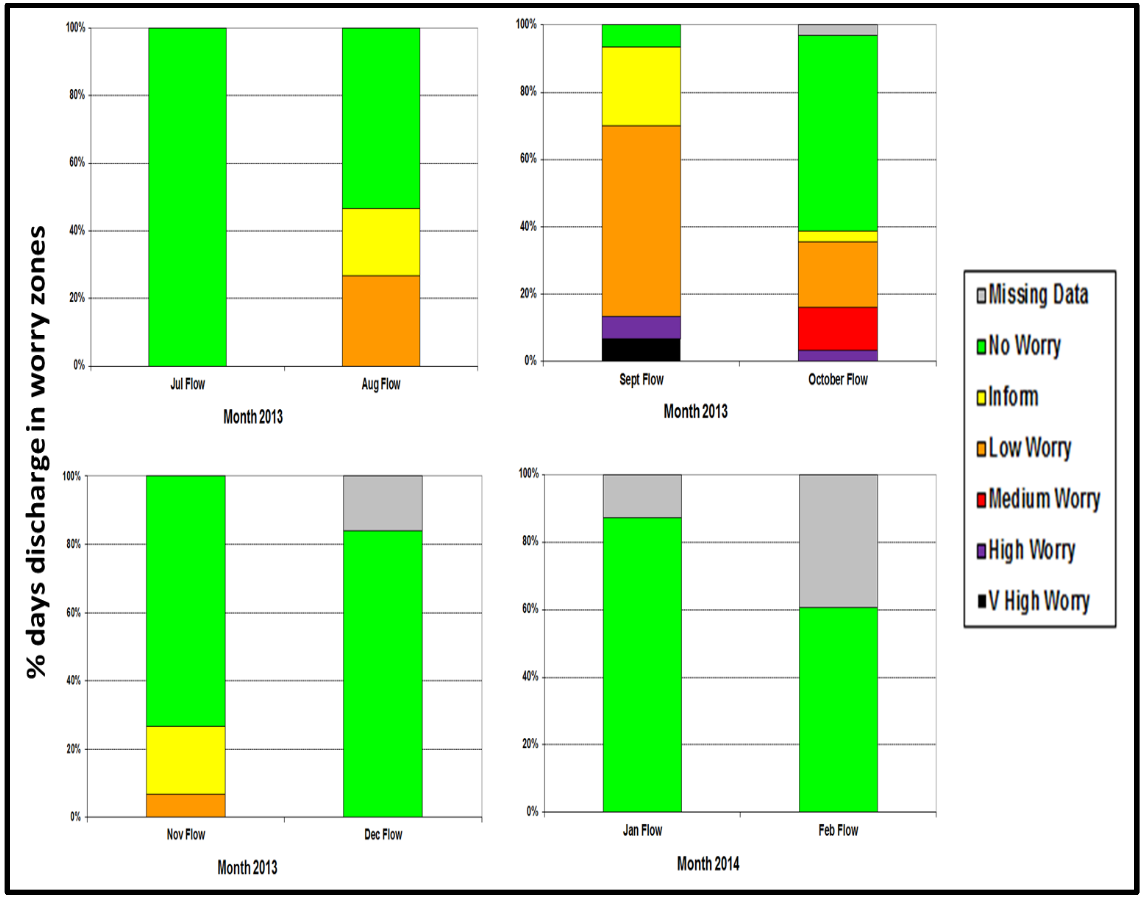
CRMIB: Crocodile River Main Irrigation Board;

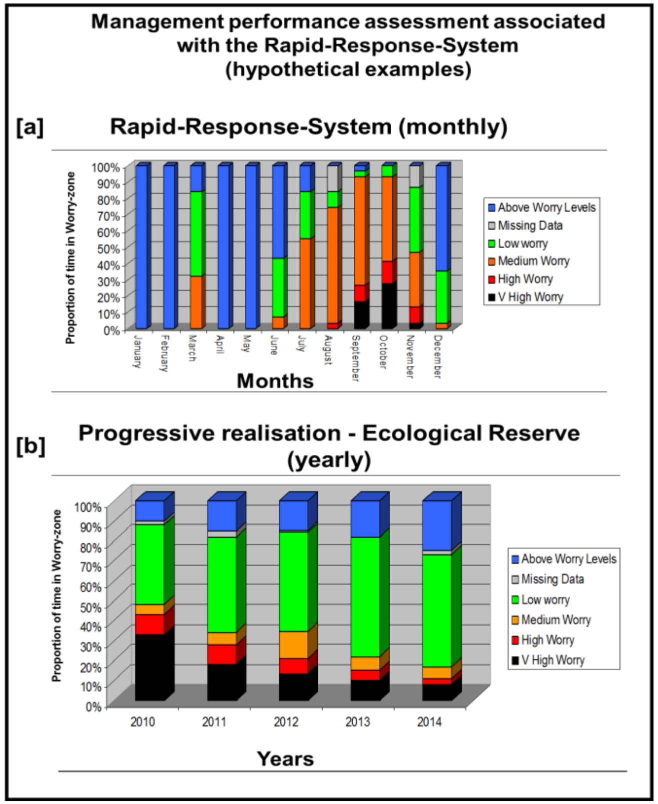
CMA: Catchment Management Agency

Appendix 2B. The management log and associated statistical outputs related to the Crocodile River Rapid-Response-System.

CROCODILE RIVER MANAGEMENT COMMUNICATION LOG SHEET

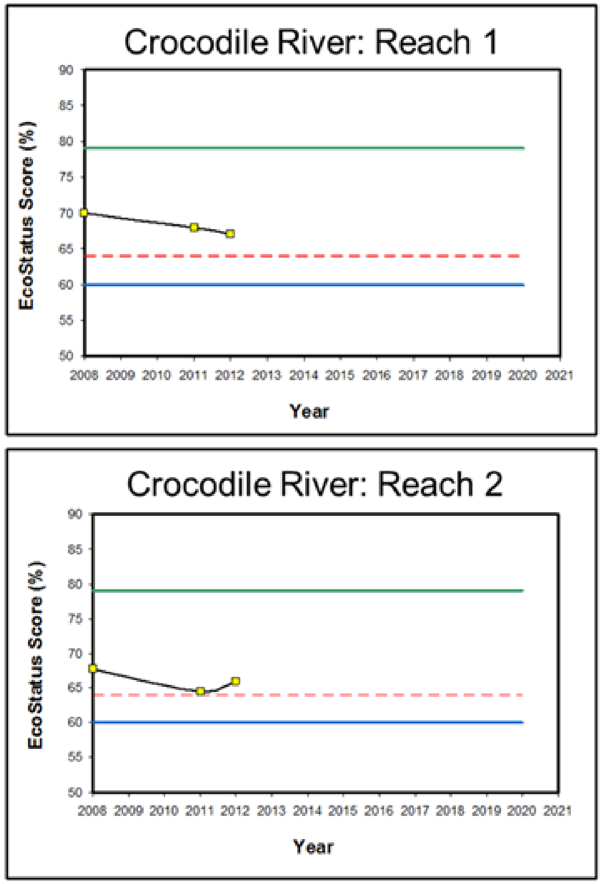
Management Problem	Management Options	Management Action	Result
11 Aug 2015 The flow in the Crocodile River at Ten Bosh dropped to the High worry level and even as low as 0 cumec at times over the weekend	1. Inform DWS / IUCMA 2. Change dam releases 3. Water Restrictions 4. Verify flow readings **Informed IUCMA**	IUCMA responds: We are investigating. We think it is correct. Not sure why. Also not sure why the reserve requirement has gone up. That is also weird as the exceedance curves for July and August are almost the same. The model is sensitive to the observed flows and they were slightly higher last week due to the short pulse of extra flow we released from Kwena the previous week. The reserve will probably come down again next week. The irrigation board has imposed further restrictions as of yesterday and we have also asked them to respond on the situation as they have promised to manage the flow situation. We are awaiting their response. We want to try and manage the flows through restrictions and different pumping hours for different farmers. The irrigation board is working on something and will revert to us shortly. We don't want to release more from Kwena if we can help it due to the drought. We are already in the upper quartile of releases from Kwena for this time of year so cannot release much more or we will exceed our upper limits and empty the dam too quickly. We have also been engaging with the municipalities to start awareness campaigns on the drought in preparations for restrictions.	Flow recovered a little after the weekend as was expected and is now in the Medium worry level





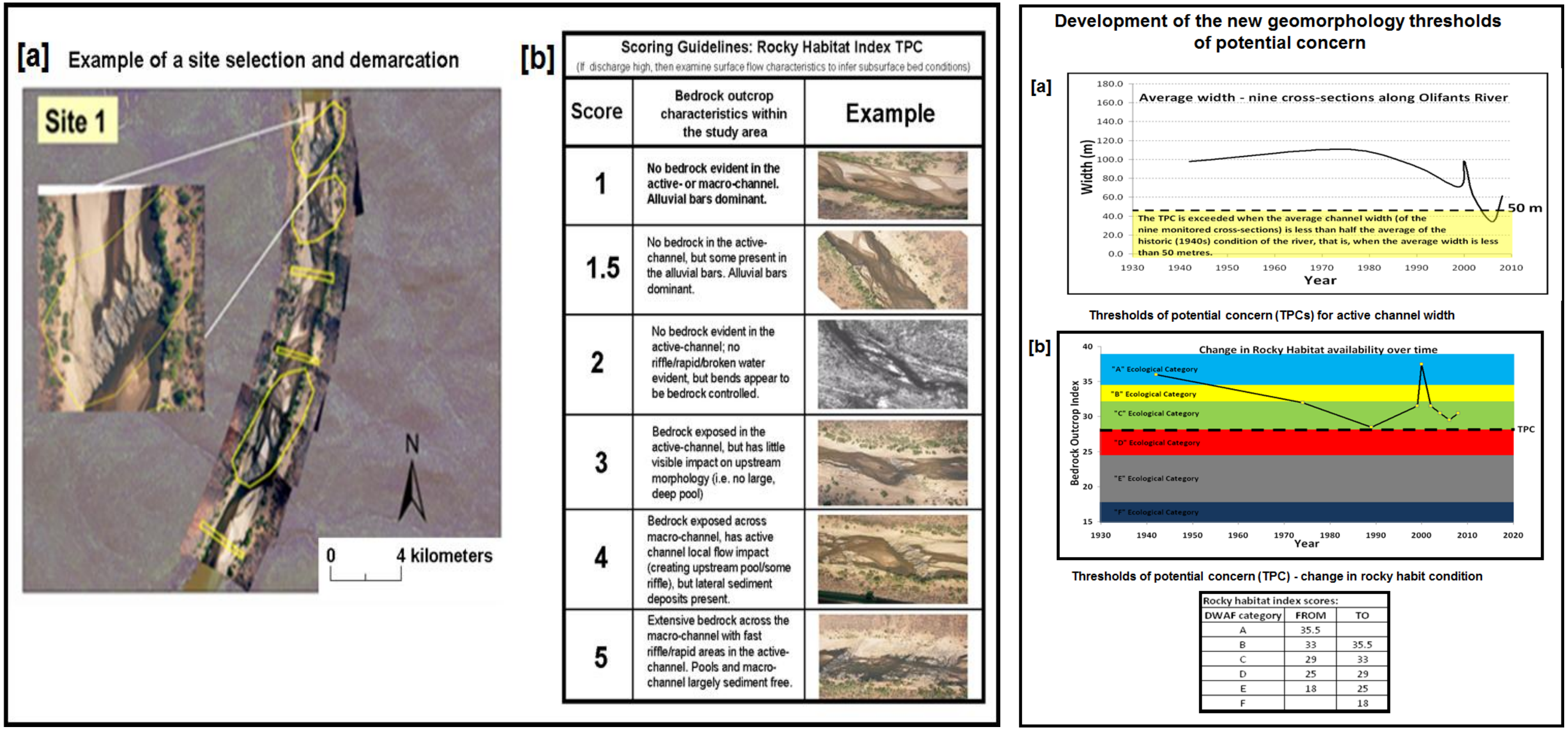
Relevant statistics presented at the bi-monthly Crocodile River Operations Committee meeting. These statistics provide stakeholders with an idea of success in delivering the Ecological Reserve in the Crocodile River, over eight months.

Appendix 2C. Monitoring outcomes linked to FEPA fish support reaches along the Crocodile River, maintaining the "C" Ecological Category.



EcoStatus score change associated with TPC outputs for Fish indicators of the Crocodile River, reach 1 (Malelane) and reach 2 (Nkongoma). The green and blue lines are the upper and lower limits, respectively, for the "C" Ecological Category. The red broken line is the worry-level for losing the "C" Ecological Category.

Appendix 2D. The new re-framed geomorphology related thresholds of potential concern for mixed bedrock-alluvial controlled rivers, such as the Crocodile River.



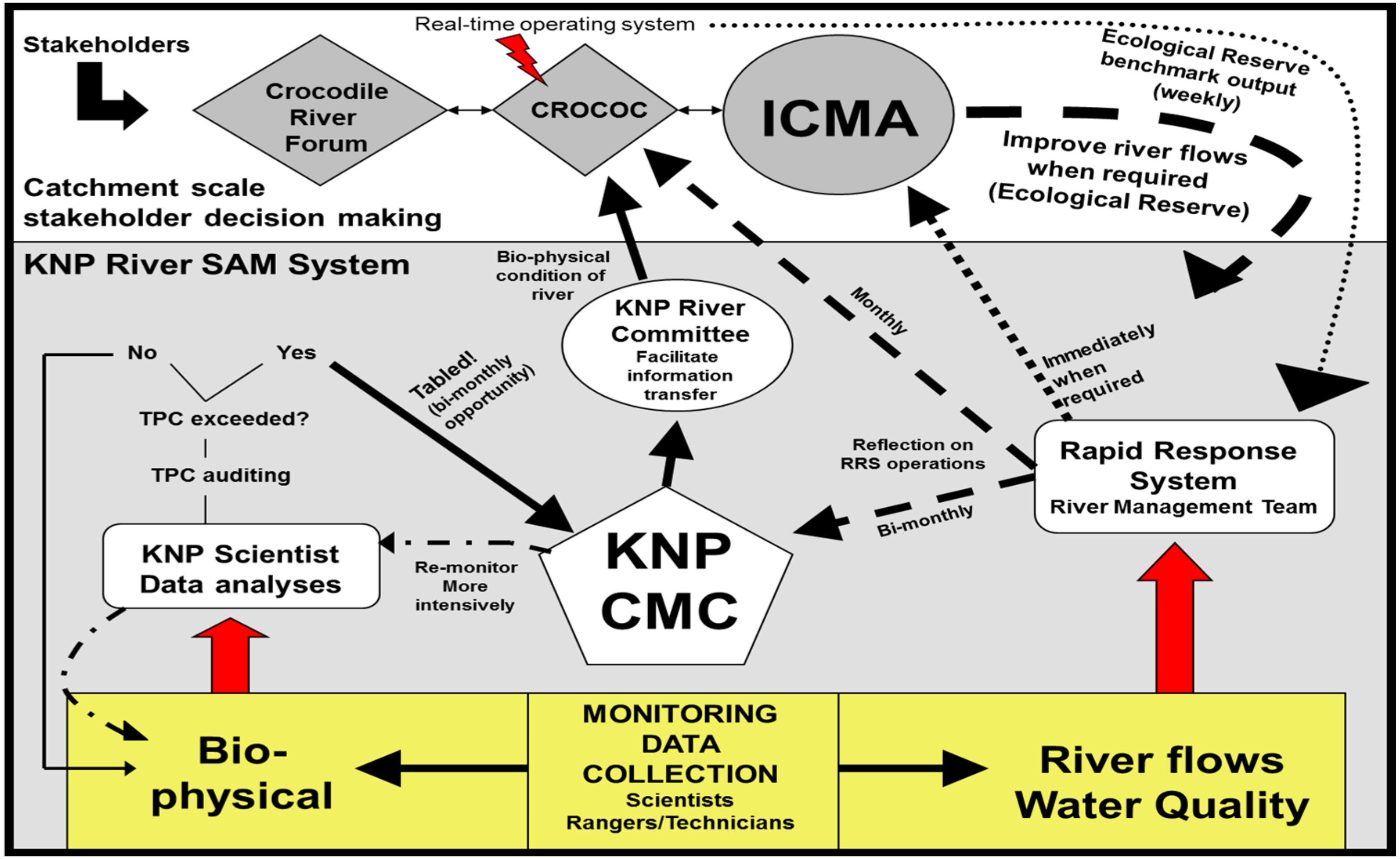
Score	Bedrock outcrop characteristics within the study area	Example
1	No bedrock evident in the active- or macro-channel. Alluvial bars dominant.	
1.5	No bedrock in the active-channel, but some present in the alluvial bars. Alluvial bars dominant.	
2	No bedrock evident in the active-channel; no riffle/rapid/broken water evident, but bends appear to be bedrock controlled.	
3	Bedrock exposed in the active-channel, but has little visible impact on upstream morphology (i.e. no large, deep pool)	
4	Bedrock exposed across macro-channel, has active channel local flow impact (creating upstream pool/some riffle), but lateral sediment deposits present.	
5	Extensive bedrock across the macro-channel with fast riffle/rapid areas in the active-channel. Pools and macro-channel largely sediment free.	

Rocky habitat index scores:

DWAF category	FROM	TO
A	35.5	
B	33	35.5
C	29	33
D	25	29
E	18	25
F		18

Left - methodology for the new geomorphology thresholds of potential concern: site selection (a) for the Rocky Habitat Index scoring system (b) for suitability of habitat. Right - new geomorphology thresholds of potential concern (TPCs) related to an Ecological Category of the Ecological Reserve. The TPCs are developed relative to a time of more pristine conditions occurring in the river: Rocky Habitat Index (a) and Active-channel Width (b) TPCs (habitat availability).

Appendix 2E. Partnership responsibilities between the Kruger National Park (KNP) and the Crocodile River Operations Committee (CROCOC) stakeholders, for implementation of the feedbacks within the SAM cycle of the Crocodile River (SAM: Strategic adaptive management, CMC: Conservation Management Committee, ICMA: Inkomati-Usuthu Catchment Management Agency).



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Name of Candidate: **Craig Anthony McLoughlin**

Name/title of Principal Supervisor: **Professor Martin Thoms**

[redacted]

12/11/2015

Candidate Date

[redacted]

12/11/2015

Principal Supervisor Date

CHAPTER 5. EMBRACING UNCERTAINTY ACROSS THREE LEVELS OF GOVERNANCE IN COMPLEX WATER REFORMS: A CASE-STUDY OF ADAPTIVE FRESHWATER MANAGEMENT IN AUSTRALIA'S MURRAY-DARLING BASIN

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Name of Candidate: **Craig Anthony McLoughlin**

Name/title of Principal Supervisor: **Professor Martin Thoms**

[redacted]

12/11/2015

Candidate　　　　Date

[redacted]

12/11/2015

Principal Supervisor　　　　Date

ABSTRACT. Embracing uncertainty under water reforms, globally, demands that adaptive freshwater management with its enhanced learning potentials replace conventional command-and-control styles of freshwater exploitation. However, increased complexity involved with practicing learning over many governance levels of freshwater management contributes to difficulties with implementing this learning. Inability to practice effective adaptive freshwater management is an impediment to successful water reforms. In Australia's Murray-Darling Basin proponents of adaptive freshwater management seek to control or eliminate uncertainty rather than embracing this uncertainty under complex water reforms. Dealing with uncertainty allows for better response of practitioners and their stakeholders to the challenges of implementing environmental watering. In this manuscript we apply the Strategic adaptive management Reflexive Learning Framework to the complex multi governance-level environmental watering system within the Murray-Darling Basin to demonstrate the ongoing societal learning, needed for effective implementation. Adaptive feedback systems are deployed to facilitate the modes of single-, double-, and triple-loop learning within adaptive management cycles per governance level, with linkages across levels. Societal learning is fostered via an explicit recognition of practitioner mandates across governance levels; never attempting to finalize objectives by adoption of a flexible objectives hierarchy and using thresholds of potential concern as end-point goals; seeking stakeholder participation with real collaboration; using adaptive management champions to steer the learning requirements; achieving an effective balance between and use of the three modes of single-, double-, and triple-loop learning; and working studiously toward implementing adaptive freshwater management in water resource plan areas of the Basin. Initiating learning at the water resource plan area scale stimulates learning in the upper governance levels. Murray-Darling Basin practitioners adopting adaptive water resource management will need to institutionalize such adaptive feedback systems if uncertainty is to be embraced and for more effective environmental watering in the Basin.

Key words: *Adaptive feedback system; adaptive management cycles; complexity; environmental watering; governance arrangements; lessons learned; Murray-Darling Basin; societal learning*

5.1 Introduction

Uncertainty in managing freshwater resources in situations of water reforms demands that adaptive freshwater management (AFM) replaces traditional styles of freshwater exploitation (Medema *et al.*, 2008; Pahl-Wostl, 2008; Pahl-Wostl *et al.*, 2011; Herrfahrdt-Pahle, 2013). Traditional freshwater management is mechanistic and technocratic in nature, and is characterized by limited appreciation of complexity and the human dimension (Holling and Meffe, 1996; Gleick, 2003; Pahl-Wostl *et al.*, 2007; Pahl-Wostl, 2009; Herrfahrdt-Pahle, 2013). Humans play a decisive role in the management of freshwater resources (Pahl-Wostl, 2002) because utilization results from co-evolving biophysical and social dynamics (Lescuyer, 2002; Wiersum and de Hoogh, 2002). A diverse set of human and biophysical values and needs must be accommodated which generates much uncertainty within the freshwater management process (du Toit and Pollard, 2008). Uncertainty in freshwater management is exacerbated further by the existence of multiple, non-linear feedbacks which are a feature of freshwater ecosystems. These feedbacks frequently provide surprises for managers as multiple outcomes can occur from similar management interventions (Pahl-Wostl *et al.*, 2011; Walker and Salt, 2012). Hence, managers of freshwater resources are increasingly dealing with uncertainty and so-called “wicked problems” (APSC 2007; Allan and Wilson, 2009), which go beyond the capacity of any one organization to understand and respond to (Ison and Watson, 2007; Ison, 2010). Adaptive management is a participatory approach (Allan and Wilson, 2009) and is advocated widely as a solution to embracing uncertainty and dealing with wicked problems in freshwater management (e.g. Rogers *et al.*, 2000; Mackay *et al.*, 2002; Medema *et al.*, 2008; Pahl-Wostl, 2008; Pahl-Wostl *et al.*, 2011; Susskind *et al.*, 2012).

Adaptive freshwater management necessitates three different modes of societal learning for its effective practice (Pahl-Wostl, 2009). These modes are “the doing” or single-loop learning, the “changing practice” or double-loop learning, and “altering governance arrangements” of triple-loop learning (Fabricius and Cundill, 2014). Progression from single-, to double-, and then to triple-loop learning involves increasing time-scales for change (Pahl-Wostl, 2009). Together these three modes define ongoing learning, and are important for working toward achieving or refining the objectives within AFM (Pahl-Wostl, 2009). The practice of societal learning requires reflexive learning through adaptive feedback systems (Pahl-Wostl *et al.*, 2007, Pollard and du Toit, 2007, Pollard *et al.*, 2011) which are deployed within adaptive management cycles (McLoughlin and Thoms 2015). Adaptive feedback systems are designed to modify inputs, assumptions and hypotheses, which are linked to improving policies, management approaches and actions along with the transformation of governance, across levels (McLoughlin and Thoms 2015). Implementing societal learning in AFM is often difficult because multiple governance levels of freshwater management exacerbate the uncertainty with achieving objectives (Pahl-Wostl *et al.*, 2013; Fabricius and Cundill, 2014). For example, such uncertainty is evidenced in programs of environmental watering in the Murray-Darling Basin of Australia (Marshall *et al*., 2013; Armitage *et al*., 2015) and flood protection in European countries (Pahl-Wostl *et al.*, 2013). Adaptive freshwater management is problematic to initiate and sustain and therefore is not practiced on a wide scale (Jeffrey and Geary, 2006; Medema *et al.*, 2008). Further exploration of adaptive feedback systems is required to assess how feedback systems function in adaptive management cycles, within and across governance levels. Promoting multi governance-level societal learning in the practice of AFM is important for embracing uncertainty under complex water reforms, and for achievement of objectives in AFM.

Freshwater management within the Murray Darling Basin (MDB), Australia, is undertaken under the Water Act 2007 and seeks the sustainable use of freshwater resources (Pittock and Finlayson, 2011). The Water Act of 2007 prescribes rehabilitation and protection of riverine ecosystems of the MDB while retaining the economic and social benefits of the Basin (Pittock and Finlayson, 2011). However, the basis of freshwater management in the MDB has been to try to eliminate and control uncertainty rather than embrace it, particularly in the reforms associated with the Water Act (Allan, 2007; Allan and Wilson, 2009). For example, implementing environmental flows in rivers requires complete knowledge about biophysical conditions and causative links with hydrology. To date, a significant quantity of environmental water has been recovered via infrastructure modifications, environmental measures and the buy-back of water from other sectors through water purchasing (MDBA, 2014a). The recovered environmental water must be used to meet broad freshwater rehabilitation and protection related objectives (MDBA, 2014b). However, delivering this environmental water takes place within and across three governance levels of the MDB, that cover the Federal Basin-scale down through five Basin-states and Territories which each contain a number of localized water resource management areas (MDBA, 2014b). This multi governance-level arrangement exacerbates the complexity involved and therefore the uncertainty with delivering environmental water for social and environmental outcomes.

There is, therefore, an urgent need to embrace uncertainty within and across these governance levels of environmental watering in the MDB by practicing AFM, but this requires effective societal learning.

The aim of this study is to apply the adaptive feedback system of the Strategic adaptive management Reflexive Learning Framework (SRLF) of McLoughlin and Thoms (2015), to environmental watering in the MDB to assess its potential to facilitate societal learning within and across the three governance levels of the Basin. We first present background and key context to the case-study including a description of the MDB, its water reforms and an outline of the Basin Plan with its Basin-wide environmental watering strategy. Second, we outline the case-study design using the SRLF, involving formulation of the adaptive management cycles within the three MDB governance levels, and mandating practitioners and their stakeholders for each adaptive management cycle. Third, we assess the adaptive feedback system for implementing environmental watering in the MDB. This assessment demonstrates multi governance-level potentials for single-, double-, and triple-loop learning, working toward achievement of objectives across these levels. We then discuss key lessons emanating from applying the adaptive feedback system, associated with how to deal with the uncertainty involved across multiple governance levels of AFM. We conclude by highlighting the importance of adaptive feedback systems for an effective environmental watering process within any water reform process.

5.2 Background and context to environmental watering in the Murray Darling Basin

5.2.1 The Murray-Darling Basin

The MDB has a diverse array of landscapes, created over millions of years (MDBA, 2010). The MDB covers an area of 1,059,000km^2 or 14 percent of the Australian land mass (Figure 5.1). It is Australia's most important agricultural region producing approximately one-third of the nation's food supply. Although only covering two percent of the Basin's area, irrigated land consumes around 90 percent of diverted waters to produce 70 percent of Australia's irrigated agriculture output, with a total value of AU$7 billion annually (Pittock and Finlayson, 2011). Agriculture and its associated industries support many regional service centers and communities (MDBA, 2014a). The MDB is also home to around 30 Aboriginal nations whose spiritual connection to their land, water and environment has extended over many thousands of years (MDBA, 2010).

Rainfall is highly variable in space and time across the MDB, averaging 457 mm annually. The highest rainfall occurs in the south-east (mean annual >1500 mm) and eastern perimeter of the Basin compared to the west (< 300 mm), with mostly summer rainfall in the north and winter rainfall in the south of the Basin (Pittock and Finlayson, 2011). The MDB includes over 77,000 km of river channels, many of which only carry water or connect to other rivers in times of flood, otherwise remaining either dry or disconnected. The three longest rivers in Australia run through the MDB: the Darling River (2740 km), the River Murray (2530 km) and the Murrumbidgee River (1690 km) (Figure 5.1). The Darling River catchment is within New South Wales and Queensland and contributes downstream flows to New South Wales, Victoria and South Australia. The Darling River catchment is much larger than the Murray catchment, however its flow is considerably lower in volume with less predictability (MDBA 2010). The Darling River meets the River Murray at the town of Wentworth in New South Wales. The River Murray arises as a small stream in the Australian Alps and meanders to its mouth near Goolwa in South Australia over a distance of 2,500 km.

The rivers of the basin are home to a range of aquatic ecosystems (MDBA, 2010).
The MDB catchment contains over 25,000 wetlands which support a wide range of complex ecosystems (MDBA, 2010). The MDB is home to at least 35 endangered bird species and 16 endangered mammal species. In addition, 46 native fish species are known to occur in the basin. However, over the past 200 years the abundance and distribution of native fish has fallen significantly and 16 species are listed as rare or threatened on state, territory or Commonwealth listings (MDBA, 2010). National parks and other reserves comprise about 7% of the total land area of the MDB but protect many of the basin's native plants and animals (MDBA, 2010).

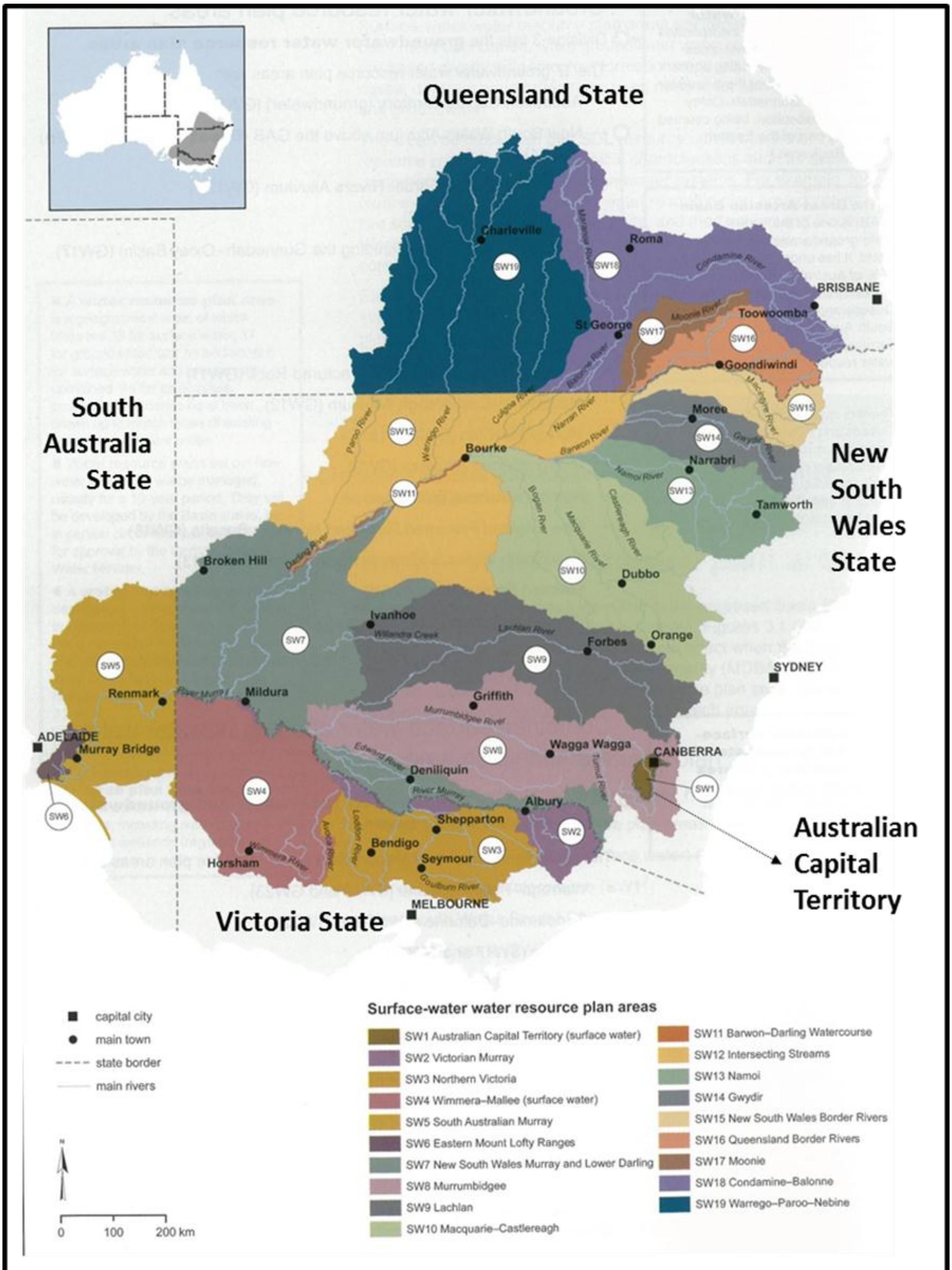

Figure 5.1. The Murray-Darling Basin and its location within Australia. Surface water resource plan areas are shown, within and across the four states and territory (adapted from MDBA, 2011; copyright Commonwealth of Australia).

5.2.2 Murray-Darling Basin water reforms

Since the mid-1990s Australia has engaged in a process of water reform steered toward promoting economic efficiency in water use within the context of ecologically sustainable freshwater management (Pigram, 2007; Grafton *et al.*, 2014). The 2003 Council of Australian Governments (COAG) National Water Initiative was adopted in 2004 and signed by all state governments in response to reviews of previous reforms implemented in the mid-1990s. The National Water Initiative aimed to develop a compatible, regulatory, and planning-based system for management of surface and groundwater resources that recognized the value of markets in delivering on this objective. As part of the National Water Initiative, the Murray-Darling Water Agreement was adopted in 2004 and set out inter-governmental arrangements to reduce the level of over-allocated water, for achievement of specific environmental outcomes in the MDB (Pigram, 2007).

The National Water Act of 2007 superseded the National Water Initiative and established the Murray Darling Basin Authority (MDBA). The National Water Act of 2007 required that the MDBA prepare and implement a Basin Plan setting out a strategic plan for managing the MDB. The Commonwealth Environmental Water Holder was also established to manage the Commonwealth's environmental water. Adaptive management principles are recognized at broad policy and legislative levels in order to achieve the desired outcomes of the Water Act of 2007, and are an integral part of management strategies at different governance levels within the MDB (national, state, and catchment) (Pagan and Crase, 2005; Pagan, 2008). However, implementation of adaptive management in the MDB has proven difficult because of intrinsic threats introduced by specification of property rights (Pigram, 2007). Other more generic threats to the implementation of adaptive management include organizations accepting policy implementation as experiments, getting managers to respond to change and surprise rather than trying to avoid these, and obtaining buy-in from various stakeholder groups (Pagan, 2008). Critically, achieving societal consensus about how much water must remain in the rivers for environmental purposes is a key aspect for adaptive management of the MDB’s freshwater resources (Ladson, 2009). However, defining the manner in which consensus is achieved is a source of debate and contention within the MDB (Pagan, 2008).

5.2.3 The Murray-Darling Basin Plan

The Murray-Darling Basin Plan (MDBP) was passed into law in November 2012 and under Australia's water reform directs integrated and sustainable management of the MDB's water resources. The Plan demands a coordinated approach to water use across the MDB's five States and Territories and attempts to balance the environmental, social and economic aspects of the Basin (MDBA, 2014a). This involves balancing water use among that for basic human needs and recreation, productive and resilient industries, and for healthy diverse ecosystems. This balance is achieved by setting sustainable diversion limits (SDLs) for surface water and groundwater in each catchment in the MDB, but still seeking to ensure sufficient water for human and industrial use. Under the MDBP, a limit of 10,876 GL of surface water is to be taken (or diverted) from the Basin annually. This reduces annual surface water diversions by 2,747 GL compared to 2009 levels. For groundwater 3,324 GL can be taken annually. According to MDBA (2014a) by 31 March 2014, almost 70% of the 2,750 GL was recovered through investment in more efficient infrastructure, environmental measures and water purchases, and further water recovery is planned.

The MDBP is to be phased in over several years, allowing time for the Basin-states, communities and the Australian Government to work together to manage the changes required. The MDBP involves several elements (MDBA, 2014b): setting of environmental management objectives and predicted outcomes; setting of SDLs with an adjustment mechanism to allow these to be modified if required; a constraints management strategy to address obstacles to delivering environmental water; an environmental watering strategy with plans to protect and restore rivers and wetlands; a water quality and salinity management plan that sets objectives and targets within the MDB; state watering plans and requirements for developing these by 2019; management of critical human water needs; rules for water trading and better access to water market information; risk management associated with water availability; and a monitoring and evaluation program.

5.2.4 The Basin-wide Environmental Watering Strategy

The Basin-wide Environmental Watering Strategy gives effect to the environmental elements of the MDBP (MDBA, 2014b). The purpose of the Basin-wide Environmental Watering Strategy and its implementation is to alleviate the adverse effects of river regulation and water consumption on ecosystems, but in a manner that provides water users with security and supports communities. To achieve these outcomes the strategy sets out environmental objectives for water-dependent ecosystems and indicators (Appendix 1). The MDB's environmental water is managed within and across three governance levels, coordinated between local agencies, states and the Commonwealth government. Water planning plays a major role within environmental watering in the MDB, and includes prioritization at the Basin and regional (water resource plan area) scale which informs the active delivery of water in real time (MDBA, 2014b) (Appendix 1). Environmental water managers typically undertake planning between January and June to identify potential environmental watering opportunities for the coming water year(s) running from July to June (MDBA, 2014b) (Appendix 1). The environmental watering priorities include environmental outcomes that the MDBA considers of significance for watering in the subsequent year (MDBA, 2014b). Overall, water dependent ecosystems are expected to respond positively over decades of environmental watering within the MDB, thus achieving environmental objectives (Appendix 1).

5.3 Case-study design

The case-study centers around the assessment of the SRLF adaptive feedback system, and the lessons learned from its facilitation of societal learning during environmental watering in the MDB. The Vision-statement for the MDB is to achieve a healthy working Basin (MDBA, 2014b). This vision is broken down into three higher objectives, namely, a healthy environment, strong communities, and a productive economy (MDBA, 2014b). Linked to the "healthy environment" higher objective, potentials for societal learning during environmental watering in the MDB using the SRLF are described below.

5.3.1 The Strategic adaptive management Reflexive Learning Framework

The generic structure of SRLF exhibits a vertical nested pattern of Strategic adaptive management (SAM) cycles distributed across three levels of governance (Figure 5.2a). Levels differentiate the types of interventions required in the SAM cycle to meet policy targets at SRLF Level-1, management targets at SRLF Level-2 and thresholds of potential concern (TPCs, see Biggs and Rogers, 2003, McLoughlin *et al.*, 2011 for a full treatise) at SRLF level-3 (Figure 5.2a). The nested distribution of SAM cycles is applied separately to each of three broad themes: Environment, Economic and Community/Social (McLoughlin and

Thoms, 2015). The Environment theme, for example, has many Level-3 SAM cycles nested within it and it is overseen by a Level-2 SAM cycle, which is represented by fewer SAM cycles (Figure 5.2a). Similarly, these Level-2 SAM cycles are nested within and are overseen by the single Level-1 SAM cycle. The objectives applicable to the Environment theme are cascaded downwards through all levels of the SRLF with increased focus and rigor (Figure 5.2a), for application within these SAM cycles. For a full treatise of the SRLF see McLoughlin and Thoms (2015).

The generic SAM cycle structure consists of two phases and these are applied within each SRLF level (McLoughlin and Thoms, 2015). The two phases are the Adaptive Planning Phase, which is composed of two adaptive components (represented in the black boxes in Figure 5.2b). The first adaptive component represents development of the objectives, corresponding to the particular level and the second represents development of the detailed end-point goals culminating at the base of these objectives. The second phase is the Adaptive Implementation Phase which is composed of five adaptive components (represented in the grey boxes in Figure 5.2b). The adaptive components in this phase include: the processes of selecting the best intervention options to meet the developed end-point goals; determining inputs for planning (associated with meeting end-point goals); operationalizing inputs via implementation of the plans; checking adequacy of plan implementation by swift response to operational outputs; assessing suitability of the operational outputs by auditing strategic outcomes (against end-point goals); and testing achievement of the broader objectives applicable at each SRLF level.

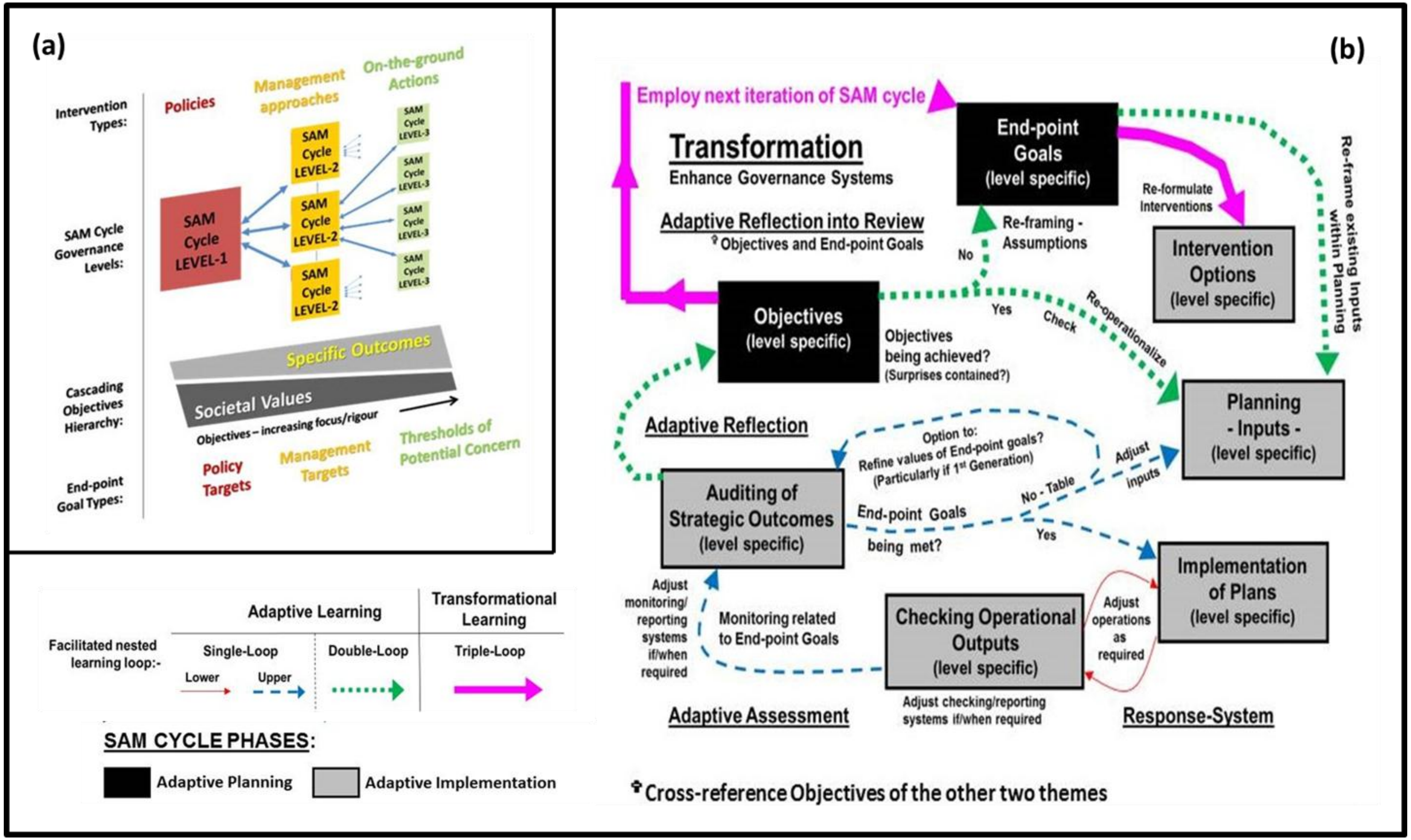

Figure 5.2. The Strategic adaptive management (SAM) Reflexive Learning Framework (SRLF). The learning process is not linear, but uses a nested set of generic overlapping adaptive feedbacks within each SAM cycle applied at governance levels SRLF Level-1, Level-2, and Level-3 (a). These feedbacks occur simultaneously but over increasing time-scales for change, by providing potential for both adaptive and transformational learning. This learning is given effect by facilitation of single-, double- and triple-loop learning for meeting objectives and associated end-point goals per level, and allows for activation, completion, and regeneration of the SAM cycle per level (b). Source: McLoughlin and Thoms (2015).

Learning is an ongoing, nested process under the SRLF and there are two kinds of learning potentials facilitated by the adaptive feedback system within the generic SAM cycle: Adaptive Learning and Transformational Learning (Figure 5.2b). Adaptive Learning encompasses single- and double-loop learning. There are two grades of feedbacks to facilitate single-loop learning. Lower grades (thin/solid arrows) give rise to the more immediate responses in ARM, to check if operational inputs are being implemented correctly, that is achieving the intended outputs. Upper grades (hashed arrows) give rise to adaptive assessment routines, auditing strategic outcomes against the end-point goal benchmarks. Feedbacks for double-loop learning (dotted arrows) give rise to adaptive reflection routines, which evaluate achievement of the broader objectives within the SAM cycle and there is potential for re-framing end-point goals and existing planning inputs. Feedbacks for triple-loop learning (thick/solid arrows) allow adaptive reflection into a holistic review process of all objectives and end-point goals. Transformational learning is achieved via a reflection and review process, which is combined with a reconsideration of underlying values for adapting governance systems and the effective regeneration of the SAM cycle.

5.3.2 Formulating the SRLF and its SAM cycles for environmental watering in the Murray-Darling Basin

To assess societal learning in environmental watering of the MDB, an example “Environment” theme SAM cycle was formulated at each governance level of the MDB (Figure 5.3; Table 5.1). These governance levels are the Basin scale (SRLF level-1), the Basin-state scale (SRLF level-2) using the four Basin-states (New South Wales, Victoria, Queensland and South Australia), and the water resource plan area (WRPA) scale (SRLF Level-3) of which there are 20 surface water WRPAs across the Basin-states (see Figure 5.1). Example elements of the MDBP and the Basin-wide Environmental Strategy, pertinent to different governance levels, were then assimilated under the different phase components making up the SAM cycle (see Figure 5.2). This included the objectives and end-point goals (Adaptive Planning Phase); intervention options, planning, implementation of plans, checking operational outputs, and monitoring against strategic outcomes (Adaptive Implementation phase) (Table 5.1). Elements used for the SAM cycles are not exhaustive of the elements given within the MDBP and its environmental watering strategy. They are merely examples used for demonstration of the adaptive management cycle structure per governance level of the MDB. To drive these SAM cycles AFM practitioners in the MDB and their associated stakeholders are mandated to oversee the SAM cycles, within and across the three governance levels. Mandating these practitioners and stakeholders works to clarify (feasible) implementation roles and responsibilities in the practice of AFM (see McLoughlin and Thoms 2015).

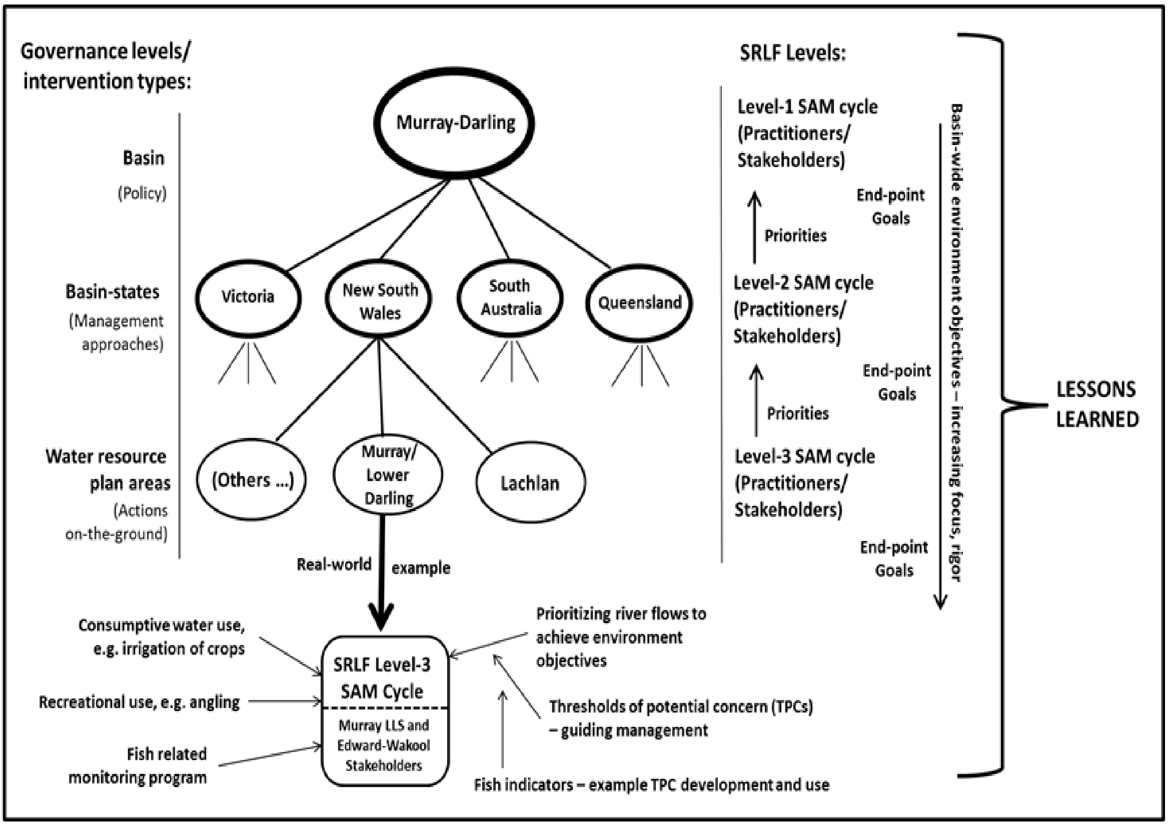

Figure 5.3. Case-study design for the Murray-Darling Basin application of the Strategic adaptive management Reflexive Learning Framework (SRLF), combined with elements of the Basin-wide Environmental Watering Strategy. SRLF Level-1, Level-2 and Level-3 SAM cycles per governance level are linked between levels. The diagram indicates a real-world application in the Murray-Lower Darling water resource plan area, using the Edward-Wakool environmental watering area (actual examples given in Appendices 1 – 6).
LLS: Local Land Service.

Practitioner and stakeholder mandates across governance levels

Key AFM practitioners operating at the Basin governance level (SRLF Level-1) are the MDBA and Commonwealth Environmental Water Office (CEWO) (Figure 5.3). Both organizations liaise continually with other stakeholders at this level, for instance agricultural agencies at the national level. Together, practitioners and stakeholders assume the largest scale of geographical influence over the MDB environmental watering process, dealing primarily with policy development and implementation. They seek to achieve predetermined policy targets as end-point goals at the Basin scale, linked to the “sustainable and healthy environment” higher objective. With this, the SRLF Level-1 oversees implementation of a SAM cycle at the scale of the MDB (see Table 5.1 SRLF Level-1 Basin scale) and to evaluate policy targets it also administers and collates information emanating from all nested Basin-state SAM cycles at SRLF Level-2. Thus, the Basin-state governance level is the lowest formal and “direct” mandate for these AFM practitioners who must also work closely with practitioners and stakeholders at SRLF Level-2 (in addition to interactions with higher government ministries as required). At SRLF Level-1 there are large constraints imposed on implementing AFM. This is because increased rigidity of governance arrangements at this level relative to the lower levels including lower rates of flexibility and self-organization (see McLoughlin and Thoms 2015).

Operating at the Basin-state governance level (SRLF Level-2, New South Wales example) key AFM practitioners include the Office of Environment and Heritage and the Department of Primary Industries - Water (Figure 5.3). These practitioners work continually with other important stakeholders at this level, such as irrigation companies and State Water. They are primarily responsible for determining and achieving management targets as end-point goals at the Basin-state scale, linked to higher-level policy. With this, the SRLF Level-2 oversees implementation of a SAM cycle within each Basin-state (see Table 5.1 SRLF Level-2 Basin-state scale) and in order to evaluate management targets each Basin-state administers and collates information emanating from all nested WRPA SAM cycles at SRLF Level-3. Thus, the WRPA governance level forms the lowest formal and “direct” mandate for these AFM practitioners who must also work closely with practitioners and stakeholders at SRLF Level-3 (in addition to assisting practitioners at SRLF Level-1 as required). The SRLF level-2 practitioners therefore have a key role in coordinating information flows vertically across the governance levels of the MDB, for operations and learning to occur throughout SRLF deployment (McLoughlin and Thoms, 2015) (see Table 5.1).

Adaptive freshwater management practitioners with the smallest geographical influence over the MDB environmental watering process operate at the WRPA governance level (SRLF Level-3, Murray and Lower Darling example) (Figure 5.3). Key practitioners here include the Murray Local Land Service who must work continually with stakeholders at this level, such

Table 5.1. Components of the Adaptive Planning and Adaptive Implementation phases of the Strategic adaptive management (SAM) cycles formulated for environmental watering in the Murray-Darling Basin. These phases of the SAM cycle are applicable to implementation of the environmental watering for working toward achievement of the MDB environmental objectives (worked examples from the SRLF Level-3 SAM cycle are given in the Appendices).
TPC: thresholds of potential concern.

SAM Phase/ Component	**SRLF Level-1: Murray-Darling Basin Scale**	**SRLF Level-2: Basin-state Scale**	**SRLF Level-3: Water Resource Plan Area Scale**
Adaptive Planning Objectives (These can be arranged to form a hierarchy, through the three SRLF levels)	Higher-objectives, emanating from the overall Vision statement. ==================== Example (1) To protect and restore water-dependent ecosystems: Sub-set of all water-dependent ecosystems (linked to Ramsar, Bonn Convention for example); biodiversity that is dependent on Basin water resources (linked to threatened species, representative populations and communities of native biota). (2) To protect and restore ecosystem functions of water-dependent ecosystems:	Sub-objectives, increasing focus and rigor, cascaded down from the Murray-Darling Basin scale. ======================== Example (1) River flows and connectivity: To improve connections along rivers and between rivers and their floodplains. (2) Riverine vegetation: To maintain the extent and improve the condition of riverine vegetation. (3) Water-birds: To maintain the current species diversity, also improve the breeding success and numbers of water-birds. (4) Fish: To maintain the current species	Detailed Sub-objectives, well-developed focus, cascaded down from the Basin-state scale ======================== Example (New South Wales Murray and Lower Darling, the Murray Fish environmental element as demonstration) (1) Murray Fish Diversity Objective: To have self-sustaining native fish communities existing throughout the freshwater systems of the Murray River. - Sub-objectives: Upper Murray; Middle Murray; Lower Murray. (2) Middle Murray sub-objective (as example): To maintain the Middle Murray system as an important population source zone for the native fish community of the whole Murray River.

SAM Phase/ Component	SRLF Level-1: Murray-Darling Basin Scale	SRLF Level-2: Basin-state Scale	SRLF Level-3: Water Resource Plan Area Scale
	Water quality not adversely affecting water-dependent ecosystems; connectivity within/between water-dependent ecosystems (diversity and dynamics of geomorphology, habitats, species and genes; ecological processes dependent on hydrologic connectivity); natural in-stream/floodplain processes; habitat diversity for biota; water dependent ecosystems that maintain populations and ecological community structure. (3) To ensure water-dependent ecosystems are resilient to climate change and other risks/threats: (4) To protect refugia; providing wetting and drying cycles and inundation intervals, not exceeding critical tolerances; mitigating human-induced threats and habitat fragmentation.	diversity, and the extent of fish distributions; also to improve the breeding success of native fish species and increase their numbers.	- Sub-objectives: Main-stem; Edward-Wakool (3) Edward-Wakool sub-objective (as example): To ensure that viable populations of native fish species occur within permanent/ephemeral creeks, rivers, flood plains and wetlands. Dependent on processes of recruitment, survival, abundance and competition. - Sub-objectives: Recruitment; Survival; Abundance; Competition (4) Edward-Wakool Recruitment sub-objective (as example): To allow adequate opportunities for recruitment (complete life cycle) of different native fish groups. - Sub-objectives: In-stream; Floodplain/wetland; Ephemeral creek (5) In-stream sub-objective (as example): To provide an in-channel flow regime to promote success for native fish.

SAM Phase/ Component	SRLF Level-1: Murray-Darling Basin Scale	SRLF Level-2: Basin-state Scale	SRLF Level-3: Water Resource Plan Area Scale
Adaptive Planning End-point Goals (Acts as the key Strategic "top-down" influence through the SRLF levels	Policy Targets, as broader end-points of the Murray-Darling Higher-objectives. These influence objective determination at the state scale. ==================== Example There are improvements in the following components (post 2019): (a) Flow regimes, measured by progress towards natural flow patterns. (b) Hydrological connectivity between river and floodplain and hydrologically connected valleys. (c) River, floodplain and wetland types, including priority environmental assets and ecosystems functions. (d) Condition of the Coorong and Lower Lakes ecosystems and Murray Mouth opening	Management Targets, as more detailed end-points of the state scale Sub-objectives (New South Wales as example). These influence objective determination at the water resource plane area scale. ======================== Example (New South Wales) (1) Connectivity : Maintain base flows at around 60% of natural levels in main catchment rivers; improve overall flow by 10% more in the Baron-Darling, 30% more in Murray River, and 30-40% more into the Murray Mouth; maintain connectivity in areas where it is relatively unaffected > between rivers and floodplains in the Warrego and Ovens; improve bank-full and low floodplain flows, by 30-60% in Murray, Murrumbidgee, and by 10-20% in all remaining catchments. (2) Riverine vegetation: Maintain current extent (and condition) of New South Wales	Thresholds of Potential Concern (TPC), as finely detailed, explicit end-points of the water resource plan area. ============================ Example (Edward-Wakool In-stream objective line) (a) Edward-Wakool/Recruitment/In-stream Fish TPCs (Appendix 2 apex predator example) (b) Edward-Wakool/Survival/In-stream sub-objective Fish TPCs (Appendix 2 apex Predator example) (c) Edward-Wakool/Abundance/In-stream sub-objective Fish TPCs (to be developed) (d) Edward-Wakool/Competition/In-stream sub-objective Fish TPCs (to be developed)

SAM Phase/ Component	SRLF Level-1: Murray-Darling Basin Scale	SRLF Level-2: Basin-state Scale	SRLF Level-3: Water Resource Plan Area Scale
	regime. (e) Condition, diversity, extent and contiguousness of native water-dependent vegetation. (f) Recruitment and populations of native water-dependent species – vegetation, birds, fish and macro-invertebrates. (g) Community structure of water-dependent ecosystems.	portion of the Basin 350,000 ha of river red gum, 402,000 ha of black box, 310,000 ha of coolabah forest/woodlands, and existing large communities of lignum; and non-woody communities near or in wetlands, streams and low-lying floodplains. (3) Water-birds (within NSW): Maintain current species diversity of all current water birds of the Basin; increase abundance of water birds by 20-25%; and improve breeding > by up to 50% more breading events for colonial nested species, and by 30-40% increase in nests and broods for the other water-birds. (4) Fish (within NSW): Improve distribution of key short and long-lived species; improve breeding success for species > short-lived - every 1-2 years, long-lived - in at least 8/10 years at 80% of sites, mulloway in at least 5/10 years; improved populations of fish > short lived - to pre-2007 levels, long lived – must be a spread of age-classes, Murray cod and golden perch - 10-15% more mature	

SAM Phase/ Component	SRLF Level-1: Murray-Darling Basin Scale	SRLF Level-2: Basin-state Scale	SRLF Level-3: Water Resource Plan Area Scale
		fish at key sites; improved fish movement > have more native fish using fish passages.	
Adaptive Implementation Intervention Options	Best Policies, expected to allow for meeting of the Policy Targets at the Murray-Darling Basin scale. ==================== Example Set Sustainable Diversion Limits (SDLs) for water use. Recover water in the Murray-Darling Basin for the environment (current estimated recovery at 2,747 GL). Adopt an environmental works program, to increase efficiency of delivering the 2,750 GL of water recovered (hence, less water actually needs to be recovered for the environment). Use water trading.	Appropriate Management approaches, expected to allow for meeting of the Management Targets at the state scale. Influenced by Policy options selected. ========================= Example Oversee SDLs limits in the basin-state. Oversee water trading in the Basin-state. Within the state, oversee and prioritize all water recovered for the environment, to all pertinent water resource plan areas as required.	Pertinent on-the-ground actions, allowing for meeting of the TPCs at the water resource plan area scale. Influenced by Management approaches selected. ============================= Example (Edward-Wakool) Hydrological manipulation using dam releases. With the quantity of environmental water allocated, deliver this water across the water resource plan area where required, in an efficient and logistically feasible manner, maximizing the benefits from this water. Habitat - rehabilitate snags for breeding and refuge. Water quality - regulate return flows from agriculture and control pollution. Fishing regulations - regulate catch allowed

SAM Phase/ Component	**SRLF Level-1: Murray-Darling Basin Scale**	**SRLF Level-2: Basin-state Scale**	**SRLF Level-3: Water Resource Plan Area Scale**
Adaptive Implementation Planning (inputs)	Broad Planning documents, incorporating inputs necessary for implementation of Policies across nested state scale entities. ===================== Example Identification and documentation of key ecosystem assets and hydrologic sites at the Basin scale. Derive methods to calculate annual amounts of water available in the Murray-Darling Basin, for use in environmental watering across the Murray-Darling Basin, and publish these methods. For example the weather forecasting scenarios – Very Dry; Dry; Moderate; Wet to Very Wet. Determine water trading rules.	Detailed Planning documents, incorporating inputs necessary for implementation of Management approaches across nested water resource plan area scale entities. ========================= Example Document methods for prioritizing environmental water made available from the Basin scale, across all water resource plan areas (will include existing state related water for the environment). For making water allocations each year, set up pertinent stakeholder networks for interactions between all pertinent stakeholders and foster communication channels for water. Document all SDLs for use throughout the Basin-state. Set up water trading rules throughout the Basin-state.	Highly detailed Planning documents, incorporating inputs necessary for implementation of Actions, within water resource plan scale entities. ========================== Example (Edward-Wakool) Identification, prioritization and documentation of all key environmental watering sites across water resource plan area. Hydrologic regime – 10 year flow regime for achieving fish objectives (apex predator, specialist and generalist indicator species) (Appendix 3). Operating protocols – Dam operating rules for delivering environmental flows, use of gauging stations. Black water issues, larval recruitment, oxygen and temperature changes (Appendix 4, example protocol for apex predators of the Edward-Wakool site). Strategic documentation – TPCs and monitoring protocols (Appendix 5,

SAM Phase/ Component	**SRLF Level-1: Murray-Darling Basin Scale**	**SRLF Level-2: Basin-state Scale**	**SRLF Level-3: Water Resource Plan Area Scale**
			example ‘Recruitment’ and ‘Survival’ bundles of TPCs of the Edward-Wakool site). Logistics – Data management and responsibilities, information/feedbacks, resources available.
Adaptive Implementation Implementation (of Plans) (Is the key Operational “top-down” link in the SRLF)	Operationalizing inputs given in the planning documents of the Murray-Darling Basin. ==================== Example (Annually before flow event) Do the calculations giving the estimated amount of environmental water available in the Murray-Darling Basin for the coming watering season. Distribute this water across the states in line with priorities determined for environmental watering. Organize workshops with pertinent stakeholders to	Operationalizing inputs given in the planning documents at the state scale. ======================== Example (Annually before flow event) Organize workshops to work with pertinent stakeholders of each water resource plan area, to distribute environmental water allocations, enforce SDLs and water trading rules in the Basin scale. Discuss predicted use of this water and outcomes foreseen.	Operationalizing inputs given in the planning documents at water resource plan area scale. ========================= Example (Edward-Wakool) (Annually commencing at the flow event and during flow event) Using available environmental water allocated from the Basin-state scale, apply dam operating rules from the Hume Dam to implement hydrological regime for the selected fish indicator (e.g. Murray Cod, apex predator). Implement all operational and strategic monitoring protocols. Stakeholder interactions, participation levels; rapid response capacity; network channels. Communication between all stakeholders – mobile, telephone, email, meetings if or when

SAM Phase/ Component	SRLF Level-1: Murray-Darling Basin Scale	SRLF Level-2: Basin-state Scale	SRLF Level-3: Water Resource Plan Area Scale
	decide and agree on all priorities.		required.
Adaptive Implementation Checking Operational Outputs	Checking implementation of Murray-Darling Basin plans. Collating operational information from across nested state entities. ==================== Example (Annually before flow event) Make sure all environmental calculations are being used correctly, all data available is used. Make sure research into identifying key hydrological sites is on track, and source additional funding for further work required. Oversee workshops with Basin states where environmental water is being allocated to each state.	Checking implementation of state plans. Collating operational information from across nested water resource area entities. ======================== Example (Annually before flow event) Make sure workshops with stakeholders of all water resource plan areas are being implemented, where Basin-state allocated environmental water is distributed to water resource plan areas. Make sure all Basin-states are up-to-date with water availability and use. Enforce SDLs and ensure water trading rules are being adhered to.	Checking implementation of water resource area plans. Collating operational information from within water resource plan entities. ========================== Example (Edward-Wakool) (Annually during flow event) Using gauging stations, daily checks on actual river flow being implemented in the river against hydrograph flows required as per fish indicator selected for the flow event. Being cognizant of current rainfall influences in order to adjust water release from the Hume Dam if/when required. Follow operational protocols – the larval recruitment, oxygen and temperature related operational data checks (see Appendix 4).

SAM Phase/ Component	SRLF Level-1: Murray-Darling Basin Scale	SRLF Level-2: Basin-state Scale	SRLF Level-3: Water Resource Plan Area Scale
Adaptive Implementation Auditing of Strategic Outcomes (Sets up the Strategic "bottom-up" link for learning in the SRLF)	Collation/synthesis of all monitoring data/information, emanating from across nested state entities. ==================== Example (Annually post flow-event) Compile a Basin wide list of water priorities for each Basin state, based on all state water priorities received. Estimate the total water that is being requested. Ongoing as required: All management target information emanating from the Basin states to be collated for auditing against the Policy Targets when appropriate to do so.	Collation/synthesis of all TPC related information emanating from across nested water resource plan entities. ========================= Example (Annually post flow-event) Compile a state-wide list of TPCs listed as exceeded. Then identify priority sites for allocation of environmental watering in the next watering season. Determine pertinent water volumes for this future watering. Ongoing as required: All TPC information emanating from the water resource plan areas to be collated for auditing against the Management Targets when appropriate to do so.	Collate information emanating from implementation of the TPC monitoring protocols, from across sites within the water resource plan area. ========================== Example (Edward-Wakool) (Annually post flow-event, involving all TPCs incorporating fast response, but including those TPCs of the medium to slow response variables when appropriate based on monitoring of these) Auditing of all ecosystem component TPCs, i.e. fish, vegetation, water birds, and connectivity as required (Appendix 6, example fish audit reports for "Recruitment" bundle of TPCs, apex predators). Update the table of TPC exceedances, including those TPCs close to being exceeded. Also close any TPCs if exceedances managed. This is to prioritize the target indicators requiring water allocations for the next watering season. For the fish TPC example, decisions are made whether to run an apex predator, generalist or specialist flow event (given in the hydrological plan).

as the various river and infrastructure operators, land and waterway managers, forestry, environmental water advisory groups, local communities and research entities. They are primarily responsible for action on-the-ground, to achieve the TPCs as end-point goals at the WRPA scale, linked to higher-level management targets. With this, the SRLF Level-3 oversees implementation of a detailed SAM cycle within each WRPA (see Table 5.1 SRLF Level-3 WRPA scale) and in order to evaluate TPCs each WRPA collates information emanating from all nested sub-scales or sites across the WRPA. Practitioners in a WRPA must work closely with all smaller stakeholder groups in the WRPA (in addition to assisting practitioners at SRLF Level-2 as required). With higher flexibility in governance arrangements and self-organization of stakeholders at SRLF Level-3, learning potentials are enhanced at this level of organization (see McLoughlin and Thoms, 2015). Practitioners of the WRPA governance level exploit this increased capacity to learn, and even under constraints of the two higher levels must seek to fully realize AFM at this level (McLoughlin and Thoms, 2015). Such capacity is demonstrated in real-world examples from the Murray and Lower-Darling WRPA associated with the Edward-Wakool environmental watering area (indicated in Table 5.1 as Appendices to the manuscript).

The SAM cycles of the Basin and Basin-state scales, and their practitioner/stakeholder mandates are both hypothetically derived in this manuscript. They provide critical context for formulation and application of the SAM cycle at SRLF Level-3 the WRPA scale. This SAM cycle application involved all key stakeholders and in this manuscript was developed to demonstrate a real-world example of deploying the SRLF SAM cycle.

5.3.3 Real-world SAM cycle formulation and application - SRLF Level-3

The Murray and Lower-Darling WRPA is used as an example WRPA within which to formulate and apply a SAM cycle at this governance level (Figure 5.3). The Murray and Lower-Darling WRPA is an inland catchment of the MDB located in southern New South Wales (Figure 5.1). The Murray section is bounded to the south and north by the Murray River and Murrumbidgee River, respectively, and to the west by the junction of these rivers and in the east by the Australian Alps. The Edward-Wakool river system in this section of the WRPA is a key environmental asset of the MDB because it contains the Werai, Millewa and Koondrook-Perricoota forests which are significant breeding and recruitment sites for many aquatic and vegetation communities (MCMA, 2011). Formulation of the SAM cycle was achieved using examples from the Edward-Wakool environmental watering area of the Murray and Lower-Darling WRPA. This SAM cycle demonstrates a tangible adaptive management cycle for application at the WRPA scale of the MDB associated with environmental watering.

Formulation of the Edward-Wakool related SAM cycle involved key stakeholders who were engaged to collaboratively formulate and then commence deploying the SAM cycle (Figure 5.3). This involved partnering with the Murray Local Land Service as the key AFM practitioner because it has local responsibility for management of the Edward-Wakool environmental watering area. In addition, there was participation from all key stakeholders, including the Office of Environment and Heritage; Department of Primary Industries; land, forestry and conservation sectors; important local community groups and researchers. Support and inputs from the CEWO and MDBA aided SAM cycle formulation. Engaging with these stakeholders is important for gaining buy-in for SAM cycle deployment.

In this manuscript the "fish" ecosystem component is used to formulate the Edward-Wakool SAM cycle (Figure 5.3; Table 5.1 SRLF Level-3 WRPA scale). However, the principles applied are applicable to all environmental components of the MDB not covered in this case-study, i.e. river flows and connectivity, native vegetation, water-birds, and water quality. In addition, lessons from applying this SAM cycle to surface water of regulated rivers are applicable to unregulated rivers within the MDB, and to ground water systems of WRPAs. To date, stakeholders have piloted fish-related objectives and end-point goals (TPCs) under the Adaptive Planning Phase of the SAM cycle (see Table 5.1; Appendix 2). This phase of the SAM cycle with the Adaptive Implementation Phase, at all governance levels, provides the structure to commence societal learning.

Implementation of the SRLF's adaptive feedback system is used for assessing societal learning within MDB environmental watering. Overall, the SRLF Level-3 SAM cycle, with the two SAM cycles presented at SRLF Level-2 and Level-1 (Figure 5.3), provide the basis for implementation of the adaptive feedback system throughout the MDB (see Table 5.1). The adaptive feedback system is used to stimulate and facilitate an appropriate balance between single-, double-, and triple-loop learning within and across governance levels. This is described below.

5.4 Multi governance-level adaptive feedback system for societal learning in environmental watering

5.4.1 Vertical linkages across governance levels

"Top-down" influences or constraints

The main top-down link under the SRLF is molded by societal values that emerge during the visioning process at the scale of the MDB. This is because the vision-statement is dependent on what society deems important. The "healthy environment" higher objective sets the tone for objective development within the SAM cycle at the Basin-scale. These objectives influence policy targets within the Environment theme, which in turn shapes the policies selected at this scale, for example the option of recovering water for the environment via buying water back from other uses (Table 5.1). Ultimately, this influences and constrains management within all nested SAM cycles at the Basin-state scale because management objectives and associated targets as end-point goals at this scale are derivatives of the higher level policy targets (Table 5.1).

In addition, the policies derived at SRLF Level-1 (Basin-scale) impact the types of management approaches allowed at the Basin-state scale. For example, the need to distribute any recovered environmental water across the Basin-state reflects the healthy environment objective (Table 5.1). Management targets of SAM cycles at the Basin-state scale then determine the TPCs required within the WRPAs. For example, significant priority is attached at the MDB scale through the Basin-state scale for using fish as indicators of ecosystem health (see Table 5.1; Appendix 2). Management approaches selected at the Basin-state scale then control and constrain all actions of the SAM cycles operating within the WRPAs, for example, an obligation to release a given amount of environmental water annually within WRPAs, in river systems as required (see Table 5.1; Appendix 3).

"Bottom-up" process or emergence factors

Thresholds of Potential Concern (TPCs) define the explicit, measurable and pragmatic end-points of the "healthy environment" "desired future state" of the MDB across all WRPAs. The TPC concept at the scale of the WRPA thus gives effect to the higher level environment objectives cascaded down the three governance levels of the MDB (Table 5.1). The TPCs are typically "decision thresholds", seen as an optimization of both "ecological" (scientific/model-based) and "utility" (value/objectives-based) thresholds (Martin *et al.*, 2009), rather than specific predicted "ecosystem" thresholds (Biggs *et al.*, 2011). The process of constructing TPCs involves collaboration between all WRPA practitioners and their stakeholders, identifying drivers within the particular system of the WRPA as well as measurable response indicators of change related to these drivers. They also recognize the natural variability of response indicators by incorporating upper and lower-levels of acceptable change. The TPCs as explicit, measurable and pragmatic end-points are also defined as a "tent boundary" formed by the collective of TPCs (or "targets" if system state is already outside the "tent boundary") (cf. Biggs *et al.*, 2011). Staying within the TPC defined "tent boundary" is the main purpose of the environmental watering program, and is achieved by not exceeding the TPCs in the first place or otherwise rehabilitating the system back to within the "tent boundary" if required. Refining the actual TPCs themselves may also be required, as scientific understanding improves and/or stakeholder values change. This role of TPCs within AFM ultimately contributes toward achieving the higher objectives agreed to at the Basin-scale, fostered by the bottom-up link in the SRLF.

The main bottom-up link of the SRLF is based on the MDB environmental watering priorities. Bottom-up operational integration (see Table 5.1) is an annual process and initially involves consolidation of all TPC auditing achieved within each WRPA (see Table 5.1). From the list of WRPA TPCs breached, close to being breached or predicted to be breached, river areas within each WRPA are prioritized for specific watering events in the following season. This prioritization is based on requirements of the TPC indicators (considering both slow and fast variables of indicators) and getting these back to within the "tent boundary"; or preventing them breaching this boundary. The volume of water required for the particular watering events is then estimated, and this information is consolidated within each Basin-state. All estimated water volumes of a Basin-state are totaled and submitted up to practitioners at the Basin-scale. Here, all environmental water requests from the Basin-states are consolidated with perusal of all justifications for this water. Total environmental water available for the next watering season in the MDB is estimated at the Basin-scale, and prioritized for distribution across the Basin-states and ultimately to the WRPAs.

5.4.2 Single-, double-, and triple-loop learning at each governance level

Practitioners and stakeholders of AFM operating at each SRLF level must bring about change in their management practice over time, and also transform their governance arrangements. Capacity to change and transform promotes end-point goal and objective achievement within the SAM cycles, and/or intelligent refinement of these over time as required. Such capacity is realized by deploying a set of overlapping adaptive feedbacks at critical time intervals within the SAM cycle, to direct and facilitate an appropriate balance between the use of single-, double-, and triple-loop learning (see Table 5.2). The adaptive feedbacks occur over different time-scales across governance levels, and associate with elements of environmental watering at each governance level (Table 5.2). These feedbacks are the main mechanism for embracing uncertainty during environmental watering in the MDB.

Learning initiated within the water resource plan areas

Bottom-up learning facilitates decision-making within and across all MDB governance levels. This is strategic learning (see Table 5.2) and commences within the WRPAs where learning potentials are highest, via single-loop learning. For example, stakeholders of the Murray and Lower-Darling (Edward-Wakool related) have initiated some single-loop learning (lower and upper grade) within deployment of their SAM cycle (Table 5.2; see Appendix 6). For instance, there is improved understanding about recruitment and survival outcomes of Murray Cod (one fish indicator of apex predators) related to environmental flows. However, full potential for learning is a work-in-progress within the ongoing SAM cycle. Importantly, future learning requires meticulous facilitation of single-, double-, and triple-loop learning potentials for achieving and/or refining all TPCs and their associated objectives over time. However, an obstacle to this learning is not gaining consensus on these TPCs or any new ones, from all stakeholders (such as for the Edward-Wakool). Following information collation and the generation of derived knowledge within WRPAs, acquired through TPC auditing (see Appendix 6), this knowledge is collated at the Basin-state governance level via feedback loops into parent SAM cycles. Consolidation at this level is for assessing if “management targets” are being met, for example breeding success for short and long-lived fish species within rivers of New South Wales. This consolidation is done in all Basin-state SAM cycles. Information is then consolidated into the one SAM cycle at the MDB scale in order to assess if the policy targets are being met. For example, at the MDB governance level, the assessment would ask if there has been any improvement in the recruitment and populations of native fish species occurring in the MDB.

With necessary change and transformation resulting from double-, and triple-loop learning per governance level, probabilities are enhanced in the MDB for achieving and/or refining the complete hierarchy of environment objectives. This process ultimately contributes toward meeting the overall Vision-statement of the MDB.

5.5 Discussion

Capacity to deal with uncertainty inherent within the MDB environmental watering process allows its practitioners and stakeholders to be better prepared for the challenges commonly imposed by "wicked problems" (Rogers and Breen, 2003; Allan and Wilson, 2009). Implementation of an effective adaptive feedback system offers a practical solution that practitioners and stakeholders can use to address such challenges. The adaptive feedback system operates within all governance levels and its main function is to facilitate an ongoing and balanced approach to the three modes of societal learning, i.e. single-, double-, and triple-loop learning, at each governance level. It is this ongoing learning at each governance level, with intelligent links between levels, which allows timely feedback of information and knowledge for decision-making. At each governance level, decisions are required for appropriately adapting management interventions in line with progressing toward achievement of end-point goals and related objectives. For example, associated with the Edward-Wakool environmental watering area, prioritization of river flow regimes is enabled by targeting, based on TPC exceedance priorities, indicator fish species of apex predators, flow specialists or generalists within the Edward and Wakool Rivers. Applying the adaptive feedback system in the MDB as demonstrated in this case-study is fostered via application of several key SRLF principles:

5.5.1 Explicit practitioner mandates across governance levels

Recognizing practitioner mandates within and across the three governance levels allows feasible roles and responsibilities to be established for the adaptive management cycles and

Table 5.2. Societal learning potentials within the Murray-Darling Basin case-study, as guided by the Strategic adaptive management (SAM) cycles of the SAM Reflexive Learning Framework (SRLF). The nested feedback system demonstrates facilitation of single-, double-, and triple-loop learning and ultimately for activating, completing, and then regenerating the SAM cycles at each governance level of the Murray-Darling Basin (actual worked examples from the SRLF Level-3 SAM cycle are given in the Appendices).

Adaptive Learning Potential			**Transformational Learning Potential**
Single-loop Learning Facilitation		**Double-loop Learning Facilitation**	**Triple-loop Learning Facilitation**
Lower Sub-loop	**Upper Sub-loop**		
Response-System Feedbacks	**Adaptive Assessment Feedbacks**	**Adaptive Reflection Feedbacks**	**Adaptive Reflection into Review, with Governance Transformation**
Water Resource Plan Area <u>SRLF Level-3:</u> Time-interval: Daily, or weekly communication - via email and or phone. Possible monthly stakeholder meeting, to determine if operations and feedback systems are occurring adequately. Rapid-Response-System concerning testing of “outputs”: Collation of results from nested sites within Level-3 entities, to decide if intended “outputs”	Water Resource Plan Area <u>SRLF Level-3:</u> Time-interval: Stakeholder meetings and workshops annually. Adaptive Assessment within each Level-3 entity, auditing strategic “outcomes”: Collation of results from on-the-ground monitoring activities at sites. TPCs, the explicit and measurable end-points, are audited to evaluate if thresholds of specified indicators are exceeded, or not.	Water Resource Plan Area <u>SRLF Level-3:</u> Time-interval: Stakeholder workshops every 2-3 years. Adaptive Reflection within each Level-3 entity, to decide if Sub-objectives at Level-3 are being met. If not, then re-framing of assumptions (hypotheses and or models) used in TPC development is required, using newly acquired knowledge. New TPCs may be developed if pertinent TPC challenges have been posed during the period. Re-framing of action planning ‘inputs’ is also required based on new knowledge, in	Water Resource Plan Area <u>SRLF Level-3:</u> Time-interval: Stakeholder workshops every 5-6 years. Adaptive Reflection within each Level-3 entity, to review the Sub-objectives and TPCs. Includes evaluation of stakeholder network systems. Increasing stakeholder participation is important. Encouragement of key innovations is required, and this is used to transform stakeholder networks into more adaptive networks, promoting flexible and

Adaptive Learning Potential			Transformational Learning Potential
at level-3 are actually transpiring. If Level-3 planning "inputs" are not being implemented as intended, with expected "outputs" not occurring at Level-3, then adjustment to implementation is required, of the planning 'inputs' at Level-3, to obtain intended output results over the short-term.	TPC rationale and monitoring protocols (Appendix 5) guide and prioritize monitoring activities at Level-3 sites. TPCs are tabled if or when exceeded, or close to being exceeded thus giving time for adjusting actions in order to avoid TPC exceedance. TPC reporting (Appendix 6) spawn feedbacks for further decision making, i.e., adjusting existing action planning "inputs", and or revising existing thresholds of TPCs (particularly if first generation TPCs).	order to achieve the revised and or new TPCs developed, with implementation of these re-framed planning 'inputs'.	informal interactions. With this, SAM cycles of Level-3 entities are completed. Regeneration, allowing for the next iteration of the SAM cycle, commences with re-formulation of Actions in order to meet newly devised Sub-objectives and associated TPCs at Level-3.
=================== Example (Edward-Wakool): Adjust water releases from the Hume Dam when/if required, as per the "Larval Monitoring Protocol" of the Rapid Response System (see Appendix 4).	=================== Example (Edward-Wakool): Based on the list of TPCs exceeded and prioritized for future river flow events (Appendix 6): Adjust the 10 year	============================ Example (Edward-Wakool): If the fish objectives at this level are not being achieved, then: Look to refine current TPCs and/or develop new TPCs. The fish associated TPCs (see Appendix 2) are biotic	======================= Example (Edward-Wakool): With review of all objectives and TPCs: Innovate new ways to monitor fish within the Edward-Wakool, to decrease costs involved.

Adaptive Learning Potential			Transformational Learning Potential
	hydrological plan (Appendix 3), i.e., select the river discharge regime for the next season. In addition, the "Recruitment" Reproductive TPC value (Appendix 2) may require adjustment for future use in the SAM cycle.	responses to the main drivers of change within the system. Another option is to develop geomorphological (habitat) based TPCs associated with fish requirements, which may be more feasible and cheaper to implement. In addition, the hydrographs per fish indicator may require changes, e.g., to the flow magnitude and duration for instance. Unintended impacts on another fish species for example, may require changes to timing of the flow regime being implemented.	Increase participation within the Edward-Wakool stakeholder meetings and workshops. Increase collaboration from all stakeholders. Option to increase stakeholder meeting frequencies if pertinent to do so. Plan to conduct more informal stakeholder gatherings to discuss pertinent issues, e.g., out on site, to foster important social learning outcomes
Murray-Darling Basin State SRLF Level-2: Time-interval: Stakeholder meetings 1-3 years. Response-System concerning testing of "outputs": Collation of results from nested Level-3 entities, to decide if intended "outputs" at level-	Murray-Darling Basin State SRLF Level-2: Time-interval: Stakeholder meetings and workshops every 3-5 years. Adaptive Assessment within each Level-2 entity, auditing strategic "outcomes": Collation of monitored results from nested Level-3	Murray-Darling Basin State SRLF Level-2: Time-interval: Stakeholder workshops every 6-8 years. Adaptive Reflection within each Level-2 entity, to decide if Sub-objectives at Level-2 are being met. If not, then assumptions associated with Management Targets require re-framing, with potential for re-developing these targets.	Murray-Darling Basin State SRLF Level-2: Time-interval: Stakeholder workshops every 8-10 years. Adaptive Reflection within each Level-2 entity, to review the Sub-objectives and Management Targets. Includes evaluation of current

Adaptive Learning Potential			Transformational Learning Potential
2 are actually transpiring. If Level-2 planning "inputs" are not being implemented as intended, with expected "outputs" not occurring at Level-2, then adjustment to implementation is required, of the planning "inputs" at Level-2, to obtain intended output results over the medium-term. ==================== Example: If the number of stakeholder workshops, and/or number of stakeholders attending these, falls below a specified value, then: Investigate why, which may	entities, to decide if Management Targets are being met. Auditing Management Targets spawns feedbacks for further decision making. If Management Targets are not met then this is tabled. Decisions required - existing management planning "inputs" at Level-2 require adjustment and re-implementation across nested Level-3 entities, and or specific target values can be revised (particularly if first generation targets). ==================== Example: If management targets are not being met: Consider adjusting how water is prioritized across the WRPAs, using the TPC based tabling system.	Re-framing of management planning 'inputs' is also required based on new knowledge, in order to achieve the revised Management Targets, with implementation of the re-framed planning 'inputs'. ============================== Example: If objectives at this level are not being achieved, then: Look at changing the 10-15% value for more mature Murray Cod at key sites. Increase the number of stakeholder workshops occurring to discuss water	institutional arrangements. Innovations must be identified and promoted; and associated constraints (e.g. lack of decision-making delegation) reduced. Working progressively towards achieving adaptable governance at Level-2 is paramount. With this, SAM cycles of Level-2 entities are completed. Regeneration, allowing for the next iteration of the SAM cycle, commences with re-formulation of Management approaches in order to meet newly devised Sub-objectives and associated Management Targets at Level-2. ======================= Example: With review of all objectives and Management Targets: Investigate communication systems within stakeholder networks, for debating annual water planning. Additionally, delegate more functions to stakeholders at Level-3, e.g.,

Adaptive Learning Potential			Transformational Learning Potential
require adjusting of communication techniques, using more teleconferencing facilitation for example.	Make sure the SDLs are being adhered to and water trading rules are being followed throughout the Basin-state.	allocation tasks each year. Consider and justify asking for more water if the total requested amounts of water allocated from SRLF Level-1 each year is not being given on a regular basis. Change logistical processes associated with overseeing of the SDLs, to enforce these better.	authority over dam release adjustments.
Murray-Darling Basin <u>SRLF Level-1:</u> Time-interval: Stakeholder meetings every 3-5 years. Response-System concerning testing of "outputs": Collation of results from nested Level-2 entities, to decide if intended "outputs" at level-1 are actually transpiring. If Level-1 planning "inputs" are not being implemented as intended, with expected "outputs" not occurring at	Murray-Darling Basin <u>SRLF Level-1:</u> Time-interval: Stakeholder meetings and workshops every 6-8 years. Adaptive Assessment within the Level-1 entity auditing strategic "outcomes": Collation of monitored results from nested Level-2 entities, to decide if Policy Targets at Level-1 are being met. Auditing Policy Targets spawns feedbacks for	Murray-Darling Basin <u>SRLF Level-1:</u> Time-interval: Stakeholder workshops every 8-10 years. Adaptive Reflection within the Level-1 entity, to decide if higher (more value-laden) Objectives at Level-1 are being achieved. If not, then assumptions associated with Policy Targets require re-framing, with potential for re-developing these targets. Re-framing of policy planning 'inputs' is also required based on new knowledge, in order to achieve the revised Policy Targets, with implementation of the re-	Murray-Darling Basin <u>SRLF Level-1:</u> Time-interval: Stakeholder workshops every 10-15 years. Adaptive Reflection within the Level-1 entity, to review the Higher- (value-laden) objectives and Policy Targets. There is evaluation of existing paradigms, with deliberation of structural context. Involves altering regulatory frameworks (e.g. rules) that may be stalling application of the SAM cycle. Key challenges exist due to

Adaptive Learning Potential			Transformational Learning Potential
Level-1, then adjustment to implementation is required, of the planning "inputs" at Level-1, to obtain intended output results over the long-term. ==================== Example: If water calculations, estimating the current amount of environmental water available, are taking longer than a specified time to complete, then: Consider adjusting the techniques used, and/or data required. Make adjustment to the known amount of water recovered for the	further decision making. If Policy Targets are not met then this is tabled. Decisions required - existing policy planning "inputs" at Level-1 require adjustment and re-implementation across nested Level-2 entities, and or specific target values can be revised (particularly if first generation targets). ==================== Example: Where policy targets are not being met: Re-prioritize the environmental works program, to WRPA and river systems. Adjust the current Sustainable Diversion Limit (SDL) of 10,876 GL, by decreasing this to a feasible value, to augment environmental water	framed planning 'inputs'. ============================== Example: If objectives at this level are not being achieved, then: There may be a need to start maintaining various ecosystem components, rather than looking to improve these. Due to for example, TPC related information from the lower levels indicates that improving ecosystem components is not feasible, which may result from logistical issues emanating from learning about on-the-ground environmental watering processes.	prohibitive rigidity of governance systems at Level-1. With this, the SAM cycle of the Level-1 entity is completed. Regeneration, allowing for the next iteration of the SAM cycle, commences with re-formulation of Policies in order to meet newly devised Higher-objectives and associated Policy Targets at Level-1. ========================= Example: With review of all objectives and Policy Targets: Here, a change in societal values may occur, e.g. a decline in environmental focus back to the social and economic components. This would imply a paradigm shift and large transformation at this level, with large implications for SAM cycles at level-2 and Level-3.

Adaptive Learning Potential			Transformational Learning Potential
environment, toward the required 2,750 GL.	recovery.	Environmental works achieved to deliver this water is insufficient to meet higher environmental objectives. Or, a need to speed up recovery processes of certain critical ecosystem components due to unacceptable implementation lags with environmental watering. Consideration to increase the amount of water so far recovered for the environment, to the required 2,750 GL. The key ecosystem assets of the MDB may require revision and new lists developed. More severe water use restrictions may need to be applied, to augment the current SDL process. Water trading is working and can continue as is.	

their feedback systems. At the WRPA governance level, practitioners often become overwhelmed by the higher level factors that constrain environmental watering processes in the MDB. Their motivation may be inhibited because higher-level factors such as policy processes and formal and inflexible governance arrangements are out of their direct control. Meanwhile, practitioners operating at the MDB scale where policy is determined may not receive satisfactory feedback from the lower levels, forcing them to extend their mandates to lower levels unnecessarily. This transference of mandate to the lower level leads to the MDB scale practitioners becoming bogged down by too much detail, diminishing their capacity to evaluate policy outcomes. Hence, clarification is needed about feasible roles and responsibilities associated with implementation of the different adaptive management cycles. This clarity within deployment of adaptive management cycles reduces confusion with implementing the adaptive feedback system across governance levels, thus fostering the facilitation of societal learning throughout the MDB.

5.5.2 A “Thresholds of Potential Concern” type mind-set

To understand significant change within a system only a small set of key variables need be identified because changes that can constrain and or redefine a system are determined by three to five key variables, at any scale (Walker and Salt, 2012). Here, the intention is to identify the minimum but sufficient data and information required in order to effectively manage a system, but in line with the values that stakeholders deem important (Holling, 2001; Walker and Salt, 2012). This idea epitomizes a resilience style of thinking, and is based on the “requisite simplicity” principle – as simple as possible, but not too simple (Walker and Salt, 2012). Many TPCs can be initially derived in any early SAM cycle of a WRPA, however, narrowing this TPC set down progressively is essential in order to have as few TPCs as possible to guide management at this scale. Narrowing the TPC set down is important because resources are typically scarce under any resource management program and monitoring is often expensive. The TPCs and their monitoring requirements are therefore realistic and affordable making them effective within any environmental watering system (McLoughlin *et al.*, 2011).

Construction of TPCs within WRPAs requires only an existing understanding of the dynamics of the ecosystem under management. This knowledge does not have to be complete, with TPC development lying along a continuum from “empirically well or fairly well understood”;

through an intermediate position "informed by expert opinion" to "intelligent early guesswork" or from a conceptual understanding of the system (Biggs *et al.*, 2011). With TPC construction all assumptions are made explicit, and there is consideration of their robustness (scientific credibility) and/or human values incorporated (Biggs *et al* 2011). Therefore, TPCs are often developed as "first generation" TPCs which are viewed as hypotheses of acceptable change and open to challenge and refinement over time, forming an inductive approach to adaptive management (Rogers and Biggs, 1999; Biggs and Rogers, 2003). This suggests that if TPCs can be constructed relatively rapidly using existing but "good enough" knowledge about the ecosystem (see Appendix 2), and incorporating stakeholder values, time and resources can then be channeled more urgently toward implementing the SAM cycles with their adaptive feedback systems. Consequently, ongoing societal learning within each WRPA SAM cycle is better facilitated (see Table 5.2) and practitioners with their stakeholders are better equipped to deal with uncertainty. Probability of achieving environmental objectives is therefore strengthened, resulting in a more effective environmental watering system.

5.5.3 Stakeholder participation with real collaboration

Adaptive freshwater management is often about developing an optimal capacity to manage the freshwater resource in an effective and participatory manner, rather than achieving or maintaining an optimal condition of the resource (Pagan, 2008). An optimum capacity to deal with uncertainty during environmental watering in the MDB will depend on freshwater scientists and their manner of seeking consensus while prioritizing various ecosystem outcomes for environmental watering. By embracing the social aspects of freshwater management, scientists become co-learners rather than "experts" in the process, and this promotes AFM (Rogers and Breen, 2003). For example, construction and use of the TPCs within the WRPA scale SAM cycles (see Appendix 2) is a collaborative venture comprising WRPA scale practitioners and their stakeholders. Here, the priority is to make sure that all stakeholders have their say in TPC development, without any domination from certain sectors. Working toward achieving consensus with derived TPCs is paramount for implementation of the SAM cycles within the WRPAs.

For increased probability of success in implementing the SAM cycles a sincere application of the "collaborative" method of public participation (see du Toit and Pollard, 2008) is practiced by all AFM practitioners, rather than "informing" stakeholders under a pretense of collaboration. Under the SRLF, adaptive networks are built across all organizational sectors within and across governance levels, and these ideally become “communities of practice” (sensu Wenger, 1998) that then oversee initiation, completion and regeneration of the SAM cycles (McLoughlin and Thoms, 2015). Without collaboration via these networks there is lost trust and AFM is more likely to be stalled by stakeholder groups that feel excluded from the process (Armitage *et al.*, 2015).

5.5.4 Adaptive management champions – the “holy grail” for implementation?

There are key practitioners at each SRLF governance level, for example MDBA (Basin), Office of Environment and Heritage (Basin-state) and the Murray Local Land Service (WRPA). Adaptive freshwater management champions are individuals within these organizations who are enlightened, motivated, adaptable, and willing to learn with a keen awareness of complexity and understanding to manage for this (Fazey and Schultz, 2009; Rogers *et al.*, 2013). For example, the Catchment Officer – Water at the Murray Local Land Service oversees the SAM cycle of the Edward-Wakool environmental watering area. This person is a key champion driving development and application of the SAM cycle (see Appendices), without which many outcomes are not possible. “Principal champions” are those practitioners operating at the Basin-state governance level because their mandates coincide with both Basin and WRPA practitioner mandates. For environmental watering in the MDB this role falls under the jurisdiction of the Office of Environment and Heritage (New South Wales example), with individuals disseminating information vertically across the governance levels in order to coordinate learning throughout all levels of the MDB. Enlightenment of such champions at each governance level is the glue that binds the adaptive process together, without which it is more likely to fail.

5.5.5 Achieving a balance between single-, double-, and triple-loop learning

Resources are typically scarce under AFM programs. It is paramount to avoid the trap of “learning for the sake of learning” (Fabricius and Cundill, 2014) by having an efficient learning strategy at each governance level of the MDB (see Table 5.2). When applying the SAM cycle at each governance level, the nested adaptive feedbacks for single-loop learning (both lower and upper) are mandatory and ongoing because these incorporate the actual doing (i.e. maintaining or improving established practices to meet end-point goals) and is where progress is made within AFM (Fabricius and Cundill, 2014). Double-loop learning feedbacks are invoked only if and when required to avoid learning when change is not absolutely necessary. To make these types of decisions involves a deeper reflection examining achievement of objectives linked to the end-point goals (see Table 5.2). If the objectives are not being met (considering any surprises) then changing practices becomes pertinent. For example, within the WRPAs devising alternative TPCs (end-point goals) via redefining assumptions (hypotheses and models), along with updating monitoring systems and existing planning inputs, may become necessary.

Triple-loop learning is required over longer time scales. Triple-loop learning involves a holistic review of all objectives at each governance level based on new scientific information and/or changing human values. It also includes revision of the end-point goals, and a deliberate attempt to transform governance systems at the particular governance level. The Environment theme SAM cycle at each governance level is completed and set for regeneration by applying all newly available knowledge in order to achieve a revised hierarchy of objectives. Notably, any transformation within SAM cycles at SRLF Level-2 will be subject to constraints from the SRLF Level-1, and similarly SAM cycles at SRLF Level-3 are subject to constraints from Level-2 (see Table 5.2). At each governance level, regeneration of the SAM cycle increases stakeholder capacity to work together, thus promoting collaboration which is needed for effective societal learning (Armitage *et al.* 2015).

5.5.6 Implement SAM cycles within the water resource plan areas

Slower response times of entities at higher levels in a hierarchy must be seen as standard practice, not failure (McLoughlin and Thoms, 2015). Hence, relative to the WRPA SAM cycles, the longer time frames for change within the SAM cycle at the Basin governance level must be conceded when inferring achievements within AFM associated with environmental watering. Hence, outcomes for single-, double-, and triple-loop learning are initially pursued within the SAM cycles of WRPAs (given constraints imposed by the higher levels) because these exhibit quicker learning potentials. Increased capacities for social learning and the development, use and auditing of TPCs within the WRPAs is supportive of this learning. Subsequently, and over longer time-scales, SRLF Level-3 SAM cycles influence learning in the upper governance levels of the MDB, via vertical feedbacks.

Moving beyond typical single-loop learning within a SAM cycle is promoted by a number of key criteria (Pahl-Wostl, 2009; Pahl-Wostl *et al.*, 2013). First, there is an informal network of participants conducting regular meetings and the rules and arrangements (for example, who is included; the operational requirements; leadership) of the network are not formally imposed. Second, it is important that the mandate of this network is open ended where results are not formally binding straightaway. Third, the network of participants must deal with specific problems, and be open to experimentation involving various approaches thus allowing for innovation. Furthermore, it is beneficial if the participant network has joint and shared practices (communities of practice; sensu Wenger (1998)), and tangible products in order to generate an identity for itself, including a history and a body of shared knowledge which is different to that of individuals within the network. Notably, there is increased ability for self-organization, creative thinking and innovation if the social networks are more autonomous and informal. These criteria are most likely to occur at SRLF Level-3 (McLoughlin and Thoms 2015), thus the WRPA scale of the MDB.

Fostering of innovation within each WRPA operates to break implementation paralysis that is often associated with AFM practice (Pollard and du Toit, 2011). It is critical to recognize that within the MDB AFM is not a "one size fits all" approach. Hence, practitioners within each WRPA (and Basin-state) coordinate and mobilize their unique set of resources (stakeholders, equipment, budgets, skills, knowledge for example) as best they can to surmount problems with getting the SAM cycle initiated. It is understandable that planning entities of the Basin, for example water resource plans, require a degree of standardization within and across Basin-states. Nonetheless, it is vital that AFM practitioners and their stakeholders within each WRPA are given freedom to experiment and innovate as necessary making use of their available resources, for instance when developing TPCs and/or the types of dam release rules for implementing river flow events. In this way the Edward-Wakool Fish Recruitment and Larval "Rapid Response System" was developed (see Appendix 4) with piloting of the Recruitment and Survival bundles of TPCs (Appendix 2), and documentation of all monitoring related activities linked to these TPCs (see Appendix 5). Achieving adaptable governance regimes across the SRLF levels of the MDB is expedient, particularly the establishment of polycentric and de-centralized governance arrangements. Under polycentric governance, decision-making powers are divulged to the lower governance levels, thus

WRPA scale practitioners and their stakeholders (and at the Basin-state scale) exhibit the freedom to oversee and implement their SAM cycle mandates as necessary.

5.5.7 Accept uncertainty under complex water reforms

Practitioners of environmental watering in the MDB and their stakeholders must not be seeking an optimum "once-off solution" to applying environmental watering in the Basin. Rather, they must engage within an ongoing process of rethinking and negotiating their options (vis-à-vis Pahl-Wostl *et al.*, 2007, Huxum and Vangen, 2000), about how to best improve their management and governance over time. An ability to adapt and change when required means that uncertainty is likely being embraced, rather than eliminated or controlled. This assists in implementing an effective environmental watering in the MDB, which moves toward achievement of a flexible set of objectives. Notably, such an AFM approach will require skillful inclusion within the various planning instruments of the MDB, within and across governance levels. Further research is needed targeting the higher governance levels within the MDB, particularly in investigating actual implementation of the Basin-wide environmental watering elements at these levels. In addition, research exploring a combination of the Environment, Economic and Community/Social themes (see McLoughlin and Thoms, 2015) of the SRLF is needed, due to the integrated nature of the Vision-statement currently tied to the MDB.

5.6 Conclusion

The practice of AFM is dependent on effective societal learning at each governance level of freshwater management with intelligent links between these levels. To achieve this learning a greater awareness about and use of adaptive feedbacks is required, within interlinked adaptive management cycles across the governance levels. It is the role of this adaptive feedback system to facilitate single-, double-, and triple-loop learning which is important for embracing uncertainty within the environmental watering program in the MDB. Lessons learned such as in this case-study, iteratively over time, and applied back into the AFM system will allow for a progressive implementation of the adaptive feedback system. With this implementation, uncertainty is better embraced leading to more effective environmental watering in the MDB that achieves objectives. These MDB case-study lessons are transferrable to other environmental watering cases globally.

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5.8 Appendices

Appendix 1. The Basin-wide Environmental Watering Strategy, summary.

(Licensed from the Murray–Darling Basin Authority, under a Creative Commons Attribution 3.0 Australia Licence. Author: MDBA (2014b)).

Environmental watering components	Description of environmental watering components
Objectives, outcomes and high level targets	The objectives of the environmental watering are: (1) Protect and restore water dependent ecosystems, e.g. rivers, wetlands and floodplains, and their plants and animals. (2) Protect and restore the ecosystem functions of water-dependent ecosystems, e.g. salt export and connectivity. (3) Ensure that water-dependent ecosystems are resilient to climate change and other risks/threats. The Basin-wide environmental watering strategy outcomes are related to four biophysical indicators: (1) River flows and connectivity. (2) Native vegetation. (3) Water-birds. (4) Native fish. (5) Water quality issues of the Murray-Darling Basin. Reasons for selecting these indicators for outcomes: - Good indicators of the health of a river system and are measurable. - Important components of healthy functioning water-dependent ecosystems. - Responsive to environmental flows. - Highly valued by people. The high-level targets are: (1) Up until 2019 - no loss or degradation. (2) Post 2019 - improvement in the ecosystem components.

Environmental watering components	Description of environmental watering components
Long term plans, roles and responsibilities	Long term plans to coordinate environmental watering across the Basin, to achieve environmental outcomes: • Basin-wide environmental watering strategy. • Water resource plans. • Long-term watering plans for each water resource plan area Responsibility of the Murray-Darling Basin Authority (MDBA): • Oversees and evaluates implementation of the MDBP. • Manage implementation of the Basin-wide environmental watering strategy. • Oversees review of the MDBP every five years in consultation with stakeholders. • Collaborates with all parties (Commonwealth, state, local) to coordinate planning, prioritization and use of environmental water. Responsibility of the Commonwealth Environmental Water Holder (CEWH): • Manages the Commonwealth's water holdings (entitlements/allocations), acquired through government investment in water-saving infrastructure and water buy-backs as part of the national water reforms. • Makes decisions about use, carryover and trade of the Commonwealth's water holdings to maximize environmental outcomes at both local catchment and basin scales. • Collaborates with all parties (Commonwealth, state, local) associated with environmental water management. Responsibility of the Basin-states: • Identify long-term and annual environmental outcomes, priorities and watering needs for environmental assets. • Manage state environmental water including planned environmental water and/or held water entitlements. • Determine best ways to use available water in the interests of achieving environmental outcomes at local catchment and Basin scales, in consideration of Basin annual priorities. • Place orders for watering actions, and collaborate with all parties associated with environmental water management at state and local levels. • Prepare long-term watering plans referenced within water resource plans for each water resource plan area. In

Environmental watering components	Description of environmental watering components
	consultation and collaboration with holders and managers of environmental water, state and Commonwealth government agencies, river operators and local communities. • Make sure water resource plans provide for environmental watering to occur in a way that is consistent with the environmental watering plan and the Basin-wide environmental watering strategy.
Annual environmental watering	Planning phase: • Informs environmental water planning and support the coordination of environmental water across the MDB. • Annually end May, Basin-states provide the MDBA with environmental watering priorities per water resource plan area • Annual environmental watering priorities consider the condition of sites; prevailing climate; history of watering; forecasts for climate; and available water resource outlooks, including likely holdings of environmental water. • MDBA identified Basin annual environmental watering priorities informed via Basin-state environmental watering priorities. • Basin-state environmental watering priorities published in June each year, describing key Basin environmental outcomes expected for coming year. • Information is used as input into the planning undertaken by relevant water holders. Implementation phase: • Starts beginning of new water year. • Detailed consideration given to current/forecasted conditions and water availability, to determine feasibly of options. • Local on-ground knowledge is important for detailing a specific watering action, i.e. flow magnitudes, timing, rates of rise and fall, the area to be inundated and triggers for commencement. • Includes detailed risk assessment that is undertaken before a decision is made on a watering action. • Decisions made by environmental water managers to commit water to an action, in consultation with environmental water managers and river operators, responsible for delivery of the water and monitoring. • Local community consultation and input is crucial during water delivery, as conditions can change rapidly and may result in the need to adjust, suspend or even cancel the watering action. • Upon completion of the watering action, a review process is undertaken to inform future watering actions and

Environmental watering components	Description of environmental watering components
	long-term management. Review informed by operational monitoring, results of ecological monitoring, and feedback provided by site managers and local community.
Principles of annual environmental watering priorities	Principles used to determine the MDB priorities include: • Being consistent with ecologically sustainable development and environmental watering plan objectives. • Flexibility and responsiveness to the condition of environmental assets and ecosystem functions, predicting likely effectiveness and risks involved with robust and transparent decision-making. Guided by these principles, the process to identify MDB annual priorities follow these steps: • Reflecting on environmental watering since the release of any previous events. • Identifying the resource availability scenario and management outcomes, assessing threats, opportunities and considering complementary outcomes and risks. • Consideration given to the Basin-state annual environmental watering priorities, informed by local experience and knowledge. • MDBA works with environmental water holders and managers to help identify regional priorities considered important at a MDB level, and consults these groups before publishing the Basin environmental watering outlook early in the calendar year. • The MDBA formally considers Basin-state annual environmental watering priorities in early June. • Feedback from consultation with governments, water holders, river operators, peak groups, community representatives and people directly affected by environmental watering. • Together with formal reporting from holders and managers of environmental water, this information is used to inform the development of priorities for further environmental watering.

Appendix 2. Thresholds of potential concern (TPC), Edward-Wakool examples - Recruitment and Survival bundles of TPCs.

River flow/quality regimes and fish: TPCs for river flow, timing, water quality, and water temperature as agents of change

Summary rationale: Inadequate river flows decreases the number of potential nesting sites (e.g. snags) inundated in the Edward-Wakool rivers and creeks, thus diminishing availability of nesting sites required by fish during the breeding season. Inadequate flow also lowers ability of individuals to gain access to potential breeding partners and return from breeding grounds to refuge sites. River flow affects water quality such as dissolved oxygen.

		Indicators	Measurement Criteria	Measurement Scale	Thresholds of Potential Concern
Apex Predators – Fish In-stream Bundle of Recruitment TPCs	Reproducing next generation adults	Presence of Adult individuals of apex predator species that require suitable nesting sites (snags) in the river in order to breed and recruit successfully.	The percentage of sites where Adults of apex predator species are found during sampling within the river sites.	Spatial: Sampling at the selected river and creek monitoring sites spread over the entire length of the Edward-Wakool in-stream channels Temporal: Annually, in June (dependant on low flow) at the 20 selected monitoring sites, prior to breeding season.	Cod Adults: Sampled at less than 50% of monitoring sites, spatially spread over the selected monitoring sites.
	Juveniles	Presence of Juvenile individuals of apex predator species that require suitable habitat (snags, wetland connectivity) in the river in order to recruit successfully.	The percentage of sites where Juveniles of apex predator species are found during sampling within the river sites.	Spatial: Sampling at the selected river and creek monitoring sites spread over the entire length of the Edward-Wakool in-stream channels Temporal: Annually, in June (dependant on low flow) at the 20 selected monitoring sites, prior to breeding season.	Cod Juveniles: Sampled at less than 50% of monitoring sites, spatially spread over the selected monitoring sites. (Note: Starting with same threshold as for Adults, but look at possible change as appropriate after next TPC audit).

River flow/quality regimes, angling, farming and fish: TPCs for river flow and quality, fishing and grazing/cropping as agents of change

Summary rationale: Managing river flow is important in order to maintain sufficient productivity in the rivers, and water quality, providing characteristics necessary for supporting healthy fish populations, dispersed across the river system. Agricultural practices, such as grazing and cropping also influence nutrient inputs into the river, thus affecting habitat suitability for fish. Furthermore, to maintain healthy and persistent fish populations, sustainable fishing practises are required.

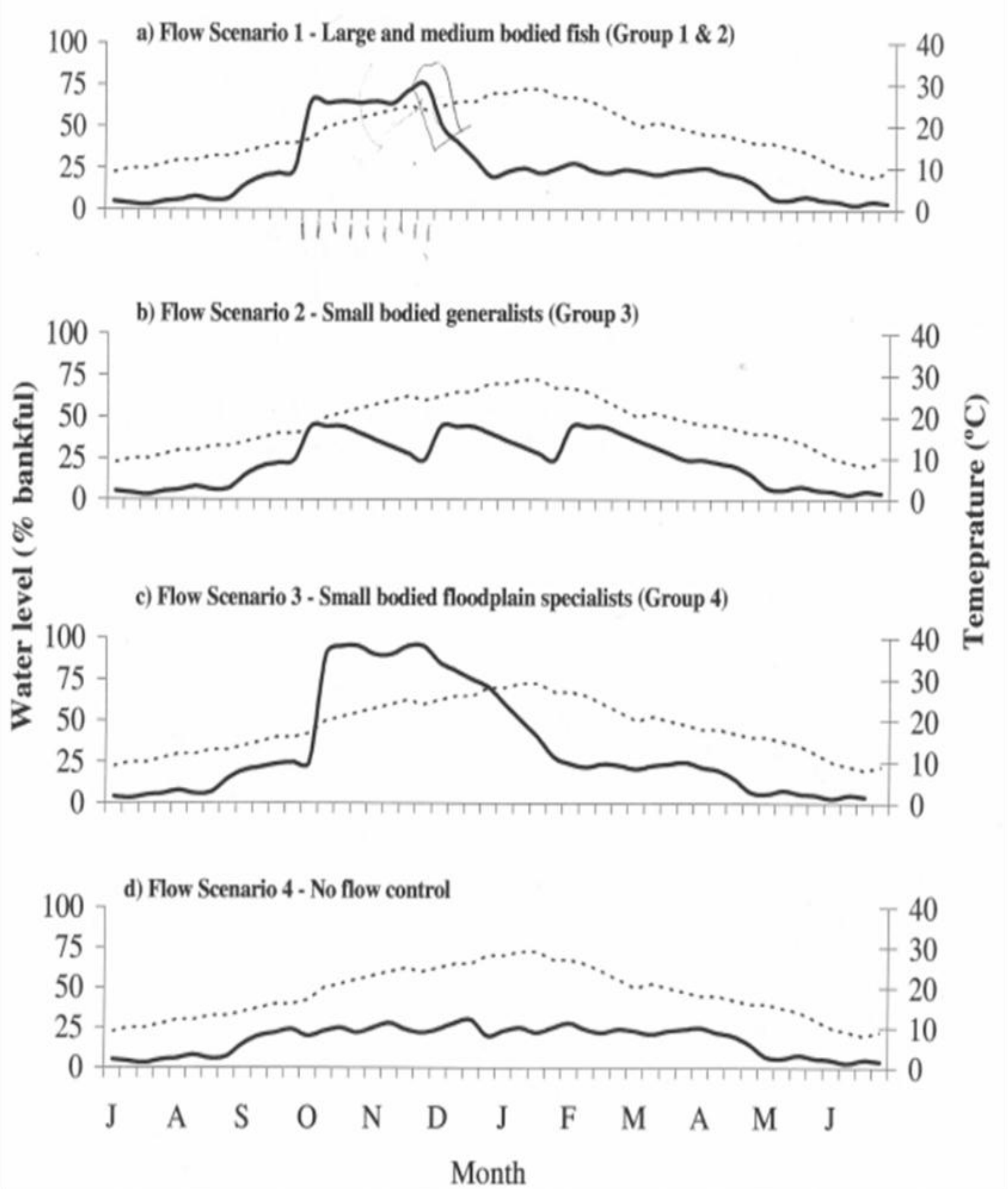
		Indicators	Measurement Criteria	Measurement Scale	Thresholds of Potential Concern
Apex Predators The In-stream Bundle of Fish Survival TPCs	Minimum number of individuals	The relative abundance of Apex predators occurring within the in-stream channels.	The minimum number of Apex predators present in the in-stream channel sites.	Spatial: Sampled across the whole system at the 18 selected monitoring sites with 6 in upper, 6 in middle, 6 in lower zones. Temporal: Annually, in June (low flow) at the 18 selected monitoring sites.	Less than 5 Cod individuals sampled at 50% or more of in-stream sites in each zone i.e. minimum of 5 individuals in at least 3 sites in each zone).
	Age-class	The variation within age classes of Apex predator populations occurring within the in-stream channels.	Age-class: The population structure characteristics of Apex predators in the in-stream channel sites across entire system.	Spatial: Sampled across the whole river at the 18 selected monitoring sites, with 6 in each zone. Temporal: Annually, in June (low flow) at the 18 selected monitoring sites.	Cod Adult Age-class: All age-classes must be represented. Minimum of 3 juveniles (<50cm), and 2 mature adults (>50cm) at 50% or more of sites in each zone.
	Condition	The relative health of Apex predator individuals occurring within the in-stream channels.	Length weight: Ratio Index of individuals of Apex predators. Parasites: The number of parasites found on individuals of Apex predators.	Spatial: Sampled across the whole river at the 18 selected monitoring sites Temporal: Annually, in June (low flow) at the 18 selected monitoring sites.	Length/weight: 3 out of every 5 individuals per zone should be above the recommended weight to length chart. Parasites: (3 out of 5 individuals should have less than 10 parasites per fish).

River flow/quality regimes, angling, farming and fish: TPCs for river flow and quality, fishing and grazing/cropping as agents of change

Summary rationale: Managing river flow is important in order to maintain sufficient productivity in the rivers, and water quality, providing characteristics necessary for supporting healthy fish populations, dispersed across the river system. Agricultural practices, such as grazing and cropping also influence nutrient inputs into the river, thus affecting habitat suitability for fish. Furthermore, to maintain healthy and persistent fish populations, sustainable fishing practises are required.

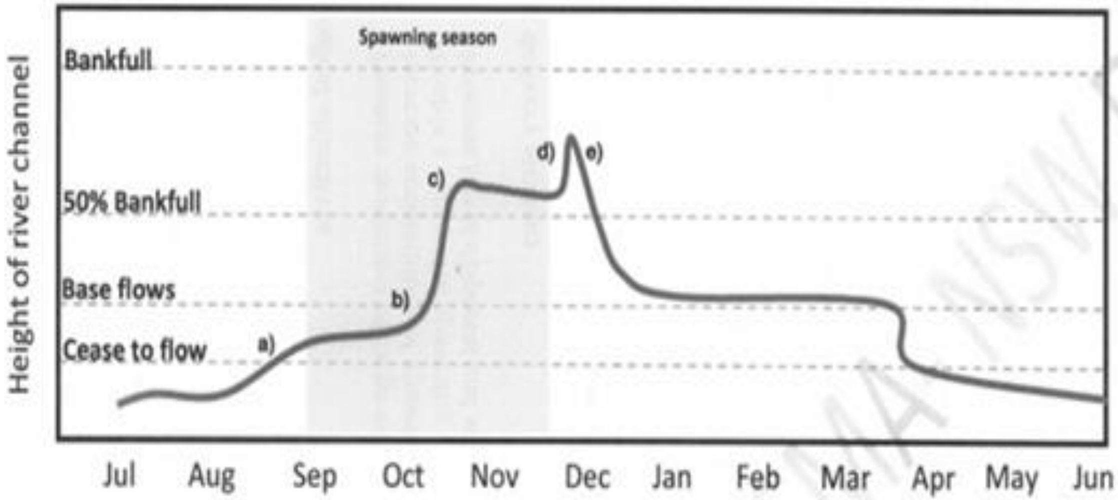
		Indicators	Measurement Criteria	Measurement Scale	Thresholds of Potential Concern
Apex Predators The In-stream Bundle of Fish Survival TPCs	Recreational Take	The number of apex predators harvested by recreational fishers within the river system	The Annual Exploitation Rate of apex predators within the river system	Spatial: Sampled across the whole system at 6 selected monitoring sites with 2 in upper, 2 in middle, 2 in lower zones. Temporal: Annually, during later period of Murray Cod season (Easter)at 6 monitoring sites.	The Annual Exploitation (U) Index is greater than 0.15

Appendix 3. Edward-Wakool related management action planning, involving envisaged hydrological regime to meet the thresholds of potential concern.



Representation of four flow scenarios developed to benefit each fish group:

- Water level expressed as a percentage of bankfull capacity (solid line).
- Mean monthly water temperature expected in the Edward-Wakool system (broken line).



Rationale

a) Cease to flow conditions increase to baseline

b) Spike to inundate Murray cod nesting habitat and stimulate movement / spawning of golden and silver perch (5 days)

c) Maintain water level to keep nest inundated and allow hatching of eggs (Murray cod) and egg dispersal (Golden / Silver perch) (25 days)

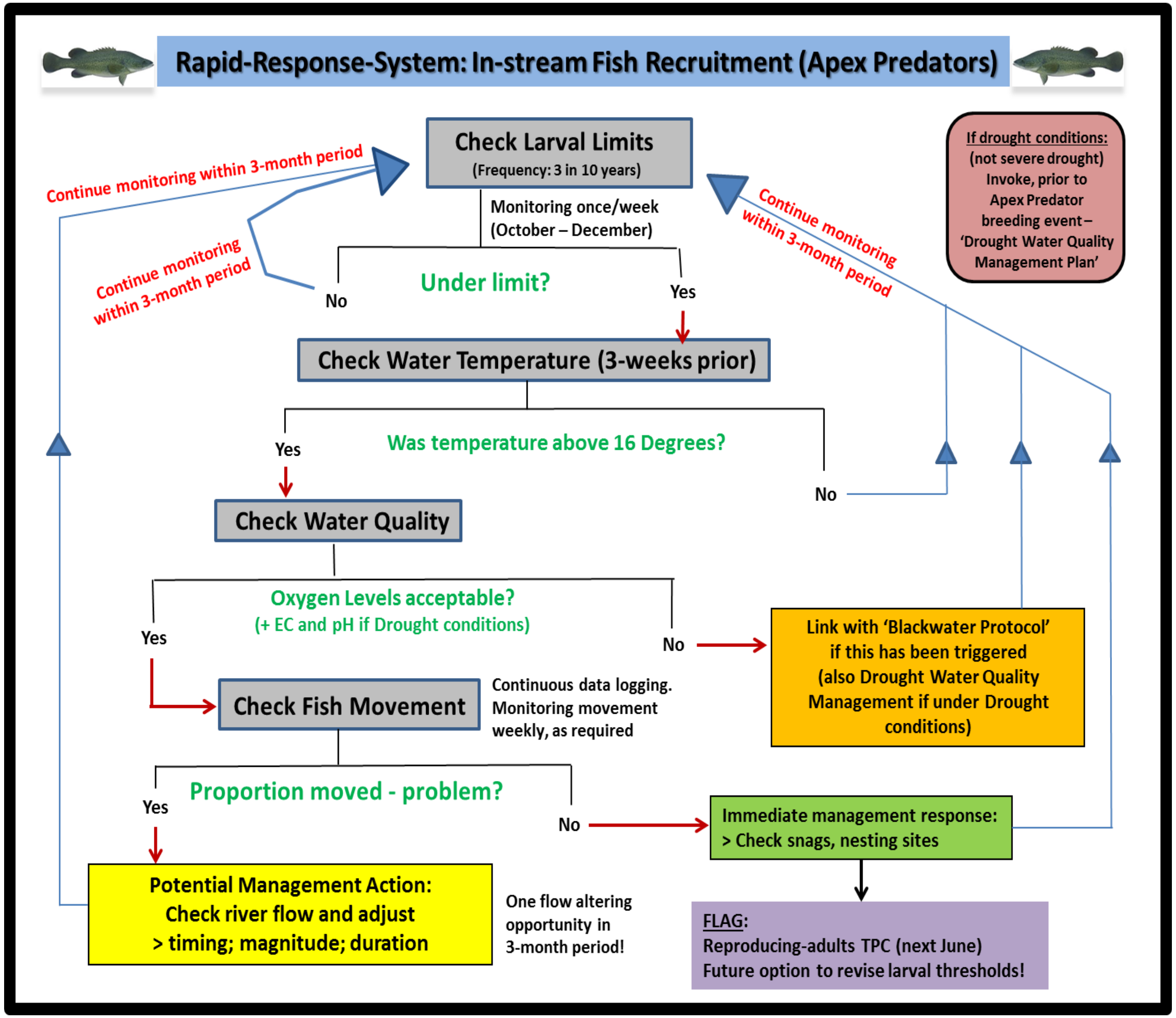
d) Spike to promote larval dispersal from nest sites (max 5 days)

e) Gradual draw-down to baseline (5-10 days)

NB: Flow should be sufficient to stimulate spawning and dispersal in medium-bodied species as well as large-bodied species. This may also benefit some small bodied species and monitoring will provide insights on potential benefits.

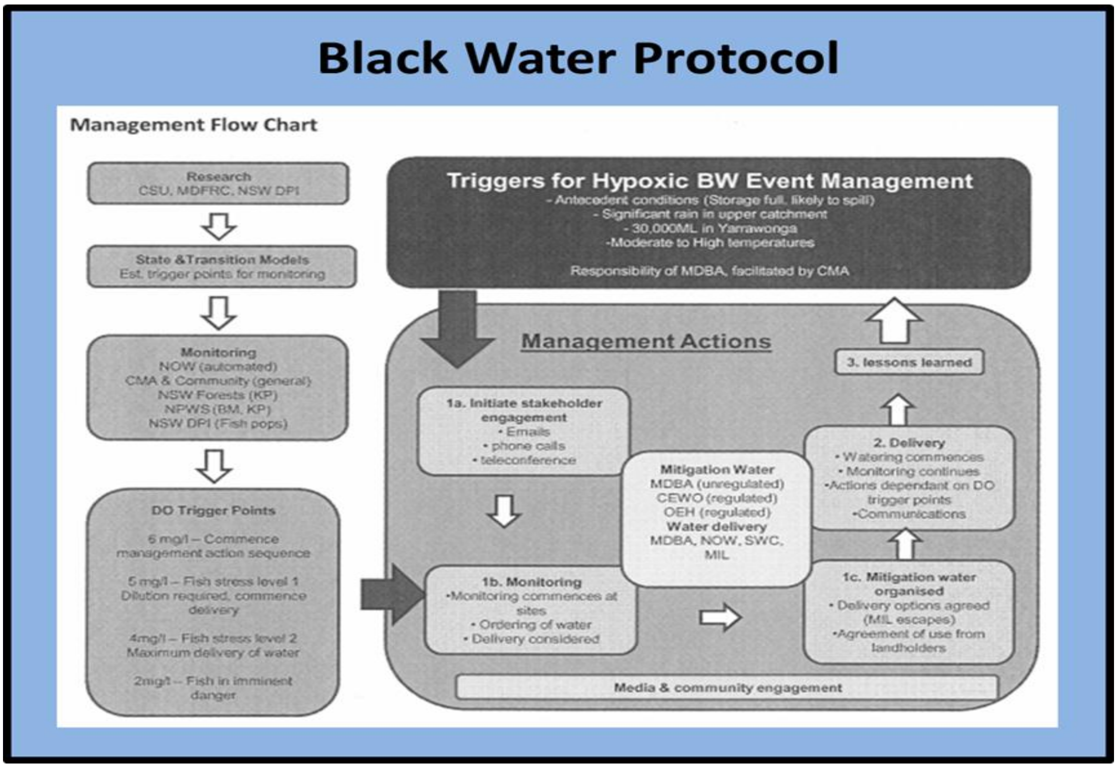
Detailed flow strategy-1 proposed: Provision of environmental flows for large-medium bodied fish

Appendix 4. Example Rapid-Response-System (RRS) – fish larval monitoring associated with implementation of the Edward-Wakool management action.



Fish Larval monitoring and limits used for the Instream Recruitment Rapid-Response-System, and the Black Water protocol.

	Indicators	Measurement Criteria	Measurement Scale	Rapid-Response-System Limits
Breeding/spawning larval recruitment	Larvae of apex predator species that require suitable habitat (snags, slackwater, macrophytes) and food sources in the river in order to recruit successfully (~3 out of 10 years).	The number of larvae found occurring within the river, belonging to apex predator species.	Spatial: Sampling at least 5 sites spread over the entire length of the Edward-Wakool in-stream channels Temporal: Weekly to bi-weekly sampling at 5 selected sites over 3 months - October to December.	October: Number of Cod larvae specimens is less than 4 at 80% or more of sites. October - December: Number of Cod larvae specimens is less than 10 at 80% or more of sites. Total for season: Less than 14 Murray Cod Larvae at 80% or more of sites.
Movement	Existence of individuals of Adult apex predators remaining within the large remnant pools during breeding season.	The proportion of apex predator sub-populations leaving the large remnant pools during breeding season.	Spatial: Sampling at the selected refuge pools (Wakool-Yallakool confluence). Temporal: Continuous logging. Movement weekly during breeding season (October - December). Do analysis > when required (see TPC Protocol)	If the proportion of Cod Adults leaving the pool (for more than 24 hours) is less than 30%.



Appendix 5. Thresholds of potential concern (TPC) documentation, Edward-Wakool examples - Recruitment and Survival bundles of TPCs.

Edward-Wakool
Thresholds of Potential Concern Bundle
Apex Predator Recruitment

1) Background and Rationale

Managing complex systems characterized by uncertainty requires an adaptive, learning-by-doing approach. Thresholds of Potential Concern are the end-points (or targets when rehabilitation is required), defined as the upper and lower levels of acceptable change that when exceeded, set in motion a process of investigation as to the reasons why the TPC was exceeded (See Appendix A for more information).

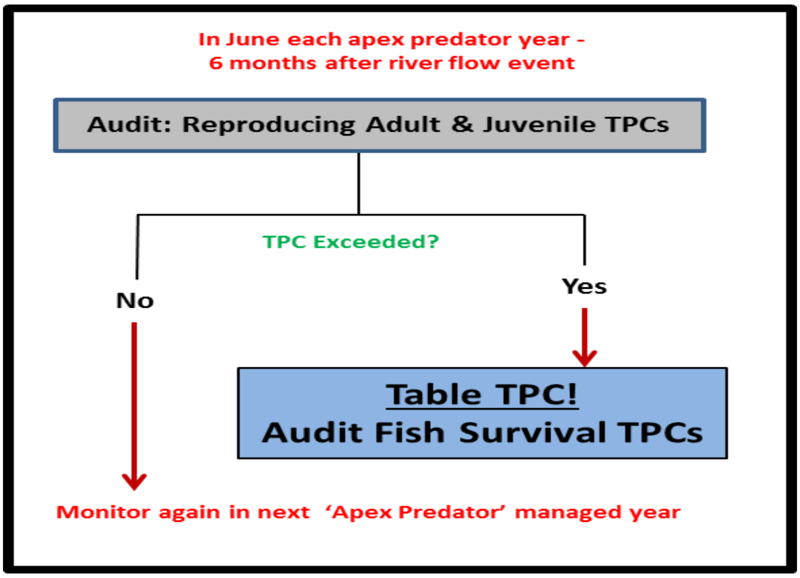
Apex fish predators such as Murray cod and Trout Cod are important both ecologically and socially within the Edward-Wakool system. Ecologically they are important for influencing the food chain as the dominant fish predator, and healthy populations are essential for maintaining ecosystem balance. Socially they are important in relation to conservation legislation and are listed under state, Commonwealth and international conservation listings. They form the basis for an economically and cultural important recreational fishery with the system and hold spiritual and food importance for the local indigenous community. These species are long-lived so to sustain the population, there is no essential requirement to spawn and recruit every year. These species simply need enough opportunities, over a lifetime, to maintain and possibly expand existing distributions.

Rationale: Inadequate river flow decreases the number of potential nesting sites (e.g. snags) inundated in the Edward-Wakool rivers and creeks, thus diminishing availability of nesting sites required by fish during the breeding season. Inadequate flow also lowers ability of individuals to gain access to potential breeding partners and return from breeding grounds to refuge sites. River flow affects water quality such as dissolved oxygen.

2) TPC Table

	Indicators	Measurement Criteria	Measurement Scale	Thresholds of Potential Concern
Reproducing next generation adults	Presence of Adult individuals of apex predator species that require suitable nesting sites (snags) in the river in order to breed and recruit successfully.	The percentage of sites where Adults of apex predator species are found during sampling within the river sites.	**Spatial**: Sampled across the whole system at the 18 selected instream monitoring sites, with 6 in each zone. **Temporal:** Annually, in June prior to breeding season.	Less than 3 Cod Adults (<50 cm) sampled at 3 of 6 instream sites in each zone
Juveniles	Presence of Juvenile individuals of apex predator species that require suitable habitat (snags, wetland connectivity) in the river in order to survive successfully	The percentage of sites where Juveniles of apex predator species are found during sampling within the river sites.	**Spatial**: Sampled across the whole system at the 18 selected instream monitoring sites, with 6 in each zone. **Temporal:** Annually, in June prior to breeding season.	Less than 2 Cod juveniles sampled at sampled at 3 of 6 instream sites in each zone.

3) TPC monitoring and decision protocol



4) Justification for "first generation" TPCs set

The Justification for setting each TPC is based off three strength categories of evidence to support each TPC; 1. Empirical Evidence, 2. Expert Opinion, 3. Intelligent guesswork, and often a combination of all three. All TPC's developed below are first generation and will be modified as new information becomes available.

Reproducing next generation of adults (Expert Opinion).
Based off consultation with fisheries experts that have been studying this system for previous 5 years.

Juveniles (Intelligent guesswork-Expert Opinion)
Based off consultation with fisheries experts and pre-blackwater data for the system.

Breeding/spawning larval recruitment (Intelligent guesswork)
Initial estimates based off 1 year of sampling. Need to be investigated further after next year of sampling.

Movement (Intelligent guesswork-Expert opinion)
Based off last 4 years of movement data in the system.

5) Monitoring plan

Next Generation of Reproducing Adults and juveniles.
Annual sampling of fish is conducted in a minimum of thirty sites within the Edward Wakool system. Sites are stratified between upper, middle and lower zones and within each zone divided into wetland and channel habitats. Fish are collected using the Sustainable Rivers Audit (SRA) electrofishing protocol augmented by a netting strategy. This sampling would inform on the adequateness of a certain number of adults that would

Breeding, spawning, larval Recruitment.
To sample for larval and juvenile fish, three quatrefoil perspex light traps containing bioluminescent light sticks are set at five sites within each of the 5 river-creek sites (15 traps in total per river). Light traps are deployed at randomly along the littoral edge at each site at dusk, and retrieved the following morning.

Movement
To monitor fish movement responses in relation to environmental water delivery using acoustic telemetry methods a series of acoustic receivers were deployed along the Wakool River and Yallakool Creek to examine fish movements. Tagged fish have been released at the confluence of the two systems and monitoring is continual.

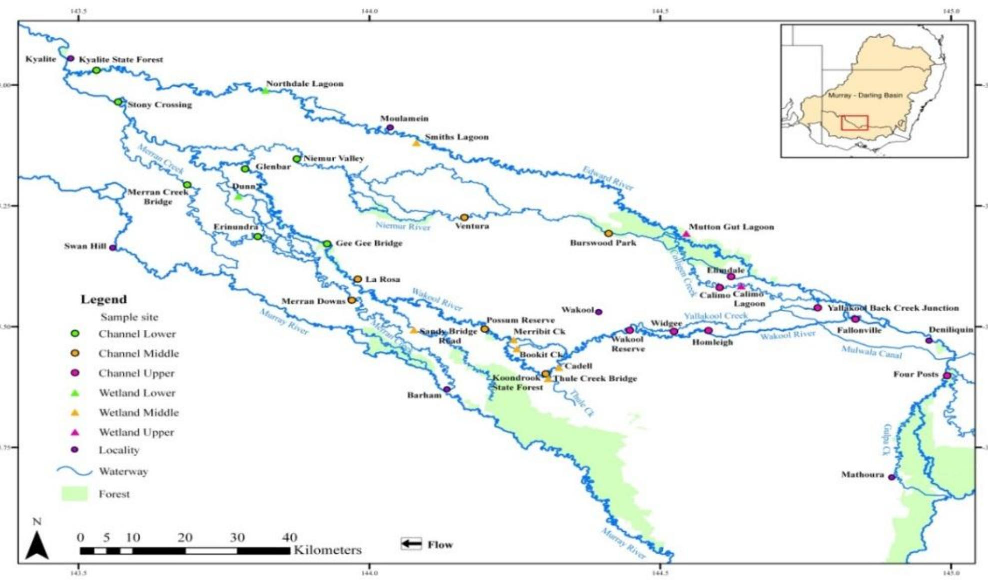


Figure 1. Map of the Edward-Wakool system including system including fish monitoring sites. Red circles represent monitoring sites being used in the TPC auditing Process.

6) Logistics

Total Budget of 100,000 Annually needed, but this includes sampling the whole fish community throughout the entire system, so as more Survival TPC's are designed for other flow groups, costs for these will not increase annual spending on the TPC's

Annual Monitoring of fish communities
Equipment needed for Initial Set-up
50 Acoustic Receivers; $2000 each, 100,000
100 Acoustic Tags; $400 each, 40,000
Approx. $150,000 initial set up.

Tagging Operations (based on 100 fish tagged)
10 days sampling

Running costs and replacement tagging operations
(To be determined)

Edward-Wakool
Thresholds of Potential Concern bundle
Apex Predator Survival

1) Background and Rationale

Managing complex systems characterized by uncertainty requires an adaptive, learning-by-doing approach. Thresholds of Potential Concern are the end-points (or targets when rehabilitation is required), defined as the upper and lower levels of acceptable change that when exceeded, set in motion a process of investigation as to the reasons why the TPC was exceeded (See Appendix A for more information).

Apex fish predators such as Murray cod and Trout Cod are important both ecologically and socially within the Edward-Wakool system. Ecologically they are important for influencing the food chain as the dominant fish predator, and healthy populations are essential for maintaining ecosystem balance. Socially they are important in relation to conservation legislation and are listed under state, Commonwealth and international conservation listings. Murray Cod form the basis for an economically and cultural important recreational fishery within the system and hold spiritual and food importance for the local indigenous community.

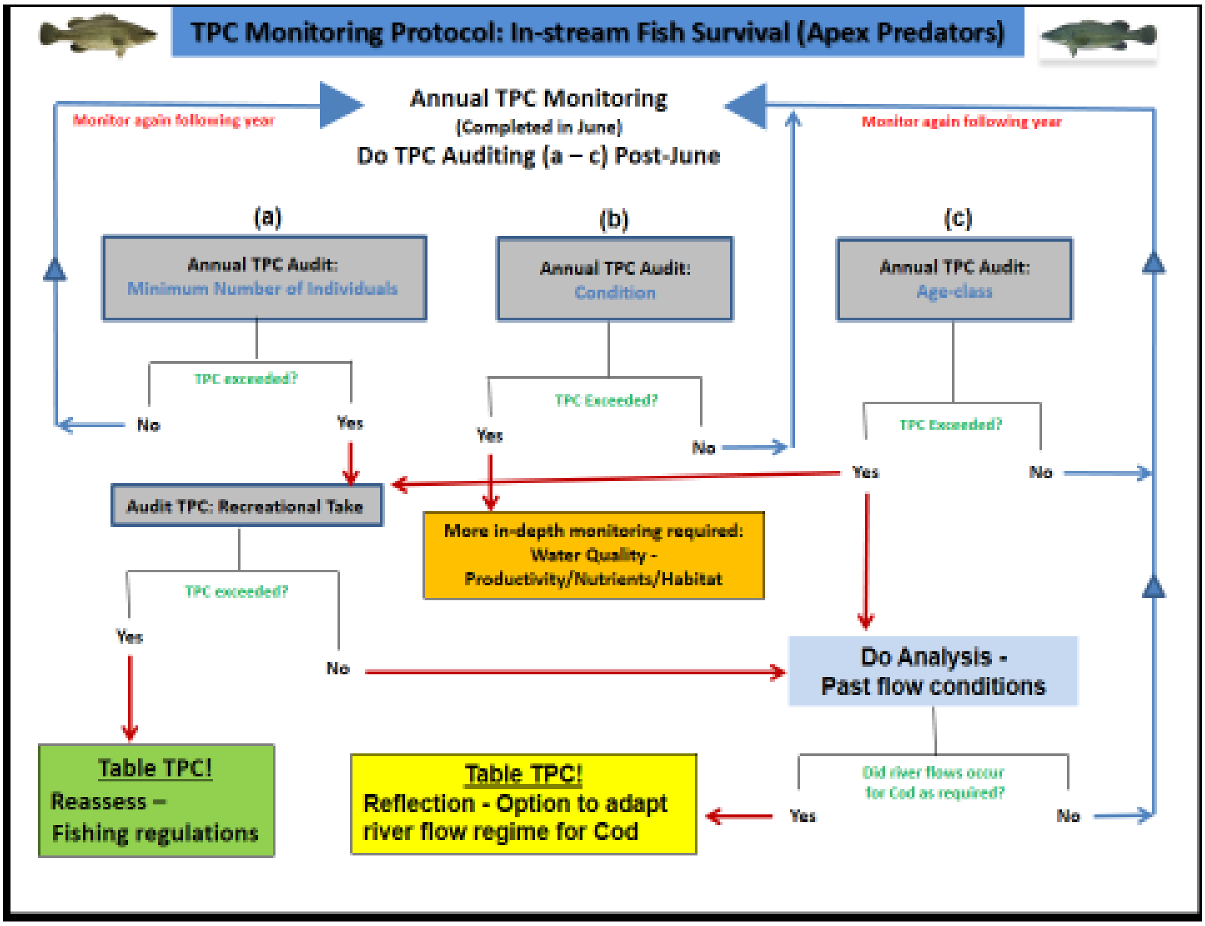
Managing river flow is important in order to maintain sufficient productivity in the rivers, and water quality, providing characteristics necessary for supporting healthy fish populations, dispersed across the river system. Agricultural practices, such as grazing and cropping also influence nutrient inputs into the river, thus affecting habitat suitability for fish. Furthermore, to maintain healthy and self-sustaining fish populations, sustainable fishing practices are required.

2) Table of TPCs

	Indicators	Measurement Criteria	Measurement Scale	Thresholds of Potential Concern
Minimum # of individuals	The relative abundance of Apex predators occurring within the in-stream channels	The minimum number of Apex predators present in the in-stream channel sites	**Spatial**: Sampled across the whole system at the 18 selected instream sites, with 6 in each zone (upper, middle, lower). **Temporal**: Annually, in June (low flow)	Less than 5 Cod individuals sampled in at least 3 sites out of the 6 in each 3 zones (upper, middle, lower)

Age-Class	The variation within age classes of Apex predator populations occurring within the in-stream channels	Age-class: The population structure characteristics of Apex predators in the in-stream channel sites across entire system	**Spatial**: Sampled across the whole system at the 18 selected instream sites, with 6 in each zone (upper, middle, lower). **Temporal**: Annually, in June (low flow)	Cod Adult Age-class: All age-classes must be represented. Minimum of 3 juveniles (<50cm), and 2 mature adults (>50cm) at 3 out of 6 sites in each zone
Body Condition	The relative health of Apex predator individuals occurring within the instream channels	**Length weight**: Condition Ratio Index of individuals of Apex predators. **Parasites**: The number of parasites found on individuals of Apex predators	**Spatial**: Sampled across the whole system at the 18 selected instream sites, with 6 in each zone (upper, middle, lower). **Temporal**: Annually, in June (low flow)	Length/weight: 3 out of every 5 individuals should be above the recommended weight to length chart (Appendix B). Parasites: (3 out of 5 individuals should have less than 10 parasites per fish
Recreational Take	The number of apex predators harvested by recreational fishers within the river system	The Annual Exploitation Rate of apex predators within the river system	**Spatial:** Creel surveys conducted across the whole system. **Temporal:** Annually, in June (low flow).	The Annual Exploitation (U) Index is greater than 0.15

3) TPC monitoring and decision protocol



4) Justification for "first generation" TPCs set

The Justification for setting each TPC is based off three strength categories of evidence to support each TPC; 1. Empirical Evidence, 2. Expert Opinion, 3. Intelligent guesswork, and often a combination of all three. All TPC's developed below are first generation and will be modified as new information becomes available.

Minimum Number of individuals (Expert Opinion).
Based off consultation with fisheries experts that have been studying this system for previous 5 years.

Age-Class (Expert Opinion)
Based off consultation with fisheries experts and literature that advocates for a varied age class.

Body Condition (Empirical based)
Based on the length-weight ratios developed by NSW Fisheries (see Appendix B, Table 1). They are not Edward-Wakool specific.

Recreational Take (Empirically based)
Based off modelling (journal paper; Allen *et al* 2009) where the model suggested that annual exploitation (U) should be held to less than 0.15 under the current MLL of 600mm total length to achieve a spawning potential ratio (SPR) >0.3, a target usually considered to prevent recruitment overfishing.

Reference: Allen, M.S, Brown, P., Douglas, J., Fulton, W., & Catalano, M. 2009. An assessment of recreational fishery harvest policies for Murray cod in southeast Australia. Fisheries Research, 95, 260 – 267.
This is expected to alter as new regulations are enacted.

5) Monitoring plan

Annual Fish Community Sampling
Annual sampling of fish is conducted in a minimum of thirty sites within the Edward Wakool system. Sites are stratified between upper, middle and lower zones and within each zone divided into wetland and channel habitats. Fish are collected using the Sustainable Rivers Audit (SRA) electrofishing protocol augmented by a netting strategy. A certain number of fish are kept each year to determine age-length ratios.

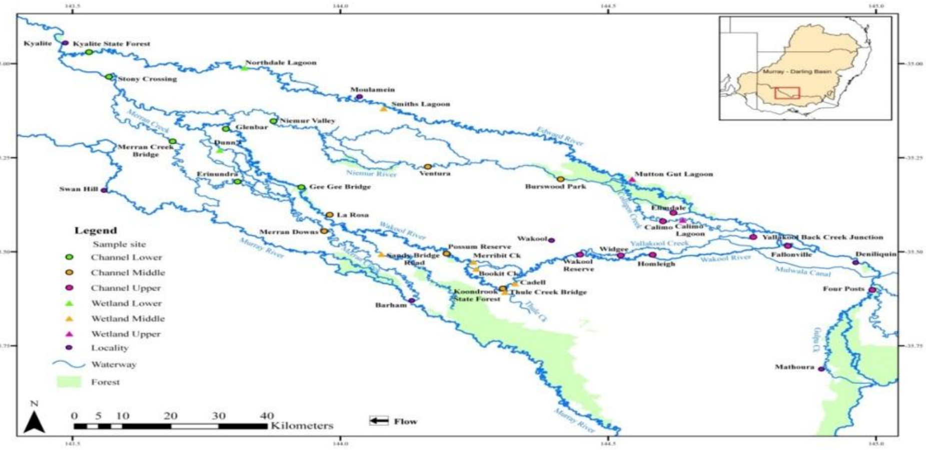


Figure 1. Map of the Edward-Wakool system including system including fish monitoring sites. Red circles represent monitoring sites being used in the TPC auditing Process.

Recreational Take
If the 'Minimum Number of Individuals' and the 'Age Class' TPC is exceeded, a recreational angler creel survey will be carried out among Edward-Wakool recreational anglers (random selection of 50 anglers from Deniliquin and District Fishing Facebook page). Illegal fishing practices would also be audited (Information to come from Fisheries Compliance Officers).
Note: For the Age Class TPC, it would only apply to the exceedance levels for the mature adults.

6) Logistics

Total Budget of 100,000 Annually needed, but this includes sampling the whole fish community throughout the entire system, so as more Survival TPC's are designed for other flow groups, costs for these will not increase annual spending on the TPC's

Annual Monitoring of fish communities
4 FTE’s 15 days sampling
1 FTE, 5 days collation and data input and manipulation (NSW Fisheries; $100/hour)

Analysis and Reporting on TPC
1 FTE, 5 days (35 hours), (CMA Representative, $100/hour), $3,500
1 FTE 7 days if creel surveys done, $4900
Approximately $5000

Creel Surveys if conducted
1 FTE, 2 days (14 hours) (CMA representative; $100/hour), $1400
2 FTE, 2 days (14 hours) (EWAA Representative; $50/hour), $700
Approximately $2500

TPC Audit Workshop (1 day)
1 FTE, 3 days (21 hours) (CMA representative; $100/ hour), $2100
Catering and room booking, $1000
Approximately $3500

Appendix 6. Thresholds of potential concern (TPC) audit reporting, Edward-Wakool example - Survival bundle of TPCs.

Edward-Wakool
Thresholds of Potential Concern audit report 2014
Apex Predator Survival

1) Background and Rationale for TPC Approach

Managing complex systems characterized by uncertainty requires an adaptive, learning-by-doing approach. Thresholds of Potential Concern are the end-points (or targets when rehabilitation is required), defined as the upper and lower levels of acceptable change that when exceeded, set in motion a process of investigation as to the reasons why the TPC was exceeded.
Auditing TPCs is essential to assess the current TPC status and if any have been exceeded. This should be done as a stakeholder driven process, and if TPCs are exceeded stakeholders involved in the decision making around possible management action, and/or revision of the actual TPC itself. Without auditing TPCs adaptive management and learning cannot occur and monitoring is ineffective.
Managing river flow is important in order to maintain sufficient productivity in the rivers, and water quality, providing characteristics necessary for supporting healthy fish populations, dispersed across the river system. Agricultural practices, such as grazing and cropping also influence nutrient inputs into the river, thus affecting habitat suitability for fish. Furthermore, to maintain healthy and self-sustaining fish populations, sustainable fishing practices are required.

Current system situation

The Edward-Wakool system had been experiencing a 10 year drought prior to 2010. In October 2010, the system experienced extensive flooding which continued into early 2011. Several system wide hypoxic blackwater events were experienced in the system with reported native fish kills system wide and in the 1000’s for Murray Cod. Environmental water was used to try and dilute the blackwater and provide critical refuges for fish survival. Environmental flows have been delivered in the system for the previous 4 years to enhance recovery efforts of native fish communities. In addition several government-community projects have been occurring to enhance recovery such as the 3 year Community Blackwater Restocking Program.

2) Definition of the TPC

Table 1. TPCs table for Murray Cod. For a species to be considered for 'maintenance management' mode, none of the TPCs can be in breach.

	Indicators	Measurement Criteria	Measurement Scale	Thresholds of Potential Concern
Minimum # of individuals	The relative abundance of Apex predators occurring within the in-stream channels	The minimum number of Apex predators present in the in-stream channel sites	**Spatial**: Sampled across the whole system at the 18 selected instream sites, with 6 in each zone (upper, middle, lower). **Temporal**: Annually, in June (low flow)	Less than 5 Cod individuals sampled in at least 3 sites out of the 6 in each 3 zones (upper, middle, lower)
Age-Class	The variation within age classes of Apex predator populations occurring within the in-stream channels	Age-class: The population structure characteristics of Apex predators in the in-stream channel sites across entire system	**Spatial**: Sampled across the whole system at the 18 selected instream sites, with 6 in each zone (upper, middle, lower). **Temporal**: Annually, in June (low flow)	Cod Adult Age-class: All age-classes must be represented. Minimum of 3 juveniles (<50cm), and 2 mature adults (>50cm) at 3 out of 6 sites in each zone

Body Condition	The relative health of Apex predator individuals occurring within the instream channels	**Length weight**: Condition Ratio Index of individuals of Apex predators. **Parasites**: The number of parasites found on individuals of Apex predators	**Spatial**: Sampled across the whole system at the 18 selected instream sites, with 6 in each zone (upper, middle, lower). **Temporal**: Annually, in June (low flow)	Length/weight: 3 out of every 5 individuals should be above the recommended weight to length chart (Appendix B). Parasites: (3 out of 5 individuals should have less than 10 parasites per fish
Recreational Take	The number of apex predators harvested by recreational fishers within the river system	The Annual Exploitation Rate of apex predators within the river system	**Spatial:** Creel surveys conducted across the whole system. **Temporal:** Annually, in June (low flow).	The Annual Exploitation (U) Index is greater than 0.15

3) Data and information supporting the TPC

In 2014, a minimum of 30 sites were monitored across the entire Edward-Wakool system using the agreed upon SRA sampling strategy with additional netting (See TPC development and protocol report for monitoring protocol). Six instream sites per zone (upper, middle, lower) and spread within each were selected for the TPC auditing process (Figure 1).

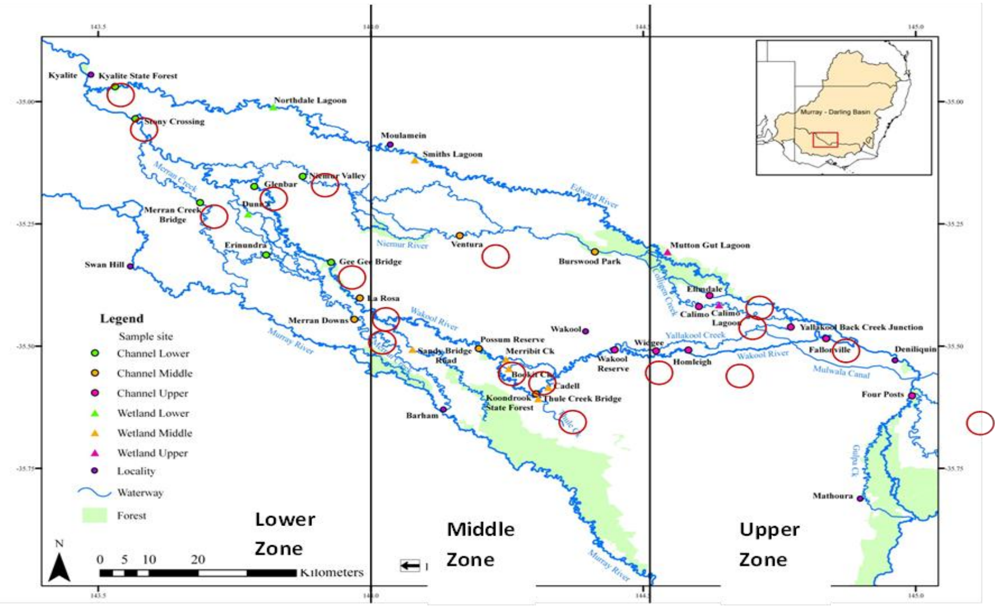


Figure 1. Map of the Edward-Wakool system including system including fish monitoring sites. Red circles represent monitoring sites being used in the TPC auditing Process.

Condition rating was only conducted for parasites on a site by site basis as weight data was not collected during sampling.
Recreational Fishing take TPC was not conducted as it has not been agreed upon by all stakeholders in how best to assess this.

4) The current status and results

There is a general trend in all zones of increasing numbers (See Figure 3, Table 2), especially in juveniles indicating breeding is occurring in all zones or there is good immigration occurring from the upper zone (Figure 4, Table 4). In addition it could be that some juveniles in the mid and lower sections are from the targeted restocking program but this is unsubstantiated as of yet. In all areas the adult TPC was breached but it was much more substantive in the middle and lower zones (Figure 4, Table 4). This is to be expected as adults were particularly affected in the mid and lower zones, but is concerning in relation to recovery of the species for recreational and apex predator considerations. A summary of TPC breaches is given in Table 5.
It is pleasing to see that the total population in the upper zone has been stable for the last 2 years and not in breach of the minimum numbers TPCs. However, even though there is a visible improvement in the general numbers in all zones, the middle and lower zones TPC were all breached, and significant management actions need to occur to aid in recovery.

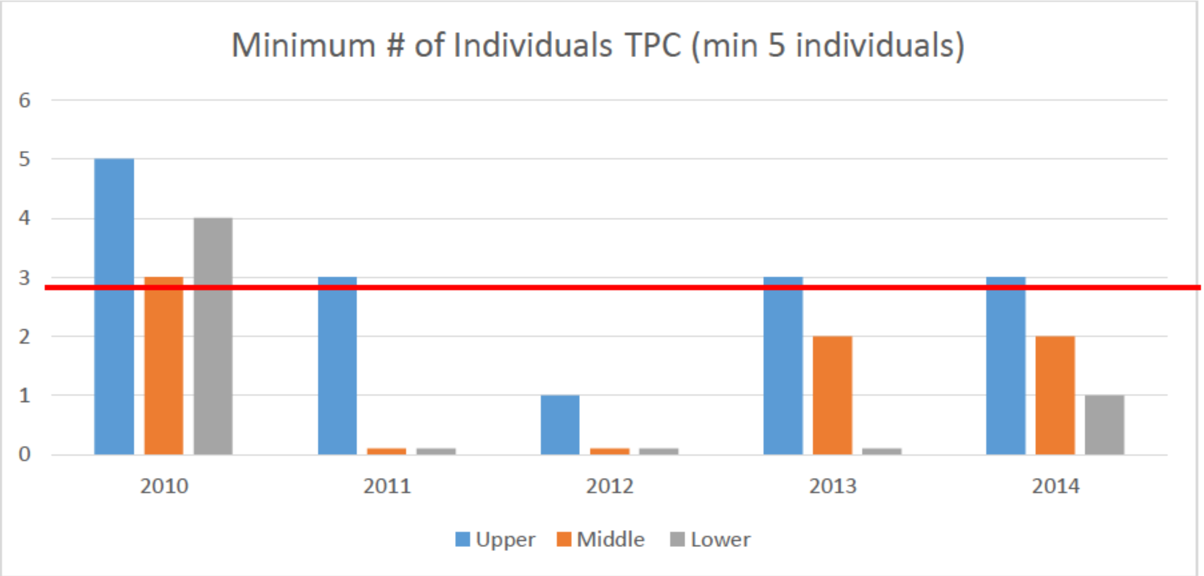


Figure 2. Minimum Number of Individuals TPC from 2010-2014. The 6 sites sampled each year on the x-axis and the years on the y-axis for each zone (upper, middle, lower). The red line indicates a TPC breach when the number of sites drops below 3 in any given zone. After the 2010-11 hypoxic blackwater, it shows an increasing trend in numbers in all zones.

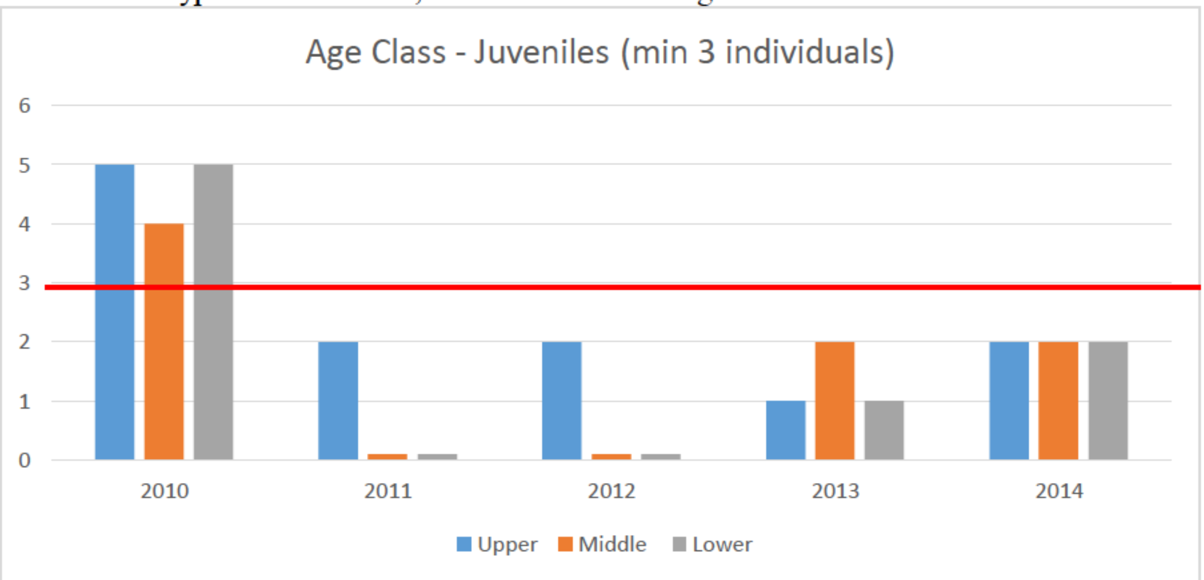


Figure 3. Age class structure Adults TPC from 2010-2014.

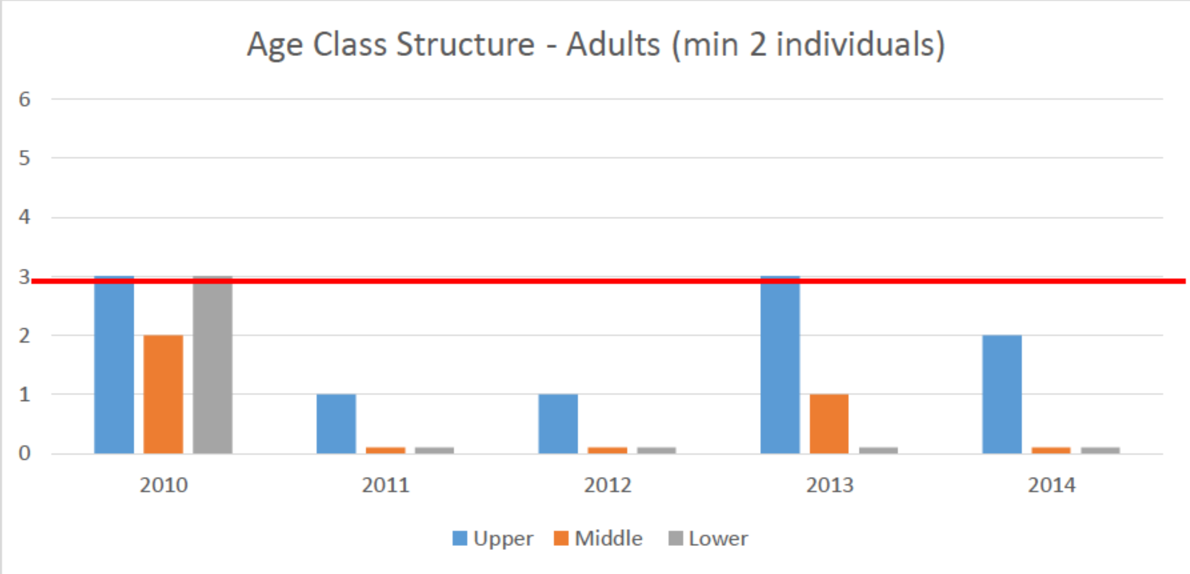


Figure 4. Age class structure for Adults TPC. Adult numbers are still in breach in all zones following blackwater 2010-11 event, especially in mid and lower zones.

Tables of Individual sites in each zone

Table 2. Upper zone

Site/TPC ranking	**Minimum # of Individuals**	**Age Class Adults**	**Age Class Juveniles**	**Condition (Index)**	**Condition (Parasites)**	**Rec Fishing Take**
Wakool reserve	8	6	2	N/A		N/A
Homleigh	6	0	6			
Y-Backcreek	3	1	2			
Calimo	1	1	0			
Elimdale	0	0	0			
Four posts	6	2	4			
	TPC (<5 ind)	TPC (<2 ind)	TPC (<3ind)	TPC (<3/5)	TPC (<10)	
Breach #	3	4	4			
TPC Breach (Table)	**N**	**Y**	**Y**	**Not Done**		**Not Done**

Table 3. Middle zone

Site/TPC ranking	**Minimum # of Individuals**	**Age Class Adults**	**Age Class Juveniles**	**Condition (Index)**	**Condition (Parasites)**	**Rec Fishing Take**
Possum R	6	0	6	N/A		N/A
La Rosa	2	0	2			
Koondrook	7	0	7			
Merran D	2	0	2			
Ventura	1	1	0			
Merribit Ck	1	0	1			
	TPC (<5 ind)	TPC (<2 ind)	TPC (<3ind)	TPC (<3/5)		U>0.15
Breach #	4	6	4			
TPC Breach (Table)	**Y**	**Y**	**Y**	**Not Done**		**Not Done**

Table 4. Lower zone

Site/TPC ranking	**Minimum # of Individuals**	**Age Class Adults**	**Age Class Juveniles**	**Condition (Index)**	**Condition (Parasites)**	**Rec Fishing Take**
Glenbar	2	0	2	Not applied		Not applied
Gee Gee B	2	0	2			
S Crossing	3	0	3			
Neimur V	1	0	1			
Merran B	1	0	1			
Kyalite F	15	0	15			
	TPC (<5 ind)	TPC (<2 ind)	TPC (<3ind)	TPC (<3/5)		U>0.15
Number	5	6	5			
TPC Breach (Table)	**Y**	**Y**	**Y**	**Not Done**		**Not Done**

Table 5. Summary of TPC breaches

Site/TPC ranking	**Minimum # of Individuals**	**Age Class Adults**	**Age Class Juveniles**	**Condition (Index)**	**Condition (Parasites)**	**Rec Fishing Take**
Upper	N	Y	Y			
Middle	Y	Y	Y			
Lower	Y	Y	Y			

Tabled TPCs
Upper Zone
Age Class Adults and Juveniles
Middle Zone
Minimum # of individuals, Age Class Adults and Age Class Juveniles
Lower Zone
Minimum # of individuals, Age Class Adults and Age Class Juveniles

5) Proposed Recommendations and Management Actions

1. Flow Recommendations

Murray Cod recruitment and dispersal flows to continue in Upper Zone, but for this year different to previous years upper zone flows should be linked with Koondrook-Perricoota outflows to encourage a system wide Cod breeding event. Flows should be timed to coincide with appropriate breeding season. The monitoring program should inform the management action of success-failure and guide adapting it into the future.

2. Additional Habitat and Social Recommendations

a) Murray Cod and Golden Perch blackwater restocking should continue to be concentrated in the middle and lower sections where inadequate numbers of Murray Cod are still being recorded. However, due to high juvenile numbers at Kyalite restocking site (see Table 6), it is recommended to move the restocking at this effort to another that has consistently low numbers of Murray Cod since the blackwater event. It is also worth considering for the 2014 stocking event to move to all new sites (see Table 6 for suggestions based on data), while the original program success is evaluated through by LLS and Fisheries.

b) At the completion of the 2014-15 stocking, an evaluation of the success of the program should be carried out to assess contribution of restocking effort to the juvenile population increase.

c) Engagement process put into place with recreational fishing groups to discuss options for reducing Murray Cod adults ‘take’ to allow adults maximum potential to contribute to recovery in the system

d) Engagement with fisheries inspectors to assess if illegal fishing practices are increasing in the area, and how to lessen impact if occurring. Involve local fishing groups

Table 6. Community Blackwater Restocking Program sites. Both current and 'future' sites included. Recommendations for new sites are based off consistently low numbers of Murray Cod since blackwater event, indicating limited natural recovery. Stocking could enhance success. See Figure 1 for all sites.

Stocking Sites	**Number of individuals**	**Adults**	**Juveniles**
Current			
Kyalite (Edward R)	15	0	15
Stony C (Wakool R)	3	0	3
Glenbar (Wakool R)	2	0	2
Gee Gee (Wakool R)	2	0	2
La Rosa (Wakool R)	2	0	2
Possible Future			
Niemur V (Niemur R)	1	0	1
Ventura (Niemur R)	1	1	0
Burswood (Niemur R)	0	0	0
Merran Br (Merran C)	2	0	2
Erinundra (Merran C)	0	0	0

6) Actual Recommendations and Management Actions carried out

TO BE AUDITED TOWARDS END OF SEASON (JUNE 2015)!

Appendix A. Length to Weight Ratio, showing the index that will be used from 2011 onwards for condition TPC.

Total Length (cm)	Weight (kg) New Index
40	0.8
42	0.9
44	1
46	1.2
48	1.4
50	1.6
52	1.8
54	2
56	2.2
58	2.5
60	2.8
62	3
64	3.4
66	3.8
68	4.1
70	4.5
72	5
74	5.3
76	5.7
78	
80	
82	7.3
84	
86	
88	
90	
92	
94	11.3
96	
98	
100	

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(To appear at the end of each thesis chapter submitted as an article/paper)

We, the PhD candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated in the *Statement of Originality*.

	Author's Name (please print clearly)	**% of contribution**
Candidate	Craig A. McLoughlin	80 %
Other Authors	John Conallin	10 %
	Martin C. Thoms	5 %
	Melissa Parsons	5%

Name of Candidate: **Craig Anthony McLoughlin**

Name/title of Principal Supervisor: **Professor Martin Thoms**

[redacted]

12/11/2015

Candidate Date

[redacted]

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We, the PhD candidate and the candidate's Principal Supervisor, certify that the following text, figures and diagrams are the candidate's original work.

Type of work	Page number/s
Journal article	182 - 260

Name of Candidate: **Craig Anthony McLoughlin**

Name/title of Principal Supervisor: **Professor Martin Thoms**

[redacted]

12/11/2015

Candidate   Date

[redacted]

12/11/2015

Principal Supervisor   Date

CHAPTER 6. REFLEXIVE LEARNING IN THE PRACTICE OF ADAPTIVE FRESHWATER MANAGEMENT: A SYNTHESIS

This final chapter provides a synthesis of the research undertaken and highlights its intention and contribution toward tackling the dilemma of learning associated with ANRM implementation. First, a summary of the chapters associated with the research objectives of the thesis is provided (i.e. those written as manuscripts for journal submission), with the highlights of their original research contributions. Second, the main philosophy emanating from the thesis is presented - the translation of ANRM theory into practice - involving a mind-set change required for the actual practice of societal learning within any given adaptive freshwater management system. In addition, how ANRM practice may integrate more fluidly with resilience practice is discussed, an overarching construct for this thesis research although not its main emphasis (detailed in Chapter One). Finally, implications of the thesis, and particularly the Strategic adaptive management Reflexive Learning Framework for future research associated with the practice of societal learning within adaptive freshwater management, are discussed.

6.1 Summary of the thesis chapters and original research contributions

The main contributions of the thesis chapters presented as manuscripts for journal submission are discussed below, and summarised in Table 6.1.

Chapter Two advances our understanding about the complexity of learning within the practice of ANRM. It achieved this by building the coherent conceptual framework covering all the interlinking components required for an effective learning-by-doing strategy. There are two main benefits emanating from the developed conceptual framework. First, all required learning components of ANRM are brought together under a single framework. This is unique because although learning components are dealt with extensively in the literature, they are mostly studied separately, in a fragmented manner. Chapter Two thus makes a contribution to the ANRM field because it amalgamates all learning components allowing linkages between components to emerge. These linkages provide an increased understanding and awareness about the complexity of the learning-by-doing strategy in ANRM. Second, the conceptual framework demonstrates explicitly the required place for reflexive learning within the practice of ANRM. Although the enabling conditions (learning-centred organisations, social learning, adaptable governance) are important for achieving societal learning (single-, double-, and triple-loop learning), which is the central learning construct in ANRM, explicit design and deliberate deployment of an adaptive feedback system is the core requirement for facilitation of single-, double-, and triple-loop learning. This feedback system is necessary for ANRM programs moving beyond typical single-loop learning. Hence, the conceptual framework is needed because it provides critical awareness about learning within the practice of ANRM, and such awareness is necessary for an improved practice of ANRM (Allan and Stankey, 2009).

The conceptual framework developed in Chapter Two is not a manual for practicing ANRM, focusing on the "what" and "why" type questions associated learning in ANRM rather than the more detailed "how-to" type questions. Notably, further understanding related to the different enabling conditions for practicing societal learning (as described in the conceptual framework) can be accessed in the literature. Rogers *et al*. (2013) and Biggs *et al*. (2015) describe complexity and uncertainty within systems and how best to deal with this. Societal learning is adequately defined by Pahl-Wostl (2009), and the social learning component is covered extensively by Mostert *et al*. (2007), Ison and Watson (2007), Pahl-Wostl (2009) and Cundill *et al*. (2011). In addition, adaptive governance arrangements are explored by Folke *et al*. (2005), Gunderson and Light (2006), Pahl-Wostl (2009), and Herrfahrdt-Pahle (2013). Stankey *et al*. (2005), Fazey and Schultz (2009), Roux *et al*. (2010) and Stirzaker *et al*. (2011) provide details of learning centred organizations. Importantly, these enabling conditions must be progressively realized over time and not seen as an obstacle to commencing societal learning within ANRM. However, it is the adaptive feedback system (reflexive learning), and its foundation role in implementing societal learning which does require further focus.

Chapter Three demonstrates a unique way for deploying an adaptive feedback system within the adaptive management cycle, for facilitating single-, double-, and triple-loop learning within and across ANRM governance levels. The Strategic adaptive management Reflexive Learning Framework is needed because it unpacks the reflexive learning process, clearly, to guide practitioners through societal learning for an effective practice of ANRM. The heuristic framework is a key enabler for implementing the adaptive management cycle using societal learning, thereby rendering increased know-how for the practice of ANRM. Deploying its adaptive feedback system compels practitioners of ANRM to deliberately use single-, double-, and triple-loop learning within their adaptive management cycles. Thus, the Strategic adaptive management Reflexive Learning Framework will promote a more effective practice of ANRM because societal learning can now be incorporated with more intent or in a less ad-hoc manner.

The Strategic adaptive management Reflexive Learning Framework serves as an exploratory map for integrative learning in the practice of ANRM. This is beneficial because subsequent modifications to the heuristic framework will provide a measure of progress in integrative thinking associated with this learning. The idea of Strategic adaptive management Reflexive Learning Framework is that is it seen as a pragmatic tool for guiding the practice of ANRM. The intention is that its principles be integrated into existing components and processes; where needed and this sets a key challenge for deploying it. Thus, applying the heuristic framework in the real-world, within and across governance levels of ANRM, will generate important lessons for practicing ANRM, and for refining the heuristic framework itself.

Chapter Four sets an important precedent for implementing adaptive freshwater management in the real-world, using single-, double-, and triple-loop learning explicitly and deliberately within the ANRM adaptive management cycle. Importantly, the case-study of the South African Crocodile River Catchment demonstrates that participation and cooperation between stakeholders as advocated in ANRM theory can occur in the real-world. Here, stakeholders are not seeking an optimum “once-off solution” to implementing the Ecological Reserve, but rather are engaging within an ongoing process of rethinking and negotiating their options. This type of stakeholder collaboration has been shown to be vital for an effective practice of ANRM (Pahl-Wostl *et al.*, 2007; Huxum and Vangen, 2000). Ongoing learning in order to adapt and change when required (enabled further by emergence of the enabling conditions) is critical for a progressive realization of the Ecological Reserve within river catchments of South Africa, albeit within constraints imposed from higher governance levels. The real-world reflexive learning lessons described in this case-study are transferrable, globally, to other adaptive freshwater management systems, in particular to deal with the complexity inherent within environmental watering.

Chapter Five advances our knowledge about how to implement adaptive freshwater management within and across governance levels of freshwater management. The chapter demonstrates that to practice an effective societal learning within the Murray-Darling Basin an adaptive feedback system must be deployed, but there are several requirements for implementing this feedback system. First, there is identification of all practitioners and their explicit mandates for driving the adaptive management cycles at each governance level, and acknowledgement of information demands across governance levels. Second, uncertainty inherent within the environmental watering process must be accepted, therefore practitioners and stakeholders do not try and finalize objectives, end-point goals and management interventions. This is because of complexity and a lack of complete knowledge about ecosystems and their responses to environmental watering. Furthermore, stakeholder values incorporated within the process of deriving objectives and end-point goals can and do change over time. Societal learning is, therefore, an ongoing process of negotiation and re-thinking options for management. Third, societal learning requires stakeholder participation with real collaboration, and there must not be any domination from any freshwater management sectors. Fourth, seeking adaptive management champions to drive the adaptive management cycles at each governance levels is critical, because these practitioners are glue that holds the adaptive freshwater management system together. Champions are motivated people with a keen understanding of complexity and the need for adaptive freshwater management. Fifth, the adaptive feedback system must be used to achieve a balance between single-, double-, and triple-loop learning. This is because double and triple-loop learning is resource expensive and too much change occurring within adaptive freshwater management can demotivate its practitioners. Sixth, making sure adaptive management cycles get implemented within the water resource plan areas of the Murray-Darling Basin, because this is where learning first commences and is needed here to stimulate learning in the upper governance levels of adaptive freshwater management.

All key lessons learned from Chapter Five must be applied back into the environmental watering process within the Murray-Darling Basin. This will improve the use of the adaptive feedback system and increase the probability of practicing societal learning within the Basin. More effective societal learning means uncertainty is being embraced and as a consequence environmental watering is more likely to achieve its objectives. This is important because environmental watering increases the uncertainty involved within freshwater management. Allocating water to the environment, actual delivery of this water within and across governance levels and determining the benefits of this water produces much complexity within the freshwater management system. Such complexity exacerbates inadequacies of the more technically based command-and-control management which is currently being exercised within the Murray-Darling Basin.

Table 6.1. Summary of thesis objectives; chapter in which each was addressed; including the contributions of each associated manuscript.

Thesis objectives	Manuscript	Key contribution of the manuscript
1. To understand the complexity of learning in adaptive natural resource management, via building a hierarchical conceptual framework of all learning components, with linkages between components.	Chapter 2. Understanding the complexity of learning in adaptive natural resource management.	• A single, coherent conceptual learning framework. • Recognising complex interlinking learning components. • Promotes an awareness and understanding about the complexity of learning, and the requirements for applying an effective adaptive natural resource management system.
2. To outline a heuristic reflexive learning framework for facilitating societal learning in the practice of adaptive natural resource management.	Chapter 3. Integrative learning for practicing adaptive natural resource management.	• Instigates integrative thinking for the practice of adaptive natural resource management. • Demonstrates a generic/explicit/pragmatic adaptive feedback system for the adaptive management cycle. • Promotes the practice of adaptive natural resource management by allowing a deliberate facilitation and use of single-, double, and triple-loop learning. • Guides societal learning within and across governance levels of adaptive natural resource management.
3. Using the heuristic framework developed in (2), to assess application of adaptive feedbacks (reflexive learning) within the practice of adaptive freshwater management, associated with learning and implementing the adaptive management cycle.	Chapter 4. Societal learning in adaptive freshwater management: a case study of the Ecological Reserve in South Africa.	• Sets an important precedent for implementing adaptive natural resource management, using societal learning. • Demonstrates collaboration between stakeholders, within an ongoing learning process. • Provides lessons learned for practicing adaptive freshwater management and implementing Ecological Reserve in South Africa, with global implications.
4. To explore the heuristic framework's potential for capacity building to deal with uncertainty in complex water reforms, associated with environmental watering across multiple governance levels.	Chapter 5. Embracing uncertainty across three levels of governance in complex water reforms: a case-study of adaptive freshwater management in Australia's Murray-Darling Basin.	• Advances knowledge about how to implement adaptive freshwater management, within and across governance levels of freshwater management. • Provides lessons learned for practicing ongoing societal learning within adaptive freshwater management, thus for embracing uncertainty.

6.2 Contribution toward translating the theory of adaptive natural resource management into adaptive freshwater management practice

To practice adaptive freshwater management more effectively, learning (and particularly related outcomes) must be seen as the main "function" of the adaptive management system. Specifically, this comprises the three modes of single-, double-, and triple-loop learning, and collectively these become the main learning functions of any adaptive freshwater management system (Fig. 6.1). These learning functions are the window through which the integrative systems of society (environment, economic, community/social) can be improved over time; this is by working toward achieving and/or refining all stakeholder-agreed objectives which are also based on current societal values (Fig 6.1). Notably, setting/refining of end-points, which are the explicit and measureable goals linked to these objectives, is important because these guide management in the achievement of the objectives. It must be emphasised that striving to meet such objectives is the main and overarching purpose of any adaptive freshwater management system.

The main philosophy emanating from this thesis is tied closely with the need for a better practice of reflexive learning within adaptive freshwater management, to facilitate societal learning and therefore for working toward objective achievement. Importantly, this reflexive learning is in combination with the enabling structures (organisational learning, social learning, adaptive governance) for societal learning (Fig. 6.1). However, these enabling structures for societal learning are too often seen as the "end result" rather than an important "means to an end" within ANRM, for example improving the sustainability of natural resources and its management (Fabricius and Cundill, 2014). With this, Fabricius and Cundill (2014) ask why such a high percentage of contemporary ANRM experiences concentrate exclusively on reporting about these enabling structures. For instance, Stirzaker *et al*. (2011) concentrated on organisational learning, Cundill *et al*. (2011) on social learning, and Herrfahrdt-Pahle (2013) on governance-related aspects of ANRM. This main focus of reporting on enabling structures is overwhelming the practice of ANRM. In particular, for the "practical" tasks required for getting adaptive freshwater management up and running in the real-world, leading in many cases, to so-called "implementation paralysis" associated with the practice of adaptive freshwater management (Pollard *et al.,* 2011). Foremost, the practice of ANRM requires a complex and intelligently designed and placed adaptive feedback system

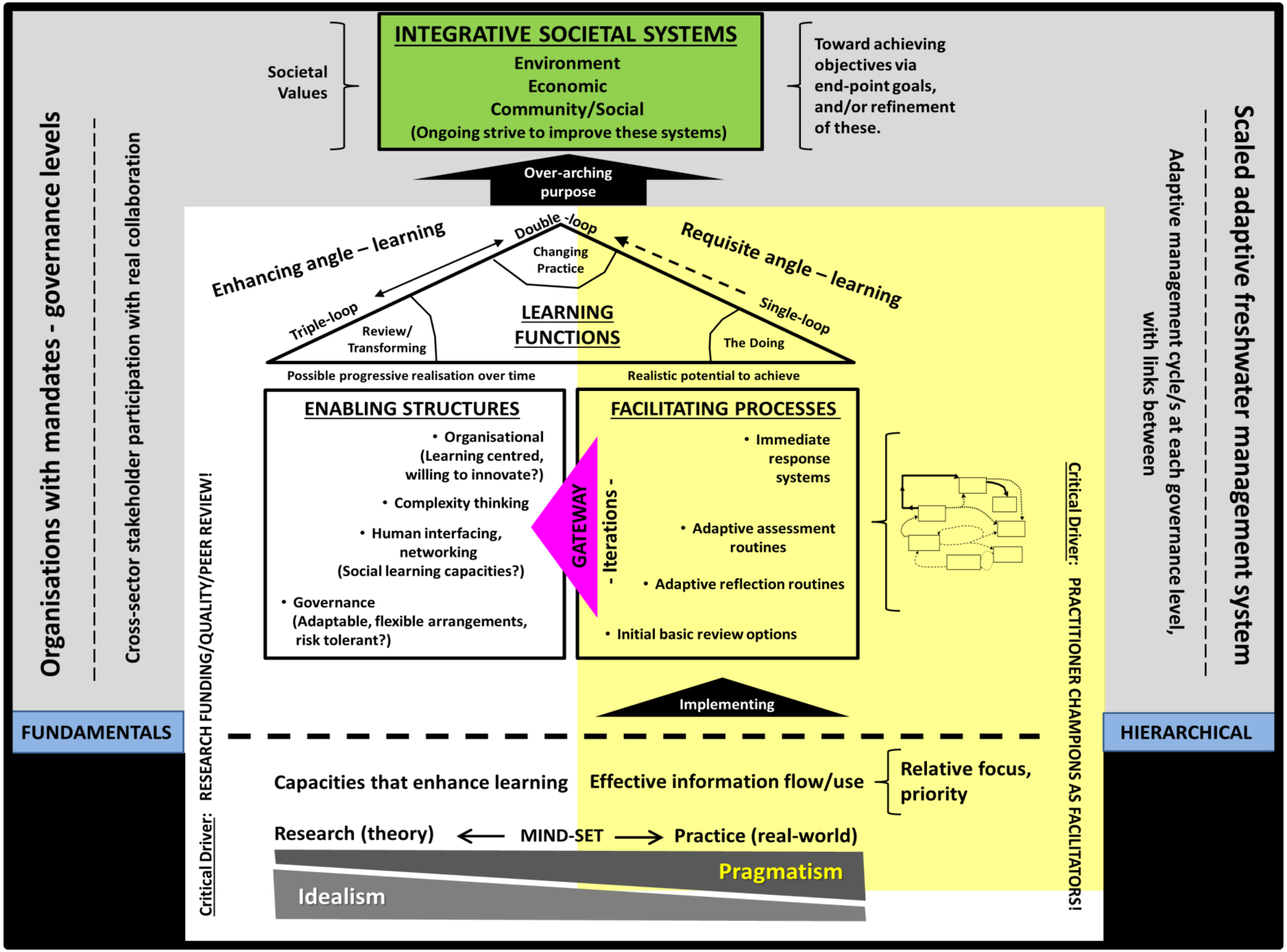

Figure 6.1. The main thesis philosophy, related to getting societal learning initiated in the real-world using reflexive learning, for the practice of any given adaptive freshwater management system.

to integrate societal learning effectively within the ANRM adaptive management cycle. This is to eliminate the more “ad-hoc” application of single-, double-, and triple-loop learning within adaptive freshwater management. Implementing an effective societal learning function within adaptive freshwater management is for meeting objectives and ultimately for improving society’s Environment, Economic and Community/Social systems (see Fig 6.1).

6.2.1 Deploying a complex adaptive feedback system to facilitate societal learning within any given adaptive management cycle

The “facilitating processes” (response system, adaptive assessment and adaptive reflection) (Fig 6.1) for societal learning are initiated by a nested, overlapping set of adaptive feedbacks within the adaptive management cycle and these are ongoing, occurring over a range of time-scales within adaptive freshwater management. Common linear interpretations of the adaptive management cycle often depict learning as a separate “evaluate and learn” step (Fig. 6.2a). These adaptive management cycles begin with objectives and problem formulation, which then flow into implementation and monitoring and then an evaluation and learning step implying subsequent feedback back into problem formulation (e.g. Stankey *et al*., 2006; Jakeman *et al*., 2009; Stathis and Jackobson, 2009; Pahl-Wostl, 2009; Gregory *et al*., 2012; Williams and Brown, 2014). This linear interpretation of the adaptive management cycle suggests that learning occurs only at discrete intervals toward the end of the adaptive management cycle. Furthermore, this implies that adaptive management cycle components are essentially halted while the “evaluate and learn” step takes place, and then proceed again post learning. This disjointed depiction of learning within the adaptive management cycle is not conducive for societal learning or reaching a balance between and use of single-, double-, and triple-loop learning within the practice of adaptive freshwater management.

A complex adaptive feedback system (Fig 6.2b) is needed to initiate the “facilitating processes” within the adaptive management cycle, for societal learning. These feedbacks are ongoing and occur over different time scales. Feedbacks work toward achieving an appropriate balance between and use of the single-, and double-loop learning functions of the adaptive management cycle, termed here as the “requisite angle to learning” within ANRM (Fig. 6.1). The mind-set here involves focusing scarce resources into generating pertinent information within the adaptive freshwater management system, but importantly also for the effective dissemination of information within and between organisations and people within the system (du Toit and Pollard, 2008). Involvement of these organisations, along with their mandates and participating stakeholders, is fundamental for initiation of the "requisite angle to learning" (Fig 6.1). This includes the collaborative setting of objectives, and implementing the all-important adaptive feedback system. Notably, a critical driver of the "requisite angle to learning" is the existence and emergence of freshwater related "champions" (Fig. 6.1). Such champions are individuals within the collaborating organizations who are highly enlightened about implementing the adaptive feedback system. These are motivated and adaptable people, willing to learn (Fazey and Schultz, 2009) with ample complexity thinking and understanding (Rogers *et al*., 2013) in order to promote the processes required for practicing adaptive freshwater management. The enlightenment of these champions, who use their knowledge to apply the required adaptive feedback system, is the glue that binds the adaptive management process together without which it is more likely to fail.

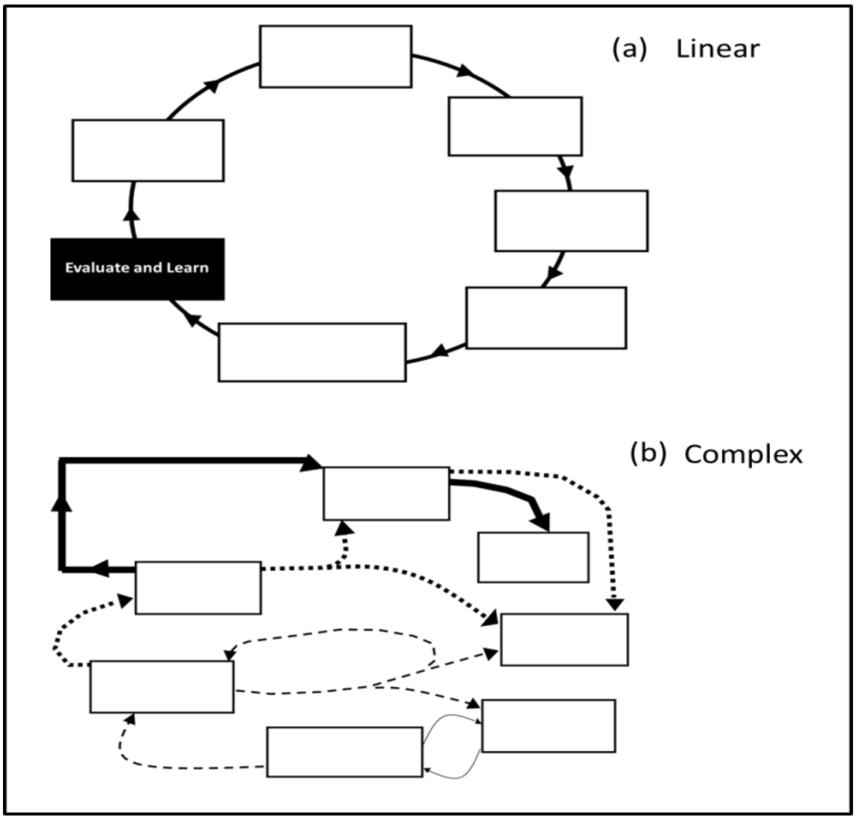

Figure 6.2. Common linear representation associated with learning within a natural resource related adaptive management cycle (a); and the more complex, nested and overlapping feedback system for balancing single-, double-, and triple-loop learning within the adaptive management cycle as advocated in this thesis (b).

Those practitioners that do become champions must oversee the "facilitating processes" of the "requisite angle to learning", the more immediate response systems, and also the adaptive assessment and reflection routines (Fig. 6.1). These facilitating processes become the core machinery of adaptive freshwater management, driven by a complex array of overlapping adaptive feedbacks while exercising the adaptive management cycle. The more immediate response systems and adaptive assessment are critical facilitating processes for implementing, first, the single-loop learning function of societal learning. Then, further activation of adaptive reflection routines will allow a pragmatic double-loop learning function to be achieved. It must be expected that (initially at least) the "enabling structures" (i.e. the learning-centred organisations, the build-up of social learning capacities and the achievement of adaptive governance arrangements, and the benefits they bequeath) are more often than not poorly developed within any given adaptive freshwater management system. It is acknowledged that cases do exist whereby these "enabling structures" are developed more intently (e.g. Pahl-Wostl, 2009; Cundill *et al*., 2011; Herrfahrdt-Pahle, 2013). However, these cases are the exception rather than the norm, globally. Without sufficient build-up of the "enabling structures", particularly adaptable governance arrangements, the triple-loop learning function is difficult to achieve and therefore also the required transformation for the completion and regeneration components of the adaptive management cycle (McLoughlin and Thoms, 2015) (Fig. 6.1). Consequently, the re-framing requirement of double-loop learning is compromised within any rigid governance arrangement (Pahl-Wostl, 2009). Hence, it is anticipated that the double-loop learning function developed under the "requisite angle to learning" is not (yet) a complete (idealised) form of this learning, as envisaged by Pahl-Wostl (2009).

The "requisite angle to learning" is central nonetheless, because it gets societal learning initiated in practice, and to at the very least commence the single-loop learning function. Single-loop learning initiation is important because this is where progress is made within ANRM (Fabricius and Cundill 2014). Then, augmenting this single-loop learning with an initial form of the double-loop learning function is required (Fig 6.1). Notably, with a basic review of the objectives and end-point goals of the adaptive management cycle, the completion and regeneration of the adaptive management cycle is plausible. However, achieving this "requisite angle to learning" within any given adaptive freshwater management system depends crucially on implementation of a complex set of overlapping adaptive feedbacks (Fig 6.2b), exercised at pertinent time intervals within the adaptive management cycle.

This thesis proposes therefore, that the commonly used “evaluate and learn” step is dropped from any depiction and implementation of the adaptive management cycle within adaptive freshwater management. This is because the adaptive feedbacks necessary to stimulate the facilitating processes for societal learning are complex, i.e. nested, overlapping and ongoing (see Fig. 6.2b). Practicing societal learning within any adaptive freshwater management system, using this complex adaptive feedback system, implies a move away from the frequently used “lessons learned” type scenarios. These scenarios commonly get conducted annually within ANRM under a pretext of effective learning. If the complex adaptive feedback system can be implemented in the real-world, within any given adaptive freshwater management system, the probability for facilitation of societal learning is increased and thus for a more effective practice of learning within adaptive freshwater management. Later, fuller and more complete double-loop learning in conjunction with the triple-loop learning function (“enhancing angle to learning”) can be achieved over time, if the critical “enabling structures” emerge for progressively realizing these modes of societal learning (Fig. 6.1).

The “enhancing angle to learning” involves a deeper and fuller practice of the double-loop function (Fig 6.1), as is envisaged by Pahl-Wostl (2009) and others. In addition, this double-loop learning function works in tandem with the triple-loop learning function (hence the double-headed arrow in Fig. 6.1). This junction between the two learning functions is necessary because without transformation of governance arrangements the re-framing requirement of double-loop learning is likely to be stalled (see Pahl-Wostl, 2009). Here, the “enabling structures” (currently an important emphasis for research associated with adaptive freshwater management, Fig 6.1) play a crucial role, i.e. in the support of the “enhancing angle to learning”. For example (as mentioned above), learning-centred organisations and the building up of social learning capacities is paramount for effective double-loop learning. In addition, achieving adaptable governance arrangements that are flexible to change when required (and risk tolerant) is highly important for practicing triple-loop learning. Such understanding via research identifies the types of capacities required and how these can/should be better developed, if and where possible within adaptive freshwater management systems.

The “enhancing angle to learning” is only a possibility within any given adaptive freshwater management system. It must not (or cannot) occur independently of the “requisite angle to learning” component (Fig. 6.1). This is because the “facilitating processes” within application of the adaptive management cycle also form the foundation for the “enhancing angle to learning”. Thus, much intricacy is introduced unreasonably within adaptive freshwater management systems which focus exclusively on the “enhancing angle to learning”, for instance on an “ideal” double-loop learning function and/or triple-loop learning function (e.g. Biggs *et al.*, 2011; Pollard *et al.*, 2011; Varady *et al.*, 2013). In addition, seeking the “enhancing angle to learning” independently of the “requisite angle to learning” means that the single-loop learning function is in effect ignored or being by-passed. Consequently, there is too much emphasis on change within adaptive freshwater management at the expense of the actual doing, demotivating the adaptive management champions. This demotivation can compromise much needed progress within any adaptive freshwater management system (Fabricius and Cundill, 2014). Adaptive freshwater management systems are, therefore more likely to lose their momentum and fail, hence a mind-set change is required when moving from theory to the practice of adaptive freshwater management.

6.2.2 Mind-set change between the theory and practice of adaptive freshwater management

A point-of-departure from the “business as usual” approach to practicing adaptive freshwater management is necessitated for getting adaptive freshwater management systems initiated and implemented under real-world situations. This thesis thus proposes that a mind-set change is required (Fig. 6.1), i.e. between research (theory) with its “idealism” frame-of-mind, and the real-world practice of adaptive freshwater management where a “pragmatism” frame-of-mind is needed. These alternate mind-sets are depicted in Figure 6.1. The pragmatic “requisite angle to learning” (Fig. 6.1; yellow-shaded portion) focuses on initiating societal learning using current resources/structures available. Second, the theory-based “enhancing angle to learning” (Fig. 6.1; white-shaded portion) emphasises how to enhance societal learning within adaptive freshwater management. The “requisite angle to learning” is fostered by practice and action-research - getting going with the adaptive feedback system, given any existing resources and/or “enabling structures” (with potential for emergence of the enabling structures). The “enhancing angle to learning” is fostered by basic research - theoretical developments advancing knowledge about the “ideal” capacities for societal learning via analytical and/or case-study based studies. This angle of learning does occur in real-world situations (e.g. Pahl-Wostl, 2009) but within any given adaptive freshwater management system is realised progressively over time.

The "requisite angle to learning" is the initial and primary learning angle to instigate within any given adaptive freshwater management system. Hence, a key question then posed by this thesis research is: is there a "gateway" (pink-arrow Fig. 6.1) formed by this foundational learning angle, from which the "enabling structures" emerge and/or are promoted? The effective operation of this "gateway" is fuelled by the adaptive management champions. These champions facilitate appropriate implementation of the adaptive management cycle iterations and work with stakeholders to increase their cooperation, collaboration and trust, as the iterations proceed. Effectively, this unlocks the "gateway" for emergence and/or further development of the "enabling structures" necessary for the "enhancing angle to learning". This "gateway" idea means that within any given adaptive freshwater management system, the yellow-shaded portion of Figure 6.1 must be focused on, initially as these systems get off the ground and are maintained over time. Such a mind-set change, as depicted in Figure 6.1, is necessary to deal more effectively with the complexity of practicing societal learning within any given adaptive freshwater management system in the real-world. Another important concept in this thesis is the hierarchical character of implementing adaptive management cycles in the real-world of adaptive freshwater management.

6.2.3 Hierarchical perspective to the adaptive freshwater management system

Is the "enhancing angle to learning" (see Fig. 6.1) ever likely to be enabled within any given adaptive freshwater management system of the real-world? Asked in a different way, in the real-world is it likely that that the "enabling structures" for this angle of learning would ever materialise within any given adaptive freshwater management system? For example, in Australia although freshwater policy exists for implementation of adaptive management within the environmental watering domain, there remain many rigid political, organisational and regulatory arrangements in place that tend to compromise effective societal learning practice and therefore adaptive freshwater management. Such rigidity is maintained by a low risk tolerance, and the existing democratic system with priority given to shorter-term goals based on government elections (Pagan, 2008). In South Africa, with more than two decades post-Apartheid a need to address social ills derived from this legacy still prevails over requirements for the sustainable use of freshwater resources (Pollard and du Toit, 2011). Thus, implementation lags remain, associated with the Ecological Reserve component of the National Water Act (Act N^{o} 36 of 1998) (McLoughlin *et al*., 2011). This represents a critical situation which requires imminent application of an effective societal learning function within adaptive freshwater management systems. Cases are documented globally that show significant progress with achieving the “enabling structures”, and these have demonstrated effective double-, and/or triple-loop learning (e.g. Pahl-Wostl, 2009; Pahl-Wostl *et al*., 2011; Fabricius and Cundill, 2014). However, these cases are the exception rather than the norm in adaptive freshwater management.

The hierarchical perspective associated with implementation of an adaptive management cycle is important for understanding the practice of adaptive freshwater management (Fig 6.1). Fundamentally, the single-, double-, and triple-loop learning functions must occur within all governance levels rather than within one large adaptive management cycle, i.e. through all levels. Importantly, the “top-down” and “bottom-up” links between these levels and adaptive management cycles are vital for success of the larger, multi-scaled adaptive freshwater management system (Fig 6.3). Although the “enabling structures” are generally difficult to achieve in the real-world (e.g. Pagan, 2008; Herrfahrdt-Pahle, 2013), these difficulties are exacerbated within the higher governance levels of any adaptive freshwater management system. Within the Australian and South African case-studies, using the Strategic adaptive management Reflexive Learning Framework this thesis demonstrated large potential for the practice of societal learning at lower governance levels of adaptive freshwater management. This was evident even under the constraints imposed from the higher governance levels (Fig. 6.3), i.e. via policy/targets at the Basin-scale and management approaches/targets at the Basin and Basin-state scale in Australia. For example, associated with environmental watering more rigid governance arrangements and predefined rules occur at the scale of the Murray-Darling Basin. However, there is flexibility in governance arrangements and thus increased potential for implementing the adaptive feedback system for societal learning within the Murray WRPA and the Edward-Wakool environmental watering area. Similar constraints occur in South Africa with the national and water management area scales. Linked to implementation of the Ecological Reserve, stakeholders of the Crocodile River Catchment (Crocodile River Operations Committee) are prone to realise “enabling structures” for the “enhancing angle to learning”. This is because there are more flexible governance arrangements occurring at this level, and better potential for build-up of social learning capacities, by utilisation of the TPC concept for instance. The probability that these stakeholders achieve the inter-linked double-, and triple-loop functions of the “enhancing angle to learning” at this governance scale, is increased. Hence, the success and effectiveness of adaptive freshwater management at these lower governance levels is promoted.

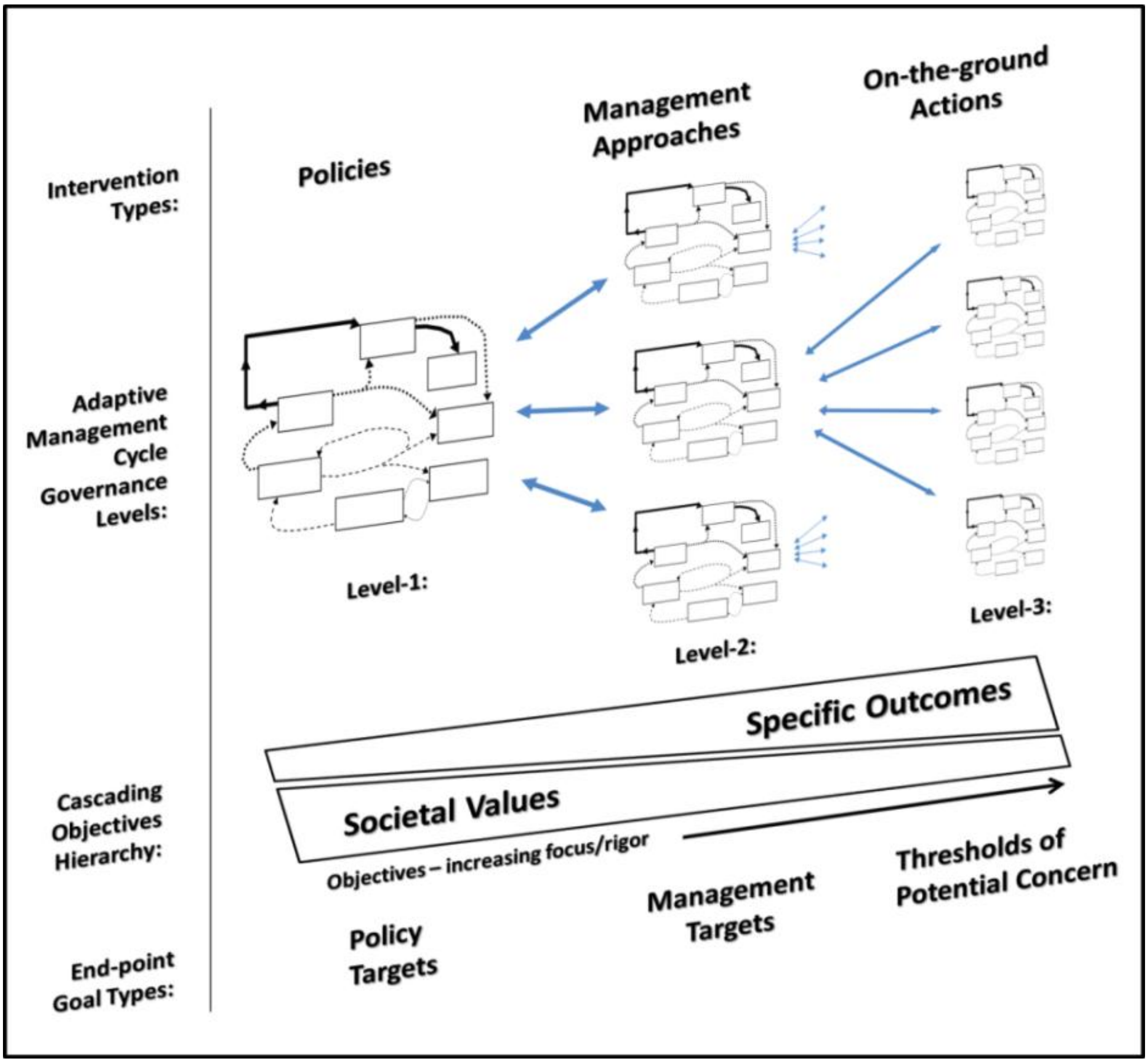

Figure 6.3. The nested structure of the SAM Reflexive Learning Framework, per theme (e.g. Environment). This hierarchy demonstrates application of an adaptive management cycle at each governance level, and each incorporates facilitation of single-, double-, and triple-loop learning. This learning within adaptive management cycles is differentiated across governance levels by intervention type, objectives hierarchy and end-point goal type.

6.2.4 Key messages for practicing societal learning within adaptive freshwater management

Implementation of any given adaptive freshwater management system should not be stalled because the ideal "enabling structures" do not (yet) exist for practicing the "enhancing angle to learning". The "requisite angle to learning" must/can be achieved, although, for application of the "requisite angle to learning" participation from organisations with their key stakeholders is needed (Fig. 6.1). Notably, within any given adaptive freshwater management system the "enhancing angle to learning" should not be attempted without any attention given to the facilitating processes" of the "requisite angle to learning" (Fig 6.1), which bequeaths a critical foundation for both learning angles. If so, the practice of societal learning is overwhelming and becomes confusing (Rist *et al*., 2013). Progressively working toward achieving both learning angles is an ideal, and would make for a more complete societal learning function within adaptive freshwater management, because these learning angles augment each other.

In addition, for assessing potential success or effectiveness of any given adaptive freshwater management system, taking a hierarchical, scaled perspective to implementation of the adaptive management cycle bestows a better gauging method. Importantly, slower response times of adaptive management cycles at higher governance levels must be seen as standard practice, not failure. Thus, the longer time frames for change within these adaptive management cycles must be conceded when inferring achievements of the adaptive freshwater management system as a whole. With this, the three functions of single-, double-, and triple-loop learning are initially pursued within adaptive management cycles of the lower governance levels, even within the constraints imposed from the higher levels. For instance, social learning capacities can be promoted via development, use and auditing of TPCs at this level. Here, there are increased capacities for the emergence of the “enabling structures”, via the “gateway”, which promotes the practice of the “enhancing angle to learning”. Subsequently, and over longer time-scales, the adaptive management cycles at the lower governance levels must seek to influence and forge learning in the upper levels, via vertical feedbacks.

Overall, a pragmatic approach to societal learning is needed within any given adaptive freshwater management system, globally, to promote a more effective practice of adaptive freshwater management. This pragmatic approach requires implementation of the “requisite angle to learning” with concerted attention given to the “facilitating processes”, via deployment over time of a complex, nested and overlapping set of adaptive feedbacks. These adaptive feedbacks facilitate single-loop learning in combination with “good-enough” double-loop learning (Fig 6.1). This thesis does, however, acknowledge that without the “enhancing angle to learning” the societal learning function of any given adaptive freshwater management system remains vulnerable. With time, progressive iterations of the adaptive management cycle bestow potential for unlocking a “gateway” – this acts to nurture initiation or further development of the “enabling structures” needed for achieving the “enhancing angle to learning” (Fig 6.1).

6.3. Resilience and practicing adaptive natural resource management

Managing a natural resource system as a resilient system requires that an ANRM approach is adopted (Biggs *et al*., 2015). However, how to apply resilience thinking and its concepts in ANRM is less clear (Walker and Salt, 2012). At the end of the section on Managing Resilience in their book entitled "Resilience practice: Building capacity to absorb disturbance and maintain function", Walker and Salt (2012) list key points for the practice of resilience within a system. These key points are outlined below demonstrating how resilience thinking and its concepts can be incorporated more fluidly within an ANRM system, for promoting resilience practice.

Key point number 1: How can interventions be implemented in an adaptive management framework?

The developed Strategic adaptive management Reflexive Learning Framework (SRLF) promotes the heuristics of adaptive management within a cohesive framework and its deployment guides adaptive resource management within and beyond typical single-loop learning modes, within and across governance levels. The SRLF emphasizes the types, roles and transfer of information within a reflexive learning context, and its adaptive feedback system works to enhance the facilitation of single-, double- and triple-loop learning. Focus on the reflexive learning process is further fostered by streamlining objectives within and across all governance levels; incorporating multiple interlinked adaptive management cycles; having societal learning as an ongoing, nested process; recognizing when and where to employ the three modes of societal learning; and distinguishing initiating conditions for this learning. SRLF contemplates practitioner mandates for societal learning, within and across governance levels of ANRM. In addition, the SRLF principles promote several emergent themes of resilience (Walker and Salt, 2012). First, thinking across multiple scales of ANRM. Second, paying attention to thresholds, and more specifically Thresholds of Potential Concern (TPCs) which are beneficial in managing uncertainty in complex social-ecological systems (see Biggs *et al*., 2015). Third, celebrating/embracing change and uncertainty/surprise and fostering of innovation, and fourth, remembering adaptive governance. Thus, the SRLF provides an important ANRM context for the practice of resilience.

Key point number 2: Appropriate actions/policies depend on the phase of the adaptive cycle the focal scale of the system is in (as well as the phases that higher and lower scales are in).

Harnessing adaptive capacity through the four phases of exploitation, conservation, release and reorganization (Holling, 2001; Gunderson and Holling, 2002), is promoted by integration of the four adaptive cycle phases with single-, double-, and triple-loop learning (Bettini *et al*., 2015). What is required however is an understanding about how these different modes of societal learning dominate within the different phases of the adaptive cycle. The effect, i.e. of maintaining, creating and disrupting, that this learning has on other system components which is critical for harnessing of adaptive capacity (see Bettini *et al*., 2015). System components may include management structures, objectives or institutional instruments used within a natural resource management system.

Harnessing of the adaptive cycle is advanced by integration of the SRLF with the reported adaptive capacity propositions of Bettini *et al*. (2015). As demonstration: (1) a maintaining “lock-in phase”: within the adaptive management cycle - the single loop learning mode becomes the only learning function being used, and there is also reduction in the amount of improvement and/or adjustment being exercised associated with implementation of adaptive management interventions; (2) a disruptive “crisis phase”: within the adaptive management cycle - there is deliberate instigation of the triple-loop learning function, comprising a review of all current objectives and end-point goals and a transformation of governance arrangements where pertinent (see point 3 below). This phase includes seeking and selecting new intervention options in order to achieve the revised objectives. The single-loop learning function is initially required in order to test implementation of operations linked to the new interventions selected; (3) a creative “reorganising phase”: within the adaptive management cycle - there is a move away from single-loop learning dominance to an inclusion of the double-loop learning function, if and when required. Surprise, which is inevitable, fuels the need to change practice when necessary; (4) a maintaining “stabilising phase”: within the adaptive management cycle - although there may be some double-loop learning still occurring, the trend is toward single-loop learning again as the know-how and efficiencies within the adaptive management cycle increase over time.

Scale is a critical factor associated with implementation of the SRLF adaptive management cycles within ANRM across governance levels. It is expected that advancement in ANRM will not occur uniformly across governance levels (or scales). While the pragmatic "requisite angle to learning" must be initiated within any ANRM system at each governance level, there will be disparate rates in realizing the critical "enabling structures" for the "enhancing angle to learning", i.e. the full double-, and/or triple-loop learning functions across the governance levels. The SRLF bestows a governance structure for Panarchy theory, and this theory with its complex adaptive cycles is expedient for assessing processes of change across levels of organization within systems (Garmestani *et al*., 2009). Hence, integration of this theory and its concepts with principles of the SRLF is important for furthering understanding about ANRM and the practice of resilience within systems.

Key point number 3: Ask yourself if your system is in a trap. If so, is transformation needed?

Transformational change within resilient systems is ongoing, therefore it must not be thought of as a once-off phenomenon (Walker and Salt, 2012). Bettini *et al*. (2015) identify the "lock-in" phase of the adaptive cycle as requiring most real-world research because rigidity in this phase accounts for low adaptive capacity. It is this phase which is most critical for an actual anticipation and planning for transformation within a resilient system. Furthermore, Walker and Salt (2012) predict that a deliberate, positive transformation within a system will have less cost associated with it, compared to an inevitable, unexpected and unplanned transformation which may initially be avoided but will occur at some point. The authors acknowledge that initiating a deliberate transformation is a relatively new concept within resilience science, mainly because the determinants of transformation are not well understood. However, there are three main factors thought to influence transformation (Walker and Salt, 2012): (1) getting beyond denial – here denial is promoted by governments who keep supporting efforts to do the same thing. Information and its generation/use is the key to breaking this state of denial, as is selecting the best intervention options to implement and adapt over time. This process must incorporate stakeholder participation with collaboration. (2) Creating or identifying options for transformation involves the encouragement of novelty and experimentation – rather than allowing the same practice to be repeated when it is not viable. (3) Having the capacity to change – which depends on effective connection or support to the scales above the focal scale of interest. In addition, the "bottom-up" approach, i.e. from the finer scales upwards, is the best way to undertake transformation within a resilient system because here it is safer and offers a great deal more variation and opportunities to test and select various types of novel ideas. Notably, it is at the finer scale where implementation of new ideas is more likely to be successful, although it may not be possible to initiate pertinent changes without prior transformation at the higher scales.

Instigating societal learning within an adaptive management cycle at each governance level promotes pertinent change and transformation within the ANRM system, across governance levels. Here, a complex, nested and overlapping set of adaptive feedbacks is needed, designed to facilitate the single-, double-, and triple-loop learning functions of societal learning, at critical times within these adaptive management cycles. Promotion of this societal learning within ANRM increases the probability of going beyond denial, and the creation of various options which contributes to capacity building to deal with change. In addition, consideration of adaptive management cycles within and across governance levels including the critical "bottom-up" learning influences, bestows an important mechanism for transformation throughout the larger ANRM system, thus promoting resilience.

Key point number 4: How can adaptive governance be introduced?

The promotion of adaptive governance within ANRM is critical, and this is better achieved via the triple-loop learning function within the adaptive management cycle. The ability to change governance is more often than not the most difficult component to achieve, but is vital for resilience practice (Walker and Salt, 2012). The SRLF is described for three different governance levels within the practice of ANRM. Importantly, there are key functional attributes across these governance levels, including stakeholder mandates, rates of informal stakeholder interactions and innovations, and timescales for change. The functional attribute "timescales for change" is dependent on flexibility of governance arrangements and degree of self-organisation among stakeholders within the ANRM system, at different levels. Hence, the SRLF introduces critical thinking tackling how to introduce adaptive governance within ANRM systems, and therefore for the systems being managed to become more resilient.

6.4 Implications of the SAM Reflexive Learning Framework and its principles for future research

The value of the developed SRLF is that it instigates integrative thinking associated with the contemporary problem of translating adaptive freshwater management theory into practice. It achieves this elegantly by demonstrating a generic, explicit and pragmatic adaptive feedback system (reflexive learning) for facilitating the three functions of societal learning (single-, double-, and triple-loop) within ANRM. The SRLF consolidates essential reflexive learning heuristics of adaptive management explicitly under one framework and its deployment guides adaptive freshwater management purposely within and beyond single-loop learning, across three governance levels. It is critical that the SRLF is seen for what it is: a pragmatic tool for guiding the practice of adaptive natural resource management. The intention of SRLF deployment is integrating its principles into existing components and processes of any adaptive freshwater management system, and this is the key challenge for deploying the SRLF.

There are, therefore, many different aspects to the SRLF (its principles) which can be used to further know-how to guide a more effective practice of any given adaptive freshwater management system. This thesis utilized the SRLF's principles in two different ways within the domain of adaptive freshwater management in South Africa and Australia. These two cases demonstrate the worth of the SRLF's adaptive feedback system in enabling implementation of an adaptive management cycle for the practice of societal learning within adaptive freshwater management. An important component of the SRLF is the SRLF entity, which is a group of interlinked SAM cycles; one for each theme including the Environment, Economy and Community/Social. Strategic adaptive management cycles contained within the SRLF entities are required to be interlinked, because it is widely accepted that ecological, economic and social systems are inextricably bound (Folke et al., 2005; Walker and Salt, 2012). Thus, when considering intervention strategies to meet the agreed objectives and end-point goals for each theme the intervention paths chosen for a particular SAM cycle must be formulated in conjunction with any potential impacts on SAM cycles of the other themes. Therefore, in order to meet the full range of objectives at each level of organization in the SRLF it is crucial that SAM cycles comprising a SRLF entity are interdependent and operating in tandem with each other. Overall, these SAM cycles give effect to the practice of ANRM under SRLF.

Further research is needed on the application of the Economic and Community/Social themes of the SRLF, in conjunction with the Environment theme within the real-world context of adaptive freshwater management. Notably, how the TPC concept can be applied within these themes is one important component to test. Research expanding on the current South African case-study – Crocodile River Catchment, and the Australian case-study – Edward-Wakool environmental watering area, would bestow potential to investigate these themes in the context of freshwater management.

Initiation of the “requisite angle to learning” in the case-studies of this thesis also sets up research opportunities for further investigation to test the “gateway” idea within the adaptive management cycle, i.e. between the “requisite angle to learning” and the “enhancing angle to learning”. For example, integrating the lessons learned associated with application of the SRLF within the Inkomati Water Management Area and the Crocodile River Catchment, with work of Jackson (2015) who is studying social learning aspects (“enabling conditions”) more intently within this catchment.

Further research over longer time scales is needed to test implementation of the SRLF principles at the upper governance levels of adaptive freshwater management, because these levels require longer time frames compared to that permitted for PhD research. The generic vertical structure of SRLF exhibits a nested pattern of SAM cycles distributed across the three levels of organization, and these levels differentiate the types of interventions required to meet different end-point goal types. The research basis set up by this thesis within the two case-studies presented provides potential ground-work for further research associated with testing principles of the SRLF at these upper governance levels. Specifically, this further research would occur at the water management area and national scales within South Africa, associated with implementation of the Ecological Reserve, and the Basin-state and Murray-Darling Basin scales within Australia associated with environmental watering throughout the Basin.

Overall, the heuristic SRLF serves as an exploratory map for integrative learning in the practice of ANRM. This is beneficial because subsequent improvements to the SRLF will provide a measure of progress in integrative thinking (Pickett *et al.*, 1999) associated with this learning. A key focus area is identifying criteria for the “potential” and “connectedness” axes of the adaptive cycle, associated with achieving the single-, double-, and triple-loop learning functions of the adaptive management cycle, as represented in the SRLF (see section 6.3). It must be expected that advancement in societal learning will not occur uniformly across governance levels of natural resource management due to the inevitable disparate rates in realizing the enabling structures for the “enhancing angle to learning” (described in section

6.2.3). Panarchy theory, with its complex adaptive cycles including the four phases of exploitation, conservation, release and reorganization (Holling, 2001; Gunderson and Holling, 2002), has been useful in assessing processes of change across levels of organization within systems (Garmestani *et al*., 2009). Thus, further study integrating this thinking into SRLF development would be beneficial, because improved understanding about change and influences across governance levels of ANRM is needed. In particular, increased understanding about change would further knowledge concerning transformation constraints with implementation of adaptive management cycles, between governance levels of adaptive freshwater management. For example, how might policy development (under contemporary paradigms) at SRLF Level-1 constrain the ability to change actions on-the-ground within the SRLF Level-3? In addition, how does learning emanating from SRLF Level-3 influence broader transformation and policy change required at SRLF Level-1, over longer time-scales?

6.5 References

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