AN ADAPTIVE OPERATIONAL WATER RESOURCES MANAGEMENT FRAMEWORK FOR THE CROCODILE RIVER CATCHMENT, SOUTH AFRICA

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As the candidate's supervisor I have/have not approved this thesis/dissertation for submission.

Graham Jewitt.

“Those who cannot change their minds

cannot change anything”

- George Bernard Shaw

ABSTRACT

River catchments are complex STEEP (Social, Technological, Economic, Environmental, Political) systems requiring an integrated and adaptive approach to their water resources management with input from diverse stakeholders to generate a shared understanding of the system, and to engage in consensus-driven decision making and cooperative action towards shared objectives.

Furthermore, semi-arid run-of-river dominated and closing river catchments are particularly susceptible to degradation and the current institutional arrangements for integrated water resource management are not generally able to adequately deal with issues of river catchment closure. Nor do they appear to effectively integrate both the technical and social-ecological aspects of integrated water resources management.

This research thesis aims to investigate, analyse, develop, implement and evaluate an adaptive operational water resources management framework for the semi-arid run-of-river dominated and closing Crocodile River catchment through a collaborative and participatory action research approach which acknowledges the dual learning pathways of science and management, and that allows for researchers, managers and stakeholders to engage in consensus-driven decision making and cooperative action for effective operational water resources management.

The research further aims to evaluate whether the framework developed can enable effective operational water resources management and so test the hypotheses that strategic adaptive management can be effectively used to conduct functional and effective operational water resources management in complex semi-arid run-of-river dominated and closing river catchments.

PREFACE

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science by research in hydrology at the University of KwaZulu-Natal, Pietermaritzburg. It has not been submitted before for any degree or examination in any other University.

Brian Richard Jackson

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ACRONYMNS AND ABREVIATIONS

ACRONYM	DESCRIPTION
AOWRMF	Adaptive Operational Water Resources Management Framework
AOWRM	Adaptive Operational Water Resources Management
APP	Adaptive Planning Process
AR	Action Research
CARM	Computer Aided River Management
CMA	Catchment Management Agency
CMS('s)	Catchment Management Strategy/(Strategies)
CRF	Crocodile River Forum
CRMIB	Crocodile River Major Irrigation Board
CROCOC	Crocodile River Operations Committee
DHI	Danish Hydrological Institute
DSS	Decision Support System
DMS	Decision Making System
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EFR	Ecological Flow Requirements
EWR	Ecological Water Requirements
FEWS	Famine Early Warning System
FWACS	Fractional Water Allocation and Capacity Sharing
ICMA	Inkomati Catchment Management Agency
IWAAS	Inkomati Water Availability Assessment Study
IWMA	Inkomati Water Management Area
IWRM	Integrated Water Resources Management
KNP	Kruger National Park
MAR	Mean Annual Runoff
MOA	Memorandum of Agreement
MTPA	Mpumalanga Tourism and Parks Agency
MWF	Mpumalanga Wetland Forum
NFEPA	National Freshwater Ecosystems Priority Areas
NOAA	National Oceanographic and Atmospheric Administration

NWA	National Water Act, Act 36 of 1998
NWRS	National Water Resources Strategy, 2004
NWRS 2	National Water Resources Strategy 2012
OR	Operating Rules
OWRM	Operational Water Resource Management
PRIMA	Progressive Realisation of the Inco Maputo Agreement
RRS	Rapid Response System
SAM	Strategic Adaptive Management
SANBI	South African National Biodiversity Institute
SANCIAHS	South African National Committee on Implementing Applied Hydrological Sciences
SANPARKS	South African National Parks
STEEP	Social, Technological, Ecological, Economic, Political
TOR	Terms of Reference
TPC	Thresholds of Potential Concern
TPTC	Tripartite Permanent Technical Committee
TRMM	Tropical Rainfall Measuring Mission
WARMS	Water Authorisation and Registration Management System
WMA	Water Management Area
WMI	Water Management Institution
WRC	Water Research Commission
WRM	Water Resources Management
WReMP	Water Resources Management Platform
WRIM	Water Resources information Management
WRIMD	Water Resources information Management Database
WRIMS	Water Resources Information Management System

GLOSSARY OF TERMS

Adaptive management:

The process of treating resource management as an experiment such that the practicality of trial and error is added to the rigour and explicitness of the scientific experiment, producing learning that is both relevant and valid" (Meffe et al., 2002).

Action research:

Action research simultaneously assists in practical problem-solving and expands scientific knowledge, as well as enhances the competencies of the respective actors, being performed collaboratively in an immediate situation using data feedback in a cyclical process aiming at an increased understanding of a given social situation, primarily applicable for the understanding of change processes in social systems and undertaken within a mutually acceptable ethical framework" (Hult and Lennung, 2006).

Closing river catchment:

River catchments are said to be closing when the supply of water falls short of commitments to fulfil demand in terms of water quality and quantity within the catchment and at the river mouth, for part or all of the year (Falkenmark and Molden, 2008; Molle et al., 2009).

Ecological flow requirements:

Ecological flow requirements are defined as "the quantity and quality of water to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource". Ecological flow requirements are referred to as the ecological reserve by DWA in South Africa instead of the more generic international terminology. The two terms are deemed to have the same meaning in the context of this thesis and may be used interchangeably.

Discourse:

A style of participatory processes that implies that there is equality among participants, and that processes are oriented towards "resolving conflicts in consensual rather than adversarial ways" (Renn et al., 1995).

Integrated Water Resources Management (IWRM):

A process which promotes the co-ordination, development, and management of water, land, and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of the vital eco systems (NWA).

IWRM stakeholder:

"any persons, or their representative organisations;

1) whose activities affect or might affect water resources within its water management area; and

2) who have an interest in the content, effect or implementation of the catchment management strategy" (NWA).

Knowledge:

For the purposes of this thesis, "knowledge" means the information, facts, principles and skills learned through experience and education. For the purposes of this thesis, the knowledge required referred to is thus the particular knowledge needed for conducting effective adaptive operational water resources management. It is acknowledge that there is a significant amount of research into knowledge and its various meanings, forms and processes etc. Reference to "knowledge" and "knowledge required" in this thesis is not meant to imply the study, use or comparison of any particular process or type of knowledge in any way. It is merely meant to refer to the requirements for conducting operational water resources management as defined above.

Participation:

Participation is a process in which stakeholders influence policy formulation, alternative designs, investment choices, and management decisions affecting their communities and establish the necessary sense of ownership" (World Bank, 1993).

Physical water scarcity:

Insufficient water to meet demands, indicated by situations when the use to availability ratio exceeds 70%, a proxy for closed river catchments.

Run-of-river:

River systems that have no or little in stream storage available for the management of the flow (ICMA CMS, 2010).

Semi-arid river:

Semi-arid rivers have highly seasonal flow regimes with a marked pattern of low or zero flow during the dry season.

Social learning:

Achieving concerted action in complex and uncertain contexts and situations (Ison and Watson, 2007).

Wicked problem:

The problem can be explained/framed in many legitimate ways; Every problem/solution is linked to other problems/ solutions by +ve and/or –ve feedbacks; There is no stopping rule for when the problem is solved, nor is there a definitive statement of how effective a "solution" was; Resolutions to wicked problems are not "right or wrong", but "good enough"; However, the public give the planner/manager no flexibility to be wrong (Rittel & Webber, 1973).

1. LITERATURE REVIEW AND PROBLEM STATEMENT

1.1. IWRM

The concept of integrated water resources management (IWRM[1]), which is closely related to the Dublin principles[2] adopted at the United Nations conference on the environment and development in Rio de Janeiro, 1992 has gained wide acknowledgement and recognition around the world. For example, 80% of countries surveyed since United Nations conference in Rio de Janeiro, 1992, have embarked on reforms to improve the enabling environment for water resources management based on integrated approaches (UNEP, 2012). IWRM also reflects the changing global shift towards consideration of sustainability, equity and integrated approaches (Swatuk, 2005; Brown, 2006), which are also explicitly recognised in South Africa in the preamble to the National Water Act of South Africa, Act 36 of 1998, (NWA) through three main principles of equity, sustainability and efficiency and further recognition of "…the need for the integrated management of all aspects of water resources".

There is a lack of clarity on IWRM for actual practice

However, the UN-Water Status Report (UNEP, 2012) shows that except for the enabling environment (policy and law), there is a strong need to improve progress in IWRM. In South Africa, the expression of the principles enshrined in IWRM is also in the very early stages (Bammer 2005; Burns et al., 2006; Pollard and du Toit, 2011). At almost every level of the water sector and civil society there appears to be a basic lack of clarity as to what the policy and legislation imply for actual practice (du Toit et al., 2005; Biggs et al., 2008). This was confirmed by Mr. R. Kasrils, the then minister of DWAF in a speech at the opening of the international conference on environmental flows for river systems in 2002 when he stated that "Much has been learned in the road we have travelled – and much has still to be mastered as we struggle to bridge the divide between legal and scientific theory, and practical operational reality" (DWAF, 2002a). More recently, the revised national water resource strategy (DWA, 2013) has also acknowledged the lack of implementation of many clearly defined priorities stemming from the previous national water resources strategy (DWA, 2004b). There is thus a clear need to update and add specificity to the principles through experience with their interpretation and practical implementation (Global Water Partnership, 2000).

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1 Defined by DWA as "A process which promotes the co-ordination, development, and management of water, land, and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of the vital eco systems".

2 The Dublin Principles:

- Freshwater is a finite and vulnerable resource, essential to sustain life, development and the environment.
- Water development and management should be based on a participatory approach, involving users, planners and policy makers at all levels.
- Women play a central part in the provision, management and safeguarding of water.
- Water has an economic value in all its competing uses and should be recognised as an economic good.

In South Africa, a particularly relevant IWRM framework has been produced (DWAF, 2007) that attempts to provide a practical approach for the implementation of IWRM legislation and policy by Catchment Management Agencies (CMA's) for use in the development of their catchment management strategies (CMS) (Figure 1). This framework was used by the Inkomati Catchment Management Agency (ICMA) in the development of their CMS (ICMA, 2010b). It recognises the need for adaptive management *(*)* and that a bundle of strategies is consequently required to achieve sustainability (DWAF, 2007; Pollard and du Toit, 2008). This framework represents the most recent and state-of-the-art thinking for the implementation of IWRM in South Africa.

(*) Refer to section 1.3.3. "Strategic Adaptive Management" for details.

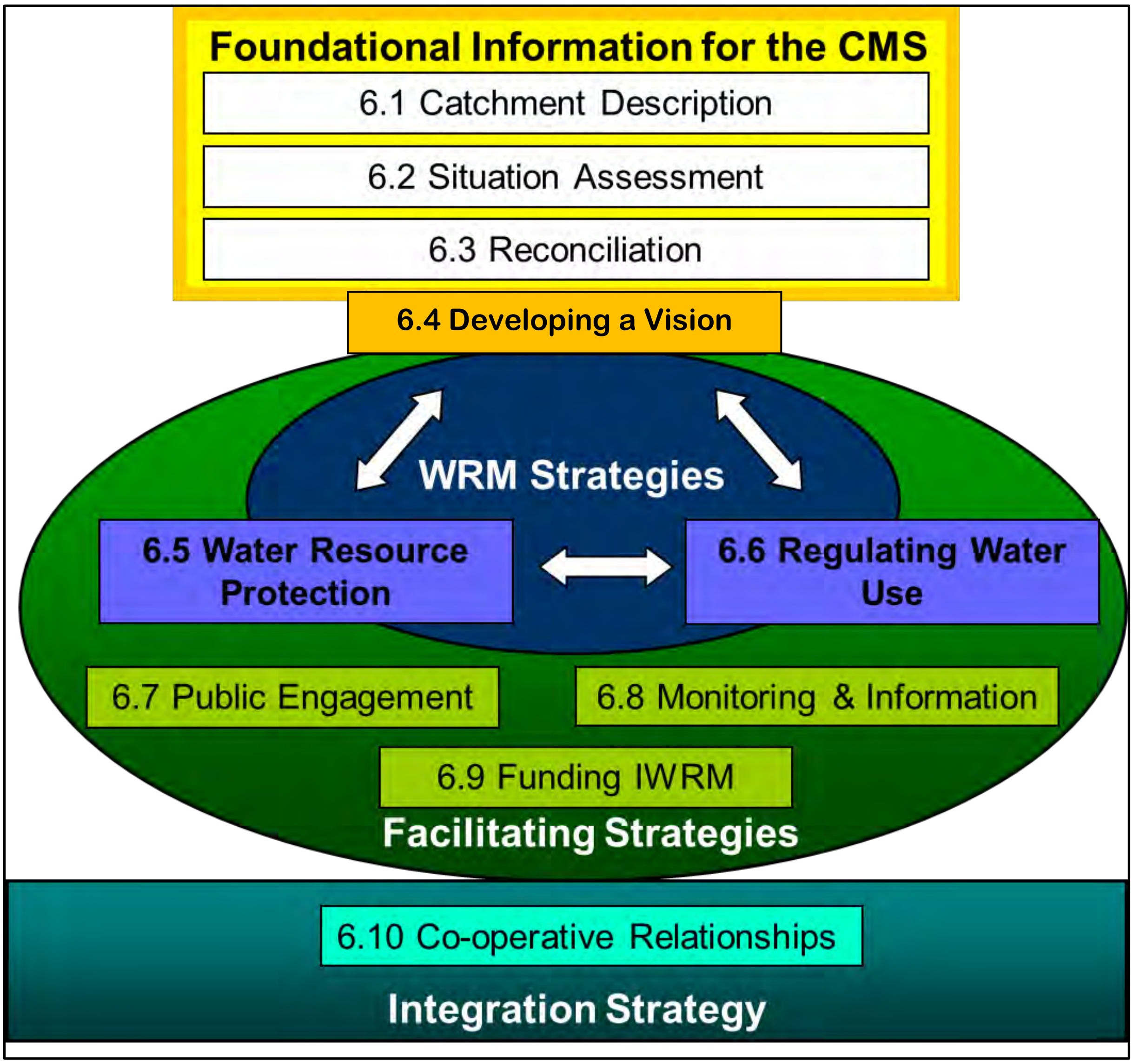

Figure 1: An IWRM framework for the development of CMS's by CMA's in South Africa (from DWAF, 2007; Pollard and du Toit, 2008).

1.1.1. Changing Resource Management Milieu

Despite the aforementioned lack of clarity some innovative progress has been made, as demonstrated by the IWRM framework for CMS's in South Africa (Figure 1), and there has been a global shift towards the consideration of integrated approaches in implementing IWRM. This has been eloquently referred to as the "changing resource management milieu" (Rogers, pers. com.) and is seen to be manifesting in three streams summarised below and presented diagrammatically in Figure 2:

1) The change in the driving paradigm from bureaucratic, to learning organisations.
2) The consequent societal decision making process changing from command / control to participative.
3) The change in the operational interpretation from expert knows to uncertainty expected.

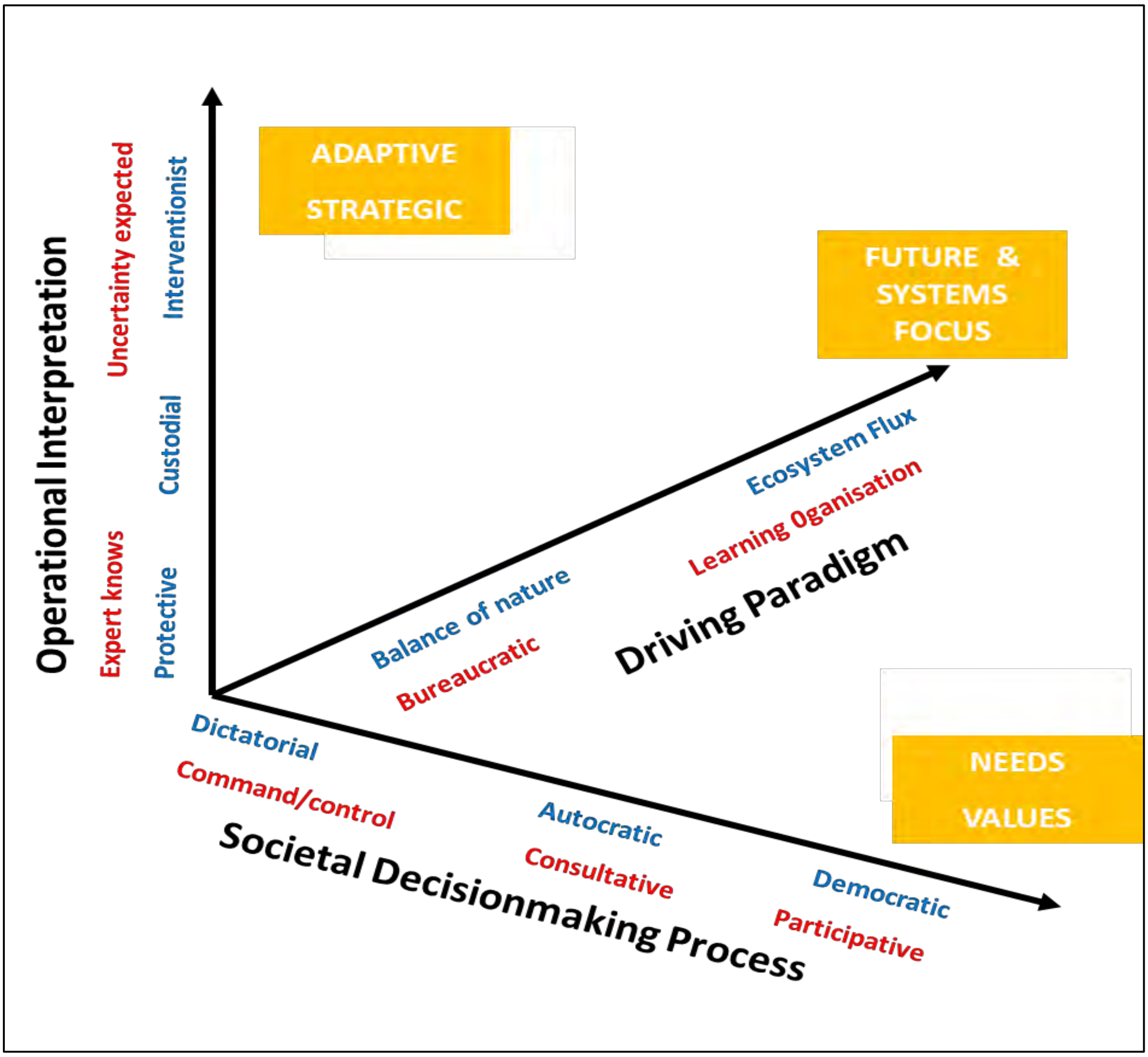

Figure 2: Diagrammatic representation of the changing resource management milieu (modified from Rogers and Bestbier, 1997).

There has been a consequent upsurge in awareness of the shifts in research and practice that are necessary to deal with this changing resources management milieu and the intractable, complex problems feeding this change.

Such problems have been given the term "wicked"[3] problems (Rittel and Webber, 1973) and IWRM can be seen to be a wicked problem; especially in closing, semi-arid, run-of-river catchments *(*)* which exacerbate and enhance the difficulty in achieving IWRM due to the intrinsic uncertainty and complexity associated with high variability in runoff and lack of storage to manage it with.

(*) Refer to section 1.2.4. "Closing, Semi-Arid, Run-of-River Catchments" for details on what this is.

Water resources managers[4] must address this issue if water resources management is to be effective.

IWRM is a wicked problem

1.1.2. Complexity

Concepts such as complexity (Cilliers, 1998) and strategic adaptive management *(#)* (Biggs and Rogers, 2003; Pollard and du Toit, 2006; Rogers and Luton, 2011) are particular examples of the growing recognition of this changing resources management milieu. For example, the Journal of Ecology and Society published a 2014 special issue entitled "Applied research for enhancing human well-being and environmental stewardship: Using complexity thinking in Southern Africa" that reinforces this recognition within South Africa and internationally.

(#) Refer to section 1.3.3. "Strategic Adaptive Management"

The concept of complexity is especially relevant to IWRM considering that it is widely recognised that water resources and catchments are complex social–ecological systems where diverse social, technical, ecological, economic and political (STEEP) characteristics and processes are interlinked and interdependent (Berkes and Folke 1998; Berkes et al., 2003; Cilliers et al., 2013). Complexity is recognised to be highly context and value dependant, having numerous legitimate needs and outcomes, and having various dependencies and feedbacks between the STEEP factors. This description of complexity has similarities with the definition of a wicked problem.

However, much of the academic literature on complexity considers what the complexity philosopher Edgar Morin (2008) would call "intellectual complexity" and is less about "lived complexity", yet real or full understanding, including that of complexity, can only come from an internalised intersection of understanding (intellectual) and practicing (lived). In line with this philosophy, there is a growing awareness of the need to adopt a post-normal approach to "science in the service of society" (Rogers and Breen, 2003) that acknowledges the complex, wicked problem of water resources management

Action research is appropriate for the complex field of IWRM

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3 The problem can be explained/framed in many legitimate ways; Every problem/solution is linked to other problems/ solutions by +ve and/or –ve feedbacks; There is no stopping rule for when the problem is solved, nor is there a definitive statement of how effective a "solution" was; Resolutions to wicked problems are not "right or wrong", but "good enough"; However, the public give the planner/manager no flexibility to be wrong.

4 For the purposes of this thesis, "manager(s)" means "a person(s) from DWA or the ICMA with the delegated authority in terms of the NWA to make decisions on the protection, use, development, conservation, management and control of the water resources within in the WMA."

and that is encouraging action research approaches that require researchers and their stakeholder partners to "live" complexity as a new paradigm for decision making.

It has also been proposed that IWRM will not be achieved within this complexity without shared understanding of the STEEP system among stakeholders, and consensus on coordinated and cooperative action that works towards shared objectives (Rogers and Luton, 2011). Thus, managing this complexity or wicked IWRM problem requires an adaptive, learning-by-doing approach (Rogers, 2003; Stankey et al., 2005) that is informed by practice (Pollard and du Toit, 2008) *(*)*.

(*) Refer to section 1.3.3.Strategic Adaptive Management".

1.1.3. Stakeholder Participation

Much of the discussion above implies extensive stakeholder involvement or participation. Participation can lead to a sense of ownership of decisions leading to reduced resistance and even cooperation in implementation (Thomas, 1995). In complex systems, stakeholders must be part of deriving management solutions since this is where and how they learn. If they are excluded, the 'system' does not learn and hence cannot adapt to change and surprise (Pollard and du Toit, 2008). Fortunately, there has been a worldwide trend of increasing public and stakeholder involvement in decision-making for natural resource management (Rhoads et al., 1999).

A distinction is sometimes drawn between stakeholder and public participation (Holmes and Scoones, 2000). Stakeholders usually refer to a smaller subset of the 'public' with a clear, often sectoral, interest in the outcome of a decision making process, whereas the 'public' is referred to in the broader sense of 'civil society'. For the purposes of this study, participation is focused on IWRM stakeholders and section 10,(2),(c) of the NWA provides an appropriate definition of an IWRM stakeholder:

Stakeholder vs public participation

"any persons, or their representative organisations;

3) whose activities affect or might affect water resources within its water management area; and
4) who have an interest in the content, effect or implementation of the catchment management strategy".

The NWA does not provide a definition of participation though. For the purposes of this thesis, the World Bank definition of participation is offered:

"Participation is a process in which stakeholders influence policy formulation, alternative designs, investment choices, and management decisions affecting their communities and establish the necessary sense of ownership" (World Bank, 1993).

1.1.4. The Importance of Consensus Based Participatory Decision Making

Recent research has shown that successful participation should be interactive, reflective, inclusive and consensual (Sansom-Sherwill, 2006). Section 79 (4) (b) of the NWA indicates that a CMA must strive towards achieving co-operation and consensus. The need for consensus based decision making has also been explicitly acknowledged by the ICMA during the development of their CMS.

Additionally, as already stated, IWRM is complex and poses a wicked problem. Fortunately, such complex systems also tend facilitate cooperation due to the interdependence of their stakeholders (Susskind and Cruikshank, 1987) and incentives to seek consensual management are high where countries have water constraints to future development (Turton and Ashton, 2008).

Renn et al. (1995) use the term 'discourse' to describe the style of participatory processes that they believe to be appropriate for handling decisions in such an environment. 'Discourse' implies that there is equality among participants, and that processes are oriented toward "resolving conflicts in consensual rather than adversarial ways" (Renn et al., 1995).

A definition of a consensus based participatory approach is required. The Round Tables of Canada (participatory decision-making groups for a variety of different governance portfolios) developed ten guiding principles of consensus processes (National round table on the environment and the economy, 1993), which are:

1) Purpose driven. People need a reason to participate in the process.
2) Inclusive not exclusive. All parties with a significant interest in the issue should be involved in the consensus process.
3) Voluntary participation. The parties who are affected or interested participate voluntarily.
4) Self-design. The parties design the consensus process.
5) Flexibility. Flexibility should be designed into the process.
6) Equal opportunity. All parties must have equal access to relevant information and the opportunity to participate effectively throughout the process.
7) Respect for diverse interests. Acceptance of the diverse values, interests and knowledge of the parties involved in the consensus process is essential
8) Accountability. The parties are accountable both to their constituencies and to the process that they have agreed to establish.
9) Time Limits. Realistic deadlines are necessary throughout the process.
10) Implementation.

Furthermore, it is important that one is able to evaluate whether a participatory approach is consensual. Susskind and Cruikshank (1987) suggest four criteria for evaluating the success of a participatory decision outcome:

1) Fairness (all interests are treated equally).
2) Wisdom (a competent decision based on all available relevant information, which in implementation achieves the goals it intended).
3) Stability (decision will not be opposed and thereby negated in the near future).
4) Efficiency. They also point out that it is far more important that a process is perceived as fair by the parties involved than for example by an abstract analyst.

Samson-Sherwill (2006) conducted an extensive evaluation of public participation in IWRM within South Africa and derived the following criteria for the evaluation of participation:

1) Level of participation.
2) Product outcome.

   a. Decision.
      i. Wise?
      ii. Fair?
      iii. Stable?
3) Process outcome.
   a. Sense of ownership.
   b. Capacity building/learning.
   c. Policy.
   d. Water resource and resource management.
   e. Others' perspectives.
4) Networks and relationships.
5) Inclusivity.
   a. Access to process.
   b. Access to information.
   c. Ability to contribute.

The importance of and need for some form of consensus based participatory decision making process as a part of effective IWRM is evident from the above discussion. The social learning criteria discussed in section 1.3.1.2 are also relevant and a combination of the consensus based participatory decision making criteria discussed here and social learning principles and criteria is suggested for the evaluation of these aspects of IWRM *(*)*.

However, reaching agreement in a consensus based participatory decision making process requires that participants are open and willing to change their views through exposure to other's perspectives. It takes frequent, focused and repeated interactions over a long period to facilitate this type of change management amongst stakeholders and this must be acknowledged *(#)*.

(*) Refer to section 3.2. "Methodology to Evaluate the Effectiveness of the Adaptive Operational Water Resources Framework" for the actual methodology used for the evaluation of consensus based participatory decision making and social learning in this thesis.

(#) Refer to section 5.3. "Evaluation of the Data, Information, Modelling and Decision Support Systems".

1.1.5. Requisite Simplicity

The sections above highlight complexity and the complex nature of IWRM. However, dealing with complex systems implies that some form of reduction is inevitable. Those tasked with managing complex systems need scientific knowledge[5] to be translated into robust guidelines, and identifying a

[5] For the purposes of this thesis, "knowledge" means the information, facts, principles and skills learned through experience and education. The "knowledge required" is thus the particular knowledge needed for conducting effective adaptive operational water resources management. It is acknowledged that there is a significant amount of research into knowledge and its various meanings, forms and processes etc. Reference to "knowledge" and "knowledge required" in this thesis is not meant to imply the study, use or comparison of any particular process or type of knowledge in any way.

requisite simplicity may provide this. I.e. ‘‘there is a requisite level of simplicity behind the complexity that, if identified, can lead to an understanding that is rigorously developed but can be communicated lucidly’’ (Holling, 2001).

Requisite simplicity attempts to discard some detail, while retaining conceptual clarity and scientific rigor, and helps one to move to a new position where one can benefit from new knowledge. Requisite simplicity offers four guiding principles in the context of practical management of complex systems (Stirzaker et al., 2010):

1) Knowledge usually advances incrementally as one investigates more detail. A requisite simplicity helps stakeholders to move to a new position where they can more usefully benefit from new knowledge.
2) A lack of certainty is no excuse for lack of action.
3) Recognise that there are no simple answers to complex problems, but simplification is part of the journey of learning how to deal with them. Simplification in the complex domain must therefore involve the identification of emergent properties of the system and simple ways to track them.
4) Dealing with complex systems demands a degree of humility from scientists because their knowledge is limited and there will be surprises.

It is thus apparent that any IWRM implementation framework would benefit from the application of requisite simplicity principles. This implies that our knowledge of IWRM should be simplified sufficiently to allow stakeholders to more usefully benefit from it. One could say we require a requisitely simple knowledge.

1.2. OPERATIONAL WATER RESOURCES MANAGEMENT

The previous sections demonstrated that IWRM is a vast and complex field with numerous interrelated and interdependent aspects. This section provides a discussion on the aspect of operational water resources management and its interrelation with water resources planning.

Water resource managers are required to perform tasks for both water resources planning and operations in implementing IWRM (van Kalken et al., 2012 and Szylkarski et al., 2013) and these are thus two relevant aspects related to the implementation of IWRM. Furthermore, both of these aspects have been identified as priority strategic actions for implementation in the catchment management strategy (CMS) of the Inkomati Catchment Management Agency (ICMA) *(*)*.

(*) Refer to section 2.3.2.1. "ICMA CMS, Strategic Action Programmes and Objectives”.

An understanding of water resources planning and water resources operations is thus needed.

1.2.1. Water Resources Planning and Water Resources Operations

Clark and Smithers (2013) provide a good summary of the understanding of both water resources planning and water resources operations for the South African context in Table 1.

Table 1: WRM tasks and decisions from a South African context (Clark and Smithers, 2013).

Task/Decision		Description
Planning	Water quantity (yield) determination	One of the primary water management tasks is to estimate the quantity of water available within a river catchment and the level of assurance of this availability. These estimates need to account for the spatial and temporal variability of the climate variables driving the hydrology. In addition to climate variability the influence of climate change also need to be considered. The methods used to estimate water availability for planning purposes needs to be compatible with the methods used for water resource operations.
	Assessing new licence applications	Water managers need to assess water use licence applications to determine: if there is sufficient quantity of water available, of a suitable quality, the impacts of any associated change in land use, and the impact of quantity and quality of water discharged.
	Water quality	There is increasing awareness and concern regarding water quality in catchments. The NWA requires water managers to assess and manage the quality of the water resources under their control.
	Impact assessment	Catchments are in a continual state of change as they develop. These changes include: urbanisation, industry, land use and management changes, irrigation, transfer of water use rights and water infrastructure such as dams. Water managers need to assess the impacts of these changes on water availability and quality.
	Water use efficiency	Water managers should promote water use efficiency, especially in stressed catchments, to increase assurance of supply to existing users or make water available to new water users. It may be possible to increase water use efficiency through the adoption of alternative water allocation methods. Water use efficiency should be considered when allocating water use licences, including socio-political criteria in addition to economic benefits.
Operations	Data management and storage	In order for water managers to make informed decisions they require data and information about the water resource they are managing. This data includes historical data, real time data and records of water trades. This data and information needs to be obtained, quality controlled, stored, accessed and analysed.

Task/Decision		Description
	Monitoring	If the required time varying data and information are not available from state or commercial sources then a monitoring network will need to be established at a suitable scale to monitor streamflow, rainfall and climate variables used to estimate evaporation such as temperature, humidity and solar radiation.
	Meeting licences / demands	The NWA makes provision for an ecological flow requirement – or reserve - to meet basic human needs and environmental needs. A reserve determination needs to be conducted, then a plan to fulfil the reserve requirements and finally how to provide water for the reserve operationally through releases from a dam or restrictions on water users. The water resources in a catchment need to be allocated to meet demands in priority order of the reserve, international obligations and then demands from other sectors (e.g. industry, irrigation). In catchments with water infrastructure such as dams and diversions it is necessary to operate this infrastructure to provide water to licensed water users downstream. Water management includes conjunctive use of both surface water and groundwater.
	Auditing and compliance	To give effect to water use licenses users need to be informed of the water allocation quantities, surplus water and restrictions during droughts. Water use licenses are only of use if all water users are honest in only using the water allocated to them and it may be necessary to monitor actual water use by means of weirs and flow meters so that water use can be audited. Monitoring of flows may also be necessary to ensure compliance with the ecological flow requirements.
	Flood management	Flood management plans need to be put in place to enable control of floods, prevent development in high risk areas and to provide early warning systems.
	Forecasting demands and supply	Recent advances in climate forecasting enable water managers to plan ahead in time to the next day, week, month or season and estimate future water demands and availability which can assist in the operational decisions they make in real time. Recent advances in remote sensing technologies provide water managers with valuable information about the current status of water resources within a catchment and potential crop water requirements.

In addition to these planning and operations tasks listed by Clark and Smithers (2013) in Table 1 above, the modelling requirements for water resources planning and operations to meet the needs of the NWA of South Africa have also been documented by Pott et al. (2008b) and are indicated below:

1) The need to model water quality in addition to water quantity.
2) The need to model at appropriate temporal and spatial scales.

Modelling needs for planning & operations

3) Models need to represent real life complexity to adequately mimic hydrological processes and realities on the ground.
4) Modelling tools are required for both planning and operations.
5) Integrated modelling in a Decision Support System (DSS) is required.
6) Alternative methods and scenarios of water allocation/apportionment, including fractional water allocation and capacity sharing (FWACS), need to be assessed in order to promote efficient water use.
7) The conjunctive use of surface water and groundwater needs to be integrated in models.
8) The modelling system should link irrigation with water supply limited by operating rules in order to simulate crop yields.
9) To assess the impacts of transferring water use rights.
10) To include modelling of economic and social impacts.
11) To assess impacts of climate change on water resources and agricultural productivity.
12) To perform real time modelling for operational management.
13) To include a DSS for managing real time volumetric water abstractions.
14) The operational modelling must account for real life operational situations.
15) Feedback loops between water demand and supply to determine impact of different operating decisions must be included.
16) Flow routing is necessary for operations modelling.
17) The modelling system should include water operating rules and releases that can be applied on a day-to-day basis.
18) Tools are required to operationalise the ecological flow requirements.
19) The modelling system must be able to use climate forecasts to aid operational decisions.
20) Water accounting and auditing of water use combined with metering and monitoring is necessary.
21) Modelling results must be verified against measured data.
22) More user friendly model front and back ends are necessary to assist in setting up models and communicating results to stakeholders.

Furthermore, the ICMA identified the following modelling requirements from their perspective (Jackson, 2009):

1) Water accounting and auditing is missing.
2) Operationalisation of the ecological flow requirements at a daily time scale.
3) Determination of the quantity and times of surplus water (i.e. in excess of allocated water).
4) Simple means of running scenarios to assess impacts of restrictions, licences and trading on water users, especially downstream users.
5) Physical modelling to evaluate land use scenarios (e.g. impact of change of land use on water resources).
6) Modelling of the impact of off-channel dams.
7) Operation of dams as part of a system, not individually.
8) Use of short and long term forecasts for planning.
9) Simple means to update models with rainfall and system state data (e.g. dam levels).

OWRM should be cognisant of planning constraints

Water resources planning is undertaken over large spatial and temporal scales, which leads to the simplification of short term processes, whereas water resources operations - or operational water resources management (OWRM) - requires precise knowledge of the dynamic catchment and river processes, as river operators work on forecast horizons much shorter than river planners and these processes cannot be adequately resolved with simplified approaches (Szylkarski et al., 2013).

Benefits can be realised if a river catchment is optimised with respect to the short-term operations, using both short-term and long-term objectives as there is often conflict between short term and long term objectives necessitating the inclusion of both (Skotner et al., 2009).

This implies that OWRM should be cognisant of long term water resources planning and should not be conducted in isolation from the long term water resources planning objectives.

Operational modelling nb. but not widely practiced

Unfortunately, while water resource modelling for planning is widely practiced in South Arica, the use of water resources modelling for operations appears to be less widely practiced and is an area that requires further development and implementation (Clark and Smithers, 2013). Water resources model development and model application within South Africa has historically focused on monthly time step models, probably because monthly time series of flow have been readily available (Mallory, 2012). This is inadequate for operational decisions requiring a daily time step, such as releases for environmental flows which mimic the natural flow regime.

The recent National Water Resources Strategy(NWRS) of South Africa version 2 (DWA, 2013) partly recognised this issue through its acknowledgement that water resources management in South Africa suffers from “Incomplete water management models and framework”, “an incomplete water management model and approach” and “deficient information and knowledge to manage a complex water business”. This suggests that the NWRS2 recognises the inadequacy of current modelling approaches but did not specifically recognise that much of this is related to operational management needs. It is suggested that it is only through the implementation of operational water resources management that many of the critical factors mentioned in the NWRS2 can be implemented.

Experience from recent research on improving river efficiency in the Murrumbidgee River in Australia has also shown that current river operations rely heavily on the experience and judgement of the river operator, (van Kalken et al., 2012) *(*)* and that the main sources of inefficiencies are unaccounted changes in channel storage, unaccounted tributary inflows and late changes in irrigation water orders. Management decisions in semi-arid, run-of-river dominated catchments have also been shown to be largely based on recent, present and future weather conditions, river flow and reservoir storage (Sawunyama et al., 2012).

(*) Refer to section 1.3.1.2. “Dual Learning Pathways” for details on the need for both scientific and management learning.

Thus, real time and forecast data as well as short term decisions on river flows and certain key water abstractions within the system are important, but should be cognisant of long term water resources planning objectives. An approach that includes long-term objectives as constraints in the optimisation could be considered to simplify the modelling burden (Skotner et al., 2009).

1.2.2. Decision Support Systems (DSS's) are required for Operational Water Resources Management

The management of scarce water resources further requires the establishment of flexible and adaptable operational Decision Support Systems (DSS) (Sawunyama et al., 2012; Global Water Partnership, 2013). DSS's can be considered to be a technical aspect of IWRM and are discussed here, whereas the social aspects are discussed more in the preceding sections 1.1.3 and 1.1.4.

A DSS for IWRM will typically include a database and processing environment, an information system, a modelling and analysis framework, a socio-economic modelling and analysis framework, and a communication framework (Global Water Partnership, 2013).

As discussed in section 1.2.1 above, effective operational water resources management is an existing management and modelling gap within South Africa that must be addressed. Further review of literature relating to operational water resources management and DSS's has highlighted several operational water resources management issues. These include:

1) Operational water resources management has historically been dealt with using management knowledge rather than scientific knowledge, which implies that learning from management experience is important *(*)*.
2) River catchment operational processes require support for real time decision making in the short term (coming hours and days) and DSS's support the operator in making these specific decisions (Szylkarski et al., 2013).
3) Operational DSS's therefore require large amounts of real time data with continual updates based on the most current river/reservoir state, and both short term and long term forecasts need to be included (Clark and Smithers, 2013; Szylkarski et al., 2013). This requires a high level of automation and sophistication in operational information technology (Szylkarski et al., 2013).
4) Models can be used for real time catchment management by linking them with data management systems that include forecast data (Labadie et al., 2007). This implies that any real time or operational modelling should be linked to data management systems and use forecasted data.

> *(*) Refer to section 1.3.1.2. "Dual Learning Pathways" for more information on the need for both management and scientific learning.*

DELFT-FEWS solution software and DHI solution software are well known, internationally used examples of modern DSS's that embrace a new data centred open concept. DELFT-FEWS forms the basis of the national flood forecasting system of the UK Environment Agency and is applied as an operational forecasting platform in over forty operational centres worldwide (Werner et al., 2004; Werner et al., 2013). This rapid growth can be attributed to the open approach allowing easy integration of models and data in the operational domain (Werner et al., 2013).

The DHI solution software is another widely used example. It has been used in the CARM project in Australia (van Kalken et al., 2012) where it won the Australian Water Association's National Award for Infrastructure and Innovation, as well as in South Africa for the Crocodile real time DSS (Hallowes et al., 2007; DWA, 2010a).

Operational Flood Warning Systems:

Operational flood warning systems have been developed in many river catchments around the world. Operational flood warning is an aspect of OWRM and a flood warning system thus includes many of the technical elements that on OWRM DSS should include. Madsen et al. (2000) list the key elements of a flood warning system operating in real time:

1) Real time data acquisition.
2) Hydrologic and hydraulic models.
3) Forecasts of meteorological conditions.
4) Updating and data assimilation.

An OWRM DSS should thus include all of these elements and both the aforementioned DELFT-FEWS and DHI solution software do. Werner et al. (2005) indicate that flood warning systems are migrating from tailor-made model-centred approaches to data-centred approaches based on open modelling systems, providing further support for the suitability of these software solutions.

Hydroinformatics:

The field of operational flood warning and the two software solutions mentioned above also embrace the notion and field of study of hydroinformatics. Hydroinformatics is an industry that integrates digital information and communications technologies with numerical modelling in a DSS framework to solve problems in water environments (Szylkarski et al., 2013). It has grown out of the earlier discipline of computational hydraulics and was foreseen over twenty years ago (Abbot et al., 1991). Water resources management in large systems is a key area where hydroinformatics is being applied today and provides support for decision making in water resources planning and operations. As river management continues to evolve through hydroinformatics, the tools are shifting towards computational hydraulics as the core with complementary technologies including hydrology, meteorology, optimisation and eco-hydraulics. The development of the current DSS's and software solutions in river management mentioned above is the realisation of the hydroinformatics vision in river management.

Learning from Current Studies and Projects Related to Operational River Management:

There are a number of projects that have recently or are currently attempting to implement river operations. These should provide a good opportunity for learning incorporating both science and management knowledge *(*)* and are described in detail in APPENDIX B.

(*) Refer to section 1.3.1.2. "Dual Learning Pathways".

It appears that although there is significant technical literature as well as several projects on river operations, the vital link between the technical requirements and the more complex social needs discussed earlier under section 1 does not appear to have been effectively implemented in a semi-arid run-of-river dominated closing river catchment (Refer to section 1.2.4. for more detail).

1.2.3. Learning from the Implementation of Ecological Flow Requirements

The implementation of ecological flow requirements[6] is an important aspect of water resources management and much research has been done into the state of art of the implementation of ecological flows. However, the implementation of ecological flow requirements has not been achieved in the vast majority of South African rivers (Figure 3). Nonetheless, a number of studies have been conducted in South Africa to investigate methods to implement the ecological flow requirements in near real time (Hughes et al., 2008; Mallory, 2010; Pollard et al., 2011 and Mcloughlin et al., 2011). All of the studies recognise the frustration expressed by managers in interpreting and operationalising outputs from ecological reserve determination studies done by DWA and attempt to propose methodologies to operationalise these determinations.

Some of these studies (Pollard et al., 2011 and Mcloughlin et al., 2011) recognise the initial attempts by the ICMA to operationalise the ecological flow requirements. For example, Pollard et al. (2011) state that none of the rivers examined met the ecological flow requirements (Figure 3) but that "…this is likely to change in the Inkomati WMA, certainly in the Crocodile River, as new IWRM approaches come on line." They also state that "Operationalising the ecological reserve moves the discourse and practice beyond water protection alone. … It is the collective contribution and synergies of a number of strategies, plans and practices." And that "…such integrated approaches are not evident in any of the catchments, with the exception of the Inkomati WMA where it is emerging through the development of the Inkomati Catchment Management Strategy". Indeed, they further state that a key focus area for future action is "Operationalising the reserve: Developing an integrated, systems view as the basis for planning and action (Supporting IWRM)" and that this requires action research and social learning approaches (as proposed by Ison et al., 2004).

These learning outcomes from research into the implementation of ecological flow requirement thus support the need for action research, social learning and adaptive management *(*)*.

(*) Refer to section 1.3. "The Importance of Making OWRM Adaptable" for details on action research, strategic adaptive management and the need for the collective contribution of a number of strategies.

[6] Ecological flow requirements are defined as "the quantity, quality and timing of water flows required to sustain freshwater ecosystems and the human livelihoods and wellbeing that depend on these ecosystems"(after the Brisbane Declaration, 2007). Ecological flow requirements are referred to as the ecological reserve by DWA in South Africa instead of the more generic international terminology. The two terms are deemed to have the same meaning in the context of this thesis and may be used interchangeably.

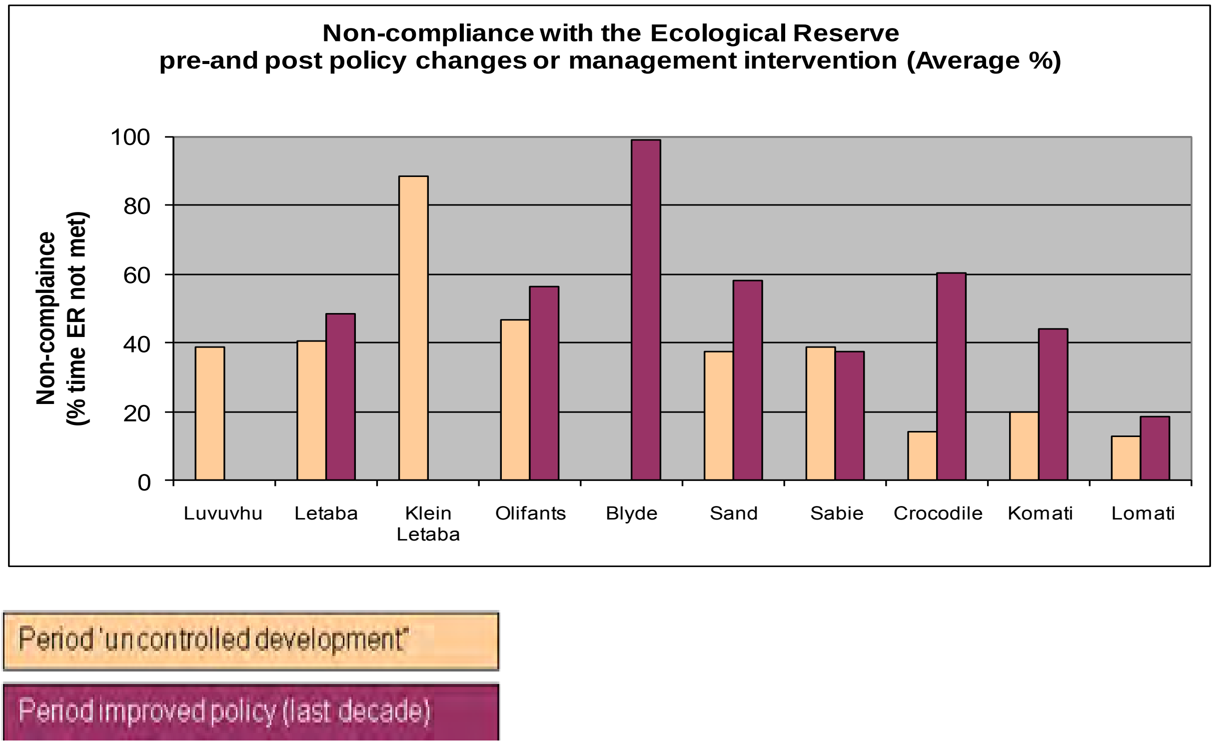


Figure 3: A summary of the incidence of non-compliance with the ecological flow requirements in the lowveld rivers over two developmental periods (pre- and post-NWA) (Pollard et al., 2011).

1.2.4. Closing, Semi-Arid, Run-of-River Catchments

As stated in section 1.1.1, closing, semi-arid, run-of-river catchments exacerbate the difficulty in achieving IWRM due to the intrinsic uncertainty and complexity associated with high variability in runoff and lack of storage to manage it with. An understanding of closing, semi-arid, run-of-river catchments is thus required.

Closing River Catchments:

River catchments are said to be closing when the supply of water falls short of commitments to fulfil demand in terms of water quality and quantity within the catchment and at the river mouth, for part or all of the year (Falkenmark and Molden, 2008; Molle et al., 2009). This is illustrated in Figure 4.

River catchment closure has developed into a sizeable challenge yet the phenomenon is a major blind spot in water resources management (Falkenmark and Molden, 2008). There is little evidence to show that current institutional arrangements for water resource management have been adequately able to address issues of river catchment closure.

Managing river catchment closure will thus require systems analysis, seeing the catchment as a complex socio-cultural-political-natural resource system, understanding how a change in water and land use in one part of the catchment impacts others in the catchment and the involvement of diverse groups of users in informed decision-making processes (Falkenmark and Molden, 2008) *(*)*.

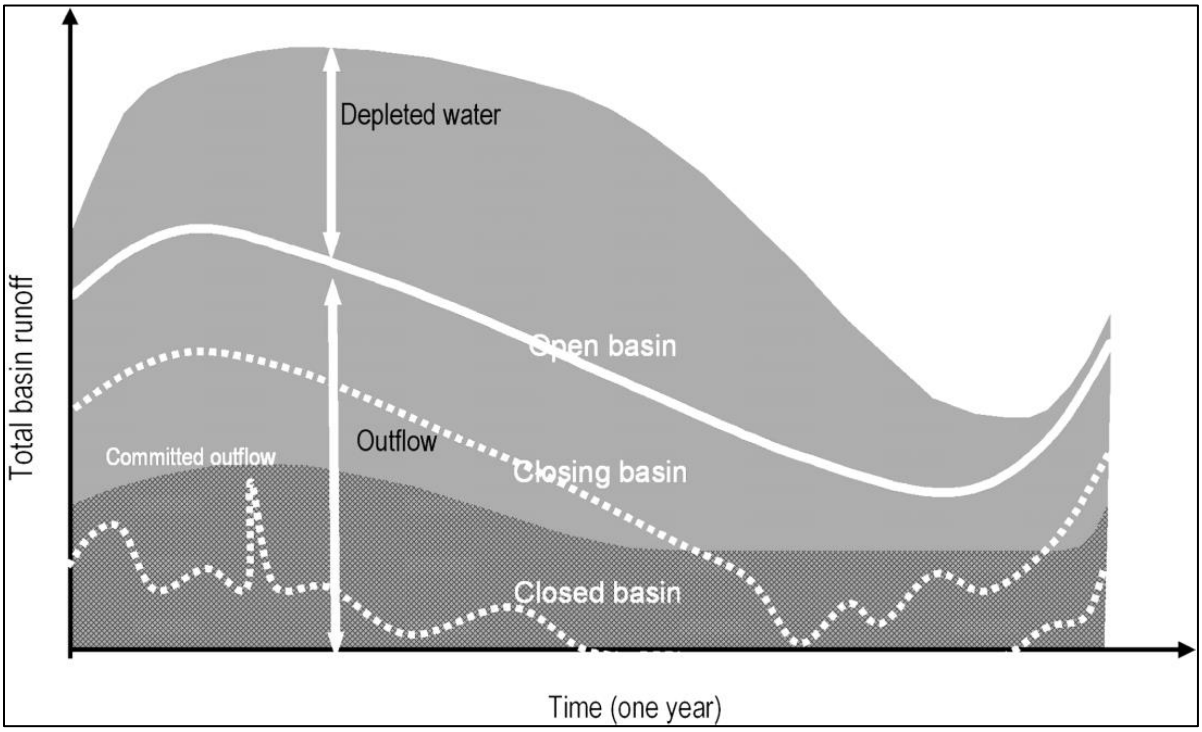


Figure 4: Illustration of the process of river catchment closure over time, where the supply of water falls short of committed outflow for part of the year (From water for food, water for life: A comprehensive assessment of water management in agriculture (http://www.earthscan.co.uk).

The studies on river catchment closure referred to above concentrate on water resources planning related management interventions to manage river catchment closure and do not explore the need to improve the short term operational water resources management of catchments. Thus, as also indicated in section 1.2.1, operational water resources management constitutes a gap, especially for semi-arid catchments with little storage dominated by run-of-river flows.

Semi-Arid and Run-Of-River Systems:

Rivers in semi-arid regions, such as the lowveld region of South Africa, have highly seasonal flow regimes with a marked pattern of low or zero flow during the dry season.

A run-of-river dominated catchment can be defined as a river system that has no or little in stream storage available for the management of the flow (ICMA CMS, 2010). These types of river catchments (semi-arid run-of-river dominated) are especially sensitive and susceptible to degradation in closing river catchments due to the intrinsic uncertainty and complexity associated with high variability in runoff and lack of storage to manage it with *(*)* and can thus be seen as systems with wicked problems (see section 1.1.1 for a definition of wicked problems).

(*) Refer to section 2.3.3. "The Crocodile River Catchment" for a description of the closing, semi-arid run-of-river status of the Crocodile River as a suitable study area.

1.3. THE IMPORTANCE OF MAKING OWRM ADAPTABLE

1.3.1. Towards Strategic Adaptive Management

1.3.1.1. Adaptive Management

“Adaptive management” was first introduced to the sphere of natural resource management by Holling (1978) with his concept of “Adaptive Resource Management”. Broadly speaking, adaptive management has been defined as “The process of treating resource management as an experiment such that the practicality of trial and error is added to the rigour and explicitness of the scientific experiment, producing learning that is both relevant and valid” (Meffe et al., 2002) *(*).*

> *(*) Refer to section 1.3.2. “Action Research”, which details the importance of trial and error coupled to scientific rigour in managing complex systems.*

Adaptive management is accepted internationally as a primary tool for the management of natural resources and the social-ecologic systems in which they are embedded (Johnson, 1999; Meffe et al., 2002).

Adaptive management differs from traditional approaches in that it addresses uncertainty directly by using management as a tool to gain critical knowledge and allows for a new science that is cognisant of practice and management experience and consequently enables both science and management to complement each other to achieve innovative approaches to IWRM, and so address the uncertainty.

Johnson (1999) recognises 5 types of management decision approaches:

1) Political/social approach.
2) Conventional wisdom approach.
3) Best-current-data approach.
4) Monitor-and-modify approach.
5) Adaptive management approach.

These five decision-making approaches constitute a progression of increasing complexity. Each successive approach adds features that focus more agency resources on the problem. Thus the costs of implementation and evaluation increase as one moves through the list. Adaptive management requires considerable time and money to organise workshops for stakeholders, develop models and policy assessments, and monitor the effects of management. However, if more complex decision-making approaches lead to more effective management, they may be cheaper in the long run and it has been proposed earlier in this thesis that IWRM is a complex field that requires adaptive management.

Adaptive management most complex approach, but nb. for IWRM

However, evidence for the successful implementation of adaptive management within the IWRM context is meagre. It is stated that although adaptive management is the best approach available to agencies for addressing this type of complex problem, its success has been limited thus far (Johnson, 1999; Pollard and du Toit, 2011). The Shared Rivers Initiative, Phase 1, of the lowveld rivers of South Africa (Pollard and du Toit, 2011) also found that such approaches are not evident in any of the catchments, except for the Inkomati WMA where it is emerging through the development of the CMS.

The term and practice of adaptive management has since morphed into many forms, with Strategic Adaptive Management (Rogers and Bestbier, 1997) being one of them *(*)*.

(*) Refer to section 2.3.2.1. "ICMA CMS, Strategic Action Programmes and Objectives" for detail on the ICMA CMS and its use of SAM.

Also refer to section 1.3.3. "Strategic Adaptive Management".

1.3.1.2. Dual Learning Pathways

The discourse on the concepts of complexity, requisite simplicity and adaptive management in the preceding sections infer that the dual learning pathways of science and management are equally important for water resources management. These concepts all acknowledge this duality in various ways.

The importance of this duality can be further supported by the fact there is often high uncertainty in the relevant science (Dorcey, 1991; Holmes and Scoones, 2000) and the complexity, uncertainty and potentially long-term duration and impact of environmental effects are seen to remove the justification for experts to decide on these problems alone (Holmes and Scoones, 2000). Allied to this, there is growing evidence of public mistrust of scientific expertise, political leaders and state institutions (Holmes and Scoones, 2000).

Within the scientific field, the technical (science and engineering) and social aspects are also equally important for water resources management as, although dependent on science and engineering, water resources management is a social process (Rhoads et al., 1999) and learning can be derived from both technical and social processes (Stankey et al., 2005).

Those tasked with managing complex systems *(#)* often complain that science delivers fragmented information that is not useful at the scale of implementation (Roux et al., 2006). As scientists, we must be prepared to move outside our specialist areas and form bridges between scientific disciplines and across the domains of science, management, and societal values (Max-Neef, 2005).

(#) Refer to section 1.1.2. "Complexity" for detail on complexity.

It is thus evident that engineering and scientific (social and technical) learning as well as management learning are equally important for the effective implementation of IWRM.

Need for Social Learning:

McLoughlin et al. (2011) emphasised the importance of social learning in adaptive resource management during their investigation into the implementation thereof for the ecological flow requirements in the lowveld river catchments of South Africa.

When conducting IWRM it is thus important to develop a methodology to both implement and facilitate a social learning process as well as to evaluate it, as the facilitation of social learning and the creation of institutions under the adaptive management umbrella are key criteria for the management of complex problem situations (Daniel and Walker, 1996; Jiggins and Roling, 2002).

In order to do that, one must first understand what social learning is.

Social learning has been defined as achieving concerted action in complex and uncertain contexts and situations (Ison and Watson, 2007, Ison et al., 2007). According to Proost and Leeuwis (2007) there is a list of preconditions to social learning. These are:

1) A sense of urgency.
2) Feelings of interdependence amongst stakeholders.
3) Stakeholders organise themselves for negotiation.
4) Meetings and other opportunities for interaction.
5) A degree of confidence that a negotiated outcome satisfying to all parties will be reached.
6) A degree of institutional space to implement outcomes.
7) Accepted leadership in the process.
8) Process facilitation.
9) Reflection built in from the start.

Mcloughlin et al. (2011) adopted the key capacities of Pahl-Wostl and Hare (2004) and the key fostering and hindering factors of Mostert et al. (2007) to measure social learning achievements within the Crocodile River catchment associated with the implementation of the ecological flow requirements.

It is thus recommended that a combination of the criteria and preconditions discussed above could be used when evaluating social learning. The consensus based participatory decision making criteria discussed in section 1.1.4 are also relevant and a combination of these consensus based participatory decision making and social learning criteria and preconditions is proposed for the evaluation of these aspects of IWRM *(*)* within this study.

(*) Refer to section 3.2 for the actual methodology used for the evaluation of consensus based participatory decision making and social learning in this thesis.

It must be noted that there is scope for further investigation into and understanding of stakeholder participation, consensus based decision making and social learning in the context of adaptive operational water resources management. However, this is not within the scope of this thesis.

Need for Management Learning:

Rogers (2006) states that managers have a very limited tool box with which to work, and that modern society has largely transferred the risk of failure to them. Rogers (2006) further states that managers need to focus on preparing society to engage the knowledge, the problem and the solutions needed to achieve some collectively defined set of future conditions; to actively engage scientists in the development of technology for altering patterns of resource use and to undertake actions needed to achieve the desired future distribution of the costs and benefits of resource use in society. Managers – or practitioners - thus carry a heavy burden for the implementation of IWRM and engaging their knowledge and learning is vital for studies within this field.

IWRM should thus be developed and implemented in an ”adaptive manner” that stimulates scientists and practitioners through the philosophy of “learn by doing” informed by practice, as traditional systems of governance and management generally do not effectively accommodate the diversity of legitimate stakeholder needs and value-sets as well as the rapidly changing circumstances that confound societal decision making.

Action research is a methodology for conducting research and Strategic Adaptive Management is a methodology for managing complex river catchments that respectively facilitate the incorporation of both scientific and management learning into the implementation of IWRM. The need for these two methodologies is described in sections 1.3.2 and 1.3.3.

1.3.2. Action Research

The discussion on complexity, participation and adaptive management in the preceding sections suggest the relevance of action research (AR) as an appropriate research methodology within IWRM and OWRM.

Susman and Evered (1978) state that the definition of AR by Rapoport (1970) is perhaps the most frequently quoted in contemporary literature. "Action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework" (Rapoport, 1970).

AR is further viewed as a means for enhancing the skills and competencies of both the researcher and the participants (Hult and Lennung, 1980). They also offer a definition of AR. "Action research simultaneously assists in practical problem-solving and expands scientific knowledge, as well as enhances the competencies of the respective actors, being performed collaboratively in an immediate situation using data feedback in a cyclical process aiming at an increased understanding of a given social situation, primarily applicable for the understanding of change processes in social systems and undertaken within a mutually acceptable ethical framework" (Hult and Lennung, 1980).

AR represents a juxtaposition of practice and theory (Mckay and Marshall, 2001). Mckay and Marshall state that one distinguishing feature of AR is the active and deliberate self-involvement of the researcher in the context of his/her investigation. The action researcher is viewed as a key participant in the research process, working collaboratively with other concerned and/or affected actors to bring about change in the problem context. AR appropriately establishes action and practice as being the prime focus of research efforts (Shanks et al., 1993). Underlying the AR process, therefore, is a rejection of many tenets of more traditional approaches to research which are embodied in the scientific method.

Researchers need to adopt a post-normal approach (Funtowicz and Ravetz, 1994) to "science in the service of society" (Rogers and Breen, 2003) that acknowledges the complex, wicked problem of water resources management and that encourages action research approaches that require researchers and their stakeholder partners to "live" *(*)* complexity as a new paradigm for decision making. It has also been proposed that managing this complexity or wicked IWRM problem requires an adaptive, learning-by-doing approach (Rogers, 2003; Stankey et al., 2005) that is informed by practice (Pollard and du Toit, 2008).

> *(*) Refer to the quote by philosopher Edgar Morin on "lived complexity' in section 1.1.2. "Complexity".*

Action research is thus deemed to be a particular relevant research methodology for this study. However, any actions taken to ameliorate a situation perceived as problematic or wicked should be applied in a defined strategic manner that is cognisant of the problem context (Susman and Evered, 1978; Avison, 1993) to ensure rigour in the research process. This implies that any action research should commence with a problem definition and follow some form of strategic and agreed process within a mutually acceptable ethical framework. *(*)*.

(*) Refer to section 3.1. "Methodology to develop and implement the adaptive operational water resources management framework " for the actual action research methodology and process used.

1.3.3. Strategic Adaptive Management

The term and practice of adaptive management has morphed into many forms, with Strategic Adaptive Management (SAM) being one of them. The preceding discussions under section 1 imply the use of SAM as suitable for the management of IWRM. But what is SAM?

Strategic Adaptive Management is an emerging local South African methodology for managing and operating complex systems that attempts to breach the social / technical and management / science divides and enable effective IWRM. SAM (Rogers and Bestbier, 1997; Biggs and Rogers, 2003; Rogers and Sherwill, 2008; Rogers and Luton, 2011) is designed to achieve the consensus based "future building" envisaged by the South African legislation.

Strategic Adaptive Management is built on the recognition that natural resource management should be framed within the concept of complex social-ecological systems (Berkes et al., 2003). SAM is thus a simple but robust system for participatory planning, decision making and review.

Strategic Adaptive Management enables institutions to move away from an emphasis on imposing, step by step, new legislation on stakeholders, to one of stakeholder centred implementation of IWRM, within resource constraints and guided by the letter and enabling spirit of the law.

These SAM principles were embedded in the CMS (ICMA, 2010b; Rogers and Luton, 2011) of the ICMA through the assistance and guidance of Professor Kevin Rogers, who was appointed by the ICMA to conduct the visioning for the CMS *(#)*. It is thus suggested that SAM should be accepted and adopted by any proposal seeking to implement IWRM in the Inkomati WMA.

(#) Refer to section 2.3.2.1. "ICMA CMS, Strategic Action Programmes and Objectives" for detail on the ICMA CMS and its use of SAM.

A Local South African SAM Framework for implementing IWRM

A framework has already been developed by Pollard and du Toit (2007) for implementing SAM in South Africa. It provides a generic description of IWRM processes under SAM phases and components. It splits SAM into 3 key phases *(@)*:

(@) Refer to APPENDIX A for the full SAM framework.

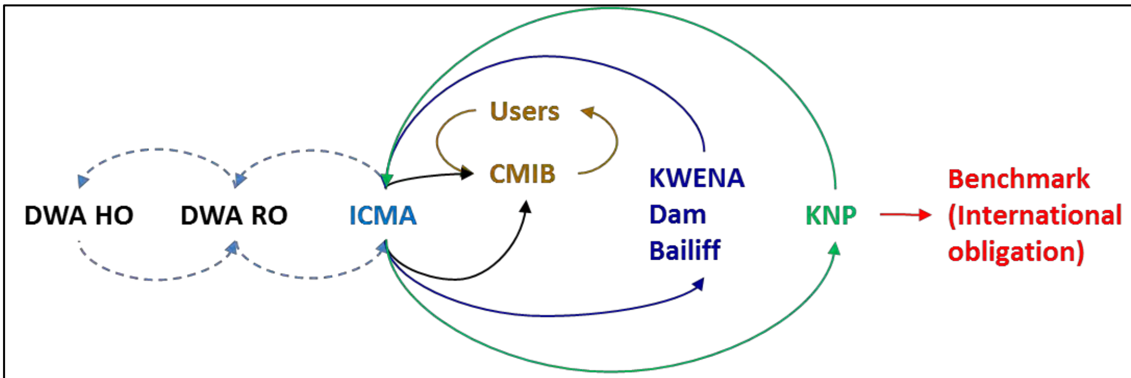
1) Adaptive planning.
2) Adaptive management.
3) Adaptive evaluation.

The adaptive planning phase has already been conducted by the ICMA during the development of its CMS but the adaptive management and adaptive evaluation phases have yet to commence. In terms of this framework, the adaptive management phase is split into the following key components:

1) Scoping management options.
2) Planning (including the design, development, testing and calibration of real time operations modelling systems; and the identification of roles and responsibilities).
3) Implementation.
4) Monitoring (this is split further into strategic monitoring and operational monitoring).

Feedback Loops:

Pollard and du Toit (2011) recommend that "functional, responsive multi-scale feedbacks are essential for management in complex systems like river catchments since they provide the basis for learning, reflection and response to an evolving context". These functional, responsive multi-scale feedbacks are more simply referred to as feedback loops. Pollard and du Toit (2011) state that the existence of these feedback loops is variable from non-existent to emergent in the lowveld rivers, but identified their emergence in the current management of the Crocodile River catchment as depicted by them in Figure 5. It is thus evident that the adoption of SAM principles and feedback loops by the ICMA is already emerging in the Crocodile River catchment through their CMS. The use of a SAM process implies the inclusion of feedback loops.



Feedback Loops in the Crocodile Catchment.
Dashed lines indicate linkages that are still being established. Solid Lines indicate emerging functional, responsive linkages and feedbacks . Note that international linkages currently happen through DWA HO. CMIB = Crocodile Major Irrigation Board; KNP = Kruger National Park; DWA HO = Department of Water Affairs Head Office; DWA RO = Department of Water Affairs Regional Office' ICMA = Inkomati Catchment Management Agency

Figure 5: Emerging feedback loops in the Crocodile River catchment (Pollard and du Toit, 2011).

The preceding discussion on SAM and feedback loops reinforces the need to ensure that continual adaptive planning, management and evaluation through feedback loops is necessary if effective operational water resources management is to be achieved.

More recently, SAM has been used locally within the Inkomati WMA to implement and test a pragmatic cycle that incorporates pertinent feedback loops with a specific objective to facilitate delivery of the ecological flow requirements (Mcloughlin et al., 2011) (Figure 6).

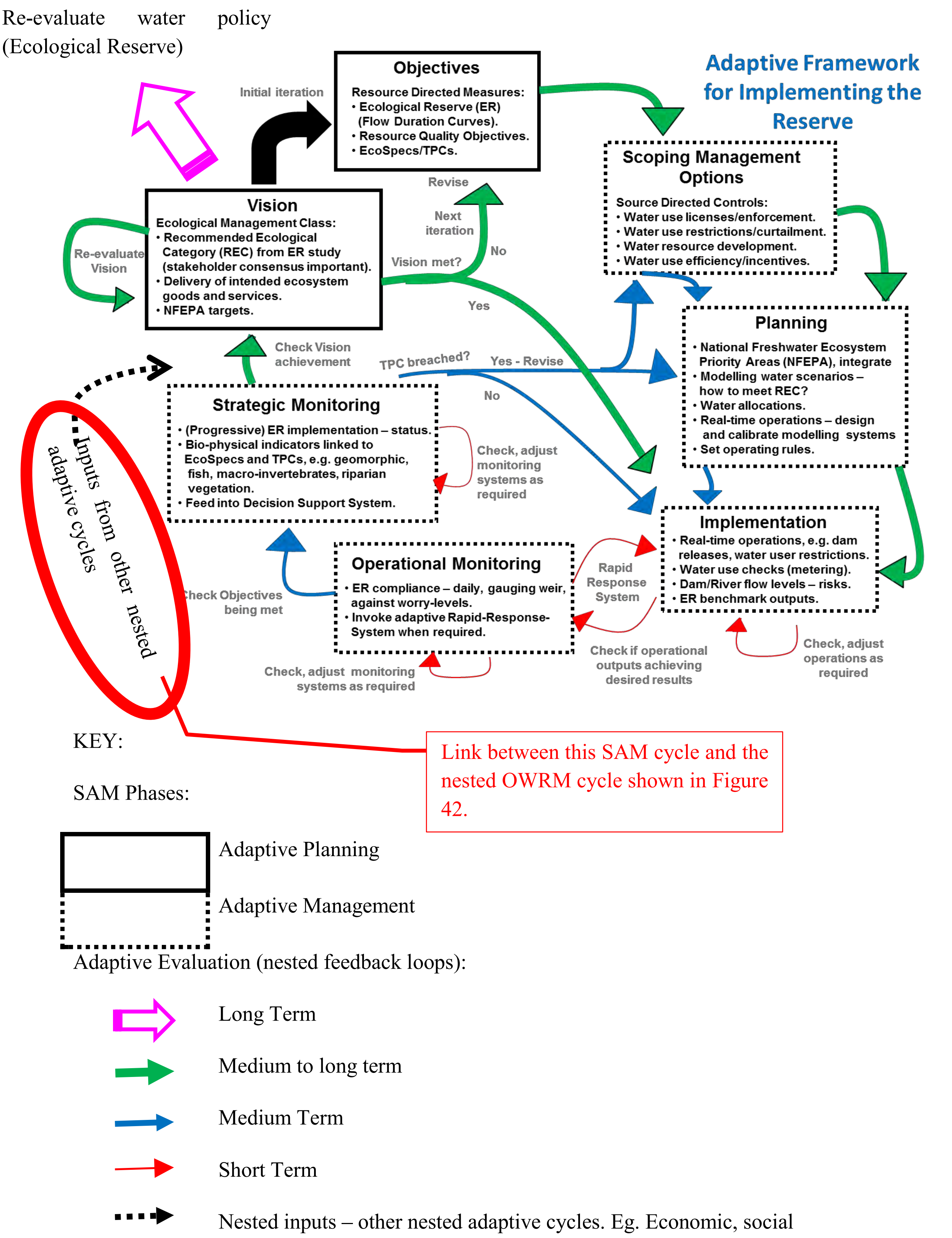


Figure 6: Pragmatic strategic adaptive management cycle associated with ecological flow requirement implementation showing feedback loops and a rapid response system (Mcloughlin et al., 2011).

This cycle represents the state-of-the-art thinking in South Africa around the implementation of SAM and encompasses most of the learning intrinsic in all of the literature reviewed. It was also developed in collaboration with the ICMA and is thus an excellent basis for the development of any adaptive operational water resources management framework (AOWRMF) within the Inkomati water management area (WMA).

However, the implementation of ecological flow requirements only forms one aspect of operational water resources management and the pragmatic SAM cycle to facilitate delivery of the ecological flow requirements (Figure 6) should thus feed into a greater nested adaptive cycle for operational water resources management (shown by the highlighted “inputs from other nested adaptive cycles” textbox in Figure 6). And consequently formed the basis for the development of the AOWRMF as presented in section 4.3 and Figure 42.

1.4. PROBLEM STATEMENT

The discussion in the literature review conducted so far highlights the problem that although IWRM is considered to be an imperative, it generally lacks readily transferable theoretical, policy and practical frameworks for the management and implementation of water resources. This can be partly attributed to the fact that water resources policies are difficult to implement and water resources decisions are difficult to make, with such decision making being challenged by the fact that water resources systems are complex, variable, incompletely known or understood and usually involve a broad range of conflicting yet legitimate needs, interests, values and outcomes (Rhoads et al., 1999). Water resources and their associated catchments are thus complex social – ecological systems where diverse STEEP characteristics and processes are interlinked and interdependent (Berkes and Folke 1998; Berkes et al., 2003) thus causing the general dearth of readily transferable theoretical, policy and practical frameworks for the management and implementation of water resources.

Managing this complexity requires an adaptive, learning-by-doing approach (Rogers, 2003; Stankey et al., 2005) that is informed by practice (Pollard and du Toit, 2008). It is also acknowledged that IWRM will not be achieved within this complexity without shared understanding of the STEEP system among stakeholders, and consensus on coordinated and cooperative action that works towards shared objectives (Rogers and Luton, 2011). In other words, in complex systems, the users must be part of deriving management solutions, yet the implementation of participatory processes for IWRM in South Africa tends to occur on the shallower, ‘specialist-centred’ and ‘product-oriented’ regions of the participatory spectrum (Pollard and du Toit, 2008). The dual learning pathways of science and management are also deemed to be equally important for water resources management and the concepts of complexity, requisite simplicity, adaptive management and action research all acknowledge this duality in various ways. Within the scientific field, learning can be derived from both technical and social processes (Stankey et al., 2005).

Traditional systems of governance and management generally do not effectively accommodate the diversity of legitimate stakeholder needs and value-sets as well as the rapidly changing circumstances that confound water resource management and decision making (Rhoads et al., 1999). Although adaptive management is readily recommended as the best approach available to agencies for addressing this type of complex problem, its success has been limited thus far (Johnson, 1999).

Coupled to this, closing semi-arid run-of-river dominated river catchments further illustrate the difficulty in achieving IWRM within this complexity. These types of river catchments are especially sensitive and susceptible to degradation due to the intrinsic uncertainty and complexity associated with high variability in runoff and lack of storage to manage it with. The legislative requirement from the NWA to implement ecological flow requirements exacerbates this further.

Trans boundary river catchments add yet another level of complexity in that they may be subject to international treaties regarding the use and management of their water resources.

Much research has been done into the state of art of the implementation of ecological flow requirements and it has been shown that ecological flows cannot be implemented without implementing real time or near real time water resources operations through the establishment of flexible and adaptable operational Decision Support Systems (Mcloughlin et al., 2011; Sawunyama et al., 2012), especially in semi-arid run-of-river dominated closing river catchments.

These statements reinforce the need to ensure that continual adaptive planning, management and evaluation including feedback loops, along with a learning-by-doing approach cognisant of management experiences but led by science and allowing for both technical and social learning is vital, if effective operational water resources management is to be achieved in semi-arid run-of-river dominating closing river catchments.

2. RESEARCH APPROACH AND AREA

2.1. STUDY RATIONALE

The literature review and problem statement have demonstrated that SAM can be an effective method to manage complex common pool resources such as water in an inherently complex IWRM context. However, there is a scarcity of examples, both locally and internationally, where operational water resources management is conducted in an adaptive manner or attempt to merge the technical, management and more complex social-ecological or STEEP aspects of IWRM into a single integrated solution. Certainly, there are no examples of this having been effectively implemented within South Africa.

The need to develop and evaluate a strategic adaptive management process as a possible approach to effectively conduct adaptive operational water resources management (AOWRM) in complex semi-arid run-of-river dominated closing river catchments is thus evident and the issue at hand is whether or not AOWRM can be effectively implemented in a closing semi-arid run-of-river dominated river catchment through an action research methodology.

The review has also shown that the ICMA is the only water management institution in South Africa to have readily adopted the principles of SAM and that the ICMA has already identified OWRM as a priority activity and commenced with the implementation of it in the Crocodile River catchment, an excellent example of a closing semi-arid run-of-river dominated catchment with a complex STEEP environment *(*)*. The Crocodile River and ICMA are thus suitable for the development, implementation and evaluation of an adaptive operational water resources management framework (AOWRMF).

The benefits of action research, incorporating the dual learning pathways of science and management, and undertaken within a mutually acceptable ethical framework *(#)* as an effective research methodology within complex environments has also been shown *(@)*.

This study thus attempts to analyse and document the requirements for implementing the various aspects, or components, of OWRM and combine them into an adaptive operational water resources management framework as an improved process to implement effective and functional OWRM, and to evaluate its effectiveness.

(#) Refer to section 4.2.2. "Stakeholder Participation and Decision Making" for details on the mutually acceptable ethical framework established during this study.

(@) Refer to section 1.1.2. "Complexity" and section 1.3.2. "Action Research".

Scrutiny of the applicable literature (complexity, requisite simplicity, SAM, OWRM and consensus based participatory decision making *inter alia*) suggests that the learning and knowledge necessary (refer to section 1.1.5 for an explanation of knowledge for the purposes of this study) to implement OWRM could be analysed, documented and evaluated under four components, as shown in Figure 7.

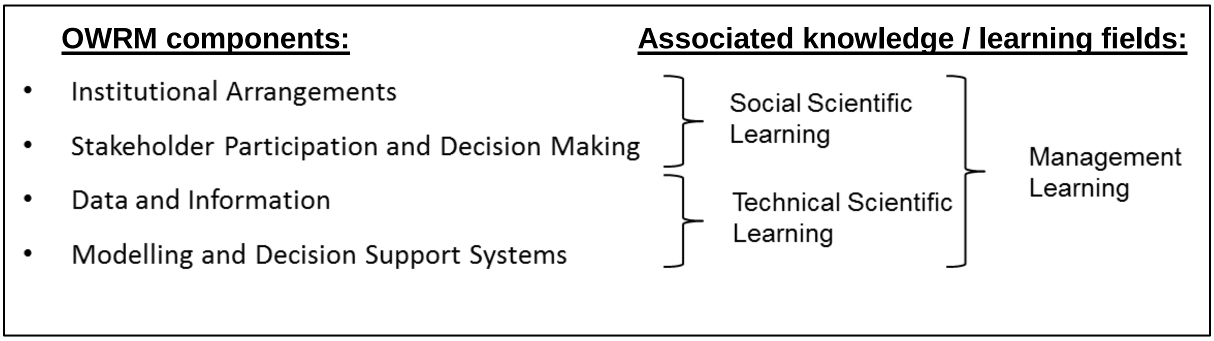


Figure 7: Suggested OWRM components for the analysis, documentation and evaluation of an AOWRMF with the associated knowledge required and learning fields.

It is submitted that a requisite understanding of the requirements for each of these OWRM components and the procedures, structures and approach required to implement it in a manner that reflects strategic adaptive management but is still functional could be pioneering work with great significance for the ICMA and other water managers around the world.

2.2. RESEARCH AIM AND QUESTIONS

The aim of this study is to develop and implement an adaptive operational water resources management framework and to evaluate whether such an adaptive management framework can enable effective operational water resources management in a closing semi-arid run-of-river dominated river catchment.

This thesis thus seeks to iteratively address the following research questions:

1(a) What are the components and associated knowledge required to conduct adaptive operational water resources management?

1(b) What are the procedures, structures and approach required to implement operational water resources management in a manner that reflects strategic adaptive management but is still functional.

2) Can an adaptive management framework enable effective operational water resources management?

A further related question that must be addressed is whether the dual learning pathways of science and management are indeed equally important for water resources management.

The investigation, analyses, documentation and evaluation will be conducted for the Crocodile River, an example of a typical closing semi-arid run-of-river dominated river catchment.

2.3 STUDY AREA

The research was carried out in the Crocodile River catchment, which forms one of the major rivers within the Inkomati Water Management Area (IWMA) and is described further in section 2.3.3. This catchment was chosen as the study area due to the fact that it is a typical closing semi-arid run-of-river dominated river catchment and because IWRM in such catchments is a particularly "wicked problem". Furthermore, the CMS of the Inkomati Catchment Management Agency (ICMA) [7] highlighted the need to prioritise the implementation of near real time operational river management in the Crocodile River and a decision support system for real time river operations had already been developed by DWA for the Crocodile River, but had not yet been implemented.

2.3.1. Inkomati Water Management Area

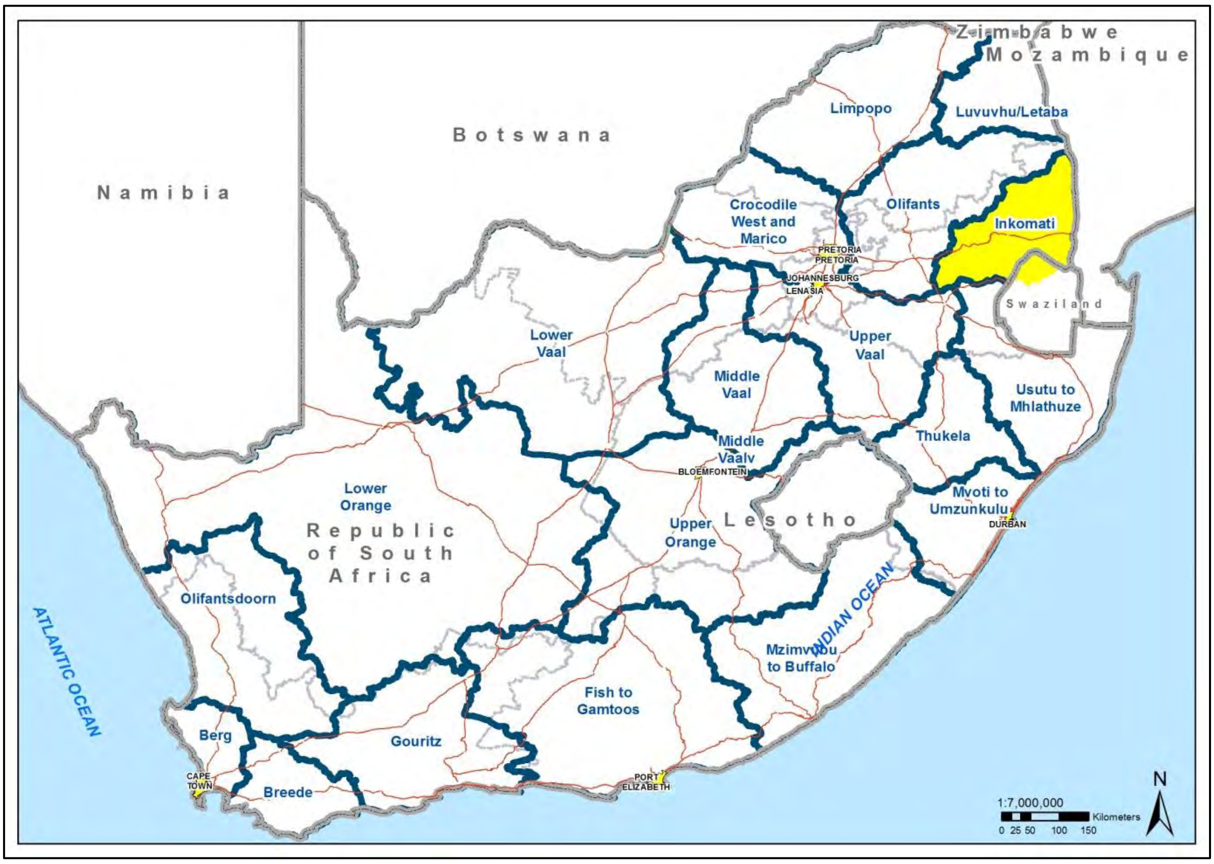


Figure 8: Location of the IWMA in South Africa (Inkomati CMS, 2010).

[7] The Inkomati Water Management Area (IWMA) is the area of responsibility of the Inkomati Catchment Management Agency (ICMA). The ICMA has recently been changed to the Inkomati-Usuthu Catchment Management Agency in 2014, but the organisation will be referred to as the ICMA for the purposes of this thesis.

The IWMA is situated in the northeast of South Africa and is wholly within the province of Mpumalanga. It covers an area of approximately 28,757 km^2. It forms part of the larger international river catchment – the InComati – with Swaziland and Mozambique and consists of four main sub catchments, the Crocodile, Komati, Sabie and the largely undeveloped Nwanedsi.

The mean annual precipitation varies from as high as 1445mm/annum in the escarpment and mountainous areas of the catchment to as low as 470mm/annum in the lowveld region of the catchment.

Figure 9: The main rivers and catchments of the IWMA within South Africa and Swaziland (Inkomati CMS, 2010).

All of the major STEEP factors within the Inkomati WMA have been described by the ICMA CMS (2010). They indicate the high level of complexity and interconnectedness prevalent in the IWMA, thus making it a river catchment in need of effective water resources management. Refer to APPENDIX C.

2.3.2. The Inkomati Catchment Management Agency

The Inkomati Catchment Management Agency (ICMA) was established by the Department of Water Affairs (DWA) in order to delegate water resource management to the regional or catchment level and to involve local communities within the framework of the National Water Resource Strategy (2004). The initial functions include the legislative mandate to investigate and advise interested persons on the protection, use, development, conservation, management and control of the water resources in its water management area; to develop a Catchment Management Strategy (CMS); to promote coordination and to promote community participation in terms of section 80 of the National Water Act, Act 36 of 1998, of South Africa (NWA).

The ICMA must thus strive to implement coordinated and cooperative participatory management that ensures water resource use is sustainable, equitable, and efficient, as required by the NWA.

It is thus a suitable institution with which to explore methodologies for implementing IWRM and for the implementation of a functional and effective adaptive operational water resources management framework (AOWRMF).

2.3.2.1. ICMA CMS, Strategic Action Programmes and Objectives

A key initial function of the ICMA was the development of its CMS. The CMS adopted the framework for IWRM shown in Figure 1 (from DWAF 2007; Pollard and du Toit, 2008) in its development. The ICMA used the Adaptive Planning Process (APP) of SAM *(*)* in the development of the CMS and its strategic action programmes, under the guidance of Professor Kevin Rogers (Rogers and Luton, 2011). The ICMA asked Professor Kevin Rogers from the University of the Witwatersrand to assist in institutionalising SAM as the basis for IWRM decision making in the ICMA and, with WRC funding, the 2009/10 Strategic Plan and CMS of the ICMA included the principles of SAM at their core (ICMA, 2009).

(*) Refer to section 1.3.3. "Strategic Adaptive Management" for further detail on the APP of SAM.

The CMS of the ICMA also includes a chapter on institutional learning. Thus, the ICMA has expressly acknowledged that it aspires to become a learning organisation that embraces SAM and that it must be able to modify its behaviour to reflect new knowledge. Furthermore, the operation of its river systems through SAM has been identified as a priority by the ICMA.

The development of the CMS and the adoption of this framework as well as the principles of SAM imparted onto the ICMA by Professor Kevin Rogers has allowed the ICMA to explore the opportunities to plan for complex and changing environments through a strategic, adaptive process that embraces learning and is informed by practice.

The CMS has set out the strategic action programmes - obtained from the stakeholder needs - that must be undertaken in order to implement fully integrated and decentralised water resource management in the IWMA. On top of this, the ICMA developed its own internal objectives through its Annual Performance Plan (ICMA APP, 2012). These complement each other (Figure 10).

The strategic action programme in the CMS relevant to this study is "Water availability and flow management", which includes the following three sub-strategic actions:

1) Facilitate the progressive, stakeholder centred implementation of the ecological flow requirements;
2) Consolidated systems for integrated planning and operations of river systems;
3) Research systems for integrated river operations.

"Consolidated systems for integrated planning and operations of river systems" is one of the priority sub-strategic actions identified by the ICMA for implementation through an adaptive planning process (Rogers and Luton, 2011). As a result, the implementation of the Crocodile River DSS developed by DWA (Hallowes, Mallory, and Greaves, 2007) has been prioritised by the ICMA.

Operational Water Resources Management Context in the Inkomati:

The CMS of the ICMA (ICMA, 2010) documented the STEEP context of the Inkomati. The aspects relevant to operational water resources management are shown in APPENDIX C. This STEEP context highlights the need for river operations, operating rules, adaptive management, cooperative governance and the implementation of the ecological flow requirements as the key aspects related to operational water resources management in the Inkomati. These reflect similar thinking to that stemming from the literature review.

However, although the ICMA has conducted the adaptive planning phase of SAM, it has yet to implement the adaptive management and evaluation phases enshrined in SAM and required for operational water resources management in the Inkomati.

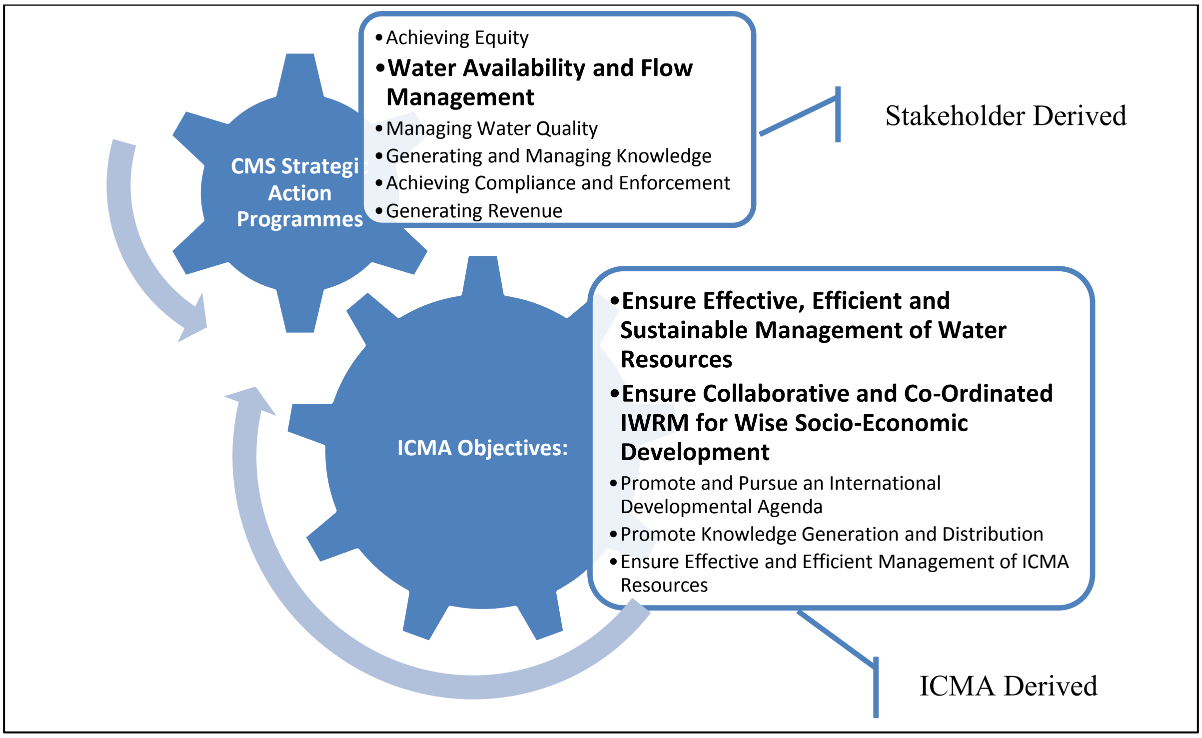


Figure 10: The strategic action programmes and objectives of the ICMA (ICMA APP, 2012).

2.3.3. The Crocodile River Catchment

The Crocodile River catchment is one of the main river catchments within the IWMA (Figure 9 and Figure 11). It originates near the town of Dullstroom, from where it flows into the Kwena Dam and eastwards through the town of Nelspruit before entering Mozambique at Komatipoort. Its lower reaches from the town of Matsulu eastwards forms the southern boundary of the Kruger National Park.

The Crocodile River catchment has relatively high rainfall on average, with rainfall in excess of 1 100 mm/annum in the mountainous area west of Nelspruit. The catchments in the lower reaches of the Crocodile River experience lower than average rainfall (~ 600 mm/annum) but benefit from the runoff from the entire catchment.

The Crocodile River catchment is considered to be a closing, or stressed, catchment (DWA, 2009; ICMA, 2010b). The closing status is a result of a number of factors including:

1) High water demand versus the available supply (Figure 12 and Table 2).
2) Significant variability and seasonality in available water in both time (Figure 13) and space.
3) Low storage capacity in relation to the water demand in the catchment. The only dam on the main stem, Kwena Dam, influences about 10% of the mean annual runoff only (i.e. It is a run-of-river dominated catchment).
4) Rainfall areas and main irrigation demand areas are spatially disparate.
5) Long river (length of approximately 250km), which make it difficult to manage during low flow periods, when losses can be significant and unpredictable.
6) International obligations for water sharing with Mozambique and Swaziland.
7) Ecologically important to the Kruger National Park and yet no ecological flow requirements have been implemented.

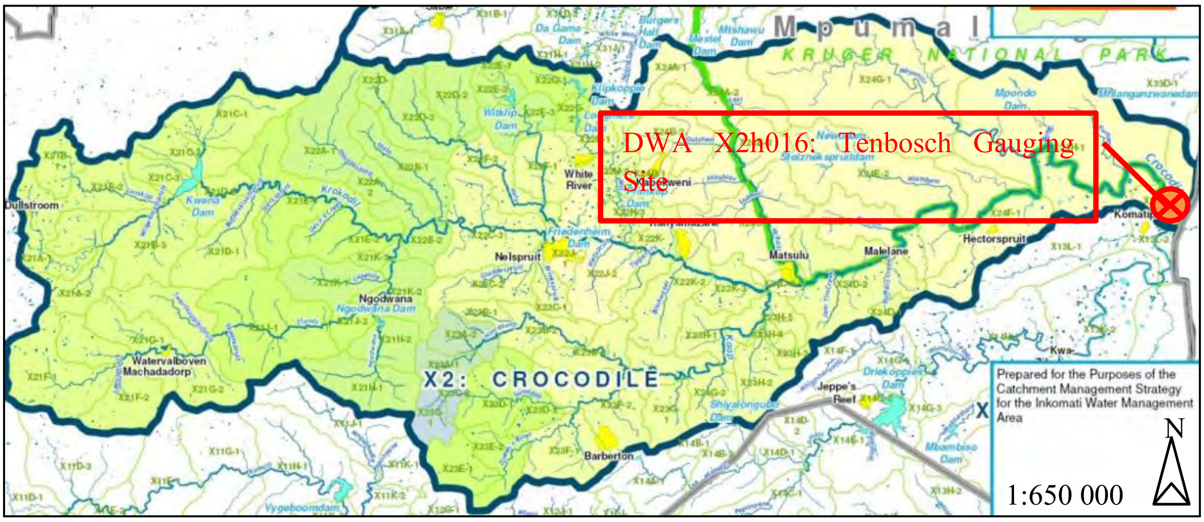


Figure 11: The Crocodile River catchment (ICMA CMS, 2010).

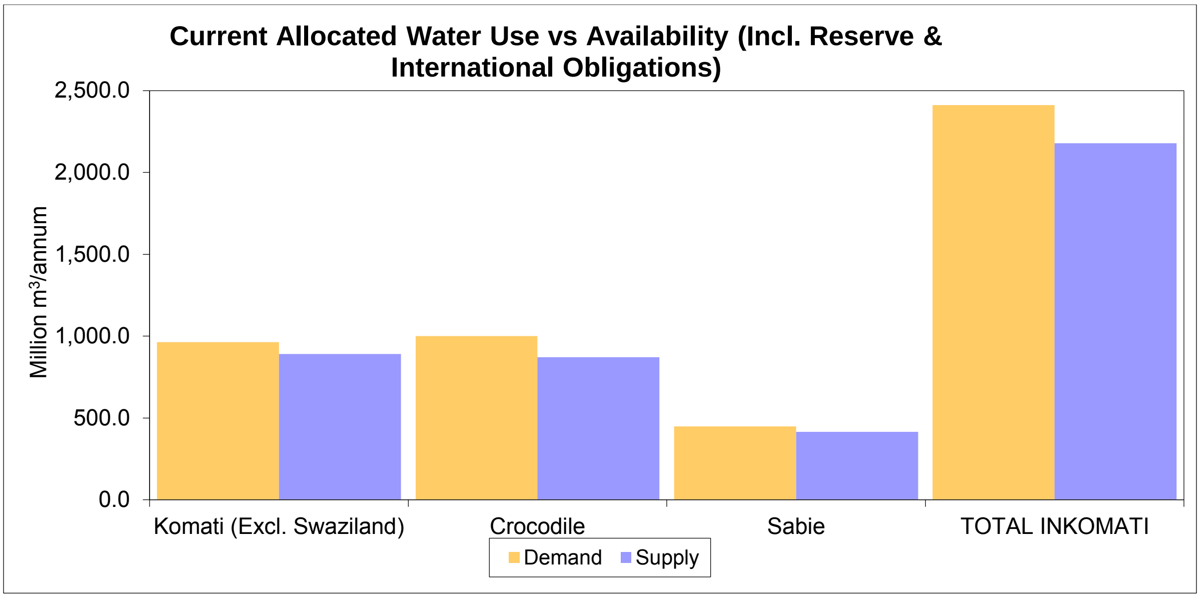


Figure 12: Current (2010) water availability and demand within the IWMA including ecological flow requirements and international obligations (ICMA CMS, 2010).

Table 2: Crocodile River water balance (ICMA CMS, 2010).

Water Use Sector	**Demand**	**Supply**	**Assurance of Supply**
	mill. m^3/annum	**mill. m^3/annum**	**%**
Crocodile			
Irrigation	482.2	355.7	74%
Domestic	46.3	43.8	95%
Transfers	0.0	0.0	0%
Industrial	26.6	26.6	100%
Strategic	0.0	0.0	0%
Afforestation	157.6	157.6	100%
Alien Vegetation	32.1	32.1	100%
Cross Border	50.5	50.5	100%
Ecological Reserve	204.6	204.6	100%
Total Crocodile	**999.9**	**870.9**	**87%**

The comprehensive assessment of water management in agriculture (Molden et al., 2007) defined the term 'physical water scarcity' as insufficient water to meet demands, indicated by situations when the use to availability ratio exceeds 70%, a proxy for closed river catchments. Table 2 indicates that the Crocodile River catchment is close to meeting this definition of physical water scarcity for the irrigation sector.

The Crocodile River is also trans boundary as it flows into Mozambique at the downstream end of the IWMA and thus forms part of an international treaty on the allocation and management of water within it.

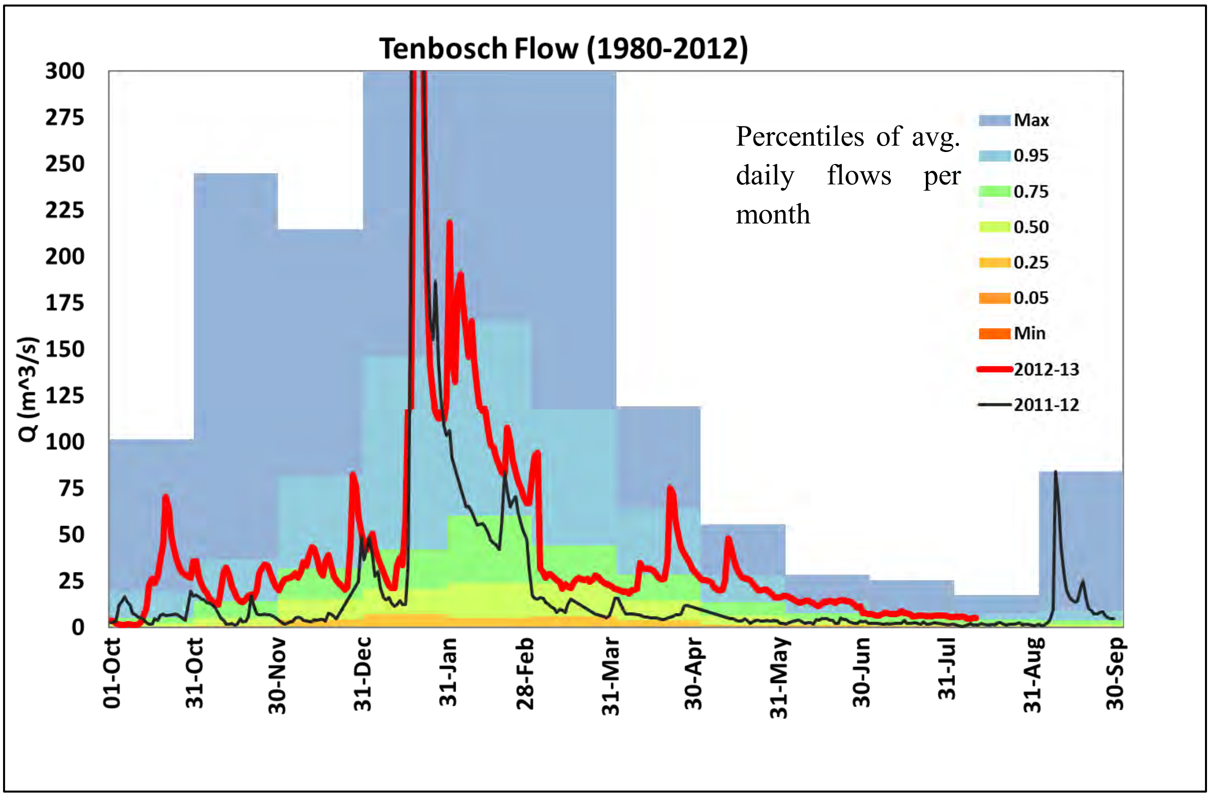


Figure 13: Indication of daily average flow variability at the Tenbosch gauging station on the Crocodile River from 1980 to 2012 (ICMA, 2012).

The ICMA CMS (2010b) indicated that the implementation of the ecological flow requirements - or ecological reserve - will result in decreased water availability as well as decreased assurances of supply. These issues require careful consideration and serve to emphasise that the process of implementing the ecological flow requirements is a key priority in the Inkomati that has a number of sensitivities attached to it and that must consequently be stakeholder centred.

The ICMA CMS (2010b) further stated that the Crocodile River catchment is dominated by run-of-river abstractions which are supplemented by releases from the Kwena Dam. I.e. Kwena Dam does not supply most of the demands. Runoff from rainfall does. The river operating rules (Hallowes et al., 2007; ICMA CMS, 2010b; DWA, 2010a) have a high impact on the availability of water in a system such as the Crocodile River catchment and the implementation of operating rules is thus critical.

A current challenge for water management internationally is to do more with less water in river catchments that are already stressed (Molle et al., 2009). This is certainly the case and challenge existing within the Crocodile River catchment. It is also a complex STEEP system (ICMA, 2010b).

It is thus an excellent example of a closing semi-arid run-of-river dominated catchment and of a complex STEEP system.

A real time river operations DSS (Hallowes, Mallory and Greaves, 2007) already developed for the Crocodile River by DWA must still be fully implemented. This has also already been identified as a key priority for the ICMA. This DSS developed by DWA is a suitable springboard for the implementation and assessment of a flexible and adaptable operational DSS in the Crocodile River catchment (as discussed in section 1.2.2), which is an aspect of one of the components of operational water resources management identified in this study (see Figure 7).

3. RESEARCH METHODOLOGY

3.1. METHODOLOGY TO DEVELOP AND IMPLEMENT AN ADAPTIVE OPERATIONAL WATER RESOURCES MANAGEMENT FRAMEWORK

Action Research:

The general methodology used to iteratively address the research questions was based on a simplified, participative action research cycle adapted from Burns (1994) as shown in Figure 14, informed by the dual learning pathways of science and management through consensus with, and involvement of stakeholders to develop, implement and evaluate an adaptive operational water resources management framework (AOWRMF) for the Crocodile River. The detailed methodology and process followed is shown in Table 3.

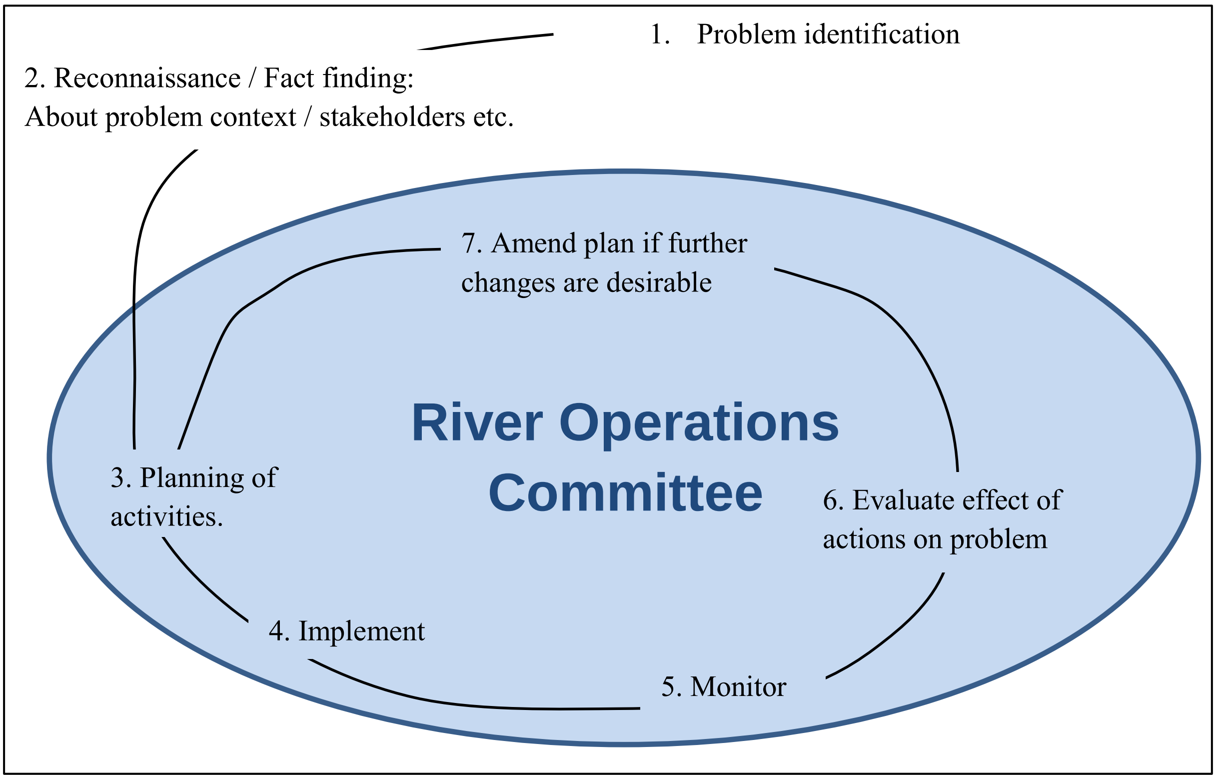


Figure 14: The action research cycle used in this study (Adapted from Burns, 1994).

The distinguishing feature of the particular action research cycle (AR) used in this study was the establishment of a river operations committee to bring together the researcher and the stakeholders to work though the AR cycle of research together. Much of the learning and knowledge gained was thus derived from and coordinated by this river operations committee. This made it a participatory action research process (Zeni, 1998).

Subjectivity:

The issue of subjectivity is acknowledged. Action research, or indeed any form of research, has several associated threats that are repeatedly reported (Kock, 2002) and one of these threats is that of subjectivity. Furthermore, for this particular study, the researcher was also the main client, in his capacity as the manager for river operations at the ICMA, which could potentially exacerbate the influence of subjectivity as the personal involvement of the researcher may push him or her into interpreting the research data in particular and potentially subjective ways (Kock, 2002). However, while deep personal involvement from the part of the researcher has the potential to bias research results, it is inherent in AR because it is impossible for a researcher to both be in a detached position and at the same time exert positive intervention on the environment and subjects being studied (Kock, 2002).

It is thus important that the influence of subjectivity on the research is minimised. A discussion on how it was minimised is presented in section 5.

Requisite Simplicity:

Requisite simplicity formed an important guiding principle for the methodology followed in this study, as it embraces the need for sufficient scientific rigour and conceptual clarity while still understanding that the lived complexity of real world water resources management requires some form of simplification to enable managers to manage. The action research process followed thus utilised the river operations committee as the platform at which discussions on the simplification of the knowledge gained to allow stakeholders to more usefully benefit from it were held. This included the identification of the emergent properties of the system and simple ways to track them and incorporated them into the TOR of the committee.

Broad Focus of Research:

As this study attempted to combine all of the relevant technical, management and social-ecological aspects of IWRM (and document under the four components of) into a single integrated solution for conducting OWRM, a broad scope of research into several fields was necessary to explore all relevant aspects and levels of the concept and practice of OWRM. The aim of this study was to identify and combine the requisitely simple knowledge required for OWRM and to develop an effective adaptive framework for its implementation. It was not to analyse any particular aspect in great detail.

Methodology Guided by existing SAM Frameworks:

The AOWRMF developed was based on and complements the SAM cycle associated with ecological flow requirements (incorporating feedback loops and a rapid response system) developed by Mcloughlin et al. (2011), and was guided by the generic SAM framework developed by Pollard and du Toit (2007).

The study thus investigated, analysed, documented and evaluated the components and associated knowledge (shown in) required to conduct effective operational water resources management as well as the procedures, structures and approach needed to implement the framework in a manner that reflects strategic adaptive management but is still functional (i.e. cognisant of requisite simplicity).

A critical assessment of SAM is beyond the scope of this thesis.

3.2. METHODOLOGY TO EVALUATE THE EFFECTIVENESS OF THE ADAPTIVE OPERATIONAL WATER RESOURCES MANAGEMENT FRAMEWORK DEVELOPED

The evaluation of the effectiveness of the AOWRMF within this study was conducted in two ways:

1) Evaluation of the AOWRMF effectiveness by the river operations committee stakeholders (social evaluation).
2) Evaluation of the AOWRMF effectiveness through the assessment of the ecological flow requirements (technical evaluation).

Social Evaluation:

Various social learning criteria and consensus based participatory decision making criteria were discussed in sections 1.1.4 and 1.3.1.2. Based on these discussions, a combination of the criteria of Susskind and Cruikshank (1987), the National Round Table on the Environment and the Economy (1993); Samson-Sherwill (2006), Pahl-Worstl and Hare (2004) and Mostert et al. (2007) were used to develop a questionnaire *(*)* for the stakeholders of the river operations committee to evaluate their perceptions of the institutional arrangements, stakeholder participation and participatory decision making aspects of the AOWRMF.

(*) Refer to APPENDIX G for the social evaluation questionnaire used and the responses received.

Technical Evaluation:

The effectiveness of the AOWRMF was also evaluated from a technical perspective by comparing the compliance with the ecological flow requirements before and after the commencement of the proposed AOWRMF. This is apt as the ecological flow requirements were not being implemented at all before the commencement of the AOWRMF and yet were the main source of concern and conflict amongst the stakeholders related to operational water resources management.

The evaluation was conducted as per the method developed by Pollard et al. (2011) and refined by Riddell et al. (2013). This method determined the % time of failure, magnitudes of failure, and the consistency of failure measured through the number of contiguous events by comparing the ecological flow requirements to the actual observed flow at a key downstream location and for different periods (the location at which this was assessed was the EWR 6 site as used by Pollard et al. (2011), otherwise known as the Tenbosch Gauging Station, shown in Figure 11. A new period was added to this existing comparison to represent the period since implementation of the AOWRMF. The ecological flow requirements used were those as used by Pollard et al. (2011), which was the C-class reserve, or ecological flow requirement, as determined by DWA.

Finally, the data, information, modelling and decision support system components of the AOWRMF were evaluated.

The detailed process followed is described in Table 3.

Table 3: Parallel action research methodology for both research questions.

AR Steps	Activities per Research Question	
	WHAT IS REQUIRED TO DEVELOP AND IMPLEMENT ADAPTIVE OPERATIONAL WATER RESOURCES MANAGEMENT	**CAN AN ADAPTIVE FRAMEWORK ENABLE EFFECTIVE OPERATIONAL WATER RESOURCES MANAGEMENT**
Problem identification	Conduct literature review. (Section 1). Define the operational water resources management problem in the Crocodile River catchment context from the learning gained during the literature review. (Section 2.3.3). Document all existing STEEP issues related to operational water resources management in the Crocodile River catchment. (Appendix C).	
Reconn aissance	Identify initial list of all institutions and OWRM stakeholders in the Crocodile River catchment. (Section 4.2.1).	
Planning of Activities	Conduct an initial general meeting to inform and discuss with stakeholders the context, need, purpose, data, models, institutions, stakeholders, roles, responsibilities, key decisions and process to be followed. (APPENDIX F). Establish and host a monthly river operations committee or Crocodile River Operations Committee (CROCOC) comprising of the OWRM stakeholders identified and agreed on at the committee. Develop a TOR for the CROCOC with the CROCOC stakeholders. (APPENDIX E).	
Implementation	In collaboration with the established CROCOC, investigate, analyse, present, discuss, agree and document the requirements for effective operational water management as per the four OWRM components below (Sections 4.1 and 4.2): *Stakeholder interactions and consensus based decision making (Section 4.2.1):* • Use the CROCOC to agree, implement, document and adjust a consensus based decision making system with the stakeholders required to support effective adaptive operational river management of the Crocodile River. Incorporate into the TOR of the CROCOC. • Implement a communications and management decisions log to keep track of all actions and decisions.	

Implementation	*Data and information (Section 4.2.2):* • Identify and document an initial list of all data and information sources relevant to OWRM. • During the initial establishment of the CROCOC and the development of its TOR, identify and document a revised list of all data, information and monitoring needs and timeframes, based on the initial list identified. • Identify and implement a method to effectively collect, archive, use, process and disseminate data and information. • Identify priority DWA river flow gauging stations in the Crocodile River for OWRM and purchase, install and commission real time river flow data loggers on them. • Install an appropriate Water Resource Information Management Database for the ICMA that can manage all data needs for operational water resources management. • 15 real time rainfall gauges were provided by the WATPLAN EU-FP7 Project. Conduct a qualitative desktop assessment based on the locality of existing real time rainfall gauges, topography, MAR and site accessibility to determine the best locations for the 15 rainfall gauges. • Identify suitable hosts in the vicinity of the identified localities, enter into agreements and install gauges. • Develop an operations and maintenance plan for the installed rainfall gauges and ICMA river flow data loggers. • Hold a follow up workshop to identify an updated list of the data and information needs of stakeholders through the CROCOC, document and incorporate into original list. Recommend priority data needs/gaps to be addressed. *Modelling and decision support systems (Section 4.2.3):* • Document the modelling framework and DSS already set up for the Crocodile River by the CROC DSS project of DWA. Present to CROCOC and get agreement to use it going forward. • Implement updates, improvements and amendments to the DSS and associated software and hardware required that may arise from CROCOC deliberations. • Investigate, implement and document a method of implementing the ecological flow requirement in collaboration with the CROCOC but based on the revised ecological flow requirements and the real time naturalisation process proposed by Mallory (2010). *Institutional arrangements and governance (Section 4.2.4):* • Undertake an organisational and functional analysis of the ICMA legislative mandate in terms of river operations and incorporate into recommended institutional roles, responsibilities and communication and decision lines for adaptive operational water resources management with the CROCOC stakeholders.

	Develop, implement and document the strategic adaptive management processes (linked to the greater existing ICMA IWRM SAM framework) and associated AOWRMF with the river operations committee to conduct operational water resources management in an adaptive manner, incorporating all of the components of operational water resources management as well as feedback loops and a rapid response system (based on the framework of Mcloughlin et al., 2011). (Section 4.3). Document the timeline of activities and actions used in the development and implementation of the AOWRMF to evaluate the timeframes required to implement an affective AOWRMF. (Section 4.1).
Evaluation and Amend	Evaluate the effectiveness efficacy of the established adaptive operational water resources management framework to facilitate effective adaptive operational water management as follows (Section 5): S*takeholder interactions and consensus based decision making (Section 5.1.2):* Interpret and evaluate the social learning achievements with the CROCOC stakeholders by means of a social questionnaire. Document. *Data and information (Section 5.3):* • Evaluate the data collection, archiving and dissemination implemented and identify any gaps. Make recommendations. *Modelling and decision support systems (Sections 5.2 and 5.3):* • Evaluate and assess the ecological reserve compliance as a measure of the effectiveness of the AOWRMF. The % time, magnitudes, contiguity and seasonality of non-compliance of the ecological flow requirement compared to the actual observed flows will be evaluated at the DWA X2H016: Tenbosch Gauging site before and after the commencement of the AOWRMF implementation in line with the method of Pollard et al. (2011) as refined by Riddell et al. (2013). (Section 5.2.1). *Institutional arrangements and governance (Section 5.1.1):* Evaluate the institutional arrangement, roles, responsibilities and communication and decision lines developed and implemented with the CROCOC. Document.

4. DEVELOPMENT AND IMPLEMENTATION OF THE ADAPTIVE OPERATIONAL WATER RESOUCES MANAGEMENT FRAMEWORK

The AOWRMF is the outcome of more than four years (October 2009 to January 2014) of action research, deliberation, interpretation, development, implementation and evaluation in collaboration with the CROCOC stakeholders. The timeline of the major activities and milestones during this period is presented in section 4.1.

The results and discussions of the components and associated knowledge (and Figure 15) required to conduct operational water resources management are presented in section 4.2.

The results and discussions on the procedures, structures and approach required to implement an adaptive operational water resources management framework in a manner that reflects strategic adaptive management but is still functional are presented in section 4.3.

4.1. TIMELINE OF ACTIVITIES

The timeline of all the main activities and milestones for this study is shown in Table 4 below. This demonstrates the frequent, focused, ongoing and lengthy deliberations and process required to develop and implement the AOWRMF. For example, it took nine CROCOC meetings over a period of nine consecutive months just to foster sufficient consensus to finalise the TOR for the CROCOC and thereby document the defined objectives and mutually acceptable ethical framework under which the action research could be undertaken.

More detail on these activities and milestones is provided in sections 4.2 and 4.3.

Table 4: Timeline of the main activities and milestones in the development of the AOWRMF for the Crocodile River.

Date	Activity
October 2009	DWA project for the real time operating DSS for the Crocodile River completed, but not implemented.
October 2009	Approval from DWA for the ICMA to implement the real time DSS project obtained.
October 2009	Mike Floodwatch based OWRM DSS installed at ICMA.
October 2009	First CROCOC meeting held at ICMA.
November 2009	CROCOC pamphlet distributed.
January 2010	Implementation of the rapid response system for ecological flow requirements

	commenced.
January 2010	Site visit held.
June 2010	Decision And communications framework finalised.
June 2010	CROCOC TOR finalised.
June 2010	OWRM and CROCOC article published in Inkomati flows magazine.
June 2010	OWRM rapid response system initiated.
October 2010	Initial technical support and maintenance contracts for water resources planning and operations models and DSS completed.
October 2010	Initial weekly ecological flow modelling based on the DWA C-class ecological flow requirements to replace the older in stream flow requirements commenced.
August 2011	MOA between ICMA and MTPA to conduct annual river Health monitoring signed.
August 2011	Contract between ICMA and SANPARKS to investigate SAM for freshwater protection signed.
October 2011	Revised weekly ecological flow modelling based on "present day flows" ecological flow requirements methodology commenced.
March 2012	15 new real time rainfall stations installed.
March 2012	28 river flow gauging stations upgraded to real time capabilities.
April 2012	Contract between ICMA and SANPARKS to investigate SAM for freshwater protection amended to an ongoing MOA and signed.
October 2012	Revised technical support and maintenance contracts for water resources planning and operations models and DSS completed.
October 2012	New OWRM server installed at ICMA.
March 2013	MIKE Customised based OWRM DSS and WRIMD installed at ICMA.
June 2013	Stakeholder workshop to review data and information needs held.
January 2014	Maintenance contract for real time river and rainfall equipment completed.
January 2014	Social learning questionnaire and evaluation completed.
January 2014	AOWRMF documented.

4.2. THE COMPONENTS OF OPERATIONAL WATER RESOURCES MANAGEMENT

As previously stated in the study rationale under section 2.1, the learning and knowledge required to conduct operational water resources management could be analysed, documented and evaluated under four components as shown in and as detailed further in Figure 15 below.

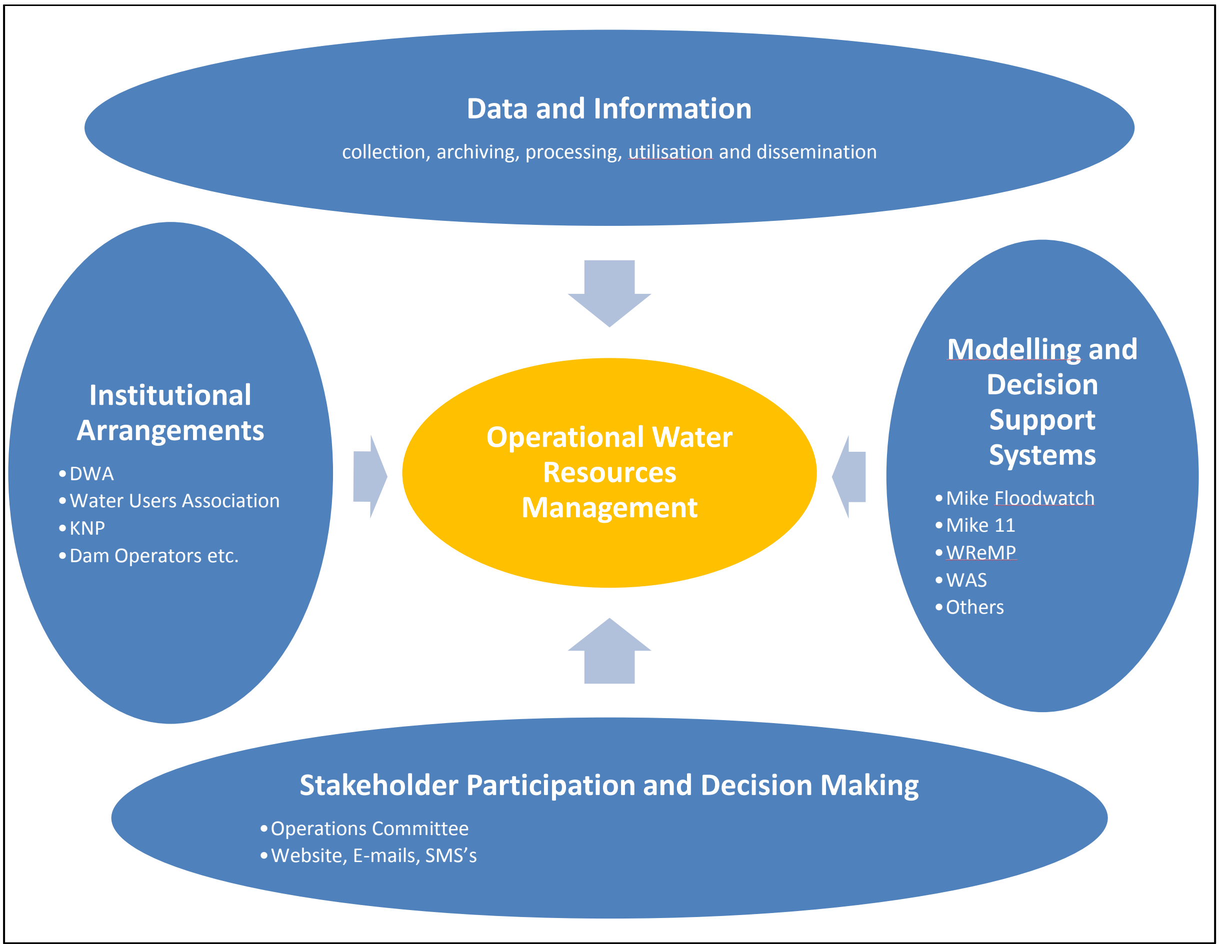


Figure 15: The four components of operational water resources management for the Crocodile River.

This section thus documents the requisitely simple knowledge required for each of the four components of operational water resources management.

4.2.1 Institutional Arrangements

As indicated in the literature review, it is imperative that the institutional arrangements are properly identified and understood by all stakeholders involved in operational water resources management so that confusion about the various roles and responsibilities, institutions and forums is minimised and effective implementation is not hindered.

The overarching institutional arrangements within South Africa and the Inkomati are already established through the National Water Act of South Africa, Act 36 of 1998 (NWA).

The NWA embraces the need for decentralisation through its requirement to establish catchment management agency's (CMA) responsible for IWRM. While CMA's are responsible for IWRM through the delegation and assignment of powers and functions in terms of section 73(4) of the NWA, the National Department of Water Affairs (DWA) ultimately remains the responsible authority. As such, there are various divisions within DWA that will continue to play an active role in the institutional arrangements and governance of catchment scale water resource management. These divisions include the office of the minister (responsible for overarching policy), the national planning office (responsible for water resources planning), the local regional office and the infrastructure branch (responsible for the operation and maintenance of dams).

The Inkomati CMA was the first CMA to be established in South Africa and has received several delegated powers and functions. These are shown in APPENDIX D. As described in section 2.3.2, a key initial function of the ICMA was the development of its CMS, which established the ICMA as an institution that utilises strategic adaptive management *(*)*.

(*) Refer to section 2.3.2.1. "ICMA CMS, Strategic Action Programmes and Objectives" for details on the SAM process followed by the ICMA.

Certain powers and functions had yet to be delegated or assigned to the ICMA at the commencement of the study creating some confusion as to the roles and responsibilities of the two organisations. However, it was agreed between DWA and the ICMA that:

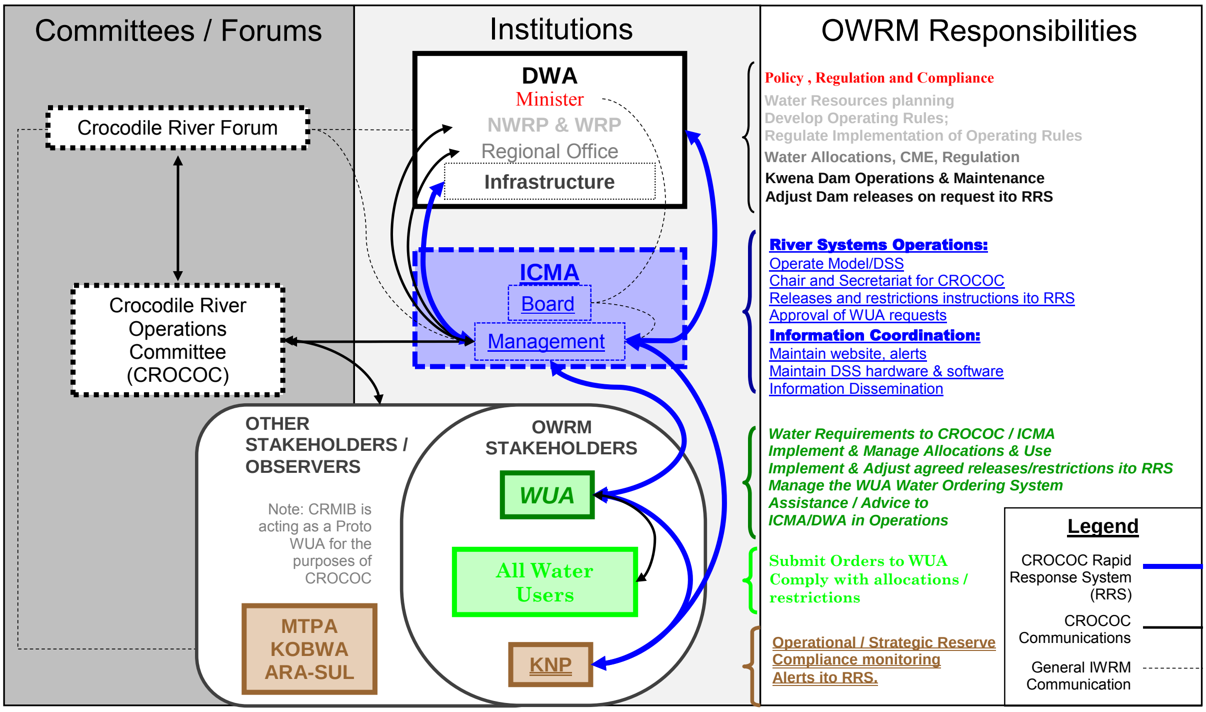
1) The ICMA assist DWA with the implementation and operation of project deliverables and outcomes.
2) The ICMA coordinate all stakeholder engagement in the catchment.

(ICMA CMS, 2010).

Consequently, agreement was reached between DWA and the ICMA for the ICMA to implement the DWA real time operations DSS project for the Crocodile River, which proved to be the kick start required for the commencement of the development and implementation of the AOWRMF *(#)*.

(#) Refer to section 4.2.4. "Modelling and Decision Support System" for more details on the DSS related development.

The realities of the overarching institutional arrangement, current delegated powers and functions, agreements with DWA, completed CMS and SAM processes followed by the ICMA have all been incorporated into the institutional arrangements, roles and responsibilities for the operational water resources management of the Crocodile River, shown in Figure 16.



DWA = Department of Water Affairs; ICMA = Inkomati Catchment Management Agency; NWRP = National Water Resource Planning; WRPS = Water Resource Planning Systems; DSS = Decision Support System; RRS = Rapid Response System; 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

Figure 16: The institutional arrangements, showing the institutions, roleplayers, responsibilities, forums, communications and feedback loops for operational water resources management in the Crocodile River.

Figure 16 also indicates the communication lines required to support the functional adaptive operational water resources management framework for the Crocodile River (Section 4.3 and Figure 42). In particular, the rapid response system (discussed in section 4.3.1) related communication lines are shown as thick blue lines and the CROCOC stakeholder (discussed in section 4.2.2) communication lines are shown as solid thin black lines.

The NWA also allows for the establishment of Water User Associations (WUA). WUA's are a key mechanism in the NWA for facilitating the decentralisation of relevant powers and functions for IWRM and thereby enable effective stakeholder engagement in IWRM at the local level. The NWA states that "although water user associations are water management institutions their primary purpose, unlike catchment management agencies, is not water management. They operate at a restricted localised level, and are in effect cooperative associations of individual water users who wish to undertake water related activities for their mutual benefit". "Water user associations must operate within the framework of national policy and standards, particularly the national water resource strategy" and "may exercise management powers and duties only if and to the extent these have been assigned or delegated to it".

Within the Crocodile River catchment, no WUA's have been established. However, Irrigation Boards do exist in terms of the previous Water Act of South Africa, Act 54 of 1956. The Irrigation Boards continue to perform their functions in terms of that act until transformed into WUA's. Their functions are much the same as WUA's, except that they only support the irrigation sector. In the Crocodile River catchment, the Crocodile River Major Irrigation Board (CRMIB) manages the allocation and use of all irrigators and is thus an important stakeholder. In Figure 16, the WUA is shown as the relevant local institutional organisation that must be involved in the institutional arrangements, but the CRMIB will play this role until such time as it is transformed into a WUA.

The NWA also required CMA's to establish catchment management committees to facilitate stakeholder engagement around IWRM at catchment level. The ICMA had already established a Crocodile River Forum (CRF) to engage with stakeholders on IWRM at the commencement of this study. This forum was approached about the institutional arrangements specific to OWRM in the Crocodile River and agreed that a separate river operations committee of relevant stakeholders should be established for OWRM that would then feed relevant information back to the greater CRF where relevant. This arrangement is in line with the social learning criteria that participation should be limited to stakeholders directly involved in the jointly identified problem *(*)* and who have a sense of interdependence *(#)* in order that sufficient, focused discussions can take place, yet still allow for openness and feedback to the general IWRM stakeholders through the link to the Crocodile River forum.

(*) Frequent, focused discussions are one of the key fostering factors of social learning (Mostert et al. 2007) used in the social evaluation of the AOWRMF in this study.

(#) Interdependence between stakeholders is one of the key capacities for social learning (Pahl-Wostl and Hare, 2004) used in the social evaluation of the AOWRMF in this study.

A river operations committee was thus established and met for the first time in October 2009. It is known as the Crocodile River Operations Committee (CROCOC). The TOR of the committee indicates that although the CROCOC has no decision making powers under current legislation, its role as a coordinating and advisory body is exceptionally important in the broader decision making process and it serves the relevant decision making authorities defined in the NWA (DWA, ICMA, WUA) as the platform for informed and consensus driven decision making *(@)*. Please refer to section 4.2.2 for more detail on the CROCOC and its establishment.

(@) The 10 criteria for effective consensus based decision making from the Round Tables of Canada have been used to evaluate the effectiveness of consensus in the CROCOC. Refer to section 4.2.2. "Stakeholder Participation and Decision Making".

Figure 16 represents the culmination of the deliberation process with the CROCOC around the institutional arrangements and indicates the various institutions, roleplayers, responsibilities, forums and committees related to operational water resources management. It recognises that operational water resources management is only one aspect of IWRM and that any institutional arrangements around it must fit into the broader IWRM realities, indicated through the link to the CRF.

4.2.2. Stakeholder Participation and Decision Making

For the purposes of this thesis, participation is focused on OWRM stakeholders as described in section 1.1.3.

The literature review reinforced the importance of extensive stakeholder involvement and participatory decision making in OWRM as it can lead to a sense of ownership of decisions and policies leading to reduced resistance and even cooperation in implementation.

Consequently, the coordination of stakeholder participation, decision making, action research and strategic adaptive management necessitated the establishment of the CROCOC (as indicated in Table 3). The committee was established by the researcher, in his capacity as the responsible manager at the ICMA, and met for the first time in October 2009, chaired by the researcher. The minutes of this first meeting are shown in APPENDIX F and detailed minutes have been kept for each meeting. The primary aim of the initial meeting was to obtain consensus on the stakeholders that should be members of the committee, to introduce the real time Decision Support System (DSS) for the Crocodile River catchment (Hallowes et al., 2007; DWA, 2010a) *(*)* and to agree on the terms of reference for the committee. The agreed membership of the committee is indicated in the TOR developed, shown in APPENDIX E.

(*) Refer to section 4.2.4. "Modelling and Decision Support System" for details of this implementation.

Presentations and discussions were made at this inaugural meeting by various stakeholders and experts on the following topics:

1) The real time DSS for the Crocodile River (DSS Developer).
2) The context and need for AOWRM (researcher).
3) Draft TOR and membership (researcher).
4) Communications and decision lines (researcher).
5) Marketing (researcher).
6) Water resources planning aspects of the DSS and OWRM (DSS Developer).
7) Water resources operations aspects of the DSS and OWRM (DSS Developer).
8) Proposed irrigation ordering method (CRMIB).
9) Draft web portal (DSS Developer).
10) Launch and field trip (researcher).

The committee met on a monthly basis thereafter and the subsequent meetings concentrated on obtaining initial agreement on the implementation of adaptive operational water resources management for the Crocodile River. The CROCOC coordinated the initial problem identification, reconnaissance and planning of activities of the action research process during the establishment of the TOR which resulted in the initial coordinated and cooperative actions for AOWRM. The implementation, monitoring, evaluation and amendments to the initial cooperative actions for AOWRM followed thereafter. The minutes of the CROCOC meetings provide information on the evaluation and amendments that have been made to refine the AOWRMF as do sections 4.2 and 4.3.

The TOR for the CROCOC was only finalised in June 2010, more than 9 months after the initial CROCOC meeting, and is shown in APPENDIX E. The TOR established the defined objectives and mutually acceptable ethical framework for AOWRM and the 9 month long deliberations around the TOR allowed for the necessary consensus on the initial coordinated and cooperative actions that work towards the shared objectives.

A pamphlet was also developed by the author and endorsed by CROCOC for distribution to members of the Crocodile River Forum and the general public to create awareness of the functions and importance of the CROCOC. It is shown in APPENDIX H. An article on the CROCOC and OWRM in the Crocodile River catchment was also published in the quarterly Inkomati Flows magazine of the ICMA in June 2010, which is distributed to all stakeholders involved in IWRM in the Inkomati, to create further awareness. These activities were conducted in accordance with the identified need for awareness stemming from the social learning criteria shown in Table 10.

A further workshop was held in June 2013 to review the data and information needs of the CROCOC stakeholders as part of the evaluation and review processes inherent in action research. The outcomes of this are presented in section 4.2.3.

Refer to section 5.1.2 for the evaluation of the effectiveness of the stakeholder participation and decision making as well as the social learning outcomes of the development and implementation of the AOWRMF.

4.2.3 Data and Information

Initial OWRM Related Data and Information Needs:

The initial investigations into the data and information sources relevant to OWRM and available at the commencement of this study relied much on the outcomes of the DWA real time operations DSS for the Crocodile River system (Hallowes et al., 2007; DWA, 2010a) and the Inkomati Water Availability Assessment Study (IWAAS) (DWA, 2009) projectsAPPENDIX . These data and information sources are shown and discussed in APPENDIX I.

CROCOC derived Data and Information Needs:

The initial information and data needs shown in APPENDIX I were presented to the stakeholders at the initial CROCOC meeting and adjusted during the following nine meetings prior to the completion of the TOR. Furthermore, a workshop with the KNP was held during November 2009 to discuss their thresholds of potential concern (TPC) and associated feedbacks relating to the ecological flow and bio-physical data. All the potential and relevant information and feedbacks between the ICMA and KNP were identified and discussed at this meeting. These information needs have all been incorporated into the CROCOC TOR at the relevant timescales as shown in APPENDIX E. The TOR for the CROCOC (APPENDIX E), developed in collaboration with the CROCOC stakeholders, summarises the main information and decision needs at various temporal scales required for the operational water resources management of the Crocodile River.

A further workshop was held in June 2013 to review the data and information needs of the CROCOC stakeholders as part of the evaluation and review processes inherent in action research. The workshop involved the following steps:

1) A refresher of the existing information requirements for AOWRM captured in the CROCOC TOR.

2) A presentation of the latest status of the Water Resources Information Management Database (WRIMD) and DSS at the ICMA.
3) An opportunity for stakeholders to complete an information needs questionnaire, shown in APPENDIX J. The stakeholders were given the following guidelines for completing the questionnaire and for the facilitated discussions thereafter:
    a) Split information for planning vs. information for real time operations.
    b) Timescales for information. I.e. What information do you require at what timescales? The suggested categories are annual. quarterly, monthly, weekly, daily.
    c) Types of decisions you would like to be involved in.
    d) How you would best like to see or access this information. Options include internet website, emails, SMS, at Operations Committees, smartphone apps etc.
    e) Types of alerts or alarms you would like to see.
    f) Institutions and responsibilities for decisions and information. E.g. Responsibilities of ICMA vs. Irrigation Boards.
    g) How can the ICMA audit its performance in meeting your needs.
4) A facilitated consensus based discussion to finalise a list of current data and information needs. This facilitated discussion obtained inputs from all stakeholders by asking each participant to write down their top three needs. Each participant was then asked to indicate their top priority and this process continued until all needs were obtained. The intention of this process was to ensure that the subjective understanding of any one actor was sufficiently transcended. Stakeholders were then asked to indicate if they felt that any needs indicated were not relevant. Lastly, discussion was allowed to obtain a final list of data and information needs as shown in Table 5.

Table 5: Outcomes of the stakeholder data and information needs workshop held in June 2013.

Main Topic	**Sub-Topic**	**Time Intervals**	**Manner of publicizing**
General.	✓ Up to date contact details of all Stakeholders. ✓ Stakeholders like the idea of smartphone apps. ✓ Stakeholders like the idea of the spatial disaggregation of data through live maps.	✓ Quarterly.	✓ Website. ✓ Website.
River Flow.	✓ Dam levels and releases. ✓ Restriction levels. ✓ Flow levels and rates. ✓ History VS current and forecast. ✓ Flood prediction and warning.	✓ Monthly. ✓ Daily. ✓ Real time.	✓ Website. ✓ Ability to download data.
Rainfall.	✓ Past, current and forecast. ✓ Comparison to historic statistics. ✓ Long term weather forecasts.	✓ Real time. ✓ Daily. ✓ Monthly. ✓ Quarterly.	✓ Website. ✓ Download data. ✓ CROCOC.
Environmental Water Requirements.	✓ Better alarms required. ✓ History VS current and forecast.	✓ Daily. ✓ Weekly.	✓ SMS best for urgent issues.

		✓ Monthly.	✓ Otherwise email and website. ✓ Download data.
Economic Benefit of Supply.	✓	✓ Annual.	✓ Main ICMA website.
Impacts of restrictions.	✓	✓ Annual.	✓ Main ICMA website.
Water Use.	✓ Demand VS population. ✓ Water conservation and demand management. ✓ Patterns (history, current and forecast). ✓ Actual use VS allocation/request. ✓ Also include ET data for land uses including natural vegetation. ✓ New developments and closures of developments. ✓ Improved crop factors that respond to current climate (eg. Closer to real time than the monthly static crop factors used currently).	✓ Annual. ✓ Annual. ✓ Annual. ✓ Monthly. ✓ Monthly. ✓ Monthly. ✓ Daily.	✓ Website. ✓ Graphs. Website. ✓ Graphs. Website. ✓ Website, CROCOC.
Water Balance.	✓ Water availability. ✓ Historic and future. ✓ Long term yield curve.	✓ Annual.	✓ Graphs. ✓ CROCOC. ✓ Website.
Dams.	✓ Historic, current and forecast. ✓ Dam levels vs stochastic probabilistic trajectories. ✓ Dam levels vs restriction levels. ✓ Scenarios for different restrictions. ✓ Scenarios for different climates.	✓ Monthly.	✓ CROCOC.
Water Quality	✓ Map of incidents for discussion. ✓ Turbidity, Ec, pH in real time). ✓ Notification of spillages. ✓ NB: Temperature. ✓ Modelled results of expected impacts of spillages / authorisation applications.	✓ Daily (real time) for parameters indicated. ✓ quarterly for rest.	✓ Sms and email in emergency. ✓ Otherwise email & Website.
Alien Vegetation.	✓ Involve working for water.	✓ Annual.	✓ Main ICMA website.
Unified Water Measuring System to easily incorporate output into website (Compatibility).	✓	✓ Daily. ✓ Monthly summarised data.	✓ Website.

Bio-monitoring Data.	✓	✓ Quarterly.	✓ CROCOC. ✓ Website.

The outcomes of this workshop, shown in Table 5, have not yet been assessed, nor incorporated into the AOWRMF and TOR of the CROCOC. They will form the basis of future amendments and additions to the information provision around AOWRM, coordinated through the CROCOC in an adaptive context.

An important outcome of this review was the stakeholders' strong indication of the need to incorporate water quality monitoring information into the CROCOC. This is in the process of being implemented. Currently, the monthly water quality monitoring results for pH, electrical conductivity and e.Coli are summarised and presented at the CROCOC meetings. Figure 17 indicates the graph for pH. The suitability of the three water quality parameters and their manner of presentation to the CROCOC as indicators of the water quality does not from part of the scope of this thesis. They are merely the three parameters deemed to currently best represent the state of the water quality by the resource protection and waste division of the ICMA (i.e. the relevant manager's knowledge and experience).

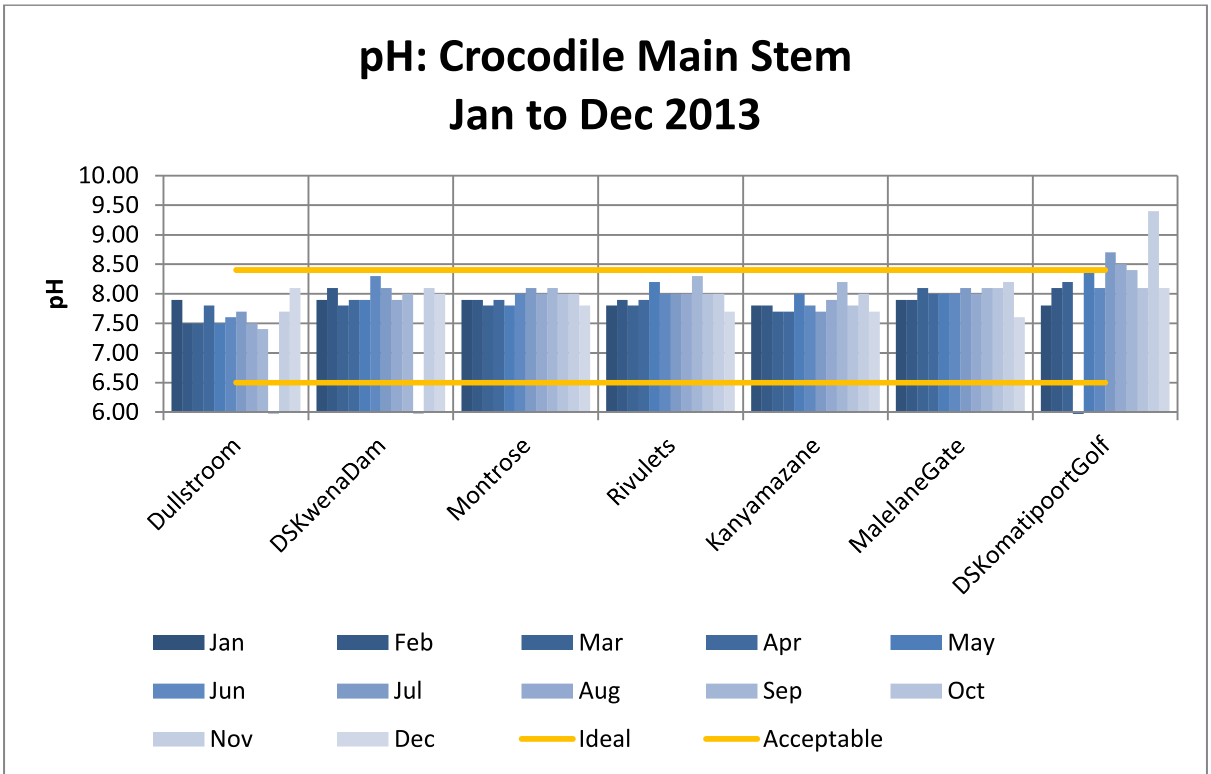


Figure 17: Initial water quality monitoring information for pH presented to CROCOC following the information needs workshop outcomes.

The addition of real time monitoring of key water quality parameters at priority water flow gauging sites may be investigated in future.

Discussion on the Data and Information Developed During the Implementation of the AOWRMF:

The previous section documented the data and information needed for OWRM in the Crocodile River stemming from previous projects, discourse at the CROCOC meetings and a stakeholder information needs review workshop. This section discusses the availability, applicability, use and suitability of that data and information. The methods and formats developed for collecting, managing, compiling, storing, archiving and disseminating the information are also discussed in this section. Finally, any gaps, shortcomings and recommendations for the future are documented and discussed under section 5.3.

The data and information can be split into three categories *(*)*. Namely long term planning, short term operations and data supporting both these aspects. The applicability and suitability of the data and information is discussed according to these categories in Table 6 below. Other indirectly relevant data available is documented in APPENDIX I.

(*) Refer to section 1.2.1. "Water Resources Planning and Water Resources Operations" in the literature review for discussion on the suitability of these categories.

Table 6: Analysis of the key information and data sources for OWRM in the Crocodile River.

Data	**Comments**	**Source of Data**
Data for Long Term Planning		
IWAAS hydrology	The latest hydrological data available for the Inkomati for long term planning is from the IWAAS study. The data available from this projects includes: • Water use information including domestic allocations, Irrigation, Industrial, mining, cross border flows, transfers and afforestation. • Alien vegetation. • Ecological flow requirements. This data was taken from the comprehensive ecological reserve determination done by DWA for the IWMA. • Water Quality. • Historical patched rainfall data, also summarised per quinary catchment. • Natural historical river flow time series and related hydrological statistics for each quinary catchment. This data was all incorporated into the long term planning model described in section 4.2.4. There is a strong serial correlation between monthly flows of rivers of the Lowveld as demonstrated in Figure 18. Serial correlation constraints were developed for the Crocodile and Sabie Rivers (Mallory, 2007) and have been incorporated into the long term planning model stochastic generator (Hallowes, Mallory and Greaves, 2009). The methodology significantly improves the accuracy and reliability of forecasted flows (and storage) through the dry season if the flow at the end of summer is known (Mallory, 2007) (Figure 18) and improves the long term model outputs disseminated to stakeholders (Figure 28).	IWAAS, DWA RDM for ecological requirements
Data for both Long Term Planning and Short Term Operation		

Rainfall	All existing rainfall stations in the Inkomati where identified as shown in APPENDIX L. Of these, the real time enabled stations were incorporated into the WRIMD from various sources shown below through mechanisms described in section 4.2.4 • SASRI weather data, via web interface (http://sasex.sasa.org.za/irricane/tables/index.asp) • SAWS Daily rainfall report (received by e-mail) • ARC Daily Rainfall Report (received by email • ICMA rainfall data, via web interface. (http://www.metos.at/fieldclimate). The ICMA rainfall data consists of 15 new real time rainfall gauging stations installed in early 2012 with funding from the WATPLAN project (Jarmain and Schaap, 2012). The locations were initially identified by the researcher through a qualitative process incorporating knowledge of the locality of existing real time rainfall gauges, topography, mean annual rainfall distribution and accessibility. The ICMA then identified suitable hosts in the vicinity of the identified sites and entered into agreements with those hosts, shown in APPENDIX M, before installation at the locations shown in Figure 19.	DWA, SAWS, SASRI, ARC, ICMA
River flow	DWA have a number of river flow gauging stations in the Crocodile River catchment. These are indicated in APPENDIX K. The stations have been prioritised in terms of their importance for OWRM and several of the stations have been equipped with real time logging equipment. This information is being collected and stored in the WRIMD described in section 4.2.4. Experience gained in the real time OWRM aspects of the DSS since commencement in 2009 quickly indicated problems with the reliability of the DWA real time river flow monitoring equipment and information. This information is critical for the DSS and some level of redundancy was needed to improve the reliability to acceptable levels. It was thus decided at the CROCOC that the ICMA should install duplicate real time river flow monitoring equipment at the 28 high and medium priority river flow gauging stations of DWA shown in APPENDIX K. Permission was obtained from DWA to install the necessary equipment at their stations, along with separate control centre software from that of DWA to further improve redundancy, and the installation and commissioning was completed in March 2012. The data is linked to the WRIMD and also directly available from the website http://www.zednet.co.za.	DWA, ICMA WRIMD, ZEDNET.
Reservoir data	DWA have reservoir storage level and release monitoring on all of their dams. This is collected into the WRIMD on a daily basis and used in both the water resources planning and operations related modelling.	DWA, ICMA WRIMD

River health program bio-monitoring data	An agreement between the MTPA and ICMA was reached whereby bio monitoring, riparian habitat and other related river health data is captured for the Sabie, Crocodile and Komati rivers on a rotational basis every three years, starting with the Sabie in 2011. The reports are available from the ICMA. The ICMA is also involved in a project with SANPARKS regarding information feedback loops between the two parties for river health data and the ecological flow requirements. The need for this information is included in the TOR of the CROCOC and the results of these two bio monitoring related agreements are presented to the CROCOC quarterly for the rapid response system related information and annually for strategic monitoring related information in order to evaluate the river health.	MTPA, SANParks
Water use data	Metered water use data on the Crocodile River is collected by the CRMIB and sent to the DSS on a weekly basis. It is based on a spreadsheet (Figure 34) developed by DWA as part of their real time operations DSS for the Crocodile River project (Hallowes et al., 2007; DWA, 2010a). Not all irrigators currently provide their data to the Irrigation Board, affecting the accuracy of model outputs and this data is consequently not being used in the model yet. Estimated water use data from the IWAAS study is used instead. There are also various sources of estimated data available. They include WARMS data and existing water use verification data from DWA. The landcover database and verification of existing lawful water use project of the ICMA have both improved the current data but must still feed into the DSS to improved hydrology and water resources modeling.	Crocodile and Kaap Irrigation Boards for metered water use. DWA or ICMA for other water use.
Data for Short Term Operations		
7 day flow forecasts	The DHI DSS, NAM model and Mike 11 model with auto calibration and data assimilation against observed data enable the production of forecast flows 7 days into the future. The accuracy of these forecasts is affected by the poor rainfall runoff modeling and poor water use information from the Irrigation Board. Improvements to the rainfall runoff modelling and water use information should be investigated.	ICMA
Weekly water use orders	These orders are not very accurate as the weekly demand patterns must still be confirmed by the Irrigation Board. Improvement to automated daily delivery of water use is thus recommended.	Crocodile Irrigation Board
River cross sections	River cross sections used in the mike 11 model for the main stem of the Crocodile were developed from 5m contours available at the time. New sources of improved cross section information such as Lidar should be investigated to improve low flow hydrodynamic	ICMA, PRIMA

	modelling.	
Weekly ecological flow require-ments	Estimated ecological flow requirements 1 week into the future are calculated in the long term model. Refer to section 4.2.4. for detail on the modelling required.	ICMA

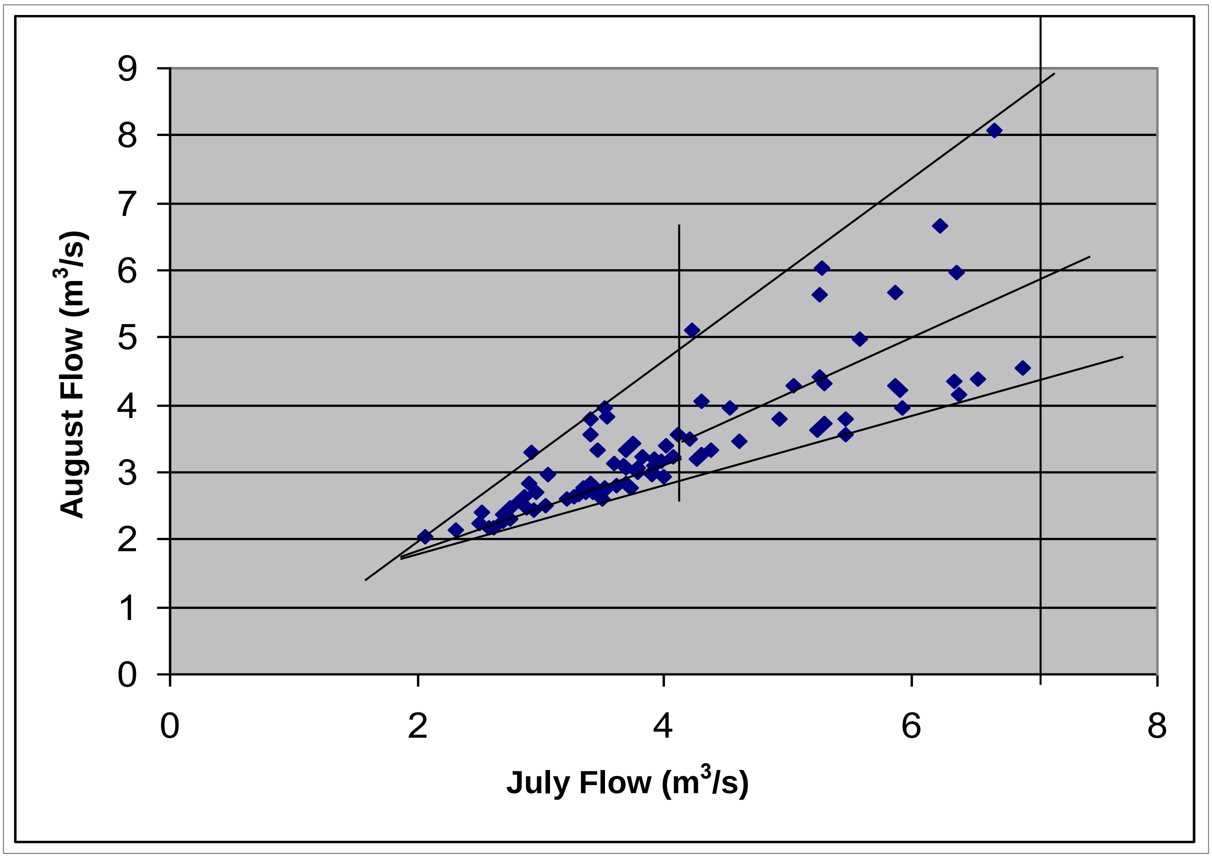


Figure 18: Example of the serial correlation in monthly flows and constraints built into the long term planning model (Mallory, 2007).

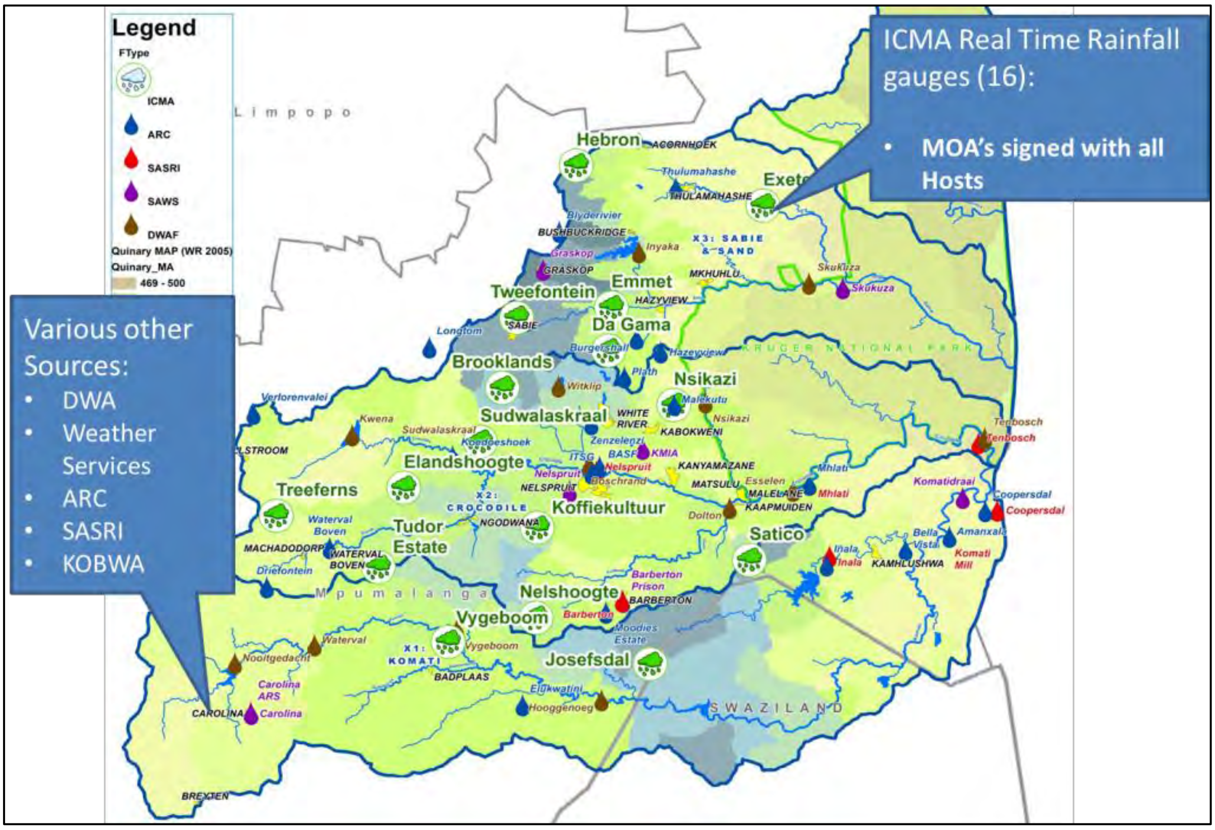


Figure 19: Map of the location of the real time rainfall stations in the Inkomati.

Other Indirect Supporting Information Needs:

A technical support and maintenance programme and contract with the equipment provider for the real time rainfall and river flow equipment was developed and implemented to ensure the continued reliable operations of the hardware, as experience during the implementation of the AOWRMF showed that real time equipment requires extensive ongoing maintenance. The required equipment and estimated costs for the maintenance of the rainfall gauges was drafted to support budgeting for the maintenance programme and is shown in APPENDIX N.

A pamphlet regarding the CROCOC was developed by the ICMA and CROCOC (APPENDIX H) to assist with awareness creation for the CROCOC amongst the wider IWRM stakeholders.

A log of all decisions and feedbacks regarding the river operations was also developed and is being maintained by the ICMA and KNP (Table 9) to help track all actions and decisions related to AOWRM. This logbook forms an important aspect of the rapid response system and strategic monitoring of the adaptive operational water resources management framework presented in section 4.3.

Following a request to do so by the CROCOC stakeholders, flow alert levels[8] were also developed for the Crocodile River to assist in the operational management of the river by combining historical flow statistics (Table 7) and management experience, facilitated through the CROCOC. Different management decisions and information dissemination can then be linked to the different flow alert levels in the real time operations decision support system.

These were initially designed to indicate low flow alerts only, shown in Figure 20. Following the data and information workshop, this was replaced with different flow alerts for each month of the year so that the alerts are useable at any time of the year, shown in Figure 21. These alerts greatly improved the usability of the river flow information disseminated as the stakeholders can easily see whether the current observed flows are low or high compared to historical statistics for any time of year.

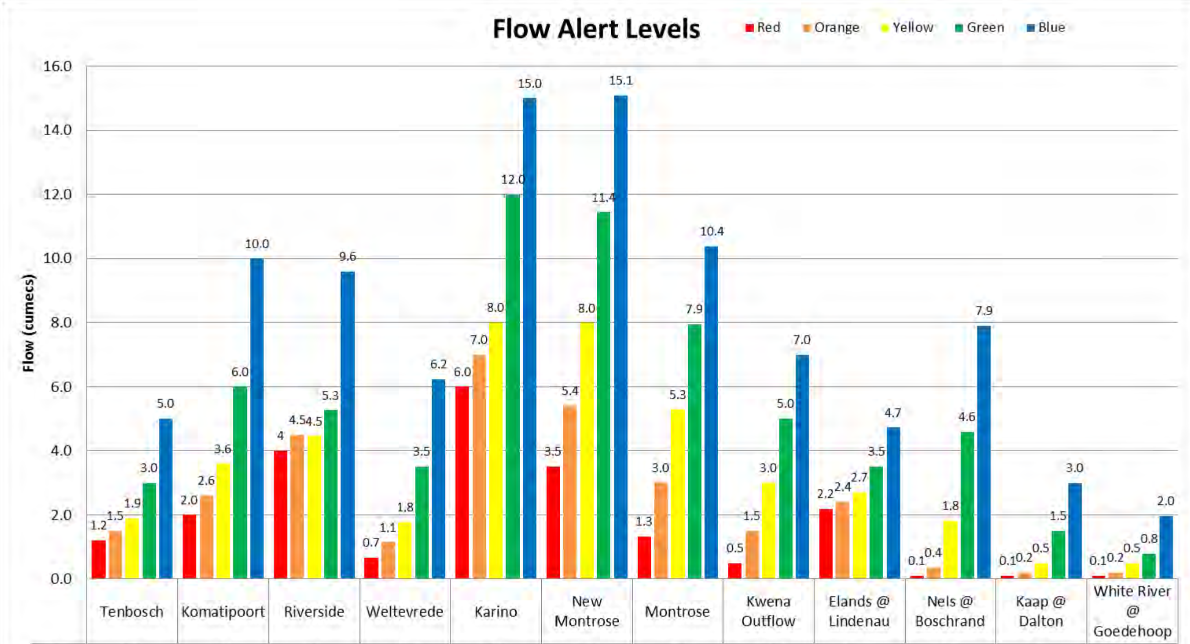
Table 7: The defined daily average flow alert level thresholds, colours and description

Colour	Percentile Range	Legends
Red	**min-0.1**	Very Low Flow
Orange	**0.1-0.25**	Low Flow
Yellow	**0.25-0.5**	Below Normal Flow
Green	**0.5-0.75**	Normal
Cyan	**0.75-0.95**	Above Normal Flow
Blue	**0.95-0.99**	Very High Flow
Dark Blue	**0.99-max**	Critically High Flow

The flow alert levels illustrated in Figure 21 are a combination of the historical percentile thresholds of Table 7 and the international obligations on the Crocodile River. The X2H016 gauging station is the most downstream gauging station on the Crocodile River and is used to monitor compliance to the international obligations. It was thus important that the flow alert thresholds accounted for the international obligations. For example, the numbers highlighted in white in Figure 21 are related to the international obligations and not the historical percentile thresholds of Table 7. These international obligations form part of the operational management of the Crocodile River, which attempts to meet them at all times and the flow alert levels at X2H016 assist in this management. T

This study did not assess the trans boundary aspects of the Crocodile River.

[8] Flow alert levels are several average daily flow rate thresholds defined for each gauging station based on the historical daily average flow statistics at each gauging station. For example, “critically high flow” indicates an observed daily average flow greater than the 99th percentile of the historically observed data. Refer to Table 7.



	Tenbosch	Komatipoort	Riverside	Weltevrede	Karino	New Montrose	Montrose	Kwena Outflow	Elands @ Lindenau	Nels @ Boschrand	Kaap @ Dalton	White River @ Goedehoop
Red	1.2	2.0	4	0.7	6.0	3.5	1.3	0.5	2.2	0.1	0.1	0.1
Orange	1.5	2.6	4.5	1.1	7.0	5.4	3.0	1.5	2.4	0.4	0.2	0.2
Yellow	1.9	3.6	4.5	1.8	8.0	8.0	5.3	3.0	2.7	1.8	0.5	0.5
Green	3.0	6.0	5.3	3.5	12.0	11.4	7.9	5.0	3.5	4.6	1.5	0.8
Blue	5.0	10.0	9.6	6.2	15.0	15.1	10.4	7.0	4.7	7.9	3.0	2.0

Figure 20: Initial low flow alert levels adopted by the CROCOC.

X2H016_Crocodile River@ Tenbosch: Daily Average Flow Alert Level Thresholds (m^3/s)

	Min	0.10	0.25	0.50	0.75	0.95	0.99	Max
Oct	0.03	0.90	1.20	2.13	5.18	18.86	47.02	101.36
Nov	0.00	0.90	1.20	5.21	13.84	35.89	66.68	244.66
Dec	0.03	0.90	4.41	15.93	33.85	82.59	114.08	214.56
Jan	0.01	0.95	7.66	21.25	41.44	141.52	312.10	1139.45
Feb	0.00	0.90	5.20	24.74	60.02	164.45	410.62	1168.78
Mar	0.00	0.90	6.26	24.34	46.10	123.77	316.22	1010.63
Apr	0.01	0.90	4.01	15.06	30.58	65.91	94.41	119.30
May	0.04	0.90	1.54	6.65	14.57	28.03	43.39	55.60
June	0.05	0.90	1.22	3.95	8.46	14.58	20.39	28.16
July	0.00	0.90	1.20	3.24	6.48	10.97	18.87	25.47
Aug	0.00	0.90	1.20	2.07	4.26	7.16	11.87	17.19
Sept	0.00	0.90	1.20	1.82	3.78	9.72	23.19	84.11

Figure 21: Revised monthly flow alert levels based on historical percentiles for daily average flow rates (m^3/s) for the X2H016 gauging station at the downstream end of the Crocodile River as shown in figure 11.

All of the data and information discussed in this section is deemed relevant to AOWRM. It is collected, managed, processed, archived and disseminated to stakeholders through the rapid response system and the CROCOC via a combination of e-mail, a web portal and CROCOC presentations. Much of this data is managed by a water resources information management database (WRIMD) described in section 4.2.4.

Information Dissemination:

The examples of the information disseminated to stakeholders and dissemination methods presented here are all the result of the extensive action research process conducted with the CROCOC stakeholders, unless otherwise indicated.

Web Portal and Email:

The information was initially disseminated through a web portal (Figure 22) developed by the DWA real time operations DSS for the Crocodile River project (Hallowes et al., 2007; DWA, 2010a) using the DHI Mike Flood Watch software. The web address for this portal was http://crocdss.inkomaticma.co.za/Website/Index.html .

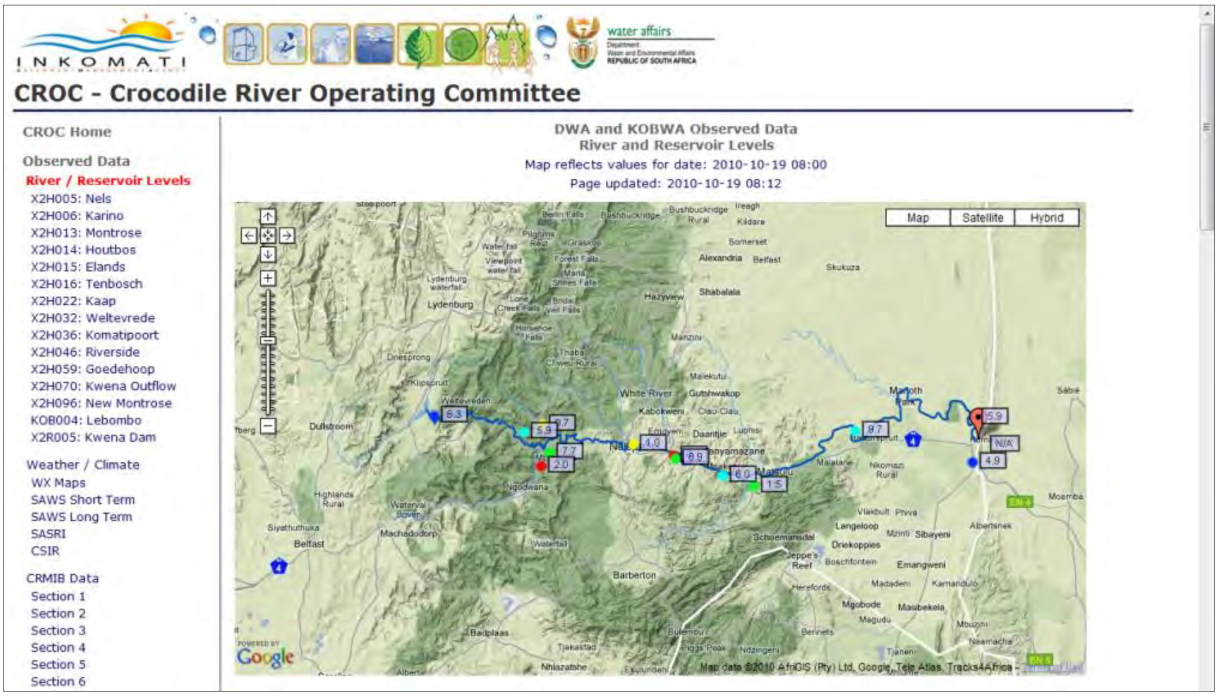


Figure 22: The initial Crocodile River operations web portal.

Shortcomings identified with this installation were that the Mike Flood Watch software was only resident on a single desktop computer and that Mike Flood Watch was designed for real time data management only, and not for data storage and archiving.

Experience in its use showed that the setup was not suitable for reliable OWRM as it could not manage the data and information needs of long term planning and the data was not being stored or backed up. This initial setup was thus replaced through the short term model support contract set up by the researcher in his capacity as the responsible manager in the ICMA. It was replaced by an improved web portal hosted on the ICMA network server and driven by the DHI Mike Customised software *(*)*, and is shown in Figure 23. The web address for this portal is http://riverops.inkomaticma.co.za.

(*) Refer to section 4.2.4 for more detail on this transition to Mike Customised software.

A network server was purchased and installed at the ICMA by the researcher - in his capacity as the responsible manager in the ICMA - to enable this change to be implemented. All OWRM related data and information can now be stored and backed up in a database on this server, managed by the Mike Customised software. This is referred to as the Water Resources Management Database (WRIMD) *(*)*.

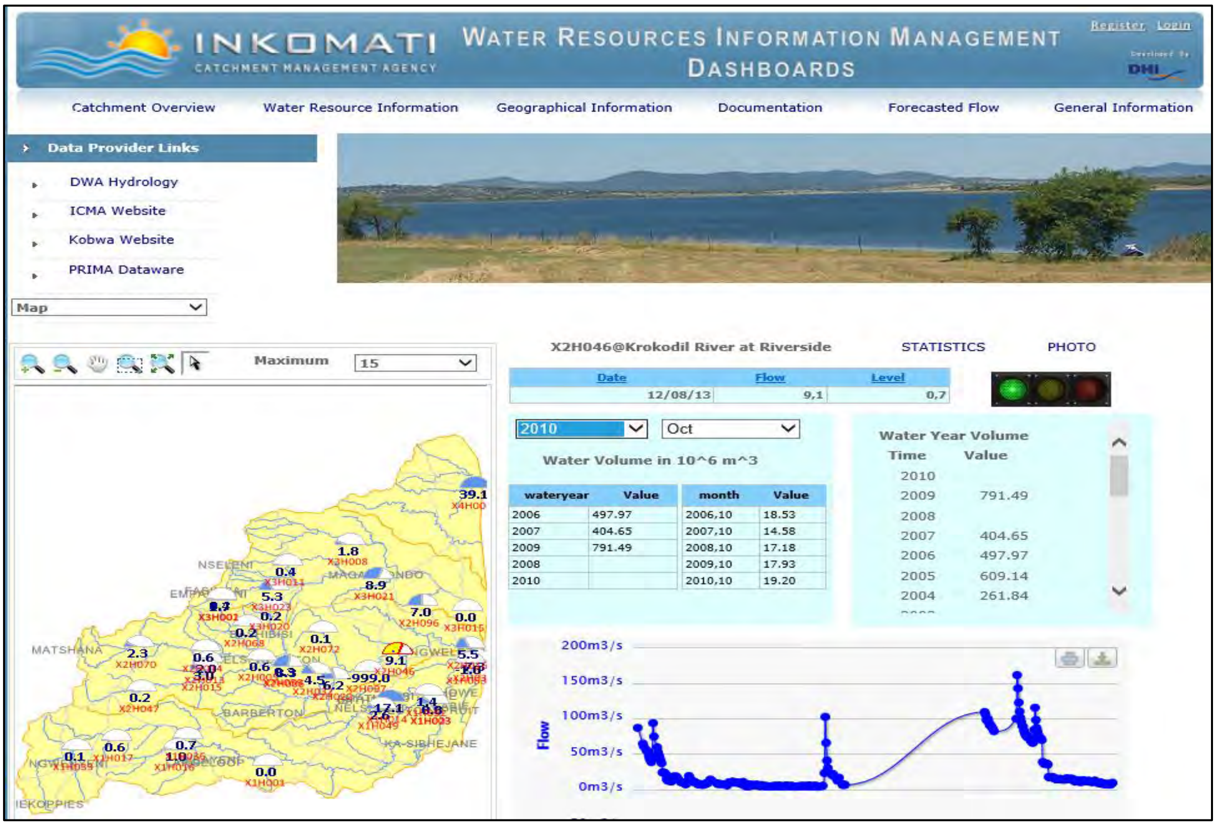


Figure 23: Current Inkomati river operations web portal.

The information managed by the revised DHI Mike Customised software is stored in the WRIMD and available on the web portal (Figure 23). All of the information discussed in Table 6 is stored as well as the supporting GIS information show below:

- Vector:
  - Hydrological coverages - e.g .Catchment coverages, ,Rainfall stations, Reservoir stations, Flow gauges, water bodies, rivers, wetlands.
  - Administrative coverages – Provincial, Local municipalities.
  - Infrastructure - canal, roads.
  - Landuse and agriculture – Communities, farm, Irrigation, forestry and Game Reserves.
  - Cadastral coverages – farm boundaries.
- Raster:
  - Digital Elevation model and Derived Data.
  - Landcover.
  - Satellite data.
    - Landsat and Spot imagery.
    - Ortho photographs, aerial photographs, topographical maps.
    - eleaf satellite data for Inkomati.
      - Rainfall.
      - Evaporation.
      - Biomass.
      - Evaporation deficit.

The DHI Mike Customised software also enabled the dissemination of information via email. Discussions at the CROCOC resulted in the implementation of a daily email shown in Figure 24 to all stakeholders who requested it. It shows the status of the river flow at the priority gauging stations.

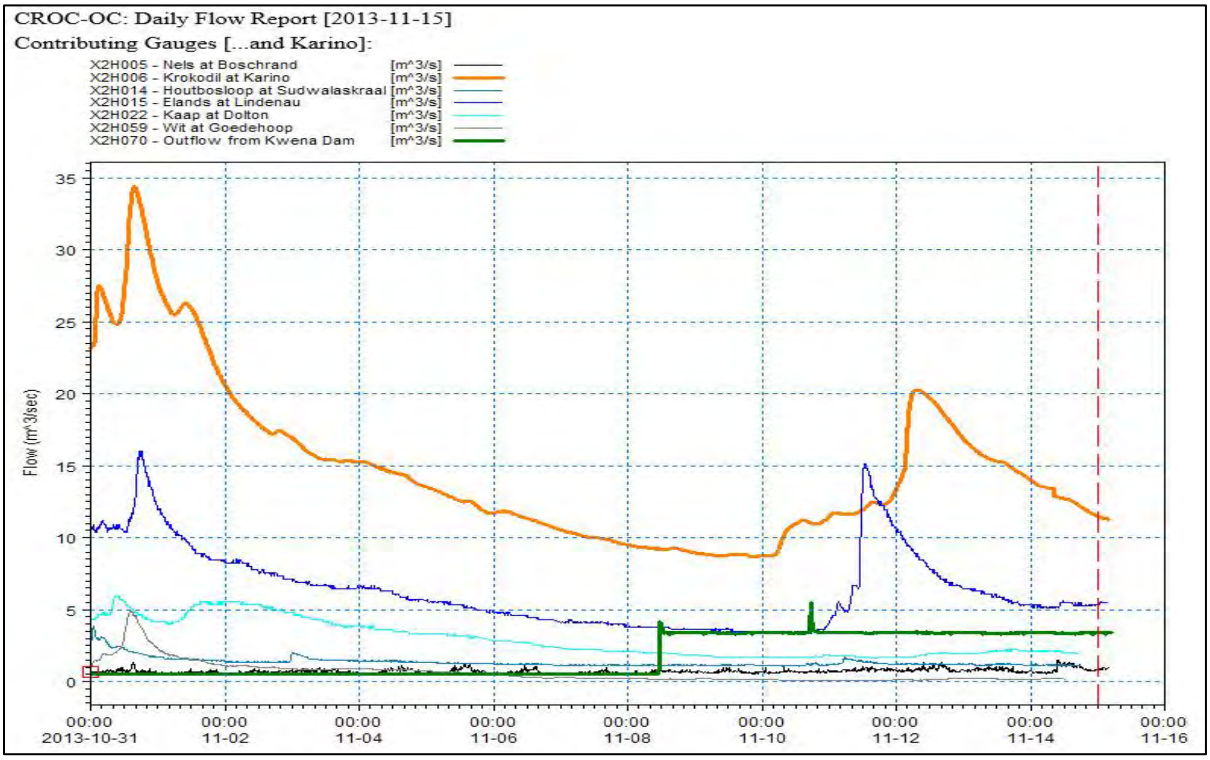


Figure 24: Example of the daily flow email sent to relevant CROCOC members.

CROCOC Presentations:

Deliberations at the CROCOC during the implementation of the AOWRMF indicated that stakeholders also desired information to be presented at the CROCOC meetings and not just disseminated through a web portal or email, so that proper informed discussions and consensus based participatory decision making could be undertaken at the CROCOC.

Consequently, a number of graphs and tables were developed by the researcher in collaboration with the CROCOC stakeholders showing current data against historical statistics for dam levels, river flows and rainfall as well as information on the ecological flow requirements, international obligations, weather forecasts, water use and climate forecasts for presentation at the monthly CROCOC meetings.

The following pages (Figure 25 to Figure 28) show examples of the information presented to the CROCOC meetings as they have evolved during the implementation of the AOWRMF into their current form. Figure 17 is a further example of the information presented to CROCOC meetings for water quality, developed after the data and information needs workshop.

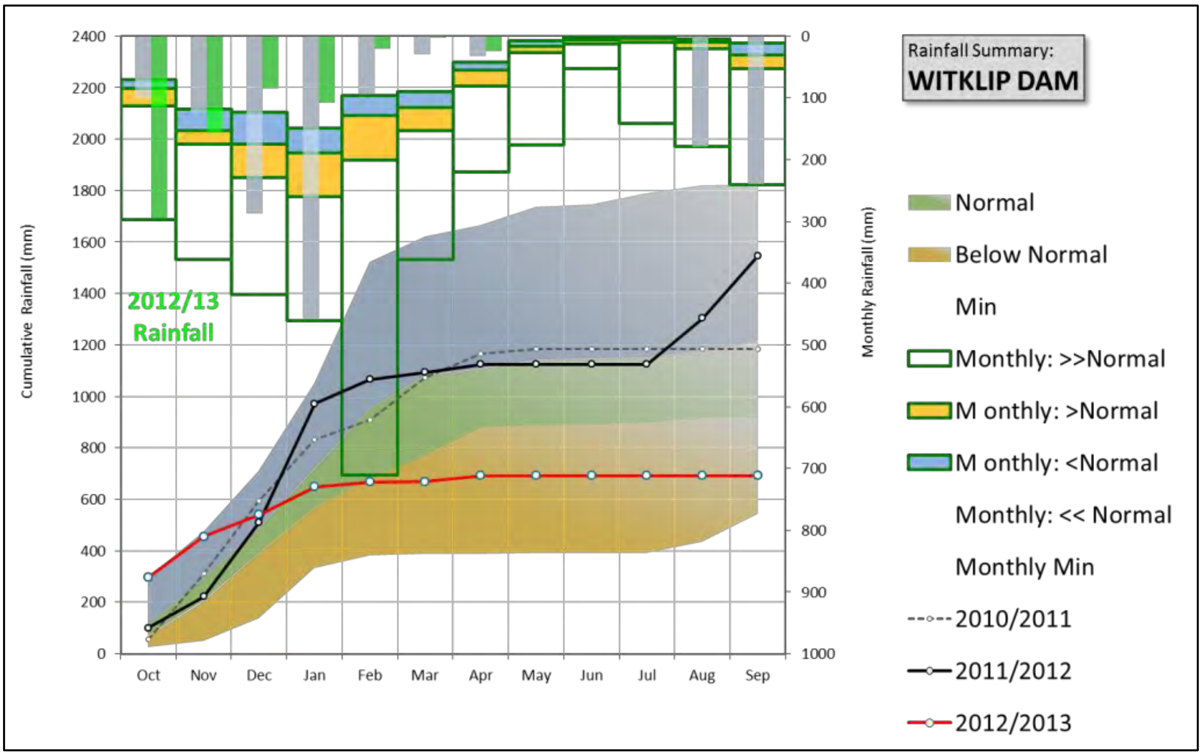


Figure 25: Illustration of the rainfall information presented to CROCOC meetings from the Witklip Dam rainfall gauge.

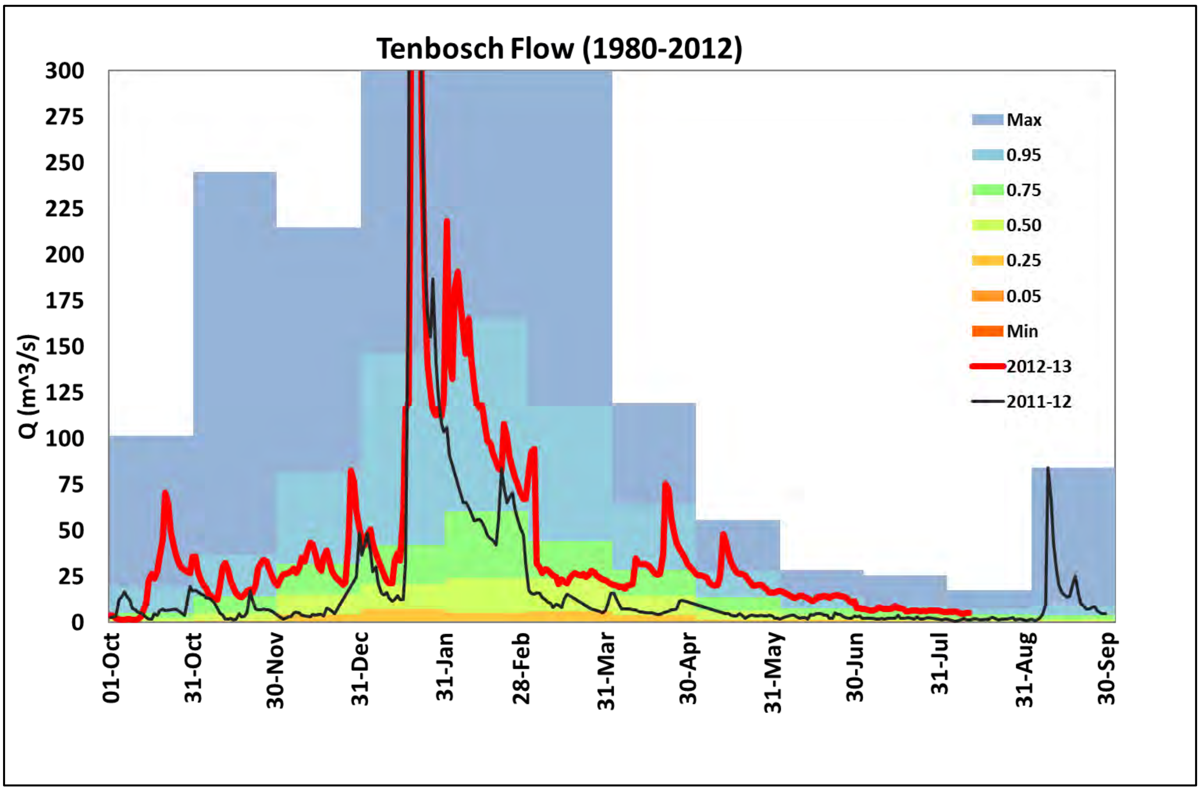


Figure 26: River flow vs. historical statistics for the Tenbosch gauging station as presented to CROCOC meetings.

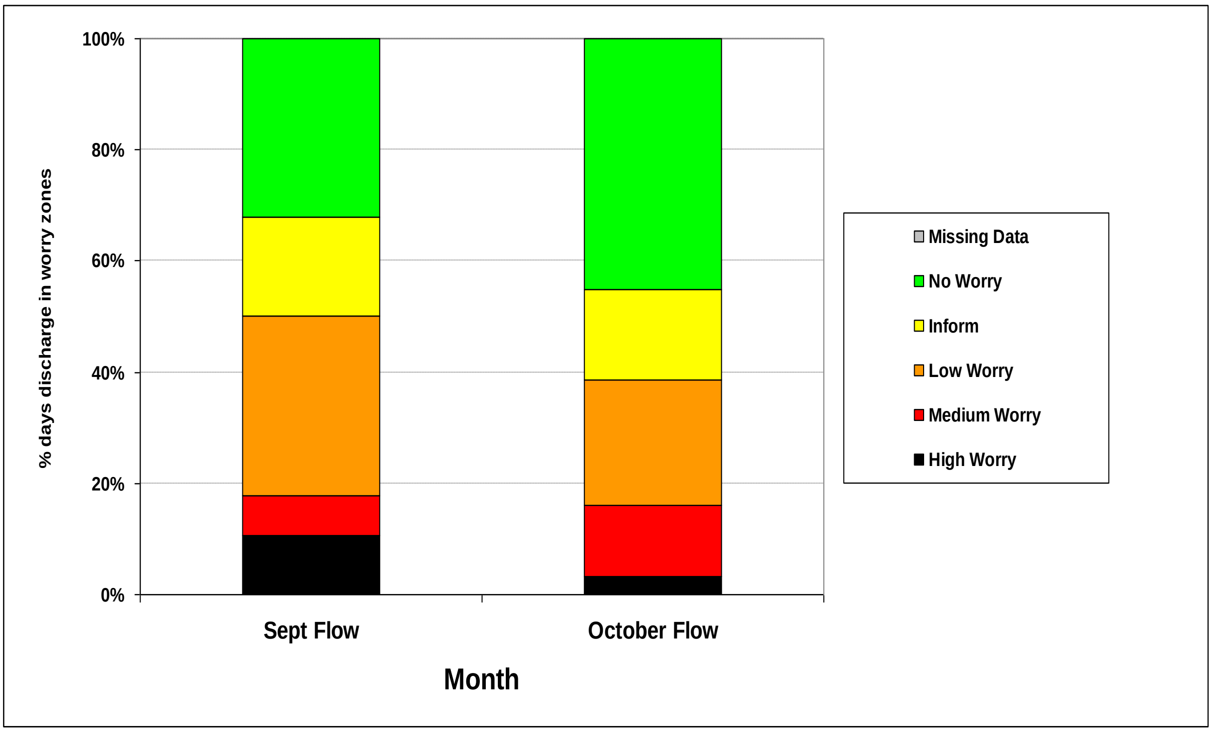


Figure 27: Worry levels associated with the EFR as presented to CROCOC meetings by the KNP.

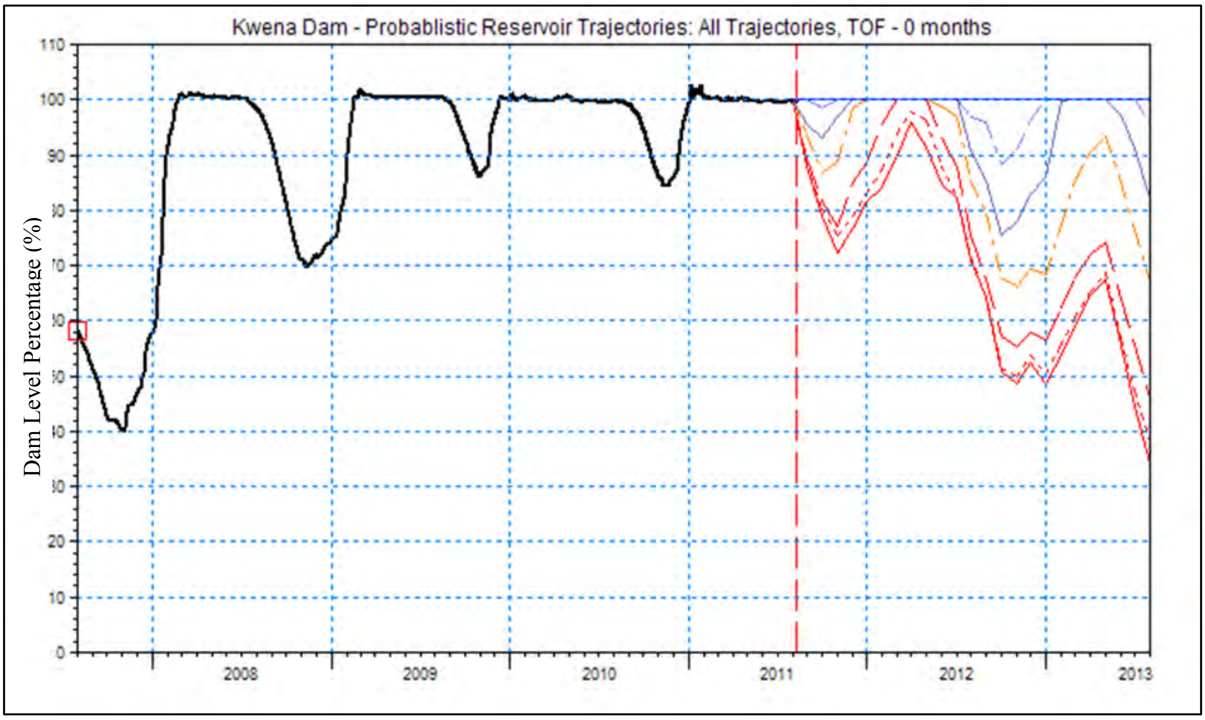


Figure 28: Observed dam levels and forecasted dam level trajectories with serial correlation constraints incorporated, as presented at CROCOC meetings.

The common principle behind the development of all of these graphs is that of requisite simplicity. They attempt to present what is highly technical and complicated data in a sufficiently simplified form that enables the CROCOC stakeholders to easily understand the state of the Crocodile River and thus engage in informed decision making. In other words, they represent the requisitely simple information required for stakeholders to engage and understand.

Figure 25 and Figure 26 both show the current and previous year information against the historically observed statistics. Figure 25 shows both the actual monthly rainfall against historical statistics as well as the cumulative rainfall for the hydrological year against historical statistics. This is deemed to be requisitely simple to enable the CROCOC stakeholders to see whether the current and recent rainfall and river flow is in an average, wet or dry situation.

Figure 27 shows the percentage of time the river flow has been above or below the ecological flow requirements and in defined worry levels associated with the ecological flow requirements, enabling a quick view of how well the river is performing in terms of meeting the ecological flow requirements.

Figure 28 shows the observed historical dam levels for the past 4 years and the possible forecasted dam trajectories for the next two years. This is an output of the long term planning model described in section 4.2.4. A combination of these dam trajectories, the current rainfall and runoff as well as the forecasted climate is discussed at each CROCOC to make informed decisions on the operations of the Crocodile River.

4.2.4. Modelling and Decision Support System

The processes that led to the implementation of the current AOWRMF for the Crocodile River presented in this document was initiated because of the need to implement the DWA real time operations DSS for the Crocodile River project (Hallowes et al., 2007; DWA, 2010a). This project developed the initial operating rules and supporting software or DSS for the Crocodile River in 2009, immediately prior to the commencement of this study.

The researcher (in his capacity as the responsible manager in the ICMA) thus obtained agreement with DWA to implement the real time operating DSS developed by them as from October 2009. This then laid the groundwork for the further development of the DSS and its incorporation into the AOWRMF developed through this study.

Real Time Operations Decision Support System:

As indicated in section 1.2.2, a DSS for IWRM typically includes a database and processing environment, a knowledge and information system (including real time data acquisition, forecasting and data assimilation), a modelling and analysis framework, a socioeconomic modelling and analysis framework, and a communication framework (Madsen et al., 2000; Global Water Partnership, 2013).

Furthermore, water resource managers are required to perform tasks for both water resources planning and operations needs, as there are both planning and operations processes within the field of water resources management (van Kalken et al., 2012 and Szylkarski et al., 2013). The initial DSS as developed by DWA for the Crocodile River recognised these needs and was based on the DHI solution software known as Mike Flood Watch.

The literature review demonstrated that DHI solution software is widely used and accepted as a suitable DSS for real time river management and has also been successfully utilised internationally for the Nile Basin Initiative and the Australian Murrumbigee Computer Aided River Management (CARM) system *(*)*.

(*) Refer to section 1.2.2. "Decision Support Systems (DSS's) are required for Operational Water Resources Management".

The Mike Flood Watch solution software already set up through the DWA real time operations DSS for the Crocodile River project (Hallowes et al., 2007; DWA, 2010a) was thus deemed to be suitable for the initial implementation of the DSS and the AOWRMF. Mike Flood Watch integrates spatial data, real time data, forecast models and dissemination tools in a GIS environment. It is capable of running model engines provided by DHI, viz Mike 11, Mike NAM, AUTOCal, and other third party model engines. It is also able to perform a set of tasks (e.g. download information from the web) which are either scheduled to take place at regular intervals or are triggered by certain events (e.g. a low flow threshold is compromised). It is through the scheduling of tasks and responses to events that information is captured, manipulated (models) and published in the Mike Flood Watch system. It imports real time data (rainfall and river flow), runs the forecast models and disseminates information with minimal human intervention and a high degree of automation. These three elements can be summarised as data acquisition, model control and information dissemination. It also takes downstream consumptive water use, tributary inflows, international water requirements and environmental water requirements into consideration.

This Mike Flood Watch software solution was integrated into an operational water resources management DSS (Figure 29) by DWA before the commencement of this study. Presentations were given by the researcher and the DSS developers on both the short term operational and long term planning aspects of the DSS to the initial CROCOC meetings in October 2009 to ensure that all stakeholders were aware of the need for and basic functionality of the DSS. The CROCOC members subsequently accepted and adopted this initial operational water resources management DSS for use.

The operational water resources management DSS was consequently installed at the ICMA in October 2009 and the researcher (in his capacity as the responsible manager in the ICMA) purchased the Mike 11 real time software package consisting of Mike 11 and Mike Flood Watch to enable the continued implementation of the DSS at the ICMA. This DSS forms a key aspect of the modelling and DSS component of OWRM shown in Figure 15 and is the DSS referred to in the AOWRMF (Figure 42).

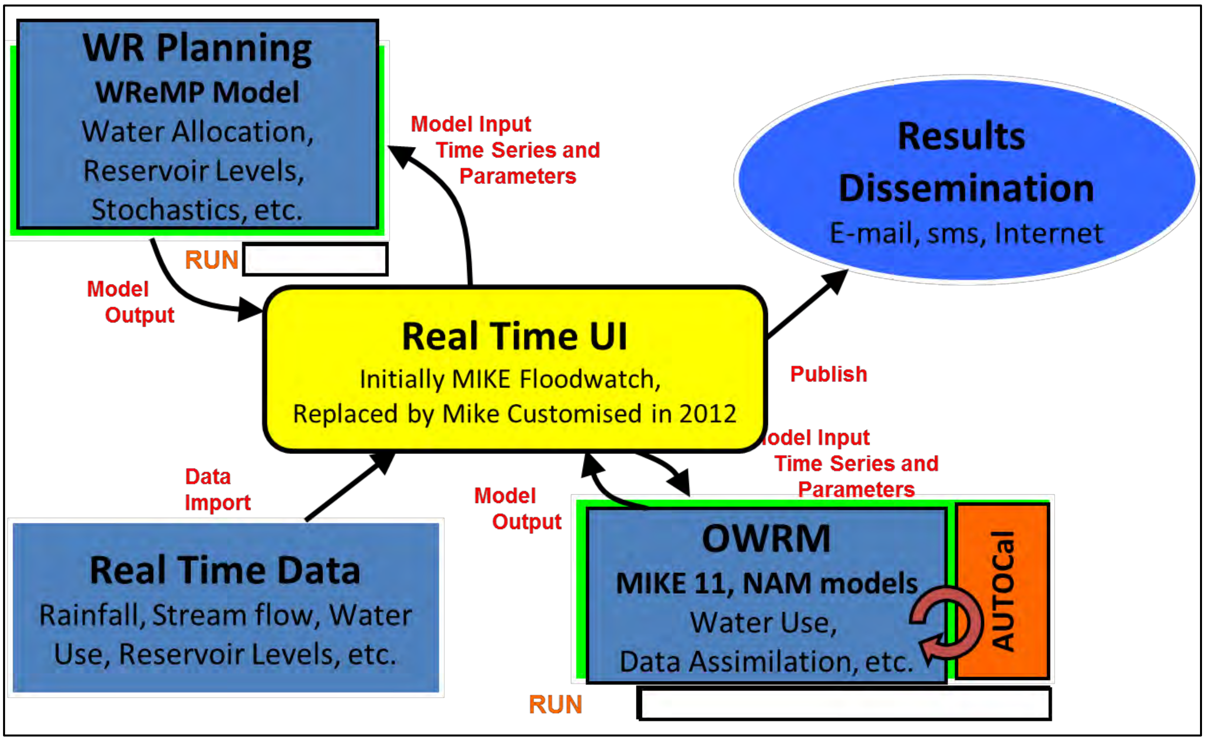


Figure 29: Conceptual representation of the operational water resources management DSS implemented in the Crocodile River catchment (Hallowes et al., 2007; DWA, 2010a).

Experience in the implementation of the DSS at the ICMA showed the need for ongoing technical support to be available from the model and DSS developers to ensure that any technical glitches and issues identified in the models could be rectified quickly, thereby ensuring stable operation of the DSS. This learning led the researcher (in his capacity as the responsible manager in the ICMA) to budget for and enter into two technical support and maintenance contracts with the relevant software developers of the short term operations and long term planning models in the DSS. The TOR for the October 2012 short term technical support contract is show in APPENDIX R.

Further experience in the use of Mike Flood Watch demonstrated several shortcomings. The software was designed solely for real time operations and as such, imported and stored all data as text files that were overwritten each month. Thus, it did not store any data in a database and could not archive any historical information. This made it unsuitable for use as a DSS for long term planning needs. As already mentioned, effective adaptive operational water resources management requires integrated long term water resources planning and short term operations. Furthermore, the CROCOC TOR and stakeholders highlighted the need to interrogate historical data against current conditions and review the long term operational planning aspects at the CROCOC meetings.

The technical support and maintenance contract of the ICMA with DHI made it possible for updated software, called Mike Customised, to be purchased by the ICMA in 2012. The researcher (in his capacity as the responsible manager at the ICMA) consequently purchased a network server and deployed the new Mike Customised software onto the ICMA IT infrastructure during 2012. This migration included hydrological data management for the entire Inkomati and the migration of the Crocodile real time Mike Flood Watch based DSS into the new Mike Customised DSS. The new customised DSS went live on March 2013 and is referred to by the ICMA as the Water Resources Information Management System (WRIMS).

Mike Customised enables the optimisation of both planning and operations. It performs all of the functions of the Mike Flood Watch system it replaced but includes the ability to store all data and results in a database. This consequently enabled the archiving and use of historical data, thereby meeting the needs of the CROCOC stakeholders.

The DHI Mike Customised DSS incorporates numerous components related to data management, real time operations and planning as shown in Figure 30. The specific components used in the Inkomati WRIMS are shown in Figure 31. The data sources and models linked to the database through the DSS interface as well the information dissemination through the web portal are shown in Figure 32. A screenshot of the Mike Customised real time operator user interface used by the ICMA is shown in Figure 33.

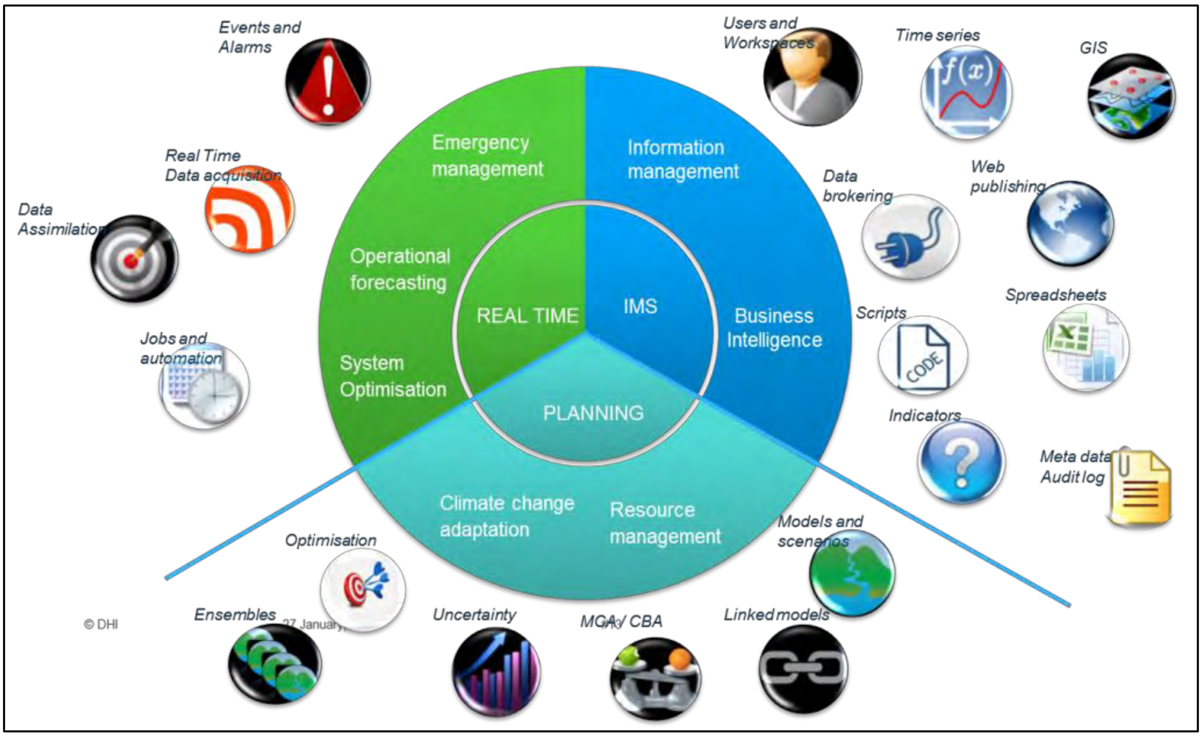


Figure 30: DHI Mike Customised DSS components.

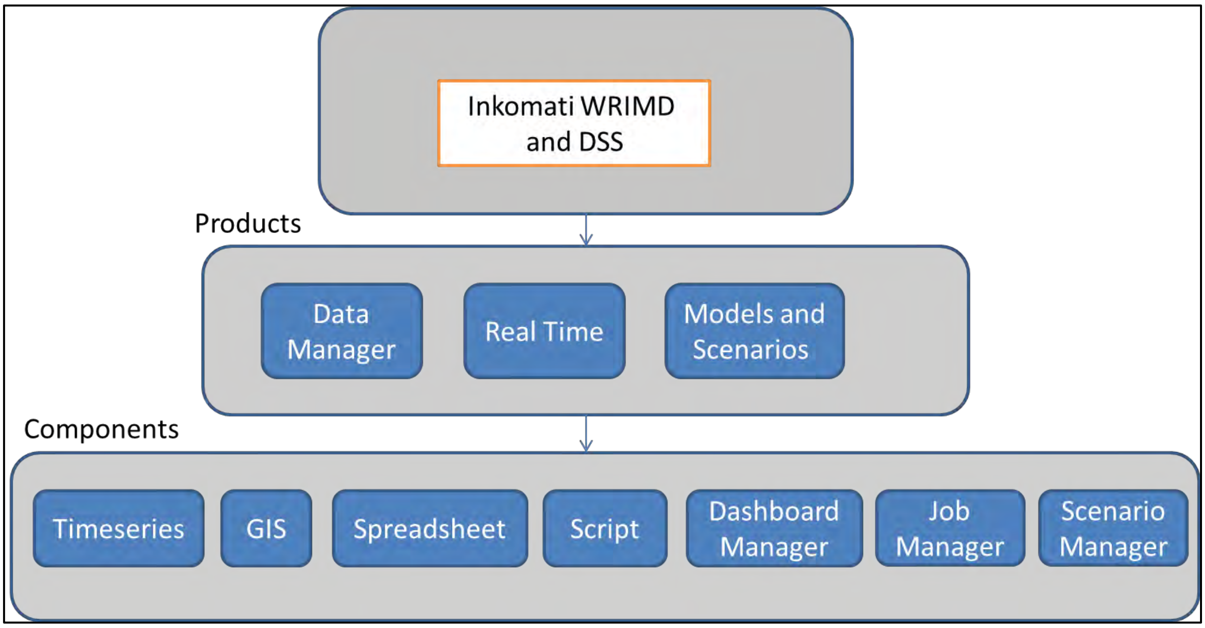


Figure 31: DHI Mike Customised DSS components used in the Inkomati WRIMS.

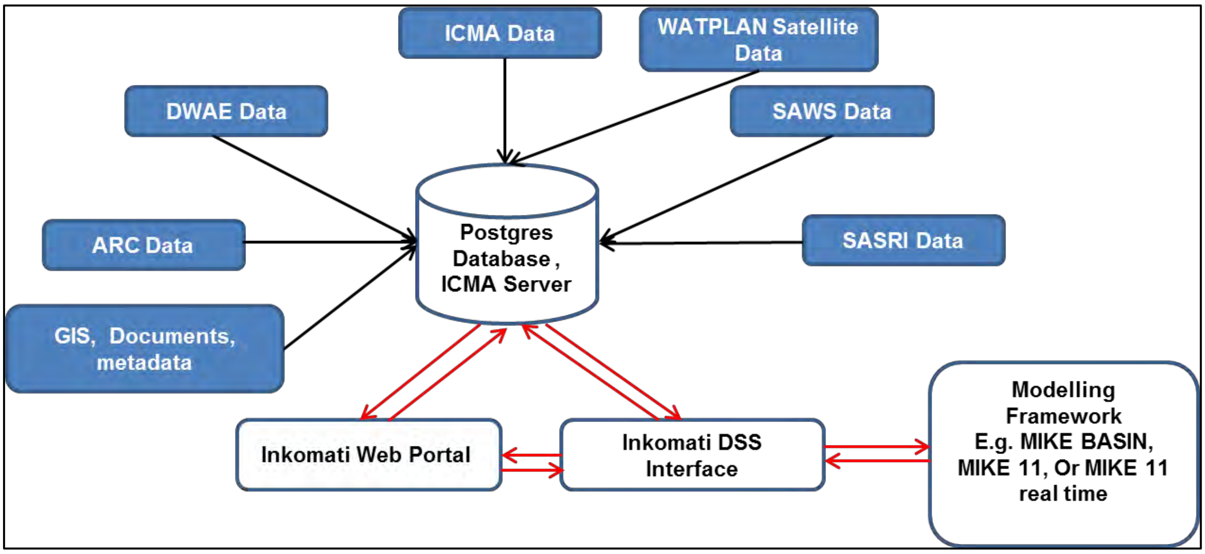


Figure 32: The Inkomati WRIMD data setup and links.

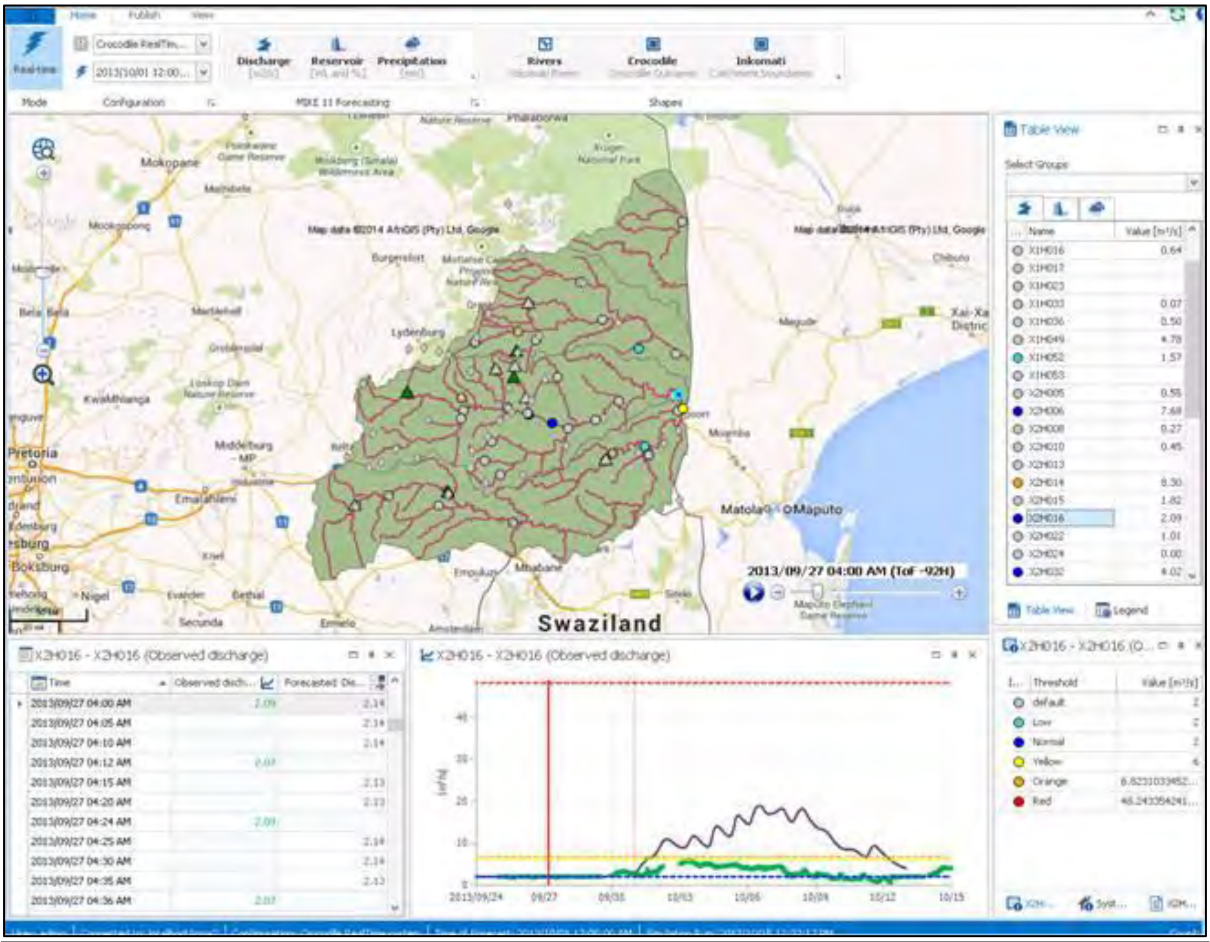


Figure 33: The ICMA Mike Customised real time operator user interface.

The application developed to assist the Crocodile River Major Irrigation Board to capture the water use data of all of their members and send it to the DSS is shown in Figure 34. This in accordance with the institutional roles and responsibilities developed (Figure 16). The application is based in excel.

Measurement | Actual | Planned Allocation | Control

Month	Day	Actual Irrigation Use Mm^3 / month	Target Mm^3 / month	Target m^3/s	Target cum	Hours per week	Hour/month general meeting	Percentage
Apr	28	10.53	14.27	5.90	14.27	55	30	83%
02/04-08/04	7	2.68	1.95	3.22	1.95	30	30	138%
09/04-15/04	7	2.55	3.24	5.36	5.19	50	30	79%
16/04-22/04	7	3.13	4.54	7.51	9.73	70	30	69%
23/04-29/04	7	2.17	4.54	7.51	14.27	70	30	48%
May	28	8.91	9.08	3.75	23.34	35	30	102%
30/04-06/05	7	2.58	3.24	5.36	3.24	50	30	80%
07/05-13/05	7	2.64	2.59	4.29	5.84	40	30	102%
14/05-20/05	7	1.89	1.62	2.68	7.46	25	30	117%
21/05-27/05	7	1.79	1.62	2.68	9.08	25	30	111%
Jun	35	7.09	7.46	2.47	30.80	23	19	97%
28/05-03/06	7	1.26	1.62	2.68	1.62	25	18	77%
04/06-10/06	7	1.32	1.62	2.68	3.24	25	18	81%
11/06-17/06	7	1.31	1.62	2.68	4.86	25	18	81%
18/06-24/06	7	1.22	1.30	2.14	6.16	20	20	94%
25/06-01/07	7	1.98	1.30	2.14	7.46	20	20	153%

Figure 34: Crocodile River Major Irrigation Board water use management spreadsheet.

The benefits of an operational DSS such as the Mike Customised system are seen to be:

1) Improved efficiency (release less water from the dam).
2) Increased accessibility to water (more water for water users from tributary flows).
3) Reduced losses (less water flowing unnecessarily from the base of system).
4) Potential to track decisions.
5) Potential to look at actual use versus entitlement.
6) Potential to identify problems on system and correct them.
7) Helps to ensure compliance with international and legal obligations.
8) Compliance with planning requirements and model outcomes can be tested.
9) Standardised information framework where information can be shared for modelling and reporting purposes.
10) Consistent framework where information can consistently be shared with many users.

The current Mike Customised solution developed during the implementation of the AOWRMF between October 2009 and March 2013 is seen as a suitable DSS solution for AOWRM in closing, semi-arid run-of-river catchments such as the Crocodile River catchment. This is supported by the social questionnaire and evaluation discussed in section 4.2.2, where the CROCOC stakeholders affirmed that the ICMA is able to act as an independent technical mediator, that the exchange of information is good and that the relationship between stakeholders and technical teams is good.

The details of the long term planning and the short term operations aspects of the DSS are presented below.

Long Term Planning:

The long term planning aspects are calculated using the WReMP model (Mallory, 2007 and Mallory et al., 2010) which is used to determine the annual operating rules and monthly restriction rules. The method and results are shown in further detail in APPENDIX O.

Stochastic time series are used in the WReMP model to statistically determine what portion of water needed to supply downstream demands can be supplied from reservoirs without compromising water availability and stipulated levels of assurance in the long term. The method used to develop the stochastic hydrology for the model incorporates monthly serial flow correlation as there is a strong serial correlation of monthly flows in the Crocodile River as demonstrated in Figure 18. Mathematically the model is described as follows:

Flowi+1 = f(Flow i).

The flow next month is a function of the flow measured this month. This is described further in APPENDIX P.

For operational use the model assesses the assurance of supply to different water user groups on a monthly basis by generating 101 stochastic possible hydrological sequences based on the starting month, the flow in the preceding month and the correlation of flow from one month to the next. A simulation is then carried out to determine a range of possible trajectories for the Kwena Dam. The output of this is shown in Figure 28. Superimposed on these trajectories are the recommended levels at which restrictions must be imposed on the various user sectors. Hence every month a decision can be made on whether or not to impose restrictions on users based on the actual level of the dam. The probability of restrictions can also be derived from the probabilistic trajectories.

A check was also carried out to ensure that the proposed allocations are in line with the long-term yield of the system (refer to APPENDIX P).

It is suggested that this monthly serial correlation could be investigated for the long term modelling of any river catchment that demonstrates a strong serial correlation as its use in the Crocodile River catchment has shown an improvement in the forecasted dam trajectories (Mallory, 2007).

Short Term Operations:

The short term operational modelling of the system is performed using the DHI Mike 11 model. The model is used to determine the short term modifications to the release from Kwena Dam and potential lifting or imposing of short term restrictions on the water users. Mike 11 uses data assimilation, which updates predicted data with actual measured information from the installed real time river flow data loggers ensuring that forecasts are always using updated boundary conditions. Added to this, suggested releases and restrictions are made using an optimisation model named AUTOCal, built into Mike 11.

A detailed description of the set up and use of these various models within the Crocodile River real time DSS has been documented by Greaves et al., (2009), a portion of which is included in APPENDIX Q.

NAM Hydrological model:

The NAM hydrological model, which is one of the hydrological models in Mike 11, is used to provide an estimate of forecasted river flows in the short term future at quinary catchment scale for all of the 83 quinary catchments (Figure 35) in the Crocodile River catchment initially delineated by the IWAAS project (DWA, 2009). The NAM Model uses rainfall as input to predict what the likely runoff from the significant ungauged tributaries may be as input into the Mike 11 model.

Under conditions of data scarcity, as prevalent in the Crocodile River catchment at that time, large uncertainties in the model set up were present. The calibrations indicated that the model performed suitably during the winter months, but failed to correctly simulate the summer hydrological pattern. This is a disappointing shortcoming of the existing model setup. However, the impact of this is largely minimized by the four data assimilation locations in the main Mike 11 model. However, this shortcoming requires further investigation. Other hydrological models and/or improved data inputs should be investigated and evaluated for their possible improvements to the rainfall runoff modelling. Greaves et al., (2009) recommended the improvement of the current and forecasted rainfall input data into the model.

Figure 35: Quinary catchments used in the Crocodile NAM model (Greaves et al., 2009).

Mike 11 Lagging and Restriction Model:

The MIKE 11 model is initiated by Mike Customised in 3 stages, an initial stage to calculate the required initial release from Kwena Dam, an optimisation routine (using AUTOcal) to modify the release to an optimal level, and a second optimisation routine to change the water user restriction if required. Once these processes have finished the information is imported into the system and then published. The process followed is shown in Figure 36.

A key output of the model is forecasted flow up to 7 days into the future as shown in Figure 37. Unfortunately, a calibration of the Mike 11 outputs conducted against observed flow by Greaves et al. (2009) showed that the volume differences between observed and simulated flows were large at certain gauges. Possible causes of this include poor water use data at the time and poor rainfall runoff (NAM) model performance, which performed suitably during the winter months, but failed to correctly simulate the summer hydrological pattern correctly. Consequently, low confidence was given to the forecast data beyond 3 days. This is hampering the forecasting of flows in the AORMF. The forecasting of flows up to seven days into the future is an important aspect of the AOWRMF as it is needed to assist the CROCOC stakeholders to make informed operational decisions, since there is a lag of about 4 to 7days from any releases made from Kwena Dam until the flow arrives at the Mozambican border (refer to Figure 37). It is possible that improved data, better calibrations or even different rainfall-runoff models may improve the situation. This must thus be investigated further. However, no comparison between various models could be made during the study period as the Mike 11 and NAM models were the only models available that could be automated and run in real time, and this is a requirement of any real time operational modelling framework.

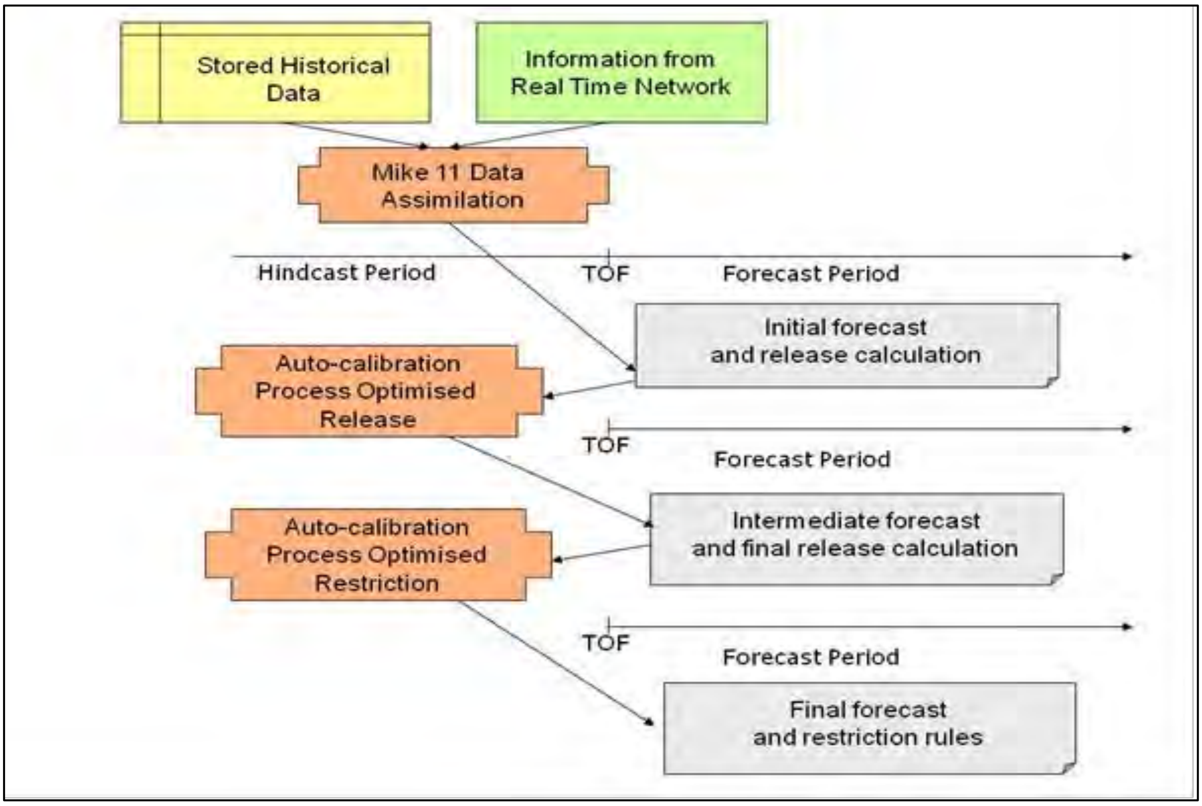


Figure 36: Illustration of the process followed by the Mike 11 model for the short term modelling (Greaves et al., 2009).

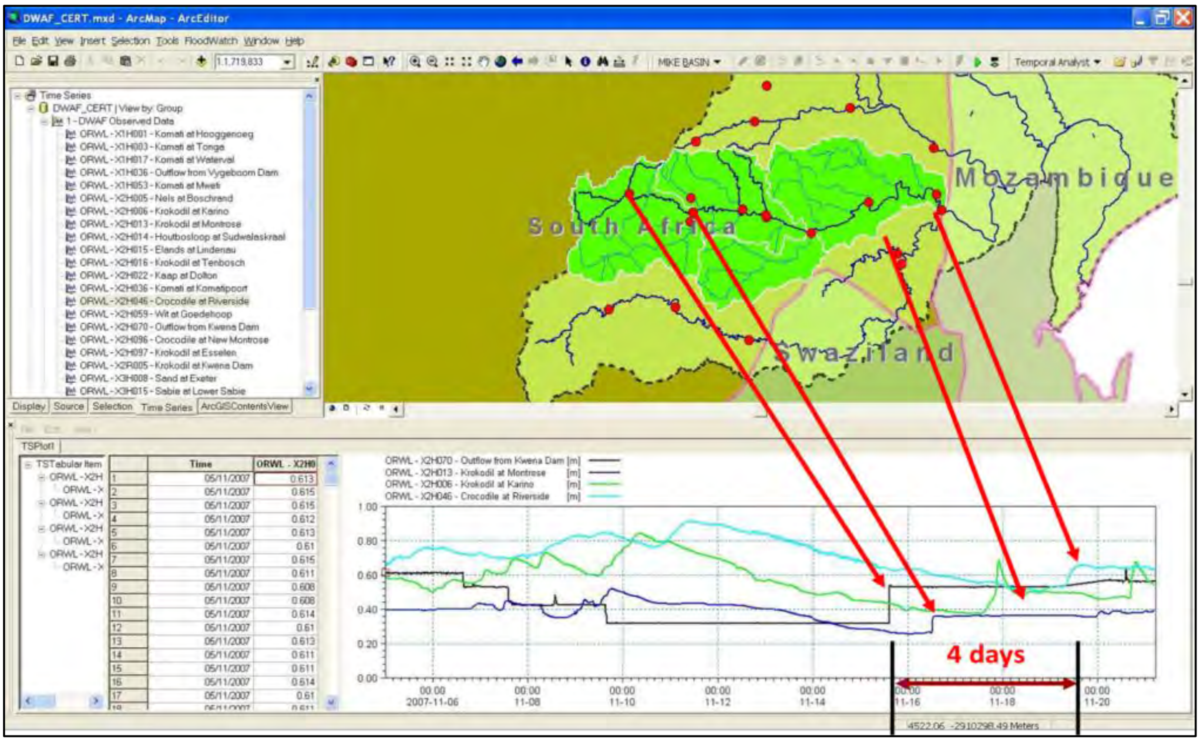


Figure 37: Illustration of a forecasted flow scenario output from Mike 11 showing the flow lag between Kwena Dam and Mozambique.

Through this study, two recommendations stemming from the DWA project WP 9429 have been implemented, supported by the CROCOC stakeholders. They are the installation of more real time rainfall gauges in the catchment and the upgrade of several tributary river flow gauging stations with telemetry to collect and transmit data in real time. The recommendations from that project also stated that "…during the operation of the DSS more helpful information may be identified. It is possible that such information could easily be added to the system". This has since been done through the water user information needs survey and incorporated where relevant.

Results of the Real Time Implementation of the Ecological Flow Requirements:

The strategic adaptive management cycle associated with ecological flow requirements (Mcloughlin et al., 2011) highlighted the need to implement real time operations as a prerequisite to implementing the ecological flow requirements. Thus, the proposed AOWRMF (Figure 42) and the adaptive management cycle associated with ecological flow requirements have been linked together through the rapid response system *(*)*.

(*) Refer to section 4.3.1. "The Rapid Response System".

Social Aspects:

The first few meetings of the CROCOC showed that the effective determination and implementation of the ecological flow requirements were the main concern and source of conflict amongst the stakeholders in October 2009 when the AOWRMF was first proposed. Prior to the commencement of the CROCOC and AOWRMF, no ecological flows were being implemented even though international and ecological flow requirements have the highest priority of supply in terms of the NWA. In fact, the implementation of the ecological flow requirements has not been achieved in the vast majority of South African rivers. This lack of implementation of the ecological flow requirements was a serious cause for concern for the KNP at the time.

As a result of this concern, a specific meeting between the KNP and the researcher (also in his capacity as the relevant manager at the ICMA) was held in November 2009 to discuss the implementation of the ecological flow requirements. The main outcomes from that meeting were:

1) There is an important need to incorporate the ecological flow requirements in the modelling system or DSS at the ICMA.
2) Decisions concerning actual implementation (what % over time for example) will have to be taken at relevant stakeholder forums and the CROCOC is a suitable forum for that.
3) The modelling system provides the technical tools for disseminating all necessary information. However, a decision making process is required (This process has been developed and implemented into the AOWRMF as part of this study).
4) It was agreed by all to do away with the outdated DWA in-stream flow requirements approach (DWAF, 2002b) and to start using the new ecological flow requirements benchmarks stemming from the DWA comprehensive ecological reserve determination study (DWA, 2010b) for selected water resources in the Inkomati, Mpumalanga.

These concerns and outcomes were then presented and discussed at the CROCOC meetings with all stakeholders between October 2009 and June 2010, when they were incorporated into the final TOR for the CROCOC. It took a further 2 years and rigorous discussions until October 2011 before an effective and trusted real time ecological flow requirement determination method and related decision making process was finally implemented at the ICMA. The minutes of the CROCOC meetings during this period (of which only the first meeting is included as APPENDIX F) bear testimony to the level of conflict and the resultant discussions that took place on this topic. The eventual resolution of the conflict by consensus demonstrates the importance of facilitated discussion amongst all stakeholders (via CROCOC in this case) on matters of conflict and the time it can take to achieve consensus, but that the result can be much improved trust and ability to implement the decision. It further demonstrates that the use of a consensus based approach in dealing with issues of conflict can be effective.

It must be noted that ecological flow requirements are defined in terms of both water quantity and water quality related parameters (DWA 2010b). In this study, implementation has been centred on the river flow quantity aspects of the ecological flow requirements only as this was the area of concern for all the stakeholders involved. The CMS (ICMA, 2010b) showed that the water quality of the Crocodile River was generally acceptable and the stakeholders were consequently less concerned about the water quality aspects. The implementation and evaluation of the water quality aspects of the ecological flow requirements is thus beyond the scope of this thesis.

Technical Aspects:

Other reasons for the delay in the implementation of the ecological flow requirements were of a technical nature. Although methods for estimating the flow regime required to ensure ecological sustainability of rivers have been developed over the last few decades and applied widely in Southern Africa, the crucial aspect of ensuring that these ecological flows are implemented in practice had received relatively little attention at the time *(*)*.

(*) Refer to section 1.2.3. "Learning from the Implementation of Ecological Flow Requirements".

Some of the issues present at the commencement of this AOWRMF study in 2009 included:

1) In South Africa, the ecological flow requirements are defined as a function of the natural flow which, because the natural flow in a system is not known at any point in time, causes difficulty with real time implementation (Pollard et al., 2011) thereof. Methods developed and applied to date in Southern Africa entailed setting up real time hydrological models to estimate natural flows given real time rainfall data. However, accurate real time rainfall data is lacking in many catchments (Pollard et al., 2011).
2) Ecological flow requirement determination methods are undertaken without consideration of the realities of operationalising these. The outputs of the determination studies need to be 'translated' into operational ecological flow requirements. The lack of consideration of the operational realities in the comprehensive ecological flow requirement determination results available from DWA are demonstrated through the presentation of results in the form of percentage exceedance curves of flows per month. Firstly, these exceedance curves are difficult for most stakeholders to understand; secondly, the monthly time step is not sufficiently short for near real time operational water management and thirdly, it is not possible to determine what the actual ecological flow requirement at any point in time is without first determining the natural flow at that point in time. A process is thus required to calculate the percentile of the natural flow against historical statistics at present day and to then use that percentile to determine the relevant position on the exceedance curve for the ecological flow and finally, the actual ecological flow requirement for the present day. This is especially troublesome if the ecological flow requirements are required to support operational near real time water resources management when forecasted natural flow is required,

as is the case in the Crocodile River. None of the above processing was in place in October 2009, when the AOWRMF was first introduced.

3) At the final steering committee meeting of the DWA ecological reserve study, it was decided to maintain the "present day flow" regime in the Crocodile River and not to implement the recommended ecological flow requirement as defined by DWA. This decision was taken because the stakeholders did not trust the results of the study. They were not properly consulted during that study and felt that according to their experience, the flows required for the recommended ecological flow requirements were a lot higher than what they observed to be occurring in the system and thus, too high. The DWA ecological reserve study did show that the current ecological status of the river was the same as the recommended ecological flow requirements, so the stakeholders could not understand why the current flow regime could not just be maintained. It did not make common sense to them that the recommended ecological flow requirements were now much higher than the observed flows, even though the current and recommended ecological flow requirement classes were the same. What "present day flow" actually meant on a daily basis was not determined. The learning to be taken from this is that stakeholders must be involved in a project if they are to accept the results and that there is a lot of value to be gained by incorporating the management knowledge of stakeholders and managers, none of which was done in the DWA ecological reserve study.

As a result of these issues, it was necessary to develop an effective methodology to calculate the ecological flow requirements in near real time. A number of studies have been conducted to investigate methods to implement the ecological flow requirement in real time using real time naturalisation (Hughes et al., 2008; Mallory, 2010; Pollard et al., 2011). However, the lack of real time data to drive such models is a serious shortcoming (Hughes et al., 2008).

Due to the lack of sufficient real time rainfall information at the time the author, in his capacity as the responsible manager in the ICMA, appointed IWR Water Resources through the technical support contract put in place during the AOWRMF implementation to develop a method to compute real time naturalisation and ecological flow requirements without the need for accurate real time rainfall data. This method uses real time observed river flows, dam levels and estimates of water use (all available) to calculate the natural flow in real time as shown below:

$\text{Natural flow}_t = \text{Observed flow}_t + \Sigma\text{Wateruse}_t + \Delta\text{Storage}$

Where t refers to a time interval rather than a point in time.

A further issue was the need to determine the "present day flows" described in the DWA comprehensive ecological flow requirements determination project. This was done by Mallory (2010) on request of the author (in his capacity as the responsible manager in the ICMA). The WReMP long term model in the Crocodile DSS was used to simulate the natural flow using an 85 year long natural record to produce a long record of "present day flows". These flows represent the flows that would have occurred if the current water use in the catchment had always been there. These "present day flows" were compared to the original ecological flow requirements stemming from the DWA project (Figure 38) and presented to the CROCOC stakeholders for discussion and adoption.

Discourse on the final ecological flows to be used took place over many months at the CROCOC. The initially calculated "present day flows" included high flow requirements (Figure 38) while the C-class ecological flow requirement from the DWA project was only determined for low flow ecological requirements. Thus the low exceedance end of the curve was higher for the "present day flows" ecological flow requirement but lower for the high exceedance end of the curve. Consensus was eventually reached on the use of a new recommended ecological flow requirement that is a combination of the lower of the "present day flows" and the DWA C-class ecological flow requirement as shown in Figure 38. This consensus emerged due to discussions at the CROCOC amongst all stakeholders, mainly as a result of the fact that the Crocodile River is strongly seasonal, as shown in Figure 18, and the constraints on meeting the ecological flow requirements are suspected to be greatest in the low flow/dry winter months.

Consensus was also reached on the implementation of the ecological reserve at the downstream end of the catchment at the DWA X2H016 Tenbosch flow gauging site only (Figure 11). This decision was taken for ease of implementation, since the ecological reserve implementation has only been operationalised for the main stem of the Crocodile River, based on the assumption that if the downstream ecological flow requirements were met then the upstream sites would also be met. This assumption may not be correct and does not hold for any tributaries. Further research is needed if the ecological flow requirements for the tributaries are to be implemented.

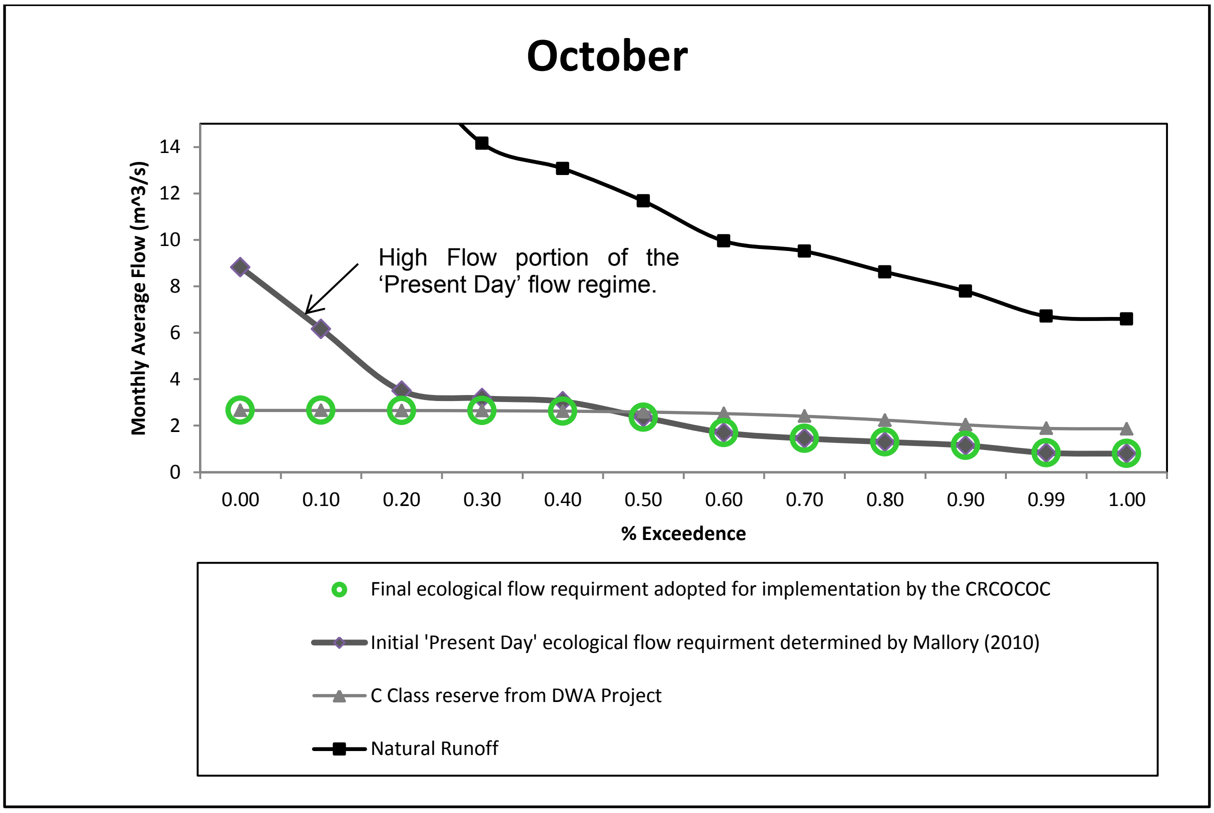


Figure 38: Present day flows EFR vs. DWA C-class EFR and the natural flow for the month of October at the X2H016 gauging station.

The model determines the real time natural flow and then calculates the agreed "present day flow" regime based ecological flow requirement by reading the current natural flow off the relevant monthly exceedance curve, followed by the corresponding ecological flow for the same percentage exceedance. The method is demonstrated in Figure 39.

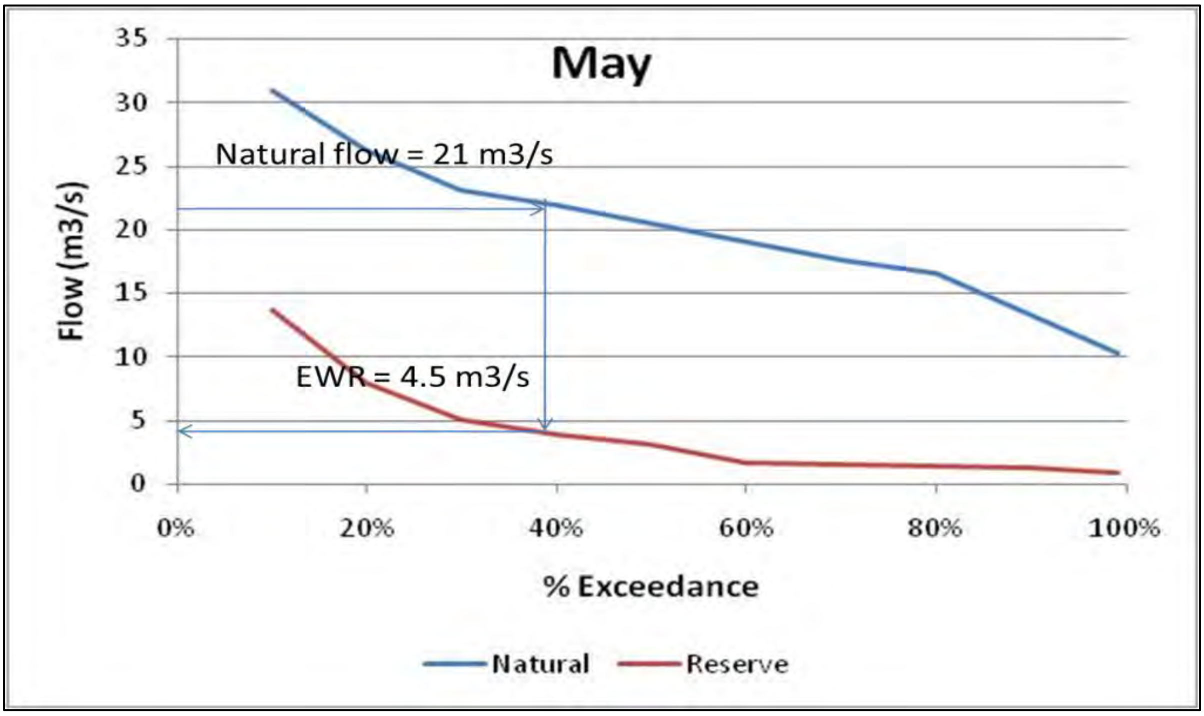


Figure 39: Illustration of the process to determine the EWR from the natural flow (Mallory, 2010).

The model is run on a weekly basis as this was agreed by all stakeholders to be the best time step for the implementation of the ecological flow requirements in the Crocodile River. This is mostly due to the approximately 7 day lag time for releases from the Kwena Dam to reach the Tenbosch gauging station during low flow periods, making it unfeasible to adjust flow releases on a daily basis.

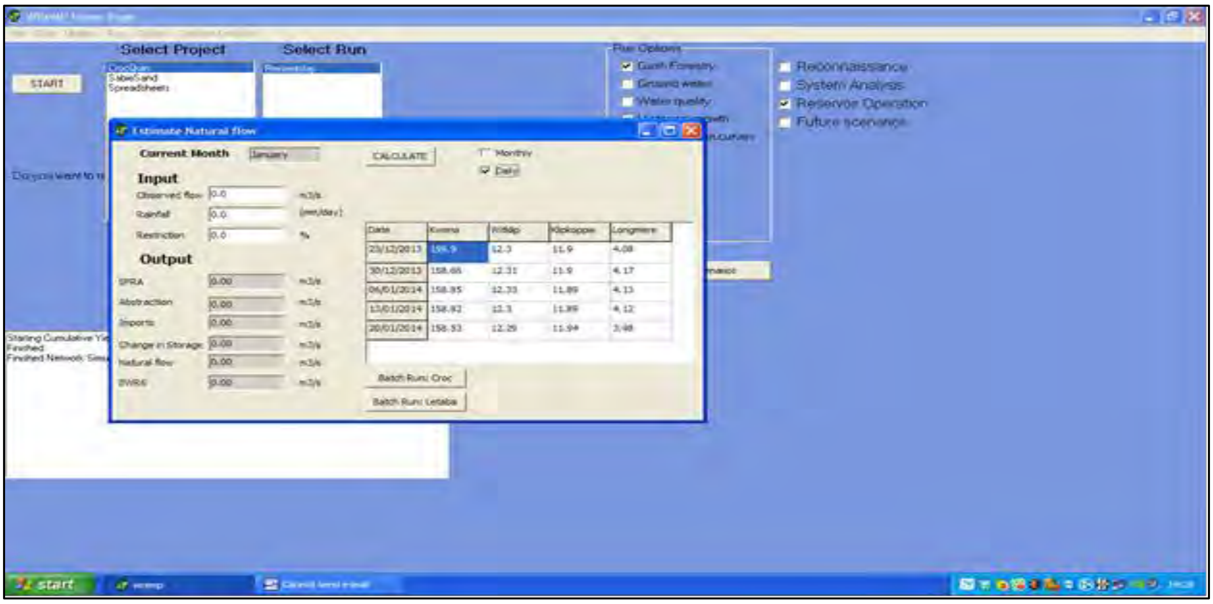


Figure 40: A screenshot of the WReMP model used to calculate the weekly EWR.

A screenshot of the user interface developed for the WReMP model used to calculate the weekly ecological flow requirements is shown in Figure 40.

The outputs from the WReMP model used to calculate the weekly ecological flow requirements at the DWA X2H016 Tenbosch flow gauging site are sent to all relevant CROCOC stakeholders via email as a spreadsheet in the format shown in Figure 41. This spreadsheet forms a critical aspect of the rapid response system and feedback loops of the AOWRMF (Figure 42) and is used by the KNP to monitor river flow compliance against the ecological flow requirements and notify stakeholders when the various worry levels are reached (the worry levels were developed by the KNP and agreed to by the CROCOC). The implementation and effectiveness of the rapid response system and feedback loops associated with the ecological flow requirement is thus reliant on the short term operations aspects of the AOWRMF and the Mike Customised DSS. This process is supported and monitored through the management logbook shown in Table 9.

Date	Observed daily flow	Forecasted 7 Day Reserve	% Reserve Target	IIMA	CRMIB	Full Reserve is % of IIMA	Full Reserve is % of CRMIB	Target Reserve is % of IIMA	Target Reserve is % of CRMIB	-40.0%	-20.0%	-5.0%	5.0%	20.0%
Monday, August 23, 2010	9.4	3.07	20.0%	0.9	1.2	341.1%	255.8%	68.2%	51.2%	1.8	2.5	2.9	3.2	3.7
Sunday, August 29, 2010	6.9	2.52	20.0%	0.9	1.2	280.0%	210.0%	56.0%	42.0%	1.5	2.0	2.4	2.6	3.0
Monday, September 6, 2010	0.6	2.52	20.0%	0.9	1.2	280.0%	210.0%	56.0%	42.0%	1.5	2.0	2.4	2.6	3.0
Monday, October 25, 2010	12.8	2.61	20.0%	0.9	1.2	290.0%	217.5%	58.0%	43.5%	1.6	2.1	2.5	2.7	3.1
Monday, November 1, 2010	13.0	4.04	20.0%	0.9	1.2	448.9%	336.7%	89.8%	67.3%	2.4	3.2	3.8	4.2	4.8
Thursday, November 11, 2010	22.7	4.05	20.0%	0.9	1.2	450.0%	337.5%	90.0%	67.5%	2.4	3.2	3.8	4.3	4.9
15 November 2010	16.8	4.05	20.0%	0.9	1.2	450.0%	337.5%	90.0%	67.5%	2.4	3.2	3.8	4.3	4.9
22 November 2010	14.3	4.04	20.0%	0.9	1.2	448.9%	336.7%	89.8%	67.3%	2.4	3.2	3.8	4.2	4.8
Monday, November 29, 2010	31.2	4.05	20.0%	0.9	1.2	450.0%	337.5%	90.0%	67.5%	2.4	3.2	3.8	4.3	4.9
Monday, December 6, 2010	37.3	4.05	20.0%	0.9	1.2	450.0%	337.5%	90.0%	67.5%	2.4	3.2	3.8	4.3	4.9
Monday, December 13, 2010	29.5	5.65	20.0%	0.9	1.2	627.8%	470.8%	125.6%	94.2%	3.4	4.5	5.4	5.9	6.8
Tuesday, December 21, 2010	66.0	5.71	20.0%	0.9	1.2	634.4%	475.8%	126.9%	95.2%	3.4	4.6	5.4	6.0	6.9
Tuesday, January 4, 2011	54.1	5.71	20.0%	0.9	1.2	634.4%	475.8%	126.9%	95.2%	3.4	4.6	5.4	6.0	6.9
Tuesday, January 11, 2011	90.8	8.19	20.0%	0.9	1.2	910.0%	682.5%	182.0%	136.5%	4.9	6.6	7.8	8.6	9.8
Monday, January 17, 2011	141.3	8.21	20.0%	0.9	1.2	912.2%	684.2%	182.4%	136.8%	4.9	6.6	7.8	8.6	9.9
Monday, January 24, 2011	169.8	8.22	20.0%	0.9	1.2	913.3%	685.0%	182.7%	137.0%	4.9	6.6	7.8	8.6	9.9

Description of headings:
Forecasted 7 Day reserve: The average forecasted ecological flow requirement in m3/s for the week ahead.
%Reserve Target: No longer applicable.
IIMA: Interim Inco Maputo Agreement (The minimum flow in m3/s to meet the international obligations).
CRMIB: Crocodile River Major Irrigation Board (The minimum flow in m3/s to meet the international obligations and CRMIB needs downstream of Tenbosch gauging station).
-40%, -20%, -5%, 5%, +20%: These are the flows in m3/s related to the worry levels defined for the ecological flow requirements.

Figure 41: Extract of the weekly EWR spreadsheet emailed to all relevant CROCOC stakeholders.

The KNP also present the level of compliance to each CROCOC meeting in the format shown in Figure 27.

Discussions at the CROCOC indicated that the actual river health status should be monitored to ensure that the ultimate goal of maintaining the present ecological status of the river is met, since merely monitoring the compliance of observed flows against an estimated ecological flows requirement is not sufficient to evaluate whether the river health is actually being maintained by the calculated ecological flows. Consequently, the researcher (in his capacity as the relevant manager at the ICMA) entered into agreements with the KNP and the Mpumalanga Tourism and Parks Agency on the ongoing biological and river health monitoring of the river. A copy of the MOA with KNP is shown in APPENDIX S. The results of these studies are presented and discussed at the CROCOC once a year.

Through these agreements, a new river health and bio-monitoring methodology that will incorporate strategic adaptive management principles is being investigated. The outcomes of that investigation will be incorporated into the AOWRMF in future when it is finalised.

4.3. THE FUNCTIONAL STRATEGIC ADAPTIVE MANAGEMENT PROCEDURES FOR THE ADAPTIVE OPERATIONAL WATER RESOURCES MANAGEMENT FRAMEWORK

Section 4.2 detailed the requisite understanding and knowledge, per component, deemed necessary to conduct operational water resources management during the development of the AOWRMF. However, the AOWRMF also required the implementation of operational water resources management in a manner that reflects SAM but is still functional. This section documents the implementation of the AOWRMF and the procedures, structures and approaches required.

As indicated in the methodology, the AOWRMF is based on and complements the pragmatic strategic adaptive management cycle *(*)* developed by Mcloughlin et al. (2011) and is guided by the generic SAM framework developed by Pollard and du Toit (2007). It is the outcome of over four years of deliberation, action research and development in collaboration with the CROCOC stakeholders and is shown in Figure 42.

(*) Refer to section 1.3.3. "Strategic Adaptive Management" for information on strategic adaptive management and adaptive planning.

SAM consists of 3 main phases: adaptive planning, adaptive management and adaptive evaluation *(*)*. At the commencement of this study, the ICMA CMS had recently been concluded. It included the adaptive planning aspect of SAM for IWRM within the Inkomati. The outcome consisted of a vision, objectives and management options of which "Consolidated Systems for Integrated Planning and Operations of River Systems" was one of the priority management options identified for implementation. Thus, the adaptive planning aspects for the AOWRMF developed in this study (namely the vision, objectives and management options) were already provided through the CMS process and the relevant information for the adaptive planning portion of the AOWRMF was merely transferred into the AOWRMF and documented.

The adaptive management and adaptive evaluation aspects of the AOWRMF documented in Figure 42 are the outcome of the action research process conducted with the CROCOC stakeholders over four years and indicate the main actions and task per each of the four OWRM components for every stage of the strategic adaptive management cycle.

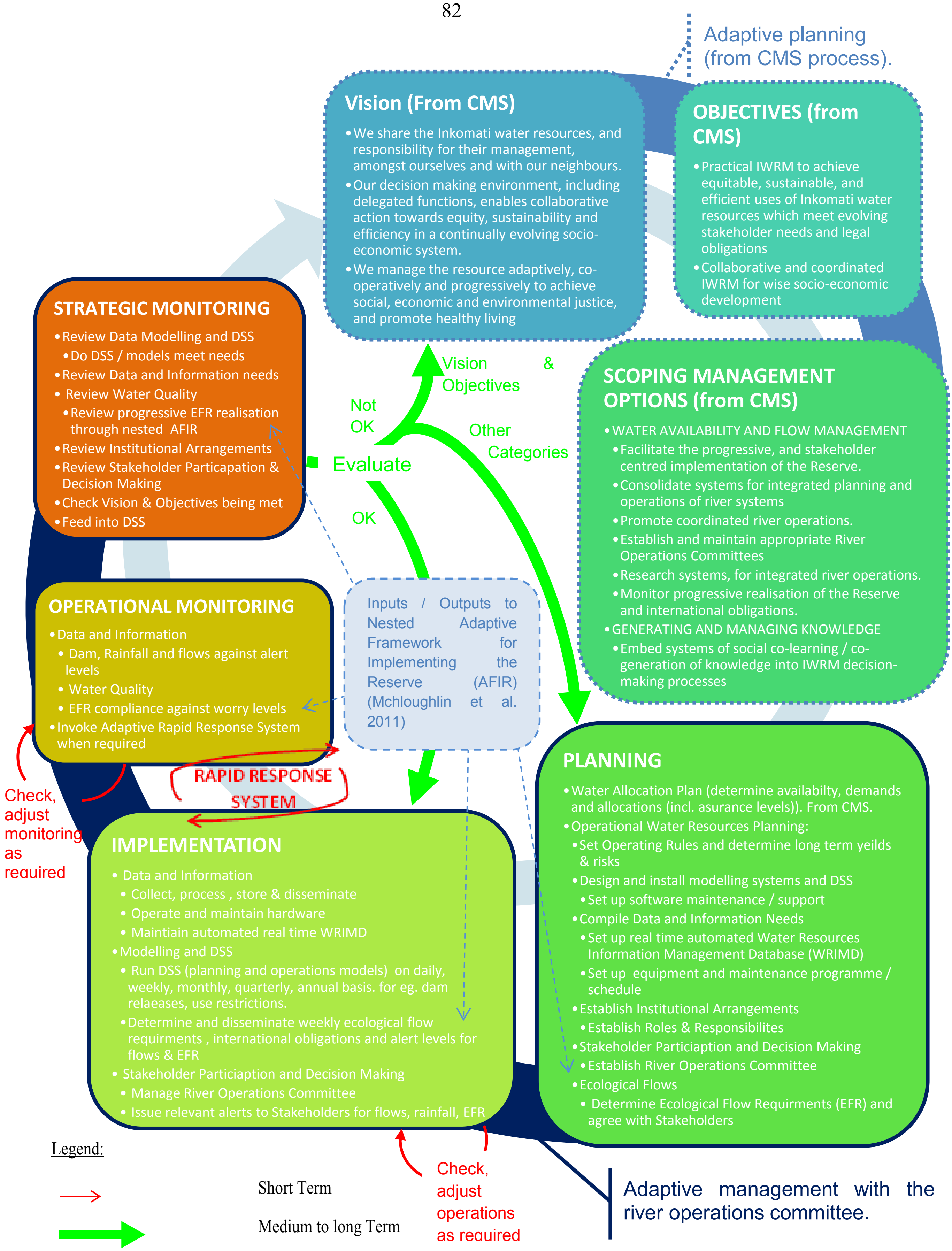


Figure 42: The functional adaptive operational water resources management framework for the Crocodile River developed to implement operational water resources management in a manner that reflects strategic adaptive management; incorporating the planning and management phases of strategic adaptive management, feedback loops, operational implementation & monitoring through a rapid response system and strategic monitoring (Activities and tasks relevant to each phase of this framework are documented per the four OWRM components).

4.3.1. The Rapid Response System

Learning and understanding gained from the literature review, and in particular from the pragmatic SAM cycle associated with the ecological flow requirements developed by Mcloughlin et al. (2011), led to the development and implementation of a rapid response system (RRS) under which to conduct the short term aspects of the adaptive management component of SAM. The RRS is in effect merely a descriptive name for the implementation of the short term aspects of the adaptive management phase of SAM for the Crocodile River.

A workshop with the KNP was held in November 2009 to discuss their thresholds of potential concern (TPC) and associated feedbacks relating to ecological sustainability and related flow requirements. At the meeting it was agreed that a direct link between the ICMA and the KNP associated with the monitoring and implementation of ecological flows was required. This meeting laid out the foundations for the RRS for ecological flows in the Crocodile River consequently developed by Mcloughlin et al. (2011) (Figure 6).

Through the deliberations of the CROCOC *(*)* it quickly became apparent that the RRS for ecological flows developed by Mcloughlin et al. (2011) should be expanded for use in operational water resources management as a whole, since the implementation of the ecological flow requirements is intrinsically linked to operational water resources management.

(*) Refer to section 4.2.2. "Stakeholder Participation and Decision Making" for detail of these deliberations.

The RRS within the AOWRMF (Figure 42 and Table 8) thus evolved to cater for both OWRM and the implementation of ecological flow requirements and also incorporates various aspects of the four OWRM components described in this thesis. It requires a real time data, the use of a DSS and simulation models as well various stakeholders, roleplayers and institutions and assists in enabling the operational implementation and monitoring phases of the AOWRMF to stimulate quick and relevant actions on the river operations, based on various defined alerts.

Thus, the RRS is the core around which the adaptive management phases of the AOWRMF are conducted for the Crocodile River and is also the key enabler of short term feedback loops as highlighted in the literature review. The RRS has also evolved to become a core enabler of openness and inclusivity in the immediate short term (day to day), as the CROCOC established to achieve much of the social objectives only meets monthly and can thus not be used for day to day short term decision making. The committee can thus not ensure that the short term operations meet the social objectives and the RRS fills this gap.

The various components of the rapid response system are shown below in Table 8:

Table 8: The components of the RRS.

Collection and dissemination of real time rainfall, runoff and dam level information through email and a web portal.
Calculation and dissemination of short term forecasted rainfall, runoff and dam levels (weekly, but updated daily).
Determination of monthly alert levels for river flows based on international obligations and historical statistics and dissemination of the current real time information vs these alert levels.

Determination of worry levels for the ecological flow requirements.
Calculation and dissemination of the weekly forecast ecological flow requirements vs the worry levels.
Automated emails and sms delivery to relevant stakeholders linked to the alert and worry levels.
Management log of all alerts and related actions, available for all.
Link to longer term aspects of the AOWRMF through the presentation of the logbook and short term monitoring results at CROCOC meetings at least once a year.

Further detail of these various aspects required for the RRS to function effectively are presented per relevant OWRM component in sections 4.2.1 to 4.2.4 on institutional arrangements, stakeholder participation and decision making, data and information and modelling and decision support systems.

An extract of the management logbook – which is an aspect of the RRS- during the dry season in 2013, is shown in Table 9.

This logbook is populated by various stakeholders and maintained by the ICMA. It is presented to the CROCOC to enable the stakeholders to be aware of the alerts and related actions being taken between meetings in terms of the RRS. The management logbook highlights the existence of feedback loops within the RRS. The management logbook is currently an offline spreadsheet. It has been recommended by all CROCOC stakeholders that the management log should evolve into an online logbook that can be populated by all relevant stakeholders and viewed by anyone at any time.

Table 9: Extract from the RRS management logbook during the dry season of 2013.

Date and issue	**Request from**	**Manage-ment Options**	**Manage-ment Action**	**Result**
29 May 2013 Crocodile River flow decrease to Low worry level	Sanparks	Investigate Flow readings	Verification of Datalogger data	ICMA initiated discussions and investigations. The problem was a faulty reading at the gauging weir. This was recalibrated and resolved the issue.
5 June 2013: The flow at Komatipoort doesn't add up to Crocodile and Komati Contributions. ICMA loggers differ from DWA loggers	CRIMB: Willie		Verification of Datalogger data	The malfunctioning logger was fixed by the ICMA on the 5th of June along with 5 other faulty loggers through an emergency maintenance contract.

5 June 2013: River flows are slowly decreasing	CRMIB:	Contact Irrigators	Restrictions	CRMIB: 5th June 2013, irrigation abstraction hours on the Crocodile River were limited to 120 hours per/week from 5 June 2013, 17 hours/day over 7 days, Mondays to Sundays, both sides of the river.
7 August 2013: Crocodile River at Ten Bosh is now starting to flow in the Low worry zone	Sanpark s	Contact Irrigators	Inform Stakeholders	See action by CRMIB below.
8 August 2013: Crocodile River at Ten Bosh is now starting to flow in the Low worry zone	CRMIB	Contact Irrigators	Restrictions	CRMIB: From Monday 12th August 2013 until further notice, hours of abstraction of irrigation water by irrigators on the Crocodile River are limited to 84 hours per/week, 12 hours/day over 7 days, Monday to Sunday, both sides of the river
12 August	Croc Canoe Club	Notify CROCOC members	Inform Stakeholders	Croc Canoe Club request 6 cumecs for Crocodile Cnoe marathon on 12 and 3 October 2013. ICMA notified relevant stakeholders of this request.
23 August 2013: SANPARKS noted that the Crocodile River at Ten Bosh flow dropped to the high worry zone	CRMIB	Contact ICMA and DWA	ICMA, requested William Matsabe at DWA Kwena	2.0 cumecs was added to the minimum flow release of 0.5 cumecs to increase release to a total of 2.5 cumecs
3 September 2013.	CRMIB	Contact ICMA and DWA	ICMA, requested William Matsabe at DWA Kwena	Flow release increased from 2.5cumecs to 3.0cumecs
16 September 2013. Due to extreme hot weather forecast for Wednesday 18 September 2013, the CRMIB requested a further release of 1cumec	CRMIB	Contact ICMA and DWA	ICMA, requested William Matsabe at DWA Kwena	The ICMA in consultation with the CRMIB decided to increase the release to 4.5cumecs; as a result of the river dropping to low worry levels for the ecological flow requirements and the weather forecast for very hot conditions.

25 Sep 2013 Crocodile River flowing in low worry level at 2.1 cumec. reserve = 2.28 cumec	1. Contact DWA / ICMA 2. Inform River manager	Inform ICMA	ICMA	Faulty Gauge readings discovered. Reading Rectified. However, ICMA found that the gauging station appears to be sending odd readings not consistent with any fluctuations recorded at Riverside and Karino upstream. The ICMA believes that there may be a blockage into the well inlet. DWA hydro requested to investigate and remove the blockages if found.

5. EVALUATION OF THE ADAPTIVE OPERATIONAL WATER RESOURES MANAGEMENT FRAMEWORK

Section 4 documented the results and discussions of the components and associated knowledge (and Figure 15) required to conduct operational water resources management as well as the procedures, structures and approach required to implement an adaptive operational water resources management framework in a manner that reflects strategic adaptive management but is still functional.

This section documents the evaluation of whether the AOWRMF developed and implemented enabled effective operational water resources management. Section 5.1 covers the social evaluation for the institutional arrangement and the stakeholder participation components of the AOWRMF. Section 5.2 covers the technical evaluation of the AOWRMF by comparing the compliance with the ecological flow requirements before and after the commencement of the proposed AOWRMF. Section 5.3 covers an evaluation of the data, information, modelling and decision support systems components of the AOWRMF.

Subjectivity:

Before evaluating the AOWRMF itself, it is necessary to first assess whether the issue of subjectivity was sufficiently minimised during the development and evaluation processes.

It is suggested that the use of a river operations committee as part of the methodology to bring together the researcher and the stakeholders in the participatory action research process undertaken enabled participant observation to be included in the evaluation and the subjective understanding of any one actor to be sufficiently transcended. The use of a consensus based participatory decision making process with the river operations committee and the frequent, focused discussions undertaken over a sufficiently long period (more than four year) also helped to foster the openness and trust required for the development of the framework to evolve, thereby further contributing to the reduction in subjectivity (the social evaluation in Table 10 indicates that a high level of consensus was achieved).

Furthermore, the use of a social learning questionnaire to facilitate participant observation and thereby evaluate the perceptions of the river operations committee stakeholders on the effectiveness of the AOWRMF as well as the scientific evaluation of the ecological flow requirements before and after the implementation of the AOWRMF as the indicators of effectiveness were both designed to reduce the influence of the researcher, or any one actor, in the evaluation and consequently any subjective influence of the researcher on that evaluation. Susskind and Cruikshank (1987) point out that it is far more important that a process is perceived as fair by the parties involved than for example by an abstract analyst and the social questionnaire was thus designed to establish whether the stakeholders did indeed perceive the process as fair (refer to section 5.1 below for detail on the evaluation).

5.1. SOCIAL EVALUATION OF THE ADAPTIVE OPERATIONAL WATER RESOURES MANAGEMENT FRAMEWORK

The social evaluation of the effectiveness of the AOWRMF included an evaluation of the suitability of the institutional arrangement established to support AOWRM as well as the assessment of a social questionnaire developed and provided to all the members of the river operations committee.

5.1.1. Institutional Arrangements

All stakeholders involved in operational water resources management through the river operations committee (CROCOC) now have a common understanding of the institutional arrangements as they were all involved in the development of and reached consensus on the institutional arrangements shown in Figure 16. This is reinforced by the outcomes of the questionnaire on social learning presented in section 5.1.2. Figure 16 incorporates decentralisation of relevant responsibilities all the way from national level to the local level, clear indication of the relevant OWRM institutions and their roles, focused decision making and implementation around OWRM through the CROCOC, feedback loops to the greater IWRM requirements through the Crocodile River forum link, the rapid response system and operational implementation and monitoring.

The institutional arrangements described above have established the ICMA as the central responsible authority for OWRM. The social learning evaluation described in section 5.1.2 and Table 10 shows that all the respondents to the questionnaire unanimously agree that the ICMA is the legitimate institution under which AOWRM should be conducted. The evaluation of the fostering factors for social learning in Table 10 also demonstrate that the respondents generally agree that the ICMA is providing the necessary delegated leadership, has a high level of commitment and is an independent technical mediator.

5.1.2 Stakeholder Participation and Decision Making

CROCOC:

During the implementation of the AOWRMF, the river operations committee, or CROCOC, was established by the ICMA as the central consultative technical advisory body for operational water resources managed by the ICMA and provides the mechanism for interaction, exchange of operational information and coordination of operational activities and decisions for the Crocodile River catchment. The committee also formed the body with which the participatory action research process was conducted. The stakeholders involved in the process were thus the members of this committee, and were chosen by the stakeholders themselves during the establishment of the committee. More detail on this process to identify the membership of the committee is given in section 4.2.2.

The committee enabled the researcher to form bridges between the domains of science, management, and societal values and to investigate the lived complexity between scientific, social and management approaches. Those tasked with managing complex systems often complain that science delivers fragmented information that is not useful at the scale of implementation (Roux et al. 2006). This was evidenced in the CROCOC as the initial presentations on the modelling and DSS aspect of AOWRM by the specialists were poorly understood. It took numerous repeated presentations and extensive discussions over at least one year to obtain a requisite level of understanding of this aspect amongst most stakeholders. The extensive discussions over the technical implementation of the ecological flows at the CROCOC are further evidence of the difficulties faced in obtaining understanding of the technical and scientific aspects amongst the stakeholders and in translating scientific information into understandable information for decision making and practical implementation. However, the social learning outcomes discussed in Table 10 and APPENDIX G have reinforced the general trust that the stakeholders now have in the ICMA as a competent technical body to manage the technical aspects of AOWRM and this has enabled much progress on the implementation of AOWRM, which it is suggested would not have been achievable without the existence of the CROCOC. As a result of this learning, it is recommended that the technical and scientific aspects of AOWRM should be presented, discussed and updated at least once every year.

It is submitted here that the awareness creation discussed above has assisted greatly in establishing the legitimacy of the CROCOC as the relevant stakeholder consultative body for operational water resources management.

Consensus Based Participatory Decision Making:

Social Learning has been defined as achieving concerted action in complex and uncertain contexts and situations (Ison and Watson, 2007). A questionnaire was developed for the stakeholders of the CROCOC to evaluate the social learning, participation and participatory decision making aspects of the AOWRMF. It was based on a combination of the criteria of Susskind and Cruikshank (1987), National Round Table on the Environment and the Economy (1993); Samson-Sherwill (2006), Pahl-Worstl and Hare (2004) and Mostert et al. (2007) discussed in the literature review and it is shown in APPENDIX G.

The questionnaire was sent to all core and advisory level CROCOC members (CROCOC has 36 members in total, of which 15 are core members, 15 are advisors and 6 are observers). The stakeholders were asked to provide a score for each question with a score of 5 indicating that they strongly agree, 1 that they strongly disagree and 3 neutral. They were also provided with the opportunity to make comments on each question.

Ten stakeholders responded and their responses and comments are shown in APPENDIX G. This is a third of the members of the CROCOC. The evaluation may thus not be fully representative of all the stakeholders. However, those that did respond were the stakeholders that consistently attend and represented a spread of the main sectors involved in OWRM including the CRMIB, KNP, DWA and consultants. They did indicate their concerns with the lack of attendance by other members as reflected in the results. My assessment of the CROCOC meetings has been that the main source of concern and conflict has been the ecological flow requirements and the implementation thereof. As a result, the stakeholders most interested in that particular issue are consequently the same stakeholders that consistently attend the CROCOC and who also responded to the questionnaire. One of the ten guiding principles of consensus processes (National round table on the environment and the economy, 1993) is that they should be purpose driven and the implementation of the ecological flow requirements has been the main purpose of the CROCOC. It is thus argued that the results of the questionnaire do still offer a good indication of the effectiveness of the CROCOC and associated AOWRM as well as the social learning that took place. After all, social learning is defined as achieving concerted action in complex and uncertain contexts and situations, and the successful implementation of the ecological flow requirements is most definitely viewed as having achieved concerted action.

The results are summarised, discussed and interpreted in Table 10. Please refer to APPENDIX G for the full results of the questionnaire and the actual comments from the respondents as well as the full wording of the questions. Only the minimum and average respondent scores to the questions are shown in Table 10 and it is thus important that APPENDIX G is also referred to. An average score of higher than three indicates that respondents are in general agreement, while a minimum score below three indicates that some respondents do not agree with the general consensus.

Table 10: Evaluation of the social learning, stakeholder engagement and participatory decision making associated with the implementation of the AOWRM through the CROCOC (based on 10 respondents).

Criteria	**Asses-ment scores: Min; & Avg.**	**Interpretation (Refer to APPENDIX G for the actual comments of the respondents).**	**Scientific Source of Criteria**
KEY CAPACITIES FOR SOCIAL LEARNING			
FAIRNESS:	3; 4.2	The stakeholders generally agree that the CROCOC meetings have allowed good stakeholder interaction and discussions that are fair, but feel that power players have more influence and certain sectors are missing.	Susskind and Cruikshank (1987) & Samson-Sherwill (2006)
WISDOM: competent decisions based on all available relevant information	3; 4.1	The stakeholders agree that decisions taken use all available information and are competent. Some feel that there is always more information that could augment decisions. All information needs were agreed to by the stakeholders and are included in the TOR for the CROCOC. Some of these needs must still be included into the AOWRMF. The web portal is an important further source of information needs over that provided at the CROCOC and the ICMA has prioritised the WRIMD and information management associated with it to ensure ongoing wisdom.	
WISDOM: Consensus in Decision Making?	4; 4.5	The CROCOC TOR specifically indicates that decision will be taken through consensus and respondents strongly agree that this is generally happening as such. However, certain stakeholders tend to participate in decisions more	

		than others and improved inclusivity of some stakeholder groups is necessary (especially municipalities and DWA).	
STABILITY:	2; 3.5	The ICMA have enthusiastically supported SAM in their CMS and strategic planning as well as the AOWRMF development and are the relevant institution to facilitate the processes. Most key stakeholders regularly attend the CROCOC and partake in the rapid response system and stakeholders are happy that the system is relatively stable, but believe that the next drought will be the first real test of stability.	
SENSE OF OWNERSHIP:	4; 4.4	Respondents indicate a high sense of common need and thus ownership on the issue of OWRM.	Samson-Sherwill (2006)
CAPACITY BUILDING / LEARNING:	2; 3.8	The CROCOC has provided for much capacity building through the involvement of the specialists, who have presented on the functioning of various aspects on many occasions. However, some respondents indicate that this requires more focus and ongoing learning.	
INCLUSIVITY: sufficiently allows for other peoples perspectives	4; 4.2	Certain stakeholder groups do engage and air their perspectives more than others, especially the CRMIB and the KNP and much of the deliberations in the CROCOC are centred on these two stakeholder groups. This is mainly due to the ecological flow requirements being the main issue of conflict and is thus not only due to any particular style of engagement. The other users have generally expressed their happiness with the CROCOC as a platform that allows them to air their views and perspectives. Certain stakeholder groups do not attend regularly, especially the municipalities and DWA.	
AWARENESS:	3; 3.9	The CROCOC pamphlet produced by the ICMA and CROCOC has created general awareness of the OWRM functions amongst the greater water users. The presentation of summarised outcomes from the CROCOC to the greater IWRM centric CRF, built into the institutional arrangements, reinforces this. Respondents are generally happy with the level of awareness but some feel that certain sectors may have hidden agendas that CROCOC is not aware of. There is also concern that the CROCOC may be too focused and could be at risk of isolating itself. This must be carefully managed and monitored in the future to ensure it does not happen.	Pahl-Wostl and Hare (2004)
AWARENESS OF SYSTEM COMPLEXITY:	3; 4	Respondents generally agree that they are aware of the concept but one respondent indicated that nobody can claim to be fully aware of complexity. The ICMA has adopted SAM and has been transparent about its reasons	

		for doing so, one of which is because of system complexity. Presentations were made about the complexity of WRM during the CMS process of the ICMA and at the initial CROCOC meetings. These should be repeated annually to ensure ongoing awareness.	
SHARED PROBLEM IDENTIFICA-TION:	3; 3.8	The CROCOC meetings have allowed rigorous debate about the OWRM problem and the implementation of the real time DSS and linked operating rules amongst the stakeholders and created a very good shared understanding of the problem. For example, it allowed progress to be made on the implementation of the ecological flow requirements through fostering a common understanding of an agreed ecological flow requirement to be implemented.	
INTERDEPEN-DENCE BETWEEN STAKEHOL-DERS:	2; 3.5	This is especially true between the KNP, CRMIB, DWA infrastructure branch and ICMA who all fully understand their interdependence relating to the management of flows and the operation of the DSS to implement the water users needs and ecological flow requirements. The various roles and responsibilities to enable this are understood by these parties and they are working well together through the established rapid response system and CROCOC. However, the municipalities do not see this same level of interdependence. Improved understanding of the various current stakeholder "responsibility areas" as well important absent stakeholders (i.e. Municipalities) may create improved interdependence with those absent sectors.	
LEARNING TO WORK TOGETHER:	3; 4.2	The development of the real time DSS to support the implementation of the ecological flow requirements and establishment of the CROCOC to allow opportunities to discuss its implementation created the environment in which the KNP and CRMIB have learnt to work together on this matter when they were previously unable to agree. However, municipalities do not attend and are an omission. This may be improved based on awareness and understanding through capacity building. It is important to include the missing stakeholders in the process in future.	
RELATION-SHIPS: formal Relationships	3; 3.8	The institutional arrangements diagram in the TOR for the CROCOC indicates the formal relationships. These are clear and well understood by all. There are also formal maintenance and support contract in place between the ICMA and the relevant software and hardware providers around the DSS and the data collection hardware. All persons hosting rainfall gauges have MOA's with the	

		ICMA. However, the formal relationship amongst absentee sectors such as the municipalities are not in place. A formal relationship with Ara-Sul in Mozambique is missing and deemed necessary in future, especially for flood warning. An informal relationship does exist though.	
RELATION-SHIPS: informal relationships	3; 3.6	There are active informal relationships around the ecological flow requirement and day to day decision making on restrictions and flow releases from Kwena Dam between the ICMA, DWA infrastructure branch, KNP and CRMIB. Also between the ICMA and Ara-Sul in Mozambique regarding high flow alerts. However, the informal relationship amongst absentee sectors such as the municipalities are not in place.	
TRUST:	3; 4.1	Respondents generally agree that the level of trust is good. However, some show concern about the absence of municipalities and possible unstated agendas as well as towards the powerful CRMIB. Nonetheless, trust has grown significantly since the inception of the CROCOC. The first year of operations involved lengthy debates around the implementation of the ecological flow requirements due to mistrust, especially between the KNP and CRMIB. The level of cooperation and trust around the ecological flow requirements has improved since to such a degree that there is sufficient trust shown between the individual stakeholders and the ICMA to implement the determined ecological flow requirements, but still some level of mistrust between some individual stakeholders. However, steady progress is being made in this regard using the CROCOC and the CRF, and the rapid response system has further enabled large gains in trust though the feedback loops and openness it creates for the ecological flow requirements at least.	
KEY FOSTERING FACTORS FOR SOCIAL LEARNING			
ONGOING HIGH MOTIVATION:	3; 4	The river operations division of the ICMA enthusiastically runs the DSS and chairs the CROCOC. Most stakeholders regularly attend the CROCOC and the rapid response system is working well. However, motivation is a function of various factors; such as the amount of water allocated to stakeholders. If the allocation is low, motivation to attend and participate is low. Suspicion of hidden agendas amongst absent sectors reduces motivation.	Mostert e al (2007)
INDEPENDENT TECHNICAL MEDIATOR:	4; 4.8	Respondents strongly agree. The ICMA plays the vital role of coordinating all the different components of OWRM, runs the DSS, collects and disseminates all	

		information and chairs the CROCOC and generally drives all the processes. They are seen as independent and objective by all stakeholders and have shown the technical ability to mediate effectively.	
HIGH COMMITMENT OF LEADERS:	3; 4.1	DWA have not delegated all functions to the ICMA and there thus remains some uncertainty over their high level commitment to the ICMA as the pivotal role player in ensuring effective OWRM. However, respondents indicate that there is excellent commitment from the ICMA management itself.	
LEGITIMACY:	5; 5	Respondents unanimously agree that the ICMA and CROCOC are the legitimate institutions to provide the outlets for promoting and achieving AOWRM as an effective method for OWRM, as the correct (accepted by the stakeholders) institutional arrangements are in place and the feedback loops are in place.	
EXCHANGE OF INFORMA-TION:	3; 4	This is achieved through sms, email, the web portal and the CROCOC meetings and is effective, but some feel it could be broadened further. The absence of actual irrigated water use from the CRMIB is seen as a serious omission in information sharing.	
INCLUSIVITY (ABILITY TO CONTRIBUTE	2; 3.9	Respondents feel that only those stakeholders who actually attend are able to contribute and that some sectors do contribute more than others. The absence of certain sectors is thus an issue.	Samson-Sherwill (2006)
DELEGATED LEADERSHIP:	3; 4	The roles and responsibilities between the ICMA and the Irrigation Board, DWA infrastructure branch, KNP and water users is clearly understood. However, some delegations must still be given to the ICMA from DWA and the replacement of the Irrigation Boards with WUA's will also require revised delegations. All thus agree that the relevant institutions are identified in policy but sufficient delegations to them have not yet taken place.	Susskind and Cruikshank (1987)
NUMBER OF PARTICIPANTS:	3; 4	The CROCOC has enabled in depth deliberations and discussions with ample time to debate the important issues around OWRM because only the relevant stakeholders are involved through membership invitation. This membership was debated at length during the formation of the CROCOC and both the CROCOC stakeholders and greater water users in the Crocodile River catchment consequently agree that the CROCOC is properly represented. Some feel that inclusivity may be compromised. However, the link to the greater IWRM CRF is meant to cater for this greater inclusivity.	Mostert et al. (2007)

FREQUENT, FOCUSED DISCUSSION:	3; 3.8	The CROCOC meetings were initially monthly and are currently quarterly. The higher frequency was initially required while common understanding and trust were still being built around the many issues. There has been in depth deliberations and discussions with ample time to debate the important issues around OWRM Some feel that the present quarterly frequency is insufficient. This should thus be reviewed at the CROCOC.	
EFFICIENCY:	3; 4.1	Respondents agree that AOWRM in the Crocodile River catchment is efficient in achieving decisions but also feel that this will only really be known during the next drought.	Susskind and Cruikshank (1987)
KEY HINDERING FACTORS FOR SOCIAL LEARNING			
INADEQUATE TIME AND RESOURCES:	3; 3.9	The ICMA as well as all roleplayers currently have sufficient time and resources, as evidenced by the effective operations of the CROCOC and DSS.	Mostert et al (2007)
LACK OF FEEDBACK OF OUTCOMES:	4; 4.2	Good feedback loops are in place through the rapid response system and CROCOC as well as through the feedback loop to the CRF.	
RELATION-SHIP BETWEEN STAKEHOL-DERS AND TECHNICAL TEAMS:	3; 4.2	The ICMA has maintenance and support contracts in place with the specialists who have developed the DSS and operating rules and they regularly attend the CROCOC meetings through these contracts. There are thus good relations between the stakeholders and technical teams.	
OVERLY TECHNICAL LANGUAGE:	2; 3.1	Some of the language is technical in nature as the operations of the DSS is technical in nature. However, the CROCOC has allowed much of these technical issues to be presented and allowed sufficient time for discussion and understanding. The ecological flow requirements implementation is also not well understood due to its technical nature. The CROCOC creates space for this to be discussed.	
LACK OF CLARITY ON PROJECT AIMS:	3; 4	The ICMA CMS vision, strategic action programs and strategic plans along with the TOR of the CROCOC provide good clarity on the key aims	
CONFLICT IN SCALE OF PROJECT AND STAKEHOLDE	3; 4.1	The scale of the project has been adjusted over time through inputs facilitated by the CROCOC. For example, the weekly decision time step for the ecological flow requirements and the methodology to determine it have	

R INTEREST:		both been implemented due to stakeholder inputs. The inclusion of water quality monitoring information has also been due to stakeholder requirements. However, several stakeholders would like the OWRM to be expanded to include other river systems and tributaries.	
LACK OF OPENNESS:	4; 4.1	Respondents generally agree that there is sufficient openness.	
CONSENSUS BASED DECISION MAKING			
PURPOSE DRIVEN:	4; 4.6	There is strong agreement amongst stakeholders that the CROCOC is very purpose driven.	Round Tables of Canada
INCLUSIVE:	3; 4.0	All stakeholders agree that the relevant degree of inclusivity is in place through the CROCOC TOR and its link to the CRF but in reality the absence of certain sectors hinders the inclusivity somewhat.	
VOLUNTARY PARTICIPA-TION:	3; 4.3	Respondents feel that they participate voluntarily, but the absent sectors are a concern.	
SELF DESIGN:	2; 3.6	Respondents feel that the design of the consensus based decision making process was done mostly by the ICMA as the champion but that the stakeholders have bought into the process nonetheless.	
FLEXIBILITY:	3; 3.8	Respondents are uncertain as the flexibility is still to be tested through a drought, but feel that there is great potential.	
EQUAL OPPORTUNITY:	3; 4	Respondents feel that this is largely dependent on being a regular attendee. Some feel that certain sectors wield more power.	
RESPECT FOR DIVERSE INTERESTS:	2; 3.8	Some feel that major water use sectors have more say but most respondents feel that there is a requisite level of respect in place.	
ACCOUNTA-BILITY:	3; 3.9	Although a high level of agreement is shown in the scores, comments indicate that the respondents are uncertain about whether parties are accountable or not. This would indicate that they believe they are but are not convinced.	
REALISTIC DEADLINES:	4; 4.2	Respondents indicate a high level of agreement that deadlines for decision making are realistic.	
IMPLEMEN-TATION:	3.5; 4.4	The respondents indicate a high level of agreement on the implementation of AOWRM and ongoing monitoring thereof.	

The assessment of the responses to the questionnaire conducted in Table 10 indicates that social learning is fairly well established in the AOWRM of the Crocodile River. The average scores of the respondents indicate a high level of agreement as they are all above 3. This highlights the importance of the CROCOC for enabling effective AOWRM and its value in fostering social learning and consensus based decision making. In fact, it is suggested that its existence and effective functioning is critical to effective AOWRM.

The CROCOC has also facilitated the cooperation of stakeholders in achieving their shared objectives documented in the TOR of the CROCOC, since they have been part of deriving management decisions. This is an important achievement as people do not readily support decisions or policies they have not been involved in creating.

Although the CROCOC deliberations highlighted the difficulties in obtaining understanding of the technical and scientific aspects associated with the modelling and DSS portions of AOWRM, it also highlighted that frequent, focused discussions amongst relevant stakeholders can facilitate sufficient understanding and enable effective implementation of AOWRM.

Furthermore, Some of the criteria for social learning evaluated in Table 10 are comparable to some of the preconditions to social learning provided by Proost and Leeuwis (2007) shown in section 1.3.1.2. All but preconditions 1) and 3) are comparable to a social learning criteria in Table 10. It is thus inferred that most of these preconditions to social learning exist within the operational water resources management of the Crocodile River and the CROCOC to an acceptable degree (the average of all the scores was above 3).

It must be noted that there is scope for further investigation, understanding and evaluation of stakeholder participation, consensus based decision making and social learning in the context of adaptive operational water resources management as a recent response by Reed et al. (2010) to the works of Pahl-Wostl (2006), Ison and Watson (2007) and Mostert et al. (2007) amongst others argues that the definitions of social learning are so broad they could encompass almost any social process and that social learning as a concept is frequently confused with the conditions or methods necessary to facilitate social learning, such as stakeholder participation. However, further exploration is not within the scope of this thesis.

The absence of certain sectors, chiefly the municipalities, has been highlighted as the main issue of concern that must be addressed. The absence of water use information from the CRMIB is another main cause of concern to be addressed.

5.2. TECHNICAL EVALUATION OF THE ADAPTIVE OPERATIONAL WATER RESOURES MANAGEMENT FRAMEWORK.

The technical evaluation of the AOWRMF was done through the assessment of the compliance to the ecological flow requirements before and after the implementation of the AOWRMF.

5.2.1. The Implementation of the Ecological Flow Requirements

The results of the lengthy process undertaken to implement the ecological flow requirements in real time have highlighted the importance of facilitated discussion amongst stakeholders (via CROCOC in this case) on matters of conflict and the time it can take to achieve consensus. However, the result is much improved trust and ability to implement decisions. This is supported by the social questionaire outcomes where the stakeholders confirm that there is a high degree of trust.

As discussed under section 4.2.4, subsection “Results of the Real Time Implementation of the Ecological Flow Requirements”, the implementation of the ecological flow requirements is reliant on the short term operations aspects of the AOWRMF. Furthermore, the effective determination and implementation of the ecological flow requirements was the main concern and source of conflict amongst the stakeholders when the AOWRMF was first proposed as no ecological flows were being implemented prior to commencement. During the formation of the AOWRMF, the implementation of the ecological flow requirements was thus a key issue for the CROCOC stakeholders and compliance with the ecological flow requirements was thus used as the main means of evaluating the effectiveness of the AOWRMF from a technical perspective.

Compliance to the ecological flow requirement can be seen in two ways, as described by Pollard et al. (2011) and Riddell et al. (2013). That is:

1) Current, or real time compliance, in order that managers may take immediate action through regulation and enforcement.
2) Historical compliance. This is important for the strategic monitoring and adaptive planning aspects of the AOWRMF.

Furthermore, the ecological flow requirements are described in terms of water quantity and water quality related parameters. In this study, implementation has been centred on the river flow quantity aspects of the ecological flow requirements and compliance was only measured in term of river flow quantity. The water quality aspects will be monitored through the strategic monitoring aspect of the AOWRMF at future CROCOC meetings and is supported by the agreements between the ICMA, the KNP and the MTPA.

Item 1) is managed through the rapid response system in the AOWRMF, where the ecological flow requirements vs. observed flows are provided to the KNP, who monitor the compliance against defined worry levels and notify relevant stakeholders when worry levels are reached. Relevant actions are then taken and everything is written to a management logbook (Table 9) that is discussed at the CROCOC meetings. This real time compliance is monitored by the KNP as shown in Figure 27. This aspect was initiated in October 2010 and has been fully implemented since October 2011 and appears to be effective in monitoring the near real time compliance in operationalising and implementing the ecological flow requirements. The improvement in the compliance to the ecological flow requirements as shown in Figure 43 since then confirms this.

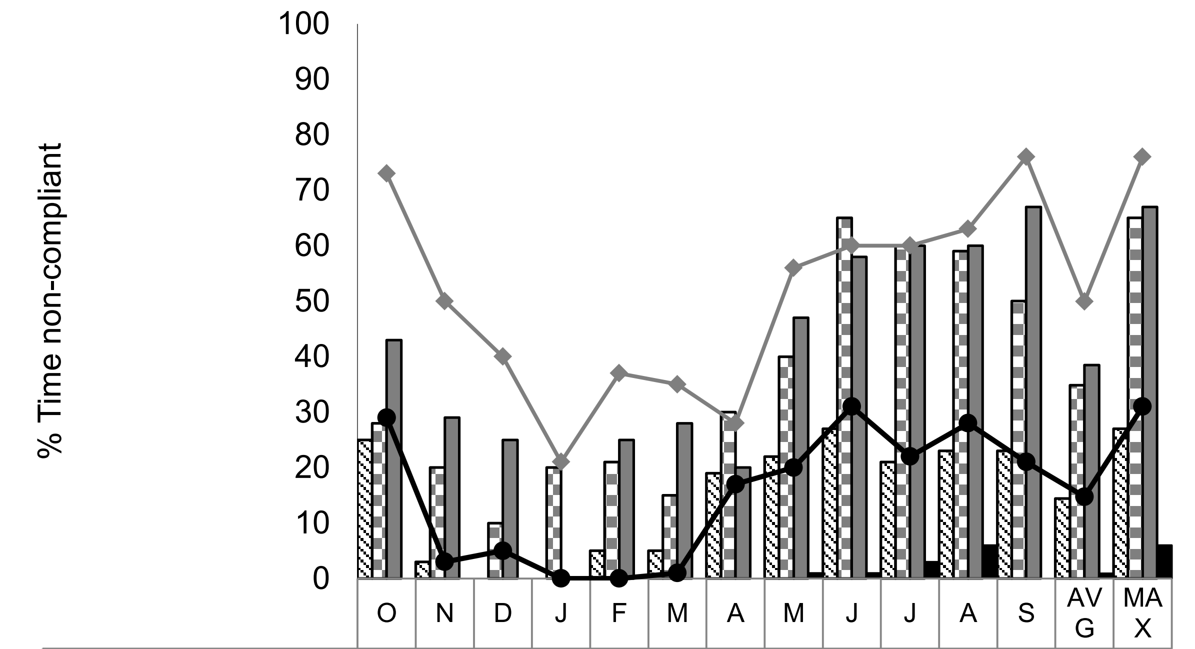
An initial methodology to assess historical compliance (item (2) above) in the Crocodile River was developed by Pollard et al. (2011) and later refined by Riddell et al. (2013). This methodology has already been used to evaluate the historical compliance in the Crocodile River up to October 2009. The same methodology has thus been applied in this project to evaluate compliance for the period from October 2009 (when the AOWRMF was first introduced) to January 2014 in order to ensure consistency in the evaluation methodology from previous research. Support towards the suitability of this method for the Crocodile River is provided by Riddell et al. (2013) who stated " …The study uses the Crocodile River, in north-eastern South Africa as a test case, since this particular system is at the forefront of implementing Integrated Water Resource Management (IWRM) principles in the country. It is anticipated that this analysis would provide valuable IWRM context for management of the river when moving into advanced stages to operationalise IWRM practices in the system."

The methodology of Riddell et al. (2013) and consequently, the methodology used in this project, determines the extent of non-compliance in terms of four categories described and discussed later in this section.

The DWA C-class ecological reserve has been used as the ecological flow requirement for evaluation during the period after October 2009 in this study to ensure further consistency when comparing the results from this study after October 2009 with the results from the research of Riddell et al. (2013). However, the more lenient "present day flow" requirement has actually been implemented since October 2009 and not the DWA C-class ecological reserve. The use of the "present day flow" requirement for evaluation would demonstrate further improved compliance than the results presented here as they are lower.

1) Percentage of time non-compliant:

The results shown in Figure 43 indicate a marked increasing trend in the percentage of time of non-compliance from 1960 up to 2010 with the average incidence of failure across all months being 14%, 35% and 39% for the periods 1960-1983, 1983-2000 and 2000-2010 respectively. However, the average incidence of failure across all months since 2010 is only 1% with the maximum being 6% during August. This is a dramatic improvement.



	O	N	D	J	F	M	A	M	J	J	A	S	AVG	MAX
Monthly 1960 - 1983	25	3	0	0	5	5	19	22	27	21	23	23	14	27
Monthly 1983 - 2000	28	20	10	20	21	15	30	40	65	60	59	50	35	65
Monthly 2000 - 2010	43	29	25	0	25	28	20	47	58	60	60	67	39	67
Monthly 2010 - 2013	0	0	0	0	0	0	0	1	1	3	6	0	1	6
Daily 2000 - 2010	73	50	40	21	37	35	28	56	60	60	63	76	50	76
Daily 2010 - 2013	29	3	5	0	0	1	17	20	31	22	28	21	15	31

Figure 43: Percentage of time observed flow non-compliant to the EWR before and after the implementation of the AOWRMF (monthly and daily average flows).

Figure 43 also shows that the percentage time of non-compliance is much lower when comparing monthly average flows as opposed to daily average flows. Although it is possible to calculate the natural flow and hence the ecological flow requirements on a daily basis for use in the rapid response system, it is suggested here that it is more appropriate to use monthly data for the evaluation of historical compliance as the ecological flow frequency distribution curves developed by DWA are based on monthly average flows and the model used to calculate the natural flow at any point in time is a monthly time step model.

2) Total number of months in which non-compliance occurred for each year:

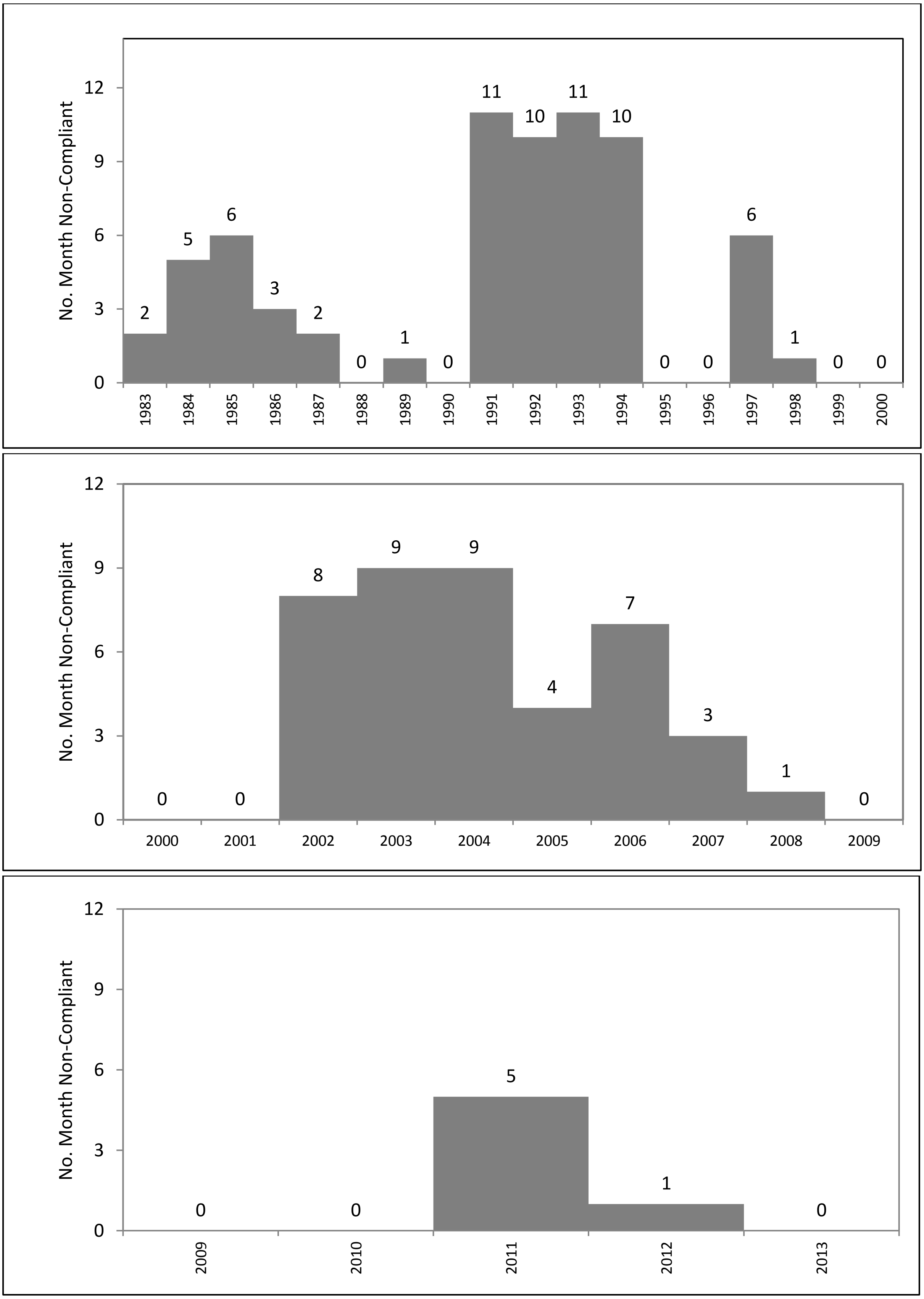


Figure 44: Number of months of non-compliance of observed flow to the EWR per year for 3 periods: 1983-2000; 2000-2010; and 2010-2014.

Analysis of Figure 44 reveals a drastic reduction in the number of months of non-compliance per year since October 2009, demonstrating significantly reduced incidences of non-compliance. The maximum number of months of non-compliance in any one year since October 2009 is 5 during the 2011 hydrological year (commencing October 2011). This is a lot lower than the previous periods of 1983-2000 which included some years with 11 months of non-compliance and 2000-2010 which included some years with 9 months of non-compliance.

3) Magnitude and contiguity of non-compliance:

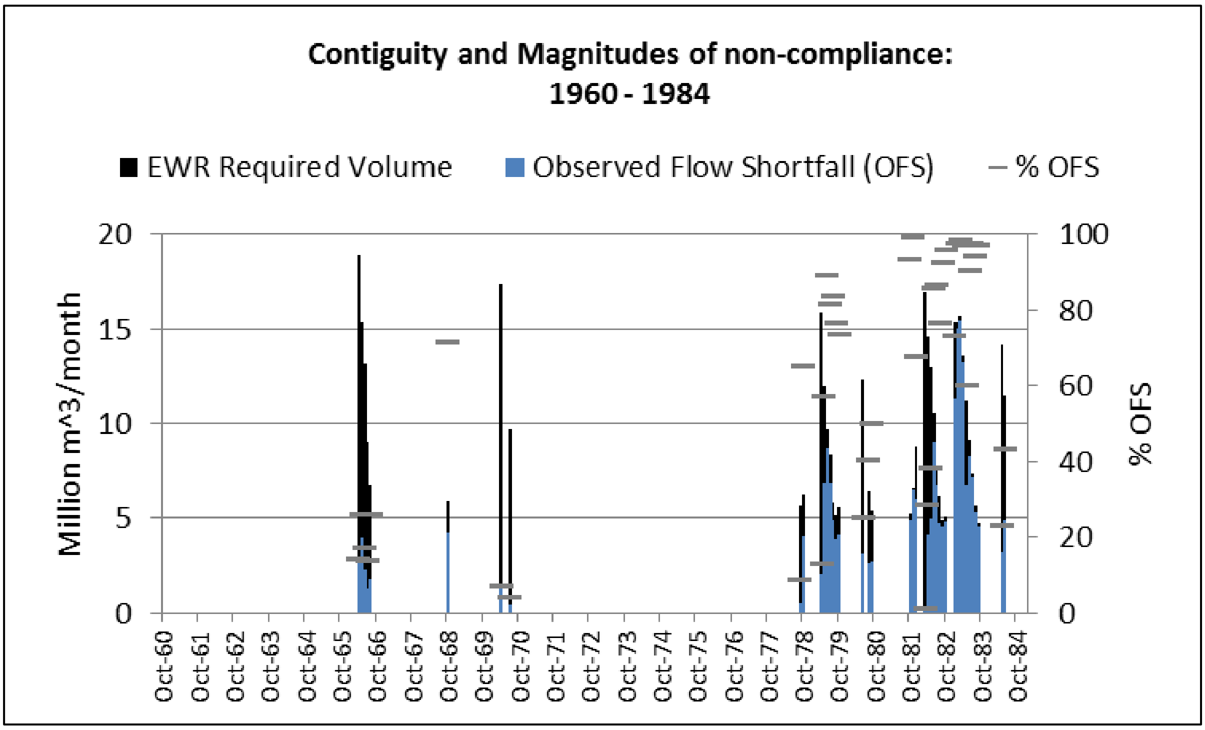


Figure 45 (a).

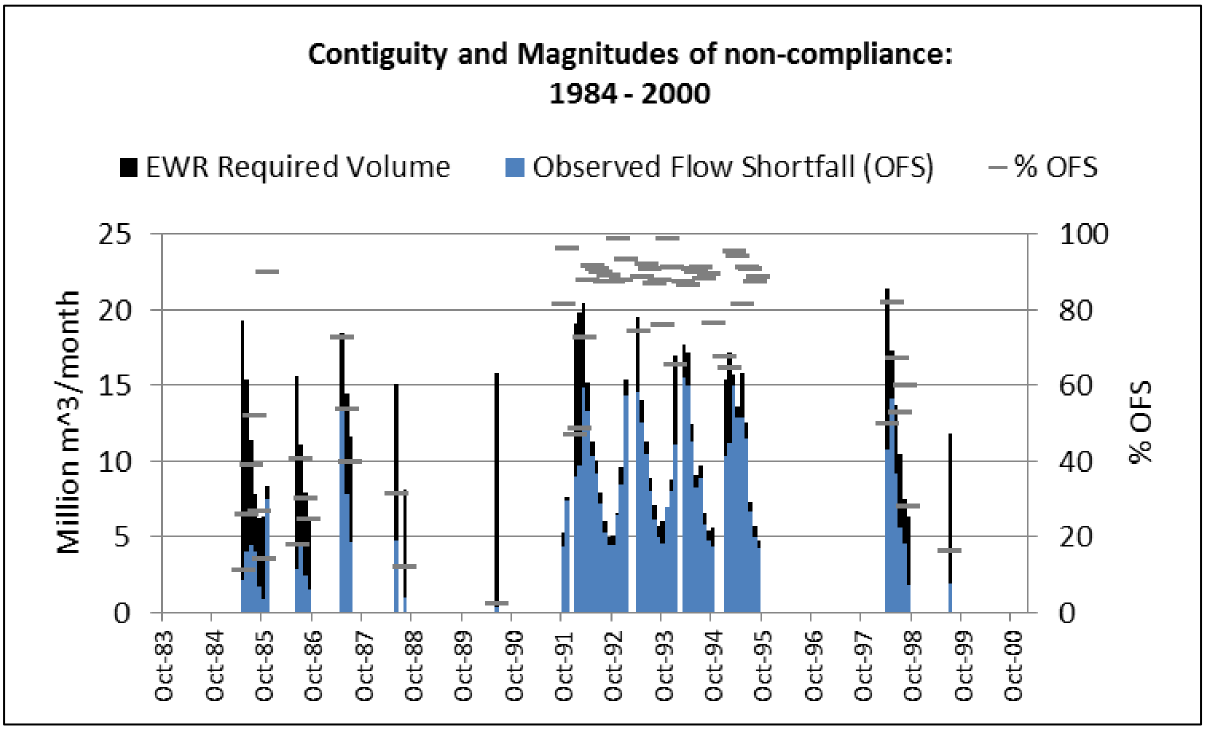


Figure 45 (b).

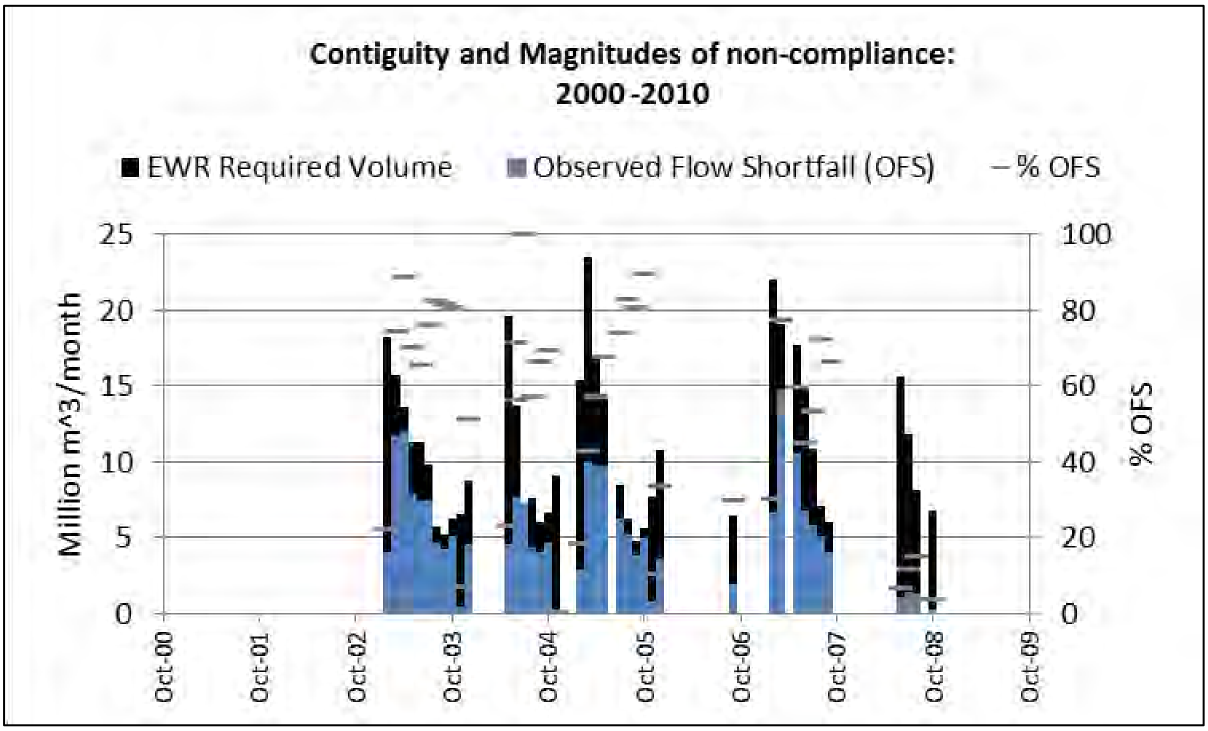


Figure 45 (c).

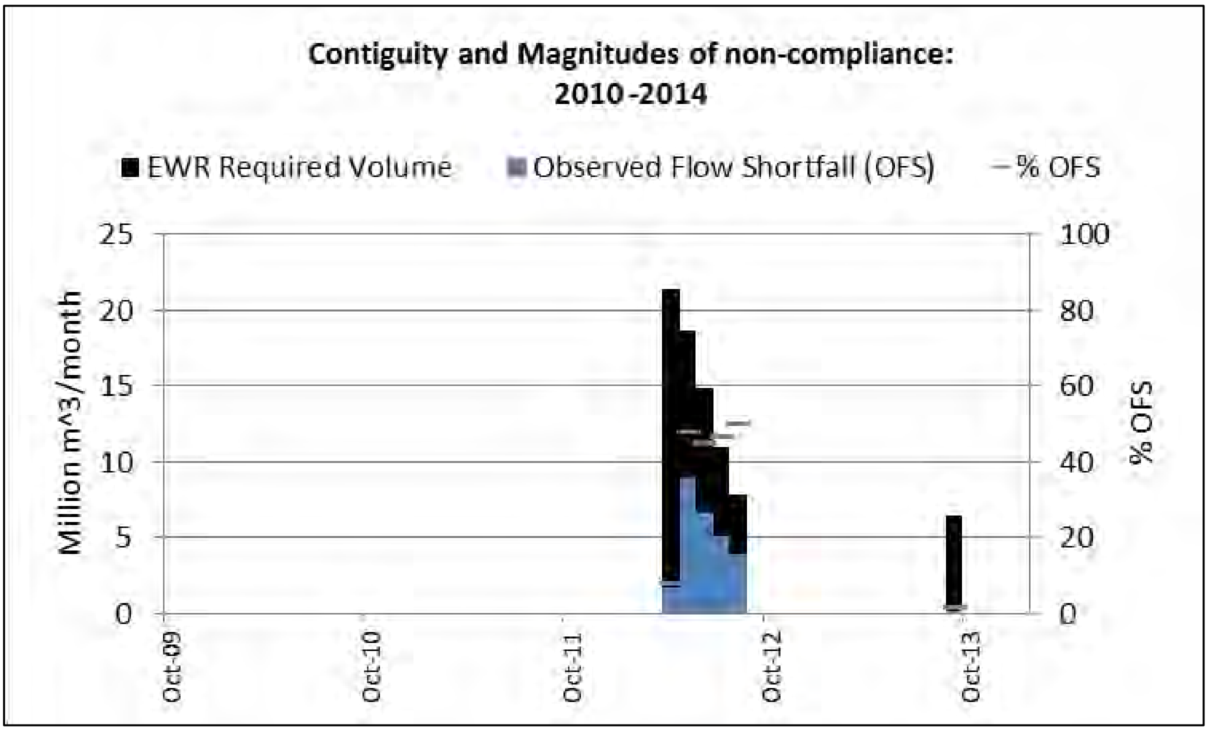


Figure 45 (d).

Figure 45: Contiguity and magnitudes of non-compliance of observed flow to the EWR by assessment of the total monthly volumetric infringements with meeting the EWR at the X2H016 flow gauging station for four periods: period 1 1960-1983 (a); period 2 1983-2000 (b); period 3 2000-2010 (c); and period 4 2010-2014 (d).

Table 11: Average percentage observed flow shortfall compared to the EWR whenever the EWR is not met.

Period	Average observed flow shortfall percentage (%)
1960 - 1983	59
1983 - 2000	68
2000 - 2010	53
2010 - 2014	33

Figure 45 indicates that infringements tend to be contiguous for several months when they occur, but are generally limited to the dry season months. During the early 1990s there was a long period of contiguous and large magnitude infringements, where the river came close to a cessation of flow. During the early 2000's, this pattern was repeated with several years of almost continuous and large infringements but with higher magnitude infringements in the dry months. These infringements coincide with dry season flows and droughts, which may be expected given the significant demands placed on the lower reaches of the Crocodile River for perennial cultivation.

Figure 45(d) and Table 11 indicate that the magnitude and percentage of non-compliance has drastically dropped since October 2009 for the period 2010-2014 when compared against the magnitude of failure before then. The only period of significant contiguous non-compliance since October 2009 was between April and August 2012 with the average for the period being 33% non-compliant in terms of the observed flow shortfall. This magnitude of non-compliance is significantly lower than the average of 68% for the period 1983-2000 and 53% for the period 2000-2010. The ICMA management logbook (Table 9) indicates that the data logger was faulty during this period. Once repaired, the noncompliance disappeared and some of the non-compliance in 2012 might be attributed to faulty data, further reinforcing the huge decrease in the magnitudes and contiguity of failure since October 2009.

Another point to note as that if the "present day flow" ecological flow requirement was used to determine non-compliance instead of the DWA C-class ecological reserve then the non-compliance in terms of both percentage time and magnitude is zero, indicating full compliance with the agreed ecological flow requirements since October 2009.

4) Seasonality i.e. did non-compliance occur during wet months (Nov-Mar) or dry months (May-Oct):

Figure 43, Figure 44 and Figure 45 all indicate that although the average incidence of failure across all months has drastically reduced since 2010, the non-compliance is still highest during the dry months from May to October.

General Comments:

As shown in subsection 1) to 3) above, the percentage time, magnitude and contiguity of non-compliance to the ecological flow requirements all significantly reduced since October 2009, when the AOWRMF was introduced. Before then, these factors all showed a steady increase in non-compliance since 1960. This is a clear indication of the impact the AOWRMF has had and its effectiveness in implementing OWRM.

It must be noted that the annual runoff has generally been above the historical average since October 2009 and it is suspected that non-compliance is higher during low flow or drought periods. The reasonably high annual runoff since October 2009 could thus be a contributing factor towards the improved compliance to the ecological flow requirements since then and the continued monitoring of non-compliance through the next dry period or drought will provide higher confidence. However, the fact that the ecological flow requirements are ultimately a function of the observed flow implies that it is reduced during low flow periods. This thus partially removes the influence of the high or low flow periods on the results and they are thus deemed to be a reliable indicator of the improved OWRM since October 2009. Nonetheless, it is recommended that further investigation into this correlation be undertaken.

The initial outcomes of this study have already been favourable referred to in other independent research (King and Pienaar, 2011; Mcloughlin et al., 2011; Pollard and du Toit, 2011; Pollard et al., 2011). For example, Pollard and du Toit (2011) state that none of the rivers examined met the ecological flow requirements (Figure 3) but that "…this is likely to change in the Inkomati WMA, certainly in the Crocodile River, as new IWRM approaches come on line." They also state that "Operationalising the ecological reserve moves the discourse and practice beyond water protection alone. … It is the collective contribution and synergies of a number of strategies, plans and practices." And that "…such integrated approaches are not evident in any of the catchments, with the exception of the Inkomati WMA where it is emerging through the development of the Inkomati Catchment Management Strategy"

5.3 EVALUATION OF THE DATA, INFORMATION, MODELLING AND DECISION SUPPORT SYSTEMS

The current Mike Customised solution developed during the implementation of the AOWRMF between October 2009 and March 2013 is deemed to be a suitable solution for the DSS related issues discussed in section 1.2.2 and it is recommended as a suitable DSS solution for AOWRM in closing, semi-arid, run-of-river catchments such as the Crocodile River. This is supported by the social questionnaire and evaluation discussed in section 5.1.2, where the CROCOC stakeholders affirmed that the ICMA is able to act as an independent technical mediator, that the exchange of information is good and that the relationship between stakeholders and technical teams is sound.

The learning from the implementation of the web portal and associated WRIMS software and hardware is that in order to ensure reliable data and information availability, a server based solution to manage and disseminated information allowing backups and managing both real time and historic data is needed.

Experience in the use of the web portal and WRIMS has also shown that the internet access reliability and speed at the ICMA has been too slow to support effective collection of data in real time and dissemination of information via a web portal. This must thus be upgraded.

There is also a need to improve the current and forecasted rainfall input data into the model. The calibration of the simulated forecasted river flows against actual observed flows is poor. Possible causes for this include poor water use data and poor rainfall runoff model performance, which performs suitably during the winter months, but fails to correctly simulate the summer hydrological pattern. This is still an issue and must be investigated further.

The current water use data in the WReMP water resources planning model is based on the 2008 IWAAS study and is becoming out of date. This affects the accuracy of the dam trajectories as well as the ecological flow determinations. The verification and landcover projects underway at the ICMA should be used to update this data to improve the long term modelling.

A presentation at the Waternet conference by Stephen Mallory (Mallory, 2012) as well as the research of Van Eekelen et al. (2015) highlight the large discrepancies in various methods of determining the water use of alien vegetation and forestry plantations. This should be investigated further so that improved estimation of the water use of these activities can be implemented in the modelling.

Remotely sensed data is an emerging source of information for rainfall. The OWRM DSS currently links to NOAA FEWS remotely sensed rainfall data. The OWRM DSS is thus set up and able to incorporate the use of near real time remote sensing data in operational water resources management when available, to improve results. However, the results of two recent studies conducted in the Crocodile River (Jarmaine, 2012; Jarmaine et al., 2014) clearly demonstrate the current lack of satisfactory remotely sensed rainfall data for use in modelling and the need to investigate the possible benefits of downscaling the existing remotely sensed rainfall data. The calibration of that data against point rainfall gauging sources in real time to improve modelling is also recommended, as an accurate description of aerial rainfall is deemed to be an essential input into most hydrological modelling applications (Lynch and Schulze, 2000).

The water meters for irrigated water use currently installed are not real time enabled. Enabling them to report water use in real time would improve the short term modelling and flow forecasting in the DSS and is recommended for improved modelling in the future.

Groundwater / surface water interactions have also been identified as a severe limitation in our understanding and needs to be investigated further (Mussa et al., 2014).

6. CONCLUSIONS AND RECOMMENDATIONS

As indicated in the problem statement in section 1.4, river catchments are complex social–ecological systems and closing, semi-arid run-of-river dominated catchments exacerbate and enhance the difficulty in achieving IWRM within this complexity. Coupled to this, traditional governance and management systems generally do not effectively accommodate the diversity of legitimate stakeholder needs.

With this in mind, the literature review and problem statement reinforced the need to ensure that strategic adaptive management including feedback loops, along with a learning-by-doing approach (participatory action research in this case) cognisant of management experiences but led by science and allowing for both technical and social learning is vital, if effective operational water resources management is to be achieved in semi-arid run-of-river dominated closing river catchments. However, no documented examples of IWRM implemented in such a manner could be found during the literature review.

Consequently, this study has attempted to develop and implement a pioneering adaptive IWRM methodology for operational water resources management, based on the above principles and to evaluate whether or not such a methodology can be effective in managing a closing semi-arid run-of-river dominated river catchment in line with the aim and research questions *(*)*. This IWRM methodology has been given the name “Adaptive Operational Water Resources Management Framework” (AOWRMF).

(*) Refer to section 2.2 for the aim and research question as well as section 3 for the methodology used.

(#) Refer to section 4 for details on the results of the development and section 5 for the evaluation thereof.

The results and evaluation *(#)* presented in sections 4 and 5 demonstrate that:

1) An AOWRMF was able to be developed in the semi-arid, closing and run-of-river dominated Crocodile River catchment.
2) The AOWRMF has been effective in implementing operational water resources management in the Crocodile River catchment from both a technical and social point of view.
3) Participatory action research was an effective methodology for the development and implementation of the AOWRMF.

Main Conclusions

The chief indicators supporting these statements are the social learning questionnaire outcomes and the significant improvements in the compliance with the ecological flow requirements since the commencement of the AOWRMF.

It can thus be concluded that a participatory action research methodology cognisant of management experiences but led by science and allowing for both technical and social learning is effective in developing an AOWRMF and that such an AOWRMF can be an effective means to implement operational water resources management in complex semi-arid, closing and run-of-river catchments in a manner that reflects strategic adaptive management but is still functional. It is also apparent that the broad scope of research enabled all of the interlinked and interdependent aspects pertaining to AOWRM to be considered.

It is further suggested that the success of the AOWRMF has been due to the collective synergies of a number of interlinked and interdependent strategies and actions as documented under the four components of OWRM discussed in section 4 and that the mere linking of the these four categories into one adaptive framework for implementation has been of key importance to this success.

It is thus recommended as a suitable methodology for implementing operational IWRM in semi-arid, closing and run-of-river dominated river catchments. Further affirmation of this can be read in the fact that the development of adaptive operational water resources management in the Crocodile River has already been referred to in other research documents (King and Pienaar, 2011; Mcloughlin et al., 2011; Pollard and du Toit, 2011).

Some important overarching learning pertaining to the development and implementation of an effective AOWRMF for semi-arid, closing and run-of-river dominated catchments stemming from the results and evaluation of this research and that are recommended for consideration should this methodology be adopted for use in similar circumstances elsewhere are:

- It is developed through an action research methodology with strong stakeholder involvement.
- It is based on Strategic Adaptive Management principles.
- It should be cognisant of management experiences but be led by science and allow for both technical and social learning.
- A broad scope of research is necessary to explore the many relevant interlinked and interdependent aspects pertaining to the concept and practice of operational water resources management.
- The setting up and use of an operations committee with a defined TOR – developed in collaboration with the stakeholders - to act as the central consultative body and to provide the mutually acceptable ethical framework for action research was very successful in enabling effective consensus based participatory decision making and the necessary frequent, focused discussions to take place during the research.
- It takes numerous, frequent and repeated discussions amongst a focused set of stakeholders to obtain a requisite level of understanding amongst the stakeholders for any real progress to be made in achieving adaptive management of operational water resources management. Although this may take a long time, the end result is a transparent decision making process that is supported by all stakeholders with little resistance to decisions.
- It includes both water resources planning and operations aspects and links them together in one framework.
- A rapid response system incorporating aspects from the four components of the OWRM is effective in implementing and facilitating the short term operational or real time aspects of AOWRM and is a core enabler of openness and inclusivity, as evidenced through the effective implementation and monitoring of the ecological flow requirements though the rapid response system.
- Requisite simplicity should form a guiding principle.

Lastly, the initial outcomes of this study have already been favourable referred to in other independent research (King and Pienaar, 2011; Mcloughlin et al., 2011; Pollard and du Toit, 2011; Pollard et al., 2011). For example, Pollard and du Toit (2011) state that none of the rivers examined met the ecological flow requirements (Figure 3) but that "…this is likely to change in the Inkomati WMA, certainly in the Crocodile River, as new IWRM approaches come on line." They also state that "Operationalising the ecological reserve moves the discourse and practice beyond water protection alone. … It is the collective contribution and synergies of a number of strategies, plans and practices." And that "…such integrated approaches are not evident in any of the catchments, with the exception of the Inkomati WMA where it is emerging through the development of the Inkomati Catchment Management Strategy". These statements reinforce the statement made that the AOWRMF has been effective in implementing operational water resources management in the Crocodile River catchment.

Further conclusions and recommendations relevant to the four components of OWRM are documented in section 6.1 to 6.4 below, including discussion on the gaps and issues identified as relevant to each component. Finally, a discussion on the overarching gaps and issues is presented in section 6.5.

6.1. INSTITUTIONAL ARRANGEMENTS

The results have demonstrated that all the stakeholders involved in operational water resources management through the river operations committee, or CROCOC, now have a common understanding of the institutional arrangements. The discussion, documentation and sharing of the various institutions, roles, responsibilities, forums and interactions was key in achieving this common understanding.

From an institutional perspective, some of the key knowledge, learning and conclusions stemming from this study include:

- The creation of institutions under the adaptive management umbrella can be an effective criterion for IWRM and AOWRM.
- Regional and local water management institutions with appropriate delegations are an effective mechanism for facilitating the decentralisation of relevant powers and functions to the regional and local level.
- The river operations committee was key in enabling the necessary frequent, focused discussions to develop and implement the AOWRMF.

The following recommendations are offered:

- Any institutional arrangements established to implement an AOWRMF must be fit into the broader IWRM realities and prevailing institutional environment and should operate within the framework of national policy and standards.
- Although the river operations committee was key in enabling the necessary frequent, focused discussions to develop and implement the AOWRMF it is important that the river operations committee still feeds relevant information back to a greater forum established for general IWRM related public engagement to ensure that the specific functioning of the river operations committee does not become isolated from these greater IWRM issues and stakeholders.

It must be noted that DWA have not delegated all relevant functions to the ICMA and some uncertainty over their high level commitment to the ICMA as the pivotal role player in ensuring effective AOWRM is evident. This is a risk to the continued successful implementation of the AOWRMF.

6.2. STAKEHOLDER PARTICIPATION AND DECISION MAKING

From stakeholder participation and decision making perspective, some of the key knowledge, learning and conclusions stemming from this study include:

- The assessment of the social learning achievements of the AOWRMF and river operations committee shown in Table 10 indicates that social learning is fairly well established in the AOWRM of the Crocodile River and that the stakeholders are happy with the AOWRM being conducted by the ICMA through this study. This demonstrates the value of incorporating social aspects into AOWRM.
- The social learning evaluation has strongly demonstrated the importance and effectiveness of a river operations committee in facilitating stakeholder engagement and consensus based decision making. In fact, it can be concluded that the role of the river operations committee as a coordinating and advisory body for the relevant decision making authority (ICMA) was exceptionally important (even though it had no decision making powers) as it provided the mechanism for interaction, exchange of operational information and coordination of operational activities and decisions and it allowed stakeholders to be a part of the decision making process. This ultimately established the necessary transparency and trust required for decision making supported by all stakeholders with little resistance to the decisions made.

A number of issues and recommendations for further investigation are discussed below:

- It is possible that the effectiveness of the committee may have been because it has no decision making powers. The potential advantages of such a committee without any formal powers should be investigated but does not fall within the scope of this thesis.
- Although the stakeholders are fully involved in the decision making process around AOWRM, certain sectors were mostly absent during the study, chiefly the municipalities. This is a gap that has led to lower scores for inclusivity and interdependence amongst the stakeholders, with certain stakeholders participating in decisions more than others. This must be mitigated in the future. Further research is required on how to mitigate this issue.
- Some of the stakeholders feel that the design of the consensus based decision making process was done mostly by the ICMA as the champion. However, they seem to have bought into the process nonetheless. The facilitation of an improved ability for the self-design of the process by the stakeholders is thus recommended in future.
- Lastly, there is scope for further investigation into social learning in the context of adaptive operational water resources management.

6.3. DATA AND INFORMATION

The data and information in support of AOWRM has been incorporated into the technical evaluation conducted in Table 6 and the full recommended data and information needs for AOWRM has been presented in section 4.2.3.

An important conclusion stemming from the implementation of the AOWRMF is that although very important, it is difficult and it takes time to obtain a requisite understanding of the technical and scientific aspects of OWRM amongst the stakeholders and that it is important to translate complicated scientific information into understandable formats for decision making and practical implementation. In other words, it takes time and is not necessarily an easy task to achieve requisite simplicity. In particular, the lengthy and rigorous debate around the determination and implementation of the ecological flow requirements documented in section 4.2.4 and in the minutes of the CROCOC meetings, have demonstrated the importance of sufficiently understandable information to enable progress, as no progress was possible on the implementation of AOWRMF until the ecological flow requirements had been determined, understood and consensus had been reached on a realistic determination. Further to this, river health and bio-monitoring should be incorporated into an AOWRMF to assist in strategic evaluation and to ensure that the ultimate goal of maintaining the present ecological status of the river is met, since merely monitoring the compliance of observed flows against estimated ecological flow requirements is not sufficient to evaluate whether the river health is actually being maintained, even though the ecological flow requirements may be met. This rigorous debate around the ecological flow requirements further demonstrated the need for frequent, focused discussions and the importance of the river operations committee to facilitate the implementation and guide ongoing development in terms of data and information needs.

From a data and information perspective, an important conclusion is that redundancy in the hardware installations supporting real time automated data collection is required to improve the reliability and availability of this data. This conclusion is a result of the frequent failure of both the real time hardware and software during the implementation of the AOWRMF resulting in improper information being available for decision making on OWRM.

A number of recommendations to further improve the data and information are presented below.

- Remote Sensing is a rapidly growing field. New sources of remote sensing data and techniques to derive water resources information are available and continue to be refined. Further research on this field is recommended and the benefit of the real time calibration of remotely sensed rainfall data against ground based point rainfall data could improve the rainfall data available for operational water resources modelling and should be explored.
- New sources of improved cross section information such as Lidar could be investigated to improve low flow hydrodynamic modelling and resultant short term forecasting.

However, it is interesting to note that although there are still improvements that can be made, OWRM can be conducted with a limited, requisite level of data and understanding if it is done through an

AOWRMF methodology. The improvements recommended above are thus only for further refinement within the strategic adaptive management cycle of the OWRMF.

Some data and information gaps were identified during the study and are discussed in section 4.2.3. These should be rectified by the ICMA where possible. Some further research and or investigation is thus recommended for the following:

- The AOWRMF has been developed for the operational management of water flows quantities as its central objective. Water quality aspects have been largely disregarded and should be incorporated to improve the operational management of the water quality aspects of integrated water resources management.
- The water use data used in the models is based on authorised allocations and not on estimated actual current water use. It is thus static information. This data could be updated to incorporate the estimation of current actual use into the models in near real time. It is suggested that this would improve their output, especially for short term flow forecasting.
- The absence of actual irrigated water use from the CRMIB is seen as a serious omission in information sharing. A method to obtain this water abstraction information in real time must be implemented.
- Large discrepancies currently exist between various methods of determining the stream flow reduction of alien vegetation and forestry plantations. This must be investigated further to improve the level of confidence in this data in the existing models. This data in the models is also static and should be updated to incorporate the estimation of current actual use into the models.
- Our understanding of groundwater / surface water interactions is limited and not effectively incorporated into the models. The benefit of improved understand in this regard could significantly improve the model outputs.
- Maintenance programmes for the real time data collection hardware are crucial to ensure reliable real time data availability.
- The high resolution and hydrologically correct DEM developed by the ICMA during the course of this study must still be incorporated into the existing models. Any improvement this could make to the modelling outputs should be evaluated.
- The high resolution landcover database and associated farm dam data derived from it (area and volumes) must still be incorporated into the planning and operations models to improve their outputs. Any improvement this could make to the modelling outputs should be evaluated.

6.4. MODELLING AND DECISION SUPPORT SYSTEMS

To enable an organisation such as the ICMA to effectively implement operational water resources management with the sophisticated software systems and models implemented during the development of the AOWRMF, technical support and maintenance contracts with the software specialist were required. Without such contracts, many of the upgrades and improvements done to the modelling and decision support system required during this study would not have been feasible and they are thus recommended as an important aspect to include in an AOWRMF.

The inclusion of both planning and operations information in an integrated DSS has enabled the ICMA and its stakeholders to keep track of both the planning and operational aspects of IWRM (documented in section 1.2.1) and make informed decisions on OWRM that is cognisant of both these aspects. The automated real time acquisition, processing, management, dissemination and archiving of both the real time and historical data through this DSS has also provided great assistance to the staff of the ICMA in managing the large volumes of data input and output, which it is assumed would not have been possible without, given the small staff contingent of the relevant ICMA division (1 hydrologist and 1 manager). This automation in conjunction with the aforementioned support contracts enabled the successful management of these large data volumes with limited staff.

Further short term operations specific recommendations:

- Any DSS and associated models should be installed on a proper network server with appropriate protocols and backup regimes in place to ensure reliability and sustainability of the DSS. This study quickly showed that the existing network, server and internet access at the ICMA was not sufficient to support the large data and information acquisition, processing, management, dissemination and archiving needs and these had to be upgraded before the AOWRMF could be fully developed.
- Weather forecasts continue to be improved and these should be compared and included into the short term model to improve the flow forecasting of the models.
- The CRMIB claim that fluctuations in weather conditions (such as temperature, wind, humidity and evaporation) from day to day significantly affect the flow in the lower portion of the Crocodile River during the low flow season (July to October). This claim has not been investigated. It is possible that an understanding of this correlation and the development of an indicator to monitor its influence could improve the short term flow forecasting and is recommended for investigation. Linked to this, an increase in the number of evaporation stations or the use of remotely sensed evaporation data is recommended.
- Data assimilation, which updates predicted data with actual measured information from the installed real time river flow data loggers ensuring that forecasts are always using updated boundary conditions, is valuable in improving flow forecasts.
- The current DHI NAM hydrological model performs suitably during the winter months, but fails to correctly simulate the summer hydrological pattern. This should be investigated further and recommendations on improvements made.
- A calibration of the Mike 11 outputs conducted against observed flow by Greaves et al. (2009) showed that the volume differences between observed and simulated flows were large at certain gauges. Possible causes of this include poor water use data and poor rainfall runoff (NAM) model performance and should be investigated further.

Further long term planning specific recommendations:

- The water use distributions patterns used in the long term model are static average distributions patterns based on allocated water use only. It might be beneficial to revisit the water use distribution patterns used in the model and replace them with near real time estimates of actual use and distribution patterns.

- The use of serial correlation constraints in the stochastic generator of the planning model significantly reduces the uncertainty of flow (and storage) forecasts through the dry season. Rivers that show strong serial correlation should consider incorporating these types of constraints in their planning models.
- The antecedent conditions are taken into account through a stochastic methodology which looks at month on month correlations in a catchment. The inclusion of a rainfall based stochastic generation technique that could be put through a hydrological model would take into account antecedent conditions and improve results particularly in extending long term planning model projections to several years in advance. This technology is now available and could be investigated to improve modelling estimates.

Conclusions and recommendations specific to the implementation of the ecological flow requirements:

A new methodology to determine the ecological flow requirements on a weekly time step was pioneered through this study (Mallory, 2010), as existing methods entailed setting up real time hydrological models using real time rainfall data as input and which was not available at a sufficient level of accuracy. It has proven to be a great success and the outputs are accepted by the CROCOC stakeholders. That methodology is thus recommended as a suitable methodology for the calculation of the ecological flow requirements where good data on river flows and water use is available and insufficient data for rainfall is available. The development of the real time DSS to support the implementation of the ecological flow requirements and the establishment of the CROCOC to allow opportunities to discuss its implementation also created the environment in which the KNP and CRMIB have learnt to work together on this matter when they were previously unable to agree. The combination of the creation of this decision making environment, DSS and the pioneering methodology to calculate the ecological flow requirements were critical to the successful implementation of the AOWRMF.

However, some gaps and issues were identified during the study and should be rectified by the ICMA where possible:

- The ecological flow determination model uses the "present day flow" ecological flow regime described in the DWA ecological reserve determination study and not the original C-class ecological reserve requirement stemming from that study. Although this is currently accepted by all stakeholders including DWA, the current ecological flow regime being implemented is only preliminary and is yet to be finalised through the DWA ecological reserve classification project that has recently commenced. This may result in a revised ecological flow requirement regime for implementation.
- It is suspected that compliance with the ecological flow requirements may exhibit a significant correlation with the annual runoff. The methodology of Riddell et al. (2013) used to evaluate compliance with the ecological flow requirements does not factor in any possible influence of the annual runoff against the MAR. Although the presentation of the ecological flow requirements as percentage exceedance curves is deemed to factor this influence into account, it is still not fully understood whether the annual runoff has a significant influence on compliance or not. This should be investigated further to better remove the impacts of long term climate fluctuations on the evaluation.

- The DWA X2H016 Tenbosch flow gauging site has shown significant fluctuation in flow between day and night. It is not understood how these sub-daily fluctuations may influence the river health. This should be investigated further.
- The assumption that if the downstream ecological flow requirements were met at the DWA X2H016 Tenbosch flow gauging site only then the upstream sites would also be met may not always be correct and does not hold for tributaries. Further research is needed if the ecological flow requirements for the tributaries are to be implemented.
- The implementation of the ecological flow requirements has been centred on the river flow quantity aspects in this study and compliance has thus only be measured in term of river flow quantity. The water quality related aspects are equally as important and must still be incorporated in the AOWRMF.

6.5. OVERARCHING GAPS AND ISSUES

Although the development and implementation of the AOWRMF is considered to have been a success and the conclusion is positive, there are several gaps and issues that have arisen during the study that should be considered for further investigation, implementation or research. These are:

- The evaluation conducted over four years did not include any dry years. Although this effect has been explained, this may have skewed the results. A sufficiently long period, including both wet and dry periods, is recommended to truly evaluate the effectiveness of an AOWRMF and provide higher confidence in the results.
- The implementation and evaluation of the ecological flow requirements was conducted at the downstream end of the Crocodile River at the DWA X2H016 Tenbosch flow gauging site only (Figure 11). This decision was based on the assumption that if the downstream ecological flow requirements were met then the upstream sites would also be met. This assumption may not be correct (and is almost certainly invalid for any tributaries) and an evaluation at other points further upstream to further confirm the outcomes is recommended.
- The influence of the trans boundary nature of the Crocodile River on the AOWRM was not explored in any detail except for the acknowledgement of the added complexity that this brings and the inclusion of the international obligations into the defined flow alert levels at the X2H016 gauging station. Thus, although the AOWRM of the Crocodile is cognisant of and attempts to meet the international obligations at all times, further assessment of this complexity is recommended.
- The issue of subjectivity is apparent in this study since the researcher was also the relevant manager at the ICMA. Although it is deemed that this issue has somewhat been overcome through the use of a participatory action research approach through the establishment and use of the operations committee and its use of consensus based decision making, thereby removing the subjective point of view of the researcher as the sole consideration in the decision making, it is acknowledged that this assessment is partly subjective in itself. The technical and social

evaluation methods used are also deemed to have further reduced the subjectivity of the researcher, but the extent of the influence that the subjectivity of the researcher may have influenced the results and their evaluation may require further understanding and investigation.

- The forecasted flows stemming from the DSS need improvement. The benefit of improved data sources found during the study (such as remote sensing) as possible new input into the DSS to generate possible improvements to the forecasted flows has not been explored. It is recommended that this be explored further to lend further technical scientific credibility.
- The field of grounded action research was not explored and could lend further scientific credibility.

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APPENDIX A

GENERIC DESCRIPTION OF IWRM PROCESSES UNDER SAM PHASES AND COMPONENTS

SAM Phase	SAM Component	SAM Sub-component	Description of IWRM Processes under SAM Phases and Components
Adaptive Planning			• Major outcome Adaptive Planning Phase - future desired state, or vision. • Vision then broken down into objectives and sub-objectives (Objectives Hierarchy), culminating in suitable end-points – measuring success of management actions on ground – in achieving objectives. • Sub-catchments within a Water Management Areas – unique characteristics, hence having different mix making up sub-vision - part of the Catchment Management Strategy process (DWAF, 2007).
	[a] Vision		• Ecological sustainability component of vision – affected via Ecological Management Class (EMC) - water resource Classification System - RDM process. • Relationship between EMC and Ecological Category (EC – from Ecological Reserve study) - see Figure 7.6. • Selection of EMC - ideally via stakeholder consultation and consensus. The EC determines degree of protection given to water resource, e.g. "A" river system receives more water for environment than "D" river system. • Due to lags in implementation of Classification System process in South Africa - recommended EC used in this study associated with a vision.
	[b] Objectives		• Resource Quality Objectives (RQOs), once determined, form specific objectives and end-points to monitor implementation of Ecological Reserve, including (Kleynhans et al., 2009): a) quantity, pattern, timing, water level and assurance of in-stream flow; b) water quality - physical, chemical and biological characteristics; c) character and condition of the in-stream and riparian habitat; and d) characteristics, condition and distribution of the aquatic biota. • End-points - critical to guide management actions on the ground. • Flow duration curves (from Ecological Reserve studies) - finer level, detailed objectives for river flows. • EcoSpecs (Eco-specifications) set to measure ecosystem change against recommended river health objectives. Thresholds of Potential Concern (TPC) act as a 'red-flag; i.e. if/when approached or breached instigate relevant feedback processes - prevent unwanted river health conditions occurring.
Adaptive Management			• Source Directed Controls (SDC) provides practical tools for scoping management options to meet associated objectives and vision set for catchments.
	[a] Scoping management options		• Combinations of SDC tools to meet Ecological Reserve goals, including: water licensing – license validation (extent of water use) and verification (legality of water sue), re-licensing if required; enforcement of lawful license conditions; water use restrictions and curtailments; development of water resources, e.g. dams; and providing incentives - promote water use efficiency. • Selection of approaches differs between catchments - varying contexts and processes. • Evaluating future impacts of SDC management options must be addressed prior to implementation.
	[b] Planning		• Strategic planning - critical to successful implementation of Ecological Reserve. • Development/testing real-time operating systems - considerably increased capacity for planning. • Modelling water allocation scenarios to implement Ecological Reserve - critical. For example - impacts on irrigation farmers (linked to economic objectives and vision) . • Hence, water allocation plans devised to meet objectives of other water users, in conjunction with Ecological Reserve implementation. • Design and calibration of real-time operations (modelling systems) must then be done – entailing development of operating rules (e.g. dam releases, water restrictions etc). • All envisaged future management responsibilities and roles must be delegated. • Incorporation of mapped Freshwater Ecosystem Priority Areas, Fish Support Areas, and Upstream Management Areas) outputted from National Freshwater Ecosystem Priority Areas (NFEPA) project (ref*final report). • NFEPA - national network of freshwater conservation areas, including: rivers, wetlands and estuaries. NFEPA builds on river component of the National Spatial Biodiversity Assessment (NSBA) 2004, taking forward implementation of Cross-Sector Policy Objectives for Inland Water Conservation. • NFEPA tools critical in planning processes - adaptive implementation of Ecological Reserve.
	[c] Implement-tation		• Implementation of strategic plans, i.e. management actions – vital. Plans developed without actual actions equates to wasted time and resources. • Real-time operational systems (mentioned above) must be implemented to management Ecological Reserve and water allocations to water sectors, including: water use restrictions, dam releases, water use monitoring and enforcement, monitoring associated with dam and river flow levels and rainfall – making reasonable forecasts about future water supply (risk).
	[d] Monitoring		• Monitoring - critical step in SAM cycle - provides necessary information for reflection and assessment, ultimately to adapt management actions where pertinent, also for furthering knowledge and learning. • Monitoring component divided into two sub-components: (1) Operational monitoring – measuring success in implementation of the selected management action, i.e. outputting the required river flows, and (2) Strategic monitoring – testing effectiveness of these river flows - achieving management goals, ultimately the vision (recommended EC).
		Operational monitoring	• Monitoring - Ecological Reserve implementation, measuring compliance, i.e. checking if desired river flows are occurring. • A number of DWA gauging weirs exist throughout South Africa - utilized for monitoring river flows. Gauging weirs on the river systems under investigation within case-studies have real-time data-loggers linked to satellite systems - information is directly and rapidly accessible off the DWA website. • A system of rapid feedback responses, linked to implementation of the management actions, is necessary to keep the process on track as this is rolled-out.
		Strategic monitoring	• Bio-physical monitoring – links ecosystem changes to river flow regimes, including: in-stream indictors – fish, macro-invertebrates and riparian indictors - geomorphology and vegetation. • Information used to assess trends in indictors - interpreted within a TPC based system (see McLoughlin et al.2011). • Strategic monitoring – by a national network of river monitoring sites throughout the country - Ecological Reserve determination study sites (EWR) and River Health Programme (see Kleynhans ref). KNP specific biodiversity associated TPCs are also relevant to this study.

(Pollard & du Toit, 2007).

APPENDIX B

CURRENT STUDIES AND PROJECTS RELATED TO OPERATIONAL RIVER MANAGEMENT

Project Name	**Details**
International	
Computer Aided River Management (CARM) for the Murrambidgee River, Australia (van Kalken et al., 2012)	The CARM project is based on MIKE CUSTOMISED by DHI and MIKE by DHI software and is an example of an operational DSS in river catchment management. The Murrambidgee region experienced its worst drought on record and this drove innovation in river operations through the CARM project. It was found that the river was operated based on the experience of the river operators using simple water balance concepts. CARM integrates models with real time measurements including rainfall, forecasts, river flow and abstractions that automatically update the model. The CARM optimised solution has been shown to significantly reduce dam releases without compromising irrigation water security (van Kalken et al., 2012). It is envisaged that the CARM system will establish the Murrambidgee river as one of the most efficient regulated river systems in the world. The project won the Australian Water Association's National Award for Infrastructure and Innovation. The solution revolves around an open IT, data and modelling decision support system, capable of integrating a wide range of data feeds, modelling tools and GIS providers and includes provision for customization to meet specific end user requirements.
DSS for Thailand's Hydro and Agro Informatics Institute (HAII)	After severe flooding along the Chao Phraya River during 2011, Thailand's Hydro and Agro Informatics Institute (HAII) developed an operational water management decision support system. The system was based MIKE CUSTOMISED by DHI solution software using rela time data to provide the required information for effective short and medium term flood forecasting and warning (DHI signature Project Flyer).
Operating Rules for the Incomati and Maputo Watercourses (TPTC, 2011)	This is one of 12 projects recently completed under the programme for the Progressive Realisation of the Inco-Maputo Agreement (PRIMA) for the Governments of the Republics of Mozambique, South Africa and the Kingdom of Swaziland. It included, amongst others, objectives to develop integrated operating objectives for the optimised management and use of the water resources in each catchment; develop operating rules for both trans-boundary river systems, taking into account the functioning of the existing systems; develop information management systems which will incorporate data such as river flows, storage volumes and water demands in the river catchments; develop operational decision support systems for the integration and optimisation of short and medium term operating rules.

	The proposed rules indicated, inter alia, that: • The short term yield-reliability functionality in the integrated MIKE Basin IncoMaputo model in conjunction with anticipated water demands and current catchment storage conditions, to assess the medium term availability of water be used. • Cross border flows should no longer be dictated by fixed minimum daily flow rates, but should rather be dictated by actual water demand in the downstream country/countries. This implies a variable cross border flow driven by ecological and/or irrigation demand patterns. • The current approach for the operation of the KOBWA and Crocodile systems, which entails a balanced system and/or annual allocations to ensure that the risk of emptying the dam(s) is within acceptable limits, be maintained. • Improve co-ordination between the lower Komati and Crocodile catchments in terms of conjunctively complying with minimum cross border flows into Mozambique be implemented • A Terms of Reference for tri-lateral Systems Operation Task Groups (SOTGs) for the Incomati and Maputo catchments respectively were developed.
Remote Sensing Cooperation with SATWATER and 5 Dutch Waterschappen	The ICMA and Waterschap Groot Salland have entered into a 3 year remote sensing cooperation for mutual learning agreement commencing in 2012. Learning from this cooperation will be incorporated.
National (South African)	
Operating Rules and Decision Support Models for Management of the Surface Water Resources. Sabie River Catchment (DWAF, 2003)	The project described in detail how the Sabie Catchment should be managed from a water resources point of view once the Inyaka Dam and Transfer Pipeline were in full operation. Part of the OR's were the decision support models, which were aimed at providing tools to assist the ICMA to manage the water resources of the Sabie catchment. However, the OR's have never been implemented mainly due to the lack of sufficiently skilled staff and the fact that the river system was not stressed at the time. There was also a lack of cooperation from the responsible government departments and a lack of knowledge about the OR's, with certain stakeholders complaining that they were not involved in the development of the rules from the beginning (Agterkamp, 2009).
A Real-Time Operating Decision Support System for the Sabie-Sand River System (Sawunyama et al., 2012)	This project has developed a yet to be implemented real time DSS that allows catchment managers to assess on an ongoing basis who requires water, at what times, what releases need to be made from the Inyaka Dam and whether or not restrictions should be imposed on certain users. This is achieved through the integration of three models. A black-box rainfall-runoff model (WRC, 2012), to forecast probable water in a system at any given time, a river flow management (hydraulic) model – WAS (Benadé et al., 1997) - which keeps an account of water release to users and abstractions made by users and a long Term Water Resources Planning

	model –WreMP (Mallory et al., 2010) – to ensure that operational decisions do not exceed long term statistics. Disaggregation software developed through the WRC project (WRC K5/1979, 2012) to disaggregate Pitman monthly hydrology to a new daily time series using sequencing from ACRU daily hydrology was extended to develop the black-box daily rainfall-runoff model to be used to generate forecasted flows. The main conclusions from the hydrology review conducted by this project are that the rapidly reducing numbers of rain gauges that remain operational are a cause for great concern and consideration should be given to re-opening old reliable stations and or the establishment of new gauges. A further concern is the inability of the various models developed and used to be linked together and run automatically, as is possible through the DELFT FEWS and DHI software solutions. They thus require manual input of data and running. However, the black –box rainfall-runoff model has demonstrated the benefit of stochastic hydrology with serial correlation constraints incorporated and this will be considered.
The RISKOMAN and WATPLAN Projects	The ICMA is currently a major client and project partner for two projects funded by European Union and the WRC in South Africa, called WATPLAN and RISKOMAN. "RISKOMAN" stands for "Risk Based Operational Management" which neatly summarises the main purpose of the project being that of improving operational river management. This implies real time or near real time management and decision making regarding water use, restrictions on water use, dam releases and river flow management to meet the conflicting needs of the ecological flow requirements, international obligations and water users while also ensuring that the long term risks of system failure are not exceeded. WATPLAN is a research project under the EU-FP7 program with the objective to develop and implement an operational earth monitoring system for the international Inkomati catchment. It is providing evapotranspiration, biomass, land use and rainfall data at a weekly time step at medium (30m) resolution.
Real-Time Decision Support System for the Crocodile East River Catchment (Hallowes et al., 2007; DWA, 2010a)	A Real-Time DSS for the Crocodile East River Catchment (CROC DSS) was developed by DWA using MIKE CUSTOMISED by DHI and MIKE by DHI software, which the ICMA has obtained approval to implement. This DSS incorporates a lot of the recent learning about river operations and the need for hydroinformatics and that planning and operations are important and must be linked to the same data sources. Two important issues stemming from the project are: • The system could be enhanced considerably, with the improvement of the monitoring network; particularly improvements to the rainfall monitoring will improve estimates, and

	• The primary driver in the model was daily rainfall per quinary catchment, based on data from NOAA satellites. This rainfall data, which is a mean rainfall depth over a grid cell at a 0.1° resolution (~10km), is not entirely suitable for use in hydrological models. The intensity of rainfall, which is high in the region due to summer thunderstorms, is not represented appropriately in the data. This changes the simulated hydrology considerably, and the project team struggled to get good regression statistics during the calibrations.

APPENDIX C

STEEP ASPECTS OF THE INKOMATI WMA RELEVANT TO OPERATIONAL WATER RESOURCES MANAGEMENT FROM THE ICMA CMS

Current (source data and stakeholders)	**Future (if Business as usual)**	**Acceptable (against the vision)**	**Implications for strategic actions in WRM**
Social			
Availability of WRM skills and knowledge is there but limited	Uncertain but could lose skills	No to loss of skills	• Skills need to spread throughout areas and sub-catchments • The attraction, development and retention of skills and expertise in water resources management is important. Establishment of WUA's & Delegation of functions
Technical			
Water Availability is highly variable	Economic Hardship	No	• Implement Operating Rules and River Systems Operations • Water Allocation Plan
Operating Rules (OR's) for infrastructure do not consider ecological processes	Compromised water security (violation of the Reserve)	No	• Strategy for review of OR's in Regulating Water use sub Strategy
OR specifically for one sector in some sub catchments and for some infrastructure	Apathy from other sectors in implementation	No	• Involve other sectors in review of OR's • Communication strategy • Awareness program
Ecological			
Non-compliance with the ecological Reserve (quantity) is widespread; Basic Human Needs Reserve needs to be examined	Compromise water security	No	• Implement operating Rules (OR's) & River Systems operations • ICMA to be responsible

Droughts	Continue	N/A	• Operating Rules and River Systems operation • Dry period reaction plan and strategy (disaster management) • Focus of Strategic actions not average years
Economic			
Economic dependence on the river and its biodiversity	Continue in catchment	Yes	• Implementation of Reserve must be Stakeholder Centred, progressive and account for all IWRM aspects.
The KNP/Lowveld, and Trout/Panorama tourism draw-cards are vital to both the catchment and national economies & dependant on sustainable river systems.	Sustainability threatened	No	• Implement the Reserve. • NFEPA priority area • Cooperative Governance with planning Institutions
Political			
Institutional alignment between DWAF and the ICMA	No alignment implies no decentralised, stakeholder orientated IWRM		• MOA must be revised and implemented
International obligations to deliver water	Continue- may change.Current use compromises ability to meet this	NA	• Co-operative governance (especially PRIMA project)
Legislative implementation is poor, particularly in terms of: the Reserve; the transformation of IB's to WUAs; establishment and transfer of functions to CMA's and co-operative governance.		No	• Implement the CMS

APPENDIX D

DELEGATED AND ASSIGNED POWERS AND FUNCTIONS OF THE ICMA

The ICMA inherited several initial functions upon its establishment. These are outlined in section 80 of the NWA as follows:

(a) to investigate and advise interested persons on the protection, use, development, conservation, management and control of the water resources in its water management area;

(b) to develop a catchment management strategy;

(c) to co ordinate the related activities of water users and of the water management institutions within its water management area;

(d) to promote the co ordination of its implementation with the implementation of any applicable development plan established in terms of the Water Services Act, 1997 (Act No. 108 of 1997); and

(e) to promote community participation in the protection, use, development, conservation, management and control of the water resources in its water management area.

On top of these initial functions, the ICMA has also been directly assigned the following functions in section 19 and 20 of the NWA:

19 Prevention and remedying effects of pollution

20 Control of emergency incidents in respect of water resource pollution or potential water resource pollution

Further functions were delegated to the ICMA by DWA in December 2010. These are summarised below:

Schedule 3	
Item 2 (a)-(e)	To – (a) manage and monitor permitted water use; (b) conserve and protect water resource and water resource quality; (c) subject to the provisions of the Act, **develop and operate a water work** in furtherance of its functions; (d) do anything necessary to implement catchment management strategies; and (e) by notice to a person taking water and after having given that person a reasonable opportunity to be heard, **limit the taking of water in terms of Schedule 1**.
Item 3(1)-(6)	Subject to item 3(2), (5) and (6) to **make rules to regulate water use**.

Item 4(1)	To require in writing that a water user – (a) **install a recording or monitoring device** to monitor storing, abstraction or use of water; (b) establish links with any monitoring or management system to monitor storing, abstraction and use of water; and (c) **keep records on the storing, abstraction and use of water** and submit the records to the water catchment management agency.
Item 5(1), (2) and (4)	To by written notice, require the owner or person in control of a water work within its area of operation to **collect and submit particular information within a specified period** to enable the catchment management agency to determine whether that water work is constructed, maintained and operated in accordance with the Act. To subject to item 5(3), **direct the owner or person in control of a water work** situated within its area of operation at the owners cost and within a specified period, **to –** (a) undertake specified alterations to the water work; (b) install a specific device; or (c) demolish, remove or alter the water work inoperable . If the owner fails to comply with a directive to – (a) undertake the alterations; (b) install the device; or (c) demolish, remove or alter the water work inoperable and recover any reasonable costs from the person to whom the directive was issued.
Item 6(1)	**In the event of a water shortage** within its area of operation and subject to item 6(2) and (3) of Schedule 3 to by notice in the Gazette or by written notice to each of the owners in the area who are likely to be affected – (i) limit or prohibit the use of water; (ii) require any person to release stored water under that persons control; (iii) prohibit the use of any water work; and (iv) require specified water conservation measures to be carried out.
Item 6(2)	A notice contemplated in sub item (1) must – (a) specify the geographical area or water resource to which the notice relates; (b) set out the reason for the notice; and (c) specify the date of commencement of the measures.
Item 6(3)	In exercising the powers under sub item (1) the catchment management agency must – (a) give preference to the maintenance of the reserve; (b) treat all water users on a basis that is fair and reasonable; and (c) consider – (i) the actual extent of the water shortage; (ii) the likely effects of the shortage on the water users; (iii) the strategic importance of any water use; and (iv) any water rationing or water use limitations by a water services institution having jurisdiction in the area in question under the Water Services Act, 1997 (Act 108 of 1997).

Item 6(4)	To – Modify or require the owner of the water work to modify the water work so that it cannot be used to take more water than that allowed for in the notice; or Remove the water work or require the owner to remove the water work if the notice contains a prohibition on the use of that water work If the owner or person in control of the water work contravenes a notice under item 6(1) of Schedule 3.
Item 6(5)	**To determine whether the owner should be held responsible for any reasonable cost** incurred in acting under sub item (4) and to recover from the owner the cost determined.

Chapter 4	
Section 34(2)	To register an existing lawful use subject to section26(1) (c).
Section 35(1)	**To verify the lawfulness or extent of an existing water use** by written notice requiring any person claiming an entitlement to that water use to apply for a verification of that use.

Chapter 8	
Section 92(1) (a)	**To establish a water user association**, give it a name, determine its area of operation and approve its constitution (i) not operating any Government infrastructure; (ii) not employing staff; (iii) that do not have any financial commitments towards DWA (State loans); or (iv) that do not have loans at other financial institutions guaranteed by DWA
Section 92(1) (b)	To amend the name, area of operation or approve an amendment to the constitution of an established water user association in the area of operation of the ICMA.
Section 92(2) (a)	To require additional information to that required by section 91(1).
Section 92(3) (a)	To publish a notice in the Gazette setting out the proposed establishment of a water user association, its name and area of operation and invite comments thereon.
Section 92(3) (b)	To consider what and take further steps appropriate to bring the content of the proposed water user association to the attention of interested parties.
Section 92(3) (c)	To consider all comments received on the proposed water user association.
Section 92(4)	To decide that sufficient consultation has taken place.
Section 98(4)	To transform Irrigation Boards (i) not operating any Government infrastructure; (ii) not employing staff; (iii) that do not have any financial commitments towards DWA (State loans); or (iv) that do not have loans at other financial institutions guaranteed by DWA

APPENDIX E

TERMS OF REFERENCE FOR THE CROCODILE RIVER OPERATIONSCOMMITTEE

TERMS OF REFERENCE FOR THE CROCODILE RIVER OPERATIONS COMITTEE

NAME

The Crocodile Catchment Operations Committee (CROCOC)

PREAMBLE

The Crocodile River Real Time Operations Decision Support System (DSS) is a real time DSS for operating the Crocodile River. The development of the DSS framework and the system annual allocation model has been done by DWA with input from the ICMA through Project Number WP 9429: A Real-Time Operating Decision Support System (DSS) for the Crocodile East River System. This operations Committee has been established as a central requirement in the procedures and processes to implement and operate the real time DSS.

The Crocodile East River system is an international river system flowing from South Africa into Mozambique. The only control structure on the main stem of the river is the Kwena Dam, some 250 km upstream of the Mozambique Border. Kwena Dam only captures the runoff from about 10% of the Crocodile East System. Most rainfall occurs downstream of this dam and so the majority of the available water is "run of river" i.e. dependant on incremental runoff that comes directly from rainfall, rather than from dam releases. While demand for water is consistently high, rainfall volume – and therefore water supply – is highly variable and the system is vulnerable to severe water use restrictions.

The DSS and CROCOC are designed, within this context, to provide sufficient water to serve the users and the development goals, without compromising the integrity of the resource or our international obligations.

Implementation of the DSS and a functional Committee will provide DWA, the ICMA and stakeholders with an excellent opportunity to create new interactive spaces where stakeholders can generate a holistic shared understanding for management of the Crocodile catchment.

OVERVIEW OF DSS

The DSS comprises hardware as well as software.

The hardware consists of stream flow gauging stations, rainfall gauges, water abstraction meters and telemetry. These must all be reliable. The CROCOC should advise on improvements and issues regarding the hardware.

The software serves two purposes: long-term planning and day-to-day operations. The former takes into account climatic predictions, volumes of water in Kwena dam and river flow to generate annual expectations of water availability and potential restrictions. The day-to-day component uses short-term rainfall and runoff monitoring, rainfall predictions and flow data, to anticipate how much water will be available for abstraction over periods of days or weeks, and along which stretches of the river it will be available. Thus, the DSS feeds data to the stakeholders and relevant decision making authorities as defined in the National Water Act (DWA, ICMA, WUA's) to enable them to make informed decisions about dam releases, abstractions and restrictions according to addendum B. The

CROCOC will assist the decision making authorities by facilitating this informed and consensus driven decision making.

The DSS will provide the flow hydrograph for releases that will satisfy the water quantity demand schedules at the different locations and times along the Crocodile East water system on a short term (Daily or weekly) basis while ensuring compliance with the long term operational rules determined annually and reviewed quarterly to ensure the correct assurance of the specified water supply to all users along the main stem of the Crocodile East River. The result will be a much refined time scale for system operations that better informs water users of the volume of water available and when when, to ensure efficient, equitable and sustainable use while still meeting international obligations.

OBJECTIVE

The CROCOC is a consultative technical advisory body managed by the ICMA which provides the mechanism for interaction, exchange of operational information and coordination of operational activities for the Crocodile East River System. The CROCOC serves the relevant decision making authorities as defined in the National Water Act (DWA, ICMA, WUA) to enable them to perform informed and consensus driven decision making.

An Addendum to this TOR - Addendum A – lists the main information and decision requirements on an annual, bi-annual, quarterly, monthly and weekly basis and must be maintained/updated by the relevant decision making authorities and made available to the CROCOC.

Although the CROCOC has no decision making powers under current legislation, its role as a coordinating and advisory body is exceptionally important in the broader decision making process of IWRM as defined in the National Water Act. This TOR is designed to enable the members of CROCOC to play their part in pioneering the process of informed consensus decision making that will lead to greater equity, efficiency and sustainability of water use. The ICMA will operate the DSS on an agency basis to assist DWA and will thus run the models to produce the required information.

The CROCOC should develop a decision/discussion/consensus seeking approach with the DWA, ICMA and WUA, that is appropriate to the task at hand and compatible with Strategic Adaptive Management as used by the ICMA. The DSS and CROCOC should be transparent and adapt as we learn more about the process.

Addendum B to this Terms of Reference outlines the communications and decision lines around the CROCOC.

AREA OF OPERATION

The Area of Operations for the DSS and the Committee will initially be the main stem of the Crocodile East River System downstream of the Kwena Dam until the confluence with the Komati River immediately upstream of the International Border with Mozambique.

In future it is intended to expand the area of operation step by step to include all tributaries of the entire Crocodile East River Catchment upstream of the confluence with the Komati River.

COMMITTEE STRUCTURE

The CROCOC will be a technical committee of the Responsible Authority.

The ICMA will provide the Secretariat and Chairperson for the CROCOC.

MEMBERSHIP

The membership of CROCOC is intended to comprise the main roleplayers within the Crocodile River catchment directly involved in the management of the river flows and related water uses.

Each organisation indicated below should have a member and an alternative, the names of who must be provided to the CROCOC in writing. In addition, each organisation to a meeting may include up to two observers or advisors. Membership is standing and Organisations can propose new members or changes of membership to the CROCOC.

The members below may be represented by delegation through agreement by the CROCOC.

Members must be involved directly with water management on the Crocodile and be readily available for and committed to attend all meetings accordance to membership status.

Core Members:

Proposed Member		
ICMA	Chair	Brian Jackson
	Secretary	ICMA I&P Division
ICMA I&P Division		Diketso Khaile
ICMA River Operations Division		Sipho Magagula
	(observer: Thabo Mahlobo)	
DWA WRPS		Celiwe Ntuli
	(observer: Ronqui Cai)	
DWA Mpumalanga (Nelspruit)		Johann van Aswegen
	(observer: Sydney Nkuna)	
DWA Infrastructure Branch		William Matsabe
	(observer: Amos Mtsweni)	
Crocodile Irrigation Board:	Chair	Dawie van Rooi
Technical		Willie du Toit
		Andre van der Merwe
Kruger National Park		Eddie Ridell
	(observers: Robin Pietersen & Jacques Venter)	
Mpumalanga Tourism & Parks Agency		Francious Roux
Mpumalanga Dept. Agriculture	Engineering services	Marius van Rooyen
Silulumanzi		Yolande van Staden
Mbombela Municipality	Technical Services	Dolphin Malokela
Nkomazi Municipality	Technical Services	Dumisani Mzolo

Advisors:

DWA NWRP		Neil van Wyk
KOBWA:		Sidney Dlamini
Ara-Sul		Erucio de Braz Macacau
ICMA	Marketing	Sylvia Machimane
DWA RDM		Barbara Weston

Ehlanzeni District Municipality		Rodney Mhlongo
White River Valley Conservation Board		Debbie Turner
Kaap River Major Irrigation Board		Cas Du Preez
Sand River Irrigation Board		Barry Carlse
Elands River Water Users Association		Andre van Tonder
Stads River		Johan smuts
Nels River		
Consultants:	Short Term model	Mehari Frezghi
	Long Term Model	Stephen Mallory
		Tendai Sawuyama

MEETING PROCEDURES

The CROCOC will initially meet on a monthly basis and will move to quarterly meetings over time or as decided by the meeting.

The ICMA will convene the meetings and advise the members of the date, time and venue for each meeting at least 7 days in advance.

The ICMA will appoint a chairperson for the meetings and provide the secretariat.

FINANCIAL ARRANGEMENTS

The members will carry their own costs for traveling, disbursements, subsistence, time spent at meetings and in preparation for meetings.

The ICMA will provide the venue.

AMENDMENT OF TERMS OF REFERENCE

The CROCOC may propose amendments to the Terms of Reference in writing to all members via the secretariat. The decision to change the TOR rests with the Relevant Authority through advice from the CROCOC.

ADDENDUM A: INFORMATION AND DECISION REQUIRMENTS:

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

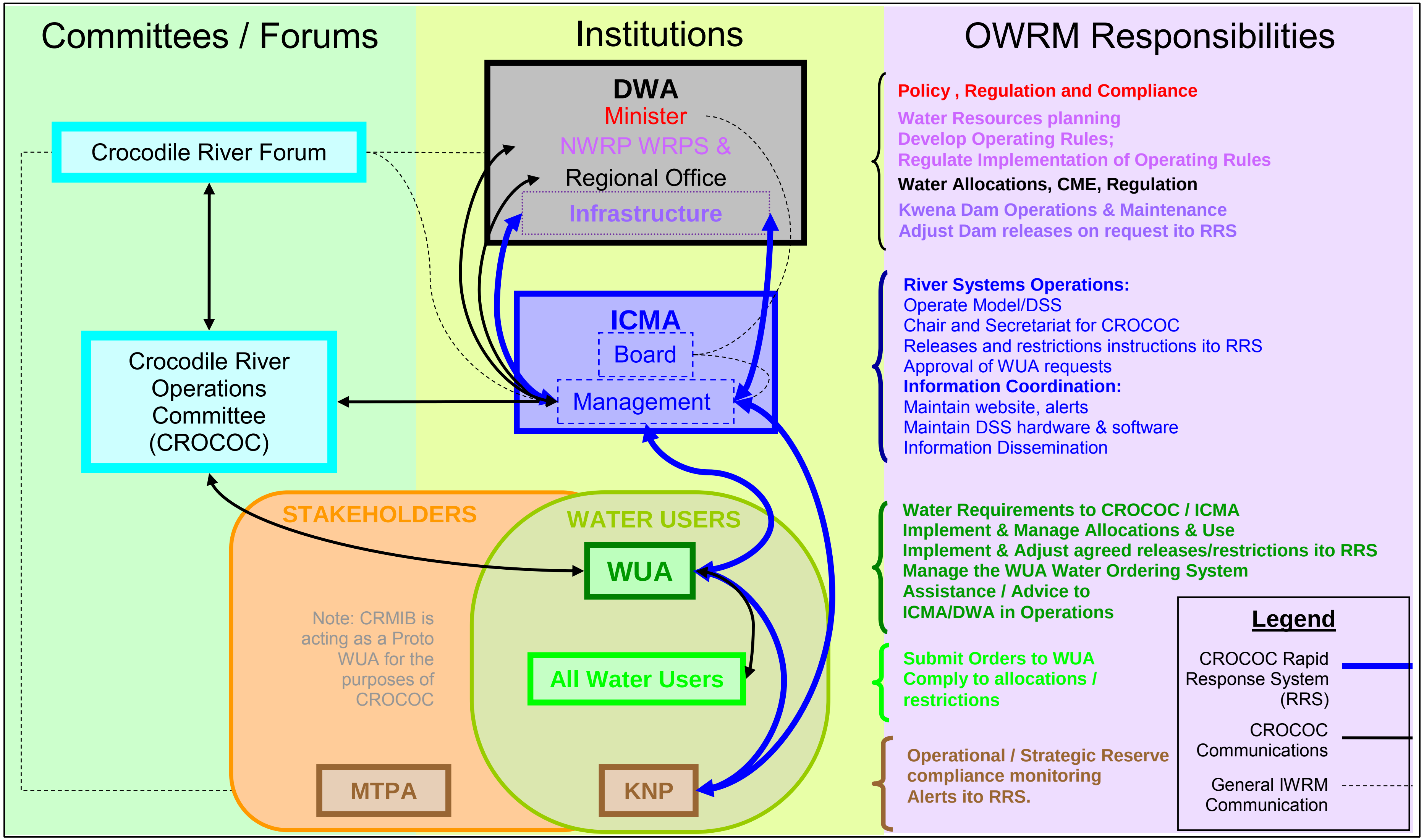
INFORMATION NEEDS	DECISIONS REQUIRED

– 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

ADDENDUM B: INFORMATION AND DECISION LINES:



APPENDIX F

MINUTES OF 1ST CROCOC MEETING HELD ON 06-10-2009

Venue: ICMA Board Room

Time: 09h30 - 13h00

Present	
Brian Jackson (BJ) - Chair	Inkomati Catchment Management Agency (ICMA) - Water Resource Planning and Programmes
Dumisani Nxumalo (DN)	ICMA – Institutions and Participation
Vanrooi Khosa (VK)	ICMA – Manager, Office of the CEO
Rongqiu Cai (RC)	Department of Water Affairs (DWA) – Water Resource Planning Systems
Celiwe Ntuli (CN)	DWA – Water Resource Planning Systems
William Matsabe (WM)	DWA – National Water Resources Infrastructure
Kobus Pretorius (KP)	DWA – National Water Resources Infrastructure
Prudence Dzambukeni (PD)	DWA – Mpumalanga Regional Office
Dawie van Rooy (DvW)	Crocodile River Major Irrigation Board (CRMIB)
Willie du Toit (WdT)	CRMIB
Ronelle Putter (RP)	CRMIB
Amelia Lombard (AL)	CRMIB
Craig McLoughlin (CM)	South African National Parks (SANParks)
Thomas Gyedu-Ababio (TGA)	SANParks
Yolande Oosthuizen (YO)	Silulumanzi
Happy Mushwana (HM)	Mbombela Municipality
S. Shabangu (SS)	Komati Basin Water Authority (KOBWA)
Eric Masereka (EM)	Department of Agriculture, Rural Development and Land Administration (DARDLA)
Francois Roux (FR)	Mpumalanga Parks Board
Kevin Rogers (KR)	Centre for Water in the Environment (CWE), Wits University
Rebecca Luton (RL) - Minutes	CWE Wits
Edward Riddell (ER)	Association for Water and Rural Development (AWARD)
Kevin Greaves (KG)	DHI South Africa
Jason Hallowes (JH)	DHI South Africa
Stephen Mallory (SM)	IWR Water Resources

Present	
Tendai Sawunyama (TS)	IWR Water Resources

Apologies	
Marcus Selepe (MS)	ICMA – Acting CEO
Sylvia Machimane (SyM)	ICMA - Marketing and Communications
Beason Mwaka (BM)	DWA – Water Resource Planning Systems
Niel van Wyk (NvW)	DWA – National Water Resource Planning
Johann van Aswegen (JvA)	DWA – Mpumalanga Regional Office
Patrick Ntabeni (PN)	DWA – Mpumalanga Regional Office
Andre van der Merwe (AvM)	CRMIB
Sidney Dhlamini (SD)	KOBWA

Action Items Arising from Meeting

Action	Persons responsible
Draft interim decision and communications framework for the Operations Committee and broader system.	BJ
Submit written comments about the proposed Terms of Reference (TOR) for the Crocodile River Operations Committee. (See section four, below, for further details).	All
Follow-up on queries regarding the model's capabilities with regards to implementing the ecological reserve.	CM, SM, TGA, ER.
Prepare DWA perspective on implementation of the reserve (See section eight, below, for further details).	NvW
Submit written comments about the proposed web page for the DSS. (See section nine, below, for further details).	All
Confirm availability of Operations Committee members for site visit, and finalise date with the KNP.	ICMA to coordinate: SM, BJ & CM
Submit written suggestions for agenda items for next Operations Committee meeting.	All

All presentations given at the meeting and the draft TOR will be included with these minutes.

N.B. All written comments should be sent to:

croc@inkomaticma.co.za **or** jacksonb@inkomaticma.co.za

1. Welcome, Introductions and Apologies

BJ welcomed all and gave a brief background of the project. It is a Department of Water Affairs (DWA) project, which concludes at the end of October 2009. This meeting was arranged to enable stakeholders to give feedback about various aspects of the model and the broader project to ensure that this feedback can be considered and acted upon before the DWA project and consultant's contracts expire.

Each participant briefly introduced themselves, stating which organisation they were representing, and their reasons for attending this meeting.

2. A real-time operating decision support system for the Crocodile East River system: Overview and background

Presentation given by RC. BJ said that this presentation served to emphasise that the utility of any model depends on the availability and quality of input data, and also on the broader decision-making processes that are set up around the model.

3. The need and context for a real-time operations decision support system to serve the stakeholders of the Crocodile: Purpose and role

Presentation given by BJ. KR then elaborated on the ICMA's choice of three projects (this Crocodile River operations project; a KNP-linked ecological reserve delivery project; and a municipality-linked project). The ICMA spent a lot of time choosing these projects, considering what would be 'do-able' within the ICMA's resource constraints, what would have a long shelf-life but also immediate impact, and what would affect the widest range of stakeholders.

DvR asked for more information about the second project, in terms of who established the project and how far along it is. KR responded that it is a SANParks initiative, that is currently at the stage of identifying which types of information need to move through which network channels in order for the ecological reserve to be implemented. BJ added that the project is about a creating a broader information exchange programme between the KNP and the ICMA, and not just about the ecological reserve. CM expressed that, in ecological reserve terms, the project is about setting up the processes that will need to be in place in order for the reserve to be implemented.

DvR also commented that Water User Associations (WUAs) are not mentioned in the TOR, and that deciding which organisations (DWA, ICMA, WUAs) will be responsible for which strategic and operational decisions must be included in the TOR. BJ agreed, explaining that this was exactly the sort of stakeholder input that was desired from this meeting. BJ emphasised that we need to be explicit upfront about the types of decisions that will need to be made, the processes by which they will be made, who will make them, and when.

BJ indicated that he would draft an interim decision and communications diagram and distribute for comments.

4. Presentation of Draft Terms of Reference and Membership Discussions

Presentation of draft TOR given by BJ. All meeting participants were asked to submit written comments about the TOR. In particular, but not exclusively, the following points-for-discussion were brought to the participants attention:

- The proposed name of the committee: Crocodile River Operations Committee (CROC)
- The length and content of the Preamble and Overview of DSS.
- The Objective of the committee.
- Addendum A, which begins to detail the information and decision-making requirements of the committee.
- Membership of the committee: i) organisations/individuals that should be included in membership; ii) full member/ observer status; iii) each organisation was asked to provide written confirmation of the names of a person/people who will be committed and regular members of the committee.
- The process of amending the TOR and, related to this, the broader processes of decision-making as defined within the TOR. For example, all committee members must be clear about the meaning of terms such as "consensus driven decision-making", all must agree on the definitions of words such as "consensus", and all must be clear about the broader implications thereof.

JH pointed out that these are the TOR for the Operations Committee, that will meet on a monthly basis, and that we must not forget that there will effectively be "sub-committees" that make decisions over shorter time periods (weekly or opportunistically). DvW agreed and said again that it is imperative that we clarify who is responsible for making decisions at various levels, and over various time-scales. He suggested that DWA is responsible for decisions at the level of policy, that the ICMA is responsible at policy and strategy levels, and that WUAs are responsible at an operational level. DvW recommended that the ICMA and local WUAs should enter into a service level agreement, so that the WUA level is where day-to-day operational decisions are taken, and the ICMA is responsible for providing the relevant information so that WUAs are able to make these decisions.

BJ agreed that it is vital that clear decisions are made about these types of responsibilities, but said that this particular meeting was not the place to do so. He proposed that stakeholders comment in writing, and these issues can be discussed at the next Operations Committee meeting.

KR responded that we need to be careful about thinking of decision-making as something that can be divided up 'like slices of cake': what we need to develop is a decision-making system that runs through, and operates across, all levels. He said we need to think in terms of an inclusive decision-making system that involves all stakeholders, in the appropriate places, that the DSS can be fitted into. KR observed that it is the combination of decision-support and decision-making systems that is fundamental to Strategic Adaptive Management, and fundamental to serving the catchment as a whole in the short-, medium-, and long-term.

DvW noted that there will always be particular criteria that are desirable for decision-making processes to have. He said that the decision-making processes that are in place for the Komati River are neither flexible nor efficient enough to properly serve the needs of the stakeholders. RP added that decisions often need to be made very rapidly (within time frames of a few hours) and so lengthy and distorted decision-making processes are completely useless.

5. DSS theory, framework and short-term model

Presentation given by JH. RP pointed out that the DSS will allow for "optimisation", not only of dam releases, but also of rainfall events. EM asked if the DSS can take into account changing water requirements, and JH responded that water requirements – as perceived by irrigators themselves – are entered into the system periodically, and that the model therefore does have the flexibility to cater for changing water requirements.

6. DSS theory, long-term model and presentation of preliminary results available from the long-term model.

Presentations given by SM. Currently, the irrigation water requirements across the year that are being used in this model are based on data from the Inkomati Water Availability Assessment Study. Although this is the latest available data there is clearly an important data gap that needs to be filled. The Operations Committee will have to decide how these gaps can be filled.

BJ highlighted that an important difference between this DSS and the model currently being used on the Komati, is that in the Komati, stakeholders are obliged to make decisions regarding restrictions at the beginning of the year only. This model is more flexible in terms of the timing of decisions.

7. Preliminary results available from the DSS-framework and short-term model.

Presentation given by KG. SS asked what the lag time is for getting water from the Kwena dam to Komatipoort. RP answered that if the river has dried up, it will take around 10-12days, but if there is still water in the system, the lag time will be about 7-8days. This should be confirmed with the model.

DvR asked in the Van Graan dam is included in the model, and KG replied that it is not: the model runs as if the Van Graan is full. DvR suggested that there could be an opportunity here to utilise the Van Graan, which holds 1.2million m^3, to provide water to the lower reaches of the system. BJ agreed that this dam should definitely be included in the DSS, and that its inclusion could be one of the first amendments made to the model.

EM queried whether this DSS can predict droughts, and BJ replied that historical drought occurrence is built into the statistics and so the model can output the probability of drought. DvR then asked that if stakeholders decide that they would like the dam to be at x-level during y-month – which will be important during drought periods – can the DSS 'work backwards' from there. SM replied that it is possible to build this function into the longer-term model, but that it has not been included yet.

CM asked for clarification about the model's capabilities in terms of various components of the ecological reserve. SM responded that day-to-day reserve components are really just being developed, and suggested that CM, TGA, ER and himself get together to follow up on this conversation further.

8. Presentation of proposed irrigation ordering method

Presentation by KG. DvR asked whether the DSS can also accommodate other users' needs (i.e. non irrigators) as, he said, this would be vital in severe drought. KG replied that the particular tool that he had just presented was designed specifically for irrigators, but that similar tools can be set up for different user groups. BJ suggested that once the Irrigation Boards have transformed into water user associations, this same tool could be adapted to include other user groups.

FR expressed a concern that the environment is not considered in this DSS model. KG responded that the ecological reserve can be built into the model, in the same way that a minimum flow to Mozambique has been specified in order to meet international obligations. BJ added that the DSS at the moment is set up to reflect the current operating rules, and that once the ecological reserve determination is finalised, new operating rules will be established so that reserve requirements are also met. FR questioned why the preliminary reserve requirements are not included in the model, and CM said that this issue had been raised at previous meetings. CM said that the current idea is that implementation of the ecological reserve will need to be incremental SM indicated that the latest available hydrology indicates that about 30% of the reserve will generally be met by meeting international obligations.

BJ added that in order to implement the whole reserve on the Crocodile River, current use would need to be curtailed by around 30%, which of course would have significant economic consequences. RC agreed, saying that NvW should perhaps give a DWA perspective of this at the next meeting, based on the DWA scenarios project which assessed various potential impacts of implementing 30%, 50%, 70% etc. of the ecological reserve. BJ raised the point that this type of assessment project now needs to be taken to the next step in a separate process of stakeholder engagement, where implementation decisions are made based on these possible future scenarios and impacts.

Overall, it was agreed that implementation of the ecological reserve needs to be a priority agenda item for future Operations Committee meetings.

9. Presentation of web page

Presentation given by BJ. All meeting participants were asked to submit comments about the content of the web page and, in particular, on the following issues:

- Which links to other websites should be present?
- Which gauges do users want to see combined in flow graphs?
- Where do users want simulated hydrology data for? e.g. where there is no weir data. BJ would like very spatially specific comments from participants on this.

There was a discussion, but no agreement, about whether DWA or the ICMA should host the website space. RC, BM and BJ are to discuss this at a later date.

10. Launch, field trip and insignia

Presentation given by BJ. Meeting participants agreed that in principle, the Crocodile River Operations Project should have a broader marketing and communications strategy, which the ICMA will develop. They also agreed to the idea of a site visit for members of the Operations Committee, which will end in a braai at the KNP. A date needs to be set for this as soon as possible so that CM can organise the braai.

11. Discussions

DvR pointed out that ordering is not the final decision concerning restrictions, but rather will serve as extra information from which decisions can be made. He emphasised that it sometimes may not be possible for irrigators to implement what has been ordered. BJ responded that the ordering can be updated frequently, for example, on a weekly basis, and then adjusted through Operations Committee decisions.

12. Agenda items for future meetings, next meeting and closure.

The ecological reserve was confirmed as a priority agenda item for the next meeting, and participants agreed they would submit further suggestions in writing.

The next meeting has been confirmed for:
Wednesday 18th November
09h00 to 13h00
ICMA Board Room
BJ thanked all participants for attending and prioritising this meeting over other related events. He emphasised the need for further input from all participants before the next meeting, at as early a date as possible.

APPENDIX G

QUESTIONNAIRE FOR SOCIAL LEARNING AND CONSENSUS BASED DECISION MAKING

Name:

Organisation:

Contact No:

E-mail:

Audience:

This questionnaire is intended for stakeholders relevant to the operational water resources management of the Crocodile River. A relevant stakeholder is:

any persons, or their representative organisations--

i) whose activities affect or might affect water resources within its water management area; and

ii) who have an interest in the content, effect or implementation of the Catchment Management Strategy".

Rationale

This questionnaire will form part of the process to update and improve the Operational Water Resources Information Management of the ICMA. The key focus of the questionnaire is to enable the ICMA to evaluate the Social Learning Achievements and level of consensus in decision making of the adaptive operational water resources management of the Crocodile River Catchment.

Purpose of the questionnaire

In this questionnaire we hope gather your impression of the effectiveness of the Crocodile River Operations Committee and the adaptive operational river management in the Crocodile River in general. It also aims to gather information on the level of consensus in decision making through the Crocodile River operations Committee.

Please note that the questions are based on social science and have been designed to be able to determine the social learning inherent in the adaptive operational water resources management in the crocodile river and are based on a combination of the social learning criteria of Susskind and Cruikshank (1987) and Samson-Sherwill (2006) as well as the key capacities of Pahl-Worstl and Hare (2004), and the key fostering and hindering Factors of Mostert et al. (2007).

The questions on Consensus are based on the 10 guiding principles of consensus processes (National Round Table on the Environment and the Economy, 1993).

Method to fill in the Questionnaire

You will be required to fill in a score of between 1 and 5 for all questions with 5 indicating that you strongly agree, 1 that you strongly disagree and 3 neutral You may tick the correct box applicable.

The questionnaire should not take much longer than 15 minutes to complete:

LEGEND

AOWRM: Adaptive Operational Water Resources Management

CROCOC: Crocodile Operations Committee

OWRM: Operational Water Resources Management

KEY CAPACITIES FOR SOCIAL LEARNING

Criteria	Users Scores												User Comments	Scientific Source
	AV	CM	ED	ER	JV	NV	RP	SM	TS	DV	Min	Avg		
FAIRNESS: Do you feel that the River Operations or AOWRM of the Crocodile, guided by the CROCOC is fair?	4	4	4	4	5	5	5	4	3	4	3	4.2	It is fair, but power-players are still the most represented in the CROCOC, hence why I don't score 5 here. I still feel stakeholders like emerging farmers are not represented; the major users may tend to influence decisions.	Susskind and Cruikshank (1987) & Samson-Sherwill (2006)
WISDOM: Do you feel that competent decisions based on all available relevant information, which in implementation achieve the goals it intended.	4	3	4	4	5	5	4	4	4	4	3	4.1	There's some unknowns I'm sure that would augment the decisions e.g. further hydrological information for example transmission losses amongst other factors.	
WISDOM: Do you feel that the above decisions are achieved through Consensus?	5	4	5	5	4	4	5	4	5	4	4	4.5	For those represented at the CROCOC, yes (but of course there are regular absentees e.g. municipality). Yes, there is always a stakeholder interaction process before decisions are made.	
STABILITY: Do you feel that the above decisions will not be opposed and thereby negated in the near future?	4	3	4	3	2	4	3	4	4	4	2	3.5	When the drought comes, there will be opposition – but at least now there is the platform for dialogue within the CROCOC. The decisions are currently supported by data which is fairly reliable and justifiable,	

												but we are leaving in a dynamic world and with improvement of information some decisions may change..	
SENSE OF OWNERSHIP: Do you feel that you have a sense of ownership and access to the OWRM process in the Crocodile River?	4	4	5	5	5	4	4	4	5	4	4	4.4		
CAPACITY BUILDING / LEARNING: Do you feel that there is sufficient capacity building and learning on OWRM through the CROCOC?	2	3	5	4	4	5	4	3	5	3	2	3.8	More focus could be given to this to bring all to a coherent general understanding. All people have equal opportunity to learn if they need to. DWA and Mbobmela Muunicipality are not coming to the party and building capacity. All stakeholders don't understand full impact of decisions.	Samson-Sherwill (2006)
CAPACITY BUILDING / LEARNING: Do you feel that the CROCOC sufficiently allows for other peoples perspectives in its deliberations?	4	4	4	5	4	5	4	4	4	4	4	4.2	Only those who have shown interest, but as before the bias is towards major water users.	

AWARENESS: Do you feel that there is good awareness amongst the CROCOC stakeholders of the goals and perspectives of the various stakeholders	3	3	4	4	5	5	4	3	5	3	3	3.9	Capacity building and awareness of each "sector" may provide improved understanding and acceptance of issues that some parties are dealing with. This has been shared widely, but buy in from some stakeholders such as municipalities is still lacking. Some stakeholders might have hidden agendas, eg Mbobmela Muunicipality are not always sharing their vision with CROCOC Amongst regular members only, but again key absentees prevent this from scoring 5. There is a difference between direct and indirect stakeholders.	Pahl-Wostl and Hare (2004)
AWARENESS OF SYSTEM COMPLEXITY: Do you feel that you are fully aware of the complexity of OWRM in the Crocodile River?	4	4	3	4	3	5	3	5	5	4	3	4	If one thinks they are fully aware of complexity (and uncertainty) then I'd worry about them!	
SHARED PROBLEM IDENTIFICATION: Do you feel that there is shared identification of the OWRM problems?	4	3	5	4	3	4	3	4	5	3	2.5	3.8	Yes, but again if the CROCOC reaches crunch time in a drought only then could one answer this question satisfactorily. Yes, all those involved in making the decisions are given equal opportunity to identify problems. The impacts are not fully shared and therefore have an impact on process.	

INTERDEPENDANCE BETWEEN STAKEHOLDERS: Do you feel that there is high interdependence between the stakeholders involved in AOWRM and the CROCOC I particular?	2	4	5	3	4	4	4	3	3	3	2	3.5	Understanding of the various current stakeholder "responsibility areas" as well important absent stakeholders (ie Munic's) may create improved interdependence. There are some stakeholders who can influence decisions of others, major versus minor water users. Relationships are there, but still hard to tell as we haven't yet had tough decisions to make. Certainly between SANParks and the ICMA I would say there is a high interdependence. The impact is not the same and therefore interdependence is lacking.	
LEARNING TO WORK TOGETHER: Do you feel that the stakeholders work together well to achieve AOWRM and do you feel and that the CROCOC has assisted in achieving this?	3	4	5	5	5	5	4	4	4	4	3	4.2	This may be improved based on awareness and understanding through capacity building. Important to include the missing stakeholders in the process. I would say the platform for working together is there, and the relationship building (trust) is proceeding well.	
RELATIONSHIPS: Do you feel that the formal Relationships and Networks around AOWRM in the Crocodile River and fostered by the CROCOC are well established?	3	4	4	4	4	4	4	4	3	4	3	3.8	The formal relationships will improve if considering above. At this stage I think the informal relationships are on a higher standard. I think more effort is needed to foster these relationships as some institutions are not represented in CROCO meetings.	
RELATIONSHIPS: Do you feel that the informal relationships and networks around AOWRM in the Crocodile River and fostered by the CROCOC are well established?	4	3	4	4	3	4	4	3	4	3	3	3.6	The informal relationship with DWA and to a lesser extent Mbombela seems to have collapsed or was never there.	

TRUST: Do you feel that there is good trust amongst the stakeholders involved in the CROCOC?	4	4	5	4	5	5	4	4	3	3	3	4.1	Largely. Some mistrust due to Mbombela's unstated agendas. I am not sure if there is good trust especially between irrigators and other water users. Its still not clear. Due to not fully understanding the different impacts, affects trust.	

KEY FOSTERING FACTORS FOR SOCIAL LEARNING

Criteria	Users Scores												User Comments	Scientific Source
	AV	CM	ED	ER	JV	NV	RP	SM	TS	DV	Min	Avg		
ONGOING HIGH MOTIVATION: Do you feel that there is ongoing high motivation amongst the stakeholders involved in AOWRM in the Crocodile River?	3	3	4	5	5	4	3	4	5	4	3	4	ICMA staff are trying their best to motivate stakeholders. Motivation is probably a function of various factors; one is "water allocation "for certain stakeholders. If the allocation is low, motivation to attend and participate could be higher. Water quality is critical but stakeholders are absent and motivation leads to frustration	Mostert et al. (2007)
INDEPENDENT TECHNICAL MEDIATOR: Do you feel that the ICMA is a good independent technical Mediator of AOWRM in the Crocodile River?	5	5	5	5	5	5	5	4	4	5	4	4.8		
HIGH COMMITMENT OF LEADERS: Do you feel that the different leaders and responsible authorities are highly committed to effective AOWRM in the Crocodile River?	4	4	5	4	5	5	3	3	4	4	3	4.1	Only some institutions, municipality still not involved. Again, uncertain about DWA (regional) and Mbombela.	

LEGITIMACY: Do you feel that the ICMA, through the CROCOC, has legitimacy to implement AOWRM in the Crocodile Catchment?	5	5	5	5	5	5	5	5	5	5	5	5		
EXCHANGE OF INFORMATION: Do you feel that there is good access to and exchange of information regarding OWRM in the Crocodile River?	3	4	4	4	5	4	4	3	5	4	3	4	Could be broadened (e.g. through the AOG dashboard). This could improve. Irrigators are not entirely transparent as their water use	
INCLUSIVITY (ABILITY TO CONTRIBUTE?): Do you feel that all stakeholders are able to effectively contribute to decisions around OWRM in the Crocodile River?	5	4	5	2	5	5	4	3	3	3	2	3.9	Like I said before there's power-players and also if stakeholders do not regularly attend then hard to effectively contribute. Only those who attend the meetings. Some stakeholder lack technical skills and do not contribute. Some lack understanding of impact.	Samson-Sherwill (2006)
DELEGATED LEADERSHIP: Do you feel that there is sufficient delegation of responsibilities down for effective AOWRM in the Crocodile River?	4	3	4	3	5	4	4	4	5	4	3	4	ICMA staff.	Susskind and Cruikshank (1987)
NUMBER OF PARTICIPANTS: Do you feel that the use of limited participants only directly relevant to OWRM in the Crocodile for the CROCOC enables improved deliberations and decisions?	5	4	4	4	3	4	3	4	4	5	3	4	Yes, but inclusivity may be compromised. Those not present at meetings may not have direct influence to decisions.	Mostert et al. (2007)

FREQUENT, FOCUSED DISCUSSION: Do you feel that there is sufficiently frequent, and focused discussion on AOWRM of the Crocodile River through the CROCOC?	3	3	4	3	3	5	4	3	5	5	3	3.8	From time to time. Frequency could be increased somewhat.	
EFFICIENCY: Do you feel that the AOWRM in the Crocodile is efficient in achieving its goals?	4	4	4	4	3	5	4	4	5	4	3	4.1	Yes, but think only be able to answer that during a critical time.	

KEY HINDERING FACTORS FOR SOCIAL LEARNING

Criteria	Users Scores												User Comments	Scientific Source
	AV	CM	ED	ER	JV	NV	RP	SM	TS	DV	Min	Avg		
INADEQUATE TIME AND RESOURCES: Do you feel that there are sufficient resources and time made available to enable effective AOWRM?	3	3	5	5	4	3	3	4	5	4	3	3.9	Resources might be a limiting factor. Being 'adaptive' in adaptive managements means you utilise information within those constraints (time&uncertainty)	Mostert et al. (2007)
LACK OF FEEDBACK OF OUTCOMES: Do you feel that there is sufficient feedback of the outcomes of decision relating to OWRM in the Crocodile River?	4	4	4	5	5	4	4	4	4	4	4	4.2		
RELATIONSHIP BETWEEN STAKEHOLDERS AND TECHNICAL TEAMS: Do you feel that there is good interaction between	3	5	5	5	5	4	3	4	4	4	3	4.2	From my own perspective within SANParks, yes. Only at CROCO meetings.	

technical teams and stakeholders?														
OVERLY TECHNICAL LANGUAGE: Do you feel that the language used in AOWRM of the Crocodile is overly technical?	2	3	4	4	2	3	2	2	5	4	2	3.1	Language is understandable by all, although concepts or theories on which its based might be vague to some. Can be for non-regular contributors.	
LACK OF CLARITY ON PROJECT AIMS: Do you feel that there is good clarity on the AIMS and GOALS of the CROCOC and the AOWRM it aims to facilitate?	5	4	4	4	3	4	3	4	5	4	3	4	For those that understand what SAM is – for broad stakeholders this may not be clear.	
CONFLICT IN SCALE OF PROJECT AND STAKEHOLDER INTEREST: do you feel that the scale of AOWRM meets the interests of stakeholders?	3	5	5	5	4	4	4	3	4	4	3	4.1	Feedback loops are not yet operational in the Adaptive management	
LACK OF OPENNESS: Do you feel that there is sufficient openness in the decision making around OWRM in the Crocodile River?	4	4	4	4	5	4	4	4	4	4	4	4.1		

CONSENSUS BASED DECISION MAKING

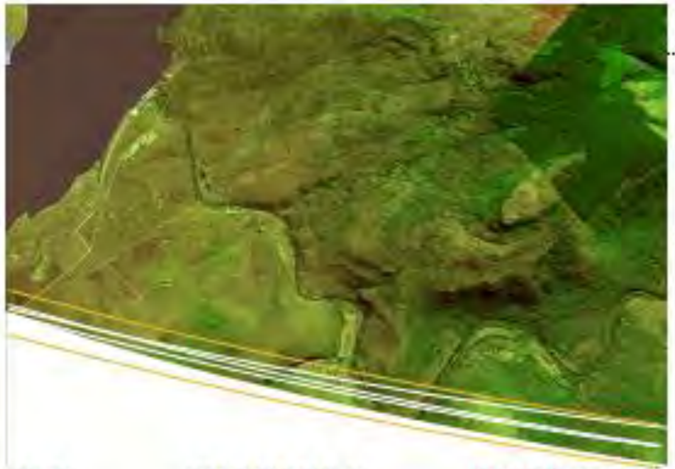
Criteria	Users Scores												User Comments	Scientific Source
	AV	CM	ED	ER	JV	NV	RP	SM	TS	DV	Min	Avg		
PURPOSE DRIVEN: Do you feel that the CROCOC is purpose driven?	5	4	5	5	5	5	4	4	5	4	4	4.6		Round Table of Canada

INCLUSIVE: Do you feel that all parties with a significant interest in the issue are be involved in the consensus process?	4	4	5	3	5	4	4	4	4	3	3	4	Again – if all parties to the quorum were present then you could say so, but otherwise no	
VOLUNTARY PARTICIPATION: Do you feel that the stakeholders participate in the CROCOC voluntarily?	4	4	5	5	3	5	3	4	5	5	3	4.3		
SELF DESIGN: Do you feel that the stakeholders have designed the consensus based decision making process themselves?	5	2	5	3	3	4	4	3	3	4	2	3.6	I would say this has been led by a champion (ICMA) but that stakeholders buy into the process. Not sure, more influence from ICMA. Not Sure.	
FLEXIBILITY: Do you feel that sufficient flexibility is designed in to the consensus based decision making process of the CROCOC?	4	3	4	4	3	5	4	3	4	4	3	3.8	There is great potential. Not Sure.	
EQUAL OPPORTUNITY: Do you feel that all parties have equal access to relevant information and the opportunity to participate effectively throughout the process	4	4	5	3	4	4	4	4	4	4	3	4	No – but this is largely dependent on being a regular attendee (in terms of personnel and organisations represented).	
RESPECT FOR DIVERSE INTERESTS: Do you feel that there is acceptance of the diverse values, interests and knowledge of the parties involved in the	2	4	5	5	3	4	4	4	3	4	2	3.8	Major water users have more say.	

consensus process?														
ACCOUNTABILITY: Do you feel that the parties are accountable both to their constituencies and to the process that they have agreed to establish?	4	4	4	3	5	4	3	3	5	4	3	3.9	uncertain. Not sure. Not sure of others.	
REALISTIC DEADLINES: Do you feel that there are realistic deadlines for decision making?	4	4	4	5	4	4	4	4	5	4	4	4.2		
IMPLEMENTATION: Do you feel that there is commitment to implementation and effective monitoring?	4	4	5	5	5	4	4	4	5	4	3.5	4.4	Most stakeholders, yes, but no commitment from DWA	

APPENDIX H

AWARENESS CREATION PAMPHLETT FOR THE CROCODILE RIVER OPERATIONS COMMITTEE



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INKOMATI

water affairs

Department: Water and Environmental Affairs

REPUBLIC OF SOUTH AFRICA

THE CROCODILE CATCHMENT OPERATIONS COMMITTEE (CROCOC) ASSISTS WITH CONSENSUS DRIVEN DECISION MAKING ON THE OPERATIONS OF THE CROCODILE RIVER SYSTEM

MONTHLY INFORMATION NEEDS

- Prevailing Conditions (flows, rainfall, releases, restrictions, Dam levels and trajectories, ecological reserve benchmark)
- Forecasts of expected conditions
- Water Orders and Use (demands)
- Bio-Physical TPC info
- Scenarios of possible futures
- Status of water quality and trends
- Historical data and comparisons to current conditions
- Communications regarding decisions and actions

INKOMATI

INKOMATI CATCHMENT MANAGEMENT AGENCY

Private Bag X11214, Nelspruit, 1200, Nelspruit
3rd Floor, Caltex Building, 32 Bell Street
Tel: 013-753 9000
Fax: 013-753 2786
http://inkomaticma.co.za/Website/Index.html

CROCOC

Crocodile Catchment Operations Committee

Crocodile Catchment Operations Committee Website:

http://crocdss.inkomaticma.co.za/Website/Index.html

THE CROCODILE RIVER DECISION SUPPORT SYSTEM

The Crocodile River Real Time Operations Decision Support System (DSS) is a real time DSS for operating the Crocodile River developed by DWA during 2009 with input from the ICMA.

The DSS consists of the following computer software to model the catchment and provide information to decision makers on the operations of the system:

- Long Term Water Resources Planning Model (WReMP). This model is used to predict the longer term (up to 18 months) behaviour of Kwena Dam.
- Short Term Hydraulic Model (MIKE 11). This model is used to track and predict the short term (1 week) river flows at various points in the Crocodile System.
- Real Time Framework (Mike Floodwatch). This software assists with the daily collection of data and running of the models.
- A Webpage where the output from models is displayed for any stakeholders to see.

THE CROCODILE CATCHMENT OPERATIONS COMMITTEE (CROCOC)

The ICMA has set up the CROCOC to support the implementation of the real time DSS.

The CROCOC is a consultative technical advisory body serving the relevant decision making authorities and is managed by the ICMA. It provides the mechanism for interaction, exchange of operational information and coordination of operational activities for the Crocodile East River System to enable informed and consensus driven decision making. The CROCOC meets monthly.

Although the CROCOC has no decision making powers under current legislation, its role as a coordinating and advisory body is exceptionally important in the broader decision making process

A Terms of Reference for the CROCOC has been developed and is available from the ICMA. The TOR lists the main information and decision requirements on an annual, bi-annual, quarterly, monthly and weekly basis.

For more details and queries please contact the ICMA at:

croc@inkomaticma.co.za or jacksonb@inkomaticma.co.za

CROCODILE CATCHMENT OPERATIONS WEBSITE

APPENDIX I

LIST AND DISCUSSION OF THE DATA SOURCES RELEVANT TO OPERATIONAL WATER RESOURCES MANAGEMENT IN THE CROCODILE RIVER AVAILABLE AT THE COMMENCEMENT OF THE STUDY

Name	Description / Comments	Source
Dams	All DWA and major dams are available with detailed hydrological data. The DWA dam safety office database is also available for all registered dams. The Inkomati Water Availability Assesmsnet Study (IWAAS) conducted by DWA attempted to identify area, storage curves for all other significant dams but this is low confidence data and must be updated. The ICMA has recently determined updated area/volume relationships for all dams identified from the high resolution landcover and DEM data sources at the ICMA. This data must still be fed into both the water resource planning and operations models used in the AOWRM to improve outputs.	DWA WRIMS, IWAAS
Rivers	DWA rivers captured from Surveyor General 1:50 000 topographical maps. ICMA rivers coverage derived from the 5m DEM developed by the ICMA	DWA WRIMS, ICMA
Natural Vegetation	Recently completed natural vegetation cover is available from SANBI. It is recommended that hydrological models such as ACRU be updated to incorporate the SANBI natural landcover as opposed to the older Acocks vegetation in future to improve their outputs.	SANBI
Landcover	A 30m resolution landcover was produced by DWA in support of the verification of existing water use in 2006 covering the years 1996, 1998 and 2004 for the Inkomati in South Africa. The ICMA also co-funded the development of a new 2,5m resolution comprehensive landcover in 2011. This landcover can be used for: • Farm Dam area volume calculations to improve the planning and operations model outputs • Irrigated land identification to improve water use estimations within the water resources planning models • Irrigated field identification to feed into possible future et, soil moisture, biomnass and water use estimates and monitoring based on remote sensing data that is becoming more readily available. This data can be fed into the planning and operations models to improve their outputs	DWA Regional Office, ICMA
WRC WR90 Data	Primary Catchment through to quaternary catchments with basic historical rainfall and hydrological data. Per quaternary catchment for use in water resources planning models.	DWA

WRC WR2005 Data	Updated data from WR90. Same as IWAAS data for Inkomati	DWA
Quinary Catchments	A 5th level of catchment boundaries (or quinary catchment boundaries) was developed by the IWAAS project in 2008. These catchments were created for water resources planning needs on the main stem of the primary and secondary rivers and recent attempts by the ICMA to expand river operations into some tributaries has revealed that the quinary catchments need to be updated before the current operational water resources management on the crocodile river can be expanded to the tributaries as they are not of sufficient detail to be used as is.	IWAAS
Remote Sensing Satellite Imagery	SPOT and Landsat Imagery is freely available. The ICMA has signed an agreement with DWA to obtain all SPOT Imagery for the Inkomati. Various Landsat Images are available for the years 1996, 1998 and 2004 from DWA and the ICMA. Remote Sensing is a rapidly growing field. New sources of satellite imagery and techniques to derive water resources information from them are available and continue to be refined. To ensure continual learning it is important to keep up with these recent development and where they may improve OWRM. Please refer to section 4.4 for more discussion on this matter.	DWA WRIMS, ICMA
Water Quality Data	The DWA water quality monitoring network and data is available for several chemical and biological indicators at several locations within the Inkomati WMA. The locations of all the monitoring sites area available as well as the national standards for each indicator. These standards have been amended on the Crocodile River to be more strict. All monitoring is done against these standards and presented at the Crocodile River Forum and CROCOC This monitoring is done on a monthly or bi monthly time step.	DWA WMS System, ICMA
Canals	Coverage of all significant canals in the Inkomati is available. These are important to capture as they can divert significant water and the planning and operations models must incorporate these diversions.	DWA
Wetlands	A National Wetlands coverage, version 3, is available from SANBI. The new landcover developed by the ICMA has improved on this and produced a revised wetland coverage. It is also available. Wetlands can have significant local impacts on runoff and must thus be properly incorporated in to operational models.	SANBI, MWF
Farm Boundaries	The current surveyor general derived cadastral database is outdated. The ICMA appointed a service provider to update this database in 2013. This data is important as water allocations are issued per farm and it can assist with understanding the actual water use vs. allocated water use of all water users, which is important for water resources planning.	Surveyor General; ICMA
Irrigation	The boundaries and lists of rateable areas for all Irrigation Boards,	DWA,

Board Boundaries and lists of Rateable areas	water users associations and government water control areas. This is important to understand the area of responsibility and magnitude of water use allocation under the management of the local water management institutions.	ICMA
Human settlements	Urban and Rural landuse settlements with population data is available from various sources. The various sources of this data differ significantly in their population data. For water demands, the IWAAS water use requirements are currently being used in the operational water resources management. These demands need to be updated.	Statistics SA, DWA
20m and 5m contours	This information has been used by the ICMA to develop a Hydrologically correct high resolution digital elevation model (DEM).	Surveyor General
DEM	90m DEM derived from freely available SRTM data is available. A high resolution DEM was developed by the ICMA in 2013 to enable improved rainfall-runoff and operational modelling. It is yet to be incorporated into the models	ICMA
WARMS data	The Water Authorisations and Registration Management System (WARMS) of DWA contains all the water use allocation data. However, it is not up to date and is not being used in the models. The verification project of the ICMA will update this information, after which it must be incorporated into WARMS.	DWA
PRIMA Data	A number of reports have been developed by the PRIMA project relating to the International aspects of operational water management of the Incomati system. It is important that these international agreements and operating principles are complied with and any AOWRM is not in conflict with them. The important reports include: • Disaster Management • IWRM • Operating Rules • Institutional arrangements	PRIMA Office, Maputo
Ecological Reserve or Environmental Flow Requirements	A Preliminary Comprehensive level Ecological Reserve Determination by DWA. Project WP 9133: Comprehensive Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Inkomati Water management Area, Mpumalanga, is available The classification of the Rivers must still be done. This will be incorporated as an aspect of the Water Allocation Plan (Chapter 2, Part 2 (S9)(e) and of the NWA) to be done by the ICMA. More detail on the environmental flow requirement and its implementation in the AOWRMF is given in section 4.1.6.2.	DWA RDM Office

APPENDIX J

RIVER OPERATIONS DATA AND INFORMATION NEEDS QUESTIONAIRE

Name: ____

Contact No: ____

E-mail: ____

Rationale

This questionnaire will form part of the process to update and improve the Operational Water Resources Information Management of the ICMA. The key focus of the questionnaire is to refine the User Requirements particularly relating to management reporting (dashboard) information to be presented on the system.

Purpose of the questionnaire

In this questionnaire we hope to identify your specific requirements and get an understanding of what information you require to support your management and operational needs. The objective of this document is to identify what you **ideally** would require. We are also primarily interested in any additional data and information requirements which you would like to have added to the current database of the ICMA for you management and operational needs as well as confirmation of data you already receive that is valuable.

Please find a legend for the tick boxes in the questionnaire below:

Legend:

How Often:	Type:
A = Annual	Hist. = Historic
B = Bi – Annual	R = Real Time
Q = Quarterly	F = Future
M = Monthly	
W = Weekly	Priority:
D = Daily	H = High
H = Hourly	M = Medium
	L = Low

RIVER OPERATIONS QUESTIONNAIRE

TECHNICAL / ENVIRONMENTAL

Data Item	Type			Priority			How often (tick 1 0r more)							Processed Information from this data you would like to See (eg, Max, Avg, Alerts,)
	Hist	R	F	H	M	L	A	B	Q	M	W	D	H	

Formats you would like to see this data in:	Map	Table	Graph	Other, elaborate below

How would you like to obtain data / Information (Tick level of Priority for each option Chosen):

Website			E-Mails			SMS’s			Presentations			Smartphone App		
H	M	L	H	M	L	H	M	L	H	M	L	H	M	L

If other, please elaborate below:

RIVER OPERATIONS QUESTIONNAIRE

SOCIAL / POLITICAL

Data Item	Type			Priority			How often (tick 1 0r more)							Processed Information from this data you would like to See (eg, Max, Avg, Alerts,)
	Hist	R	F	H	M	L	A	B	Q	M	W	D	H	

Formats you would like to see this data in:	Map	Table	Graph	Other, elaborate below

How would you like to obtain data / Information (Tick level of Priority for each option Chosen):

Website			E-Mails			SMS's			Presentations			Smartphone App		
H	M	L	H	M	L	H	M	L	H	M	L	H	M	L

If other, please elaborate below:

RIVER OPERATIONS QUESTIONNAIRE

ECONOMIC:

Data Item	Type			Priority			How often (tick 1 0r more)							Processed Information from this data you would like to See (eg, Max, Avg, Alerts,)
	Hist	R	F	H	M	L	A	B	Q	M	W	D	H	

Formats you would like to see this data in:	Map	Table	Graph	Other, elaborate below

How would you like to obtain data / Information (Tick level of Priority for each option Chosen):

Website			E-Mails			SMS's			Presentations			Smartphone App		
H	M	L	H	M	L	H	M	L	H	M	L	H	M	L

If other, please elaborate below:

ANY GENERAL ADDITIONAL COMMENTS OR NEEDS:

APPENDIX K

RIVER FLOW GUAGING STATIONS IN THE CROCODILE CATCHMENT

Bold Underlined = High Priority

Bold = Medium Priority

Normal = Low Priority

Name:	Existing Real Time
Crocodile River:	
X2H006 Crocodile at Karino (Cable Length = 10m)	Y
X2H013 Crocodile River at Montrose (Cable Length = 30m)	Y
X2H016 Crocodile River at Ten Bosch (Upstream of Komati River confluence) (Cable Length = 150m)	Y
X2H036 Komati River at Komatipoort (Downstream of Crocodile confluence at Mozambique Border) (Cable Length = 160m)	Y
X2H046 Crocodile at Riverside (Malelane) (Cable Length = 60m)	Y
X2H070 Crocodile River at Kwena Dam (Measuring releases from Dam) (Cable Length = 5m)	Y
X2H096 Crocodile River at New Montrose (D/S of Elands Confluence) (Cable Length = 150m)	Y
X2H005 Nels River at Nelspruit (Cable Length = 5m)	Y
X2H022 Kaap River at Dalton (Immediate upstream of Crocodile River) (Cable Length = 30m)	Y
X2H014 Houtbosloop River at Sudwalaskraal (major tributary to the Crocodile River after confluence with the Elands River) (Cable Length = 50m)	Y
X2H015 Eland River at Lindenau (Immediate Upstream of Crocodile confluence) (Cable Length = 60m)	Y
X2H059 White River at Crocodile River confluence (Cable Length = 60m)	Y
X2H072 Nzikazi River at Matlabantu (Cable Length = 50m)	N
X2H008 Queens River at Sassenheim (Barberton) (Cable Length =10m)	N
X2H010 Noord Kaap River at Bellevue (Barberton) (Cable Length =10m)	N

X2H024 Suidkaap River at Glenthorpe (Cable Length =10m)	N
X2H031 Suidkaap River at Bormansdrift (Cable Length = 10m)	N
X2H047 Swartkoppiespruit at Kindergoed (Major tributary to Crocodile upstream of Elands River Confluence) (Cable Length = 10m)	N
X2H068 Sand River at Witklip Dam (Measuring releases from Dam) (Cable Length = 5m)	N
X2H032 Crocodile at Weltevrede (Croc River Gorge) (Cable Length = 10m)	Y
X2H012 Dawsonspruit (Upper Reaches and main tributary to the Elands River (Cable Length = 5m)	N
X2H068 Weir d/s of Witklipdam (Cable Length = 10m)	N

APPENDIX L

EXISTING RAINFALL STATIONS IN THE INKOMATI

Real Time?	Owner	Name
Real Time	ARC	DE GROOT
Real Time	ARC	Tulamahashe
Real Time	ARC	Thaba Chweu: Blyderivier_NatPark
Real Time	ARC	Lydenburg; Olifantshoek
Real Time	ARC	Thaba_Chweu: Enkeldoorn
Real Time	ARC	HAZYVIEW
Real Time	ARC	LYDENBURG; LONGTOM
Real Time	ARC	BURGERSHALL: AWS
Real Time	ARC	Highlands: Verlorenvalei_NatPark
Real Time	ARC	MALEKUTU
Real Time	ARC	PLATH - WHITE RIVER
Real Time	ARC	Mbombela: Koedoeshoek
Real Time	ARC	Mbombela: Zenzelenzi
Real Time	ARC	NELSPRUIT; BASF
Real Time	ARC	NELSPRUIT; ITSG
Real Time	ARC	MHLATI
Real Time	ARC	COOPERSDAL:AWS
Real Time	ARC	KOMATIPOORT; AMANXALA
Real Time	ARC	Inala: Kaalrug
Real Time	ARC	Lows Creek: Bella Vista
Real Time	ARC	HIGHLANDS: WATERVAL BOVEN
Real Time	ARC	BELFAST: DRIEFONTEIN
Real Time	ARC	Barberton: Moodies Estate
Real Time	ARC	ELUKWATINI: AWS
Real Time	SASRI	WS - SASRI - Komatipoort - Tenbosch
Real Time	SASRI	WS - SASRI - Nelspruit - Nelspruit
Real Time	SASRI	WS - SASRI - Malelane - Mhlati
Real Time	SASRI	WS - SASRI - Amanxala - Komati Mill

Real Time	SASRI	WS - SASRI - Coopersdal - Sasri Research Institu
Real Time	SASRI	WS - SASRI - Kaalrug - Inala
Real Time	SASRI	WS - SASRI - Barberton - Barberton
Real Time	SASRI	Nkomazi Mzinti
Real Time	DWA	Witklip Dam
Real Time	DWA	Kwena Dam
Real Time	DWA	Inyaka Dam
Not Real Time	DWA	Da Gama Dam
Not Real Time	DWA	Driekoppies Dam
Not Real Time	DWA	Vygeboom Dam
Real Time	DWA	Nooitgedacht Dam
Real Time	SAWS	CAROLINA ARS
Real Time	SAWS	BARBERTON PRISON ARS
Real Time	SAWS	MACHADODORP AWS
Real Time	SAWS	KOMATIDRAAI
Real Time	SAWS	NELSPRUIT
Real Time	SAWS	GRASKOP AWS
Real Time	SAWS	CAROLINA
Real Time	SAWS	SKUKUZA
Real Time	SAWS	KRUGER MPUMALANGA INT. AIR.
Not Real Time	SAWS	BREYTEN
Not Real Time	SAWS	BREYTEN
Not Real Time	SAWS	BADPLAAS- POL
Not Real Time	SAWS	NOOITGEDACHT DAM - IRR
Not Real Time	SAWS	NELSHOOGTE BOS
Not Real Time	SAWS	HIGHLANDS
Not Real Time	SAWS	BARBERTON -TNK
Not Real Time	SAWS	BARBERTON -TNK
Not Real Time	SAWS	VAALKOP
Not Real Time	SAWS	ONVERWACHT
Not Real Time	SAWS	KAMHLABANE
Not Real Time	SAWS	WELTEVREDEN
Not Real Time	SAWS	MACHADODORP

Not Real Time	SAWS	MACHADODORP
Not Real Time	SAWS	LOUWS CREEK-POL
Not Real Time	SAWS	BERLIN - BOS
Not Real Time	SAWS	BERLIN - BOS
Not Real Time	SAWS	ELANDSHOOGTE
Not Real Time	SAWS	ELANDSHOOGTE
Not Real Time	SAWS	MAYFERN
Not Real Time	SAWS	MALELANE
Not Real Time	SAWS	ALKMAAR
Not Real Time	SAWS	ALKMAAR
Not Real Time	SAWS	KROKODILBRUG
Not Real Time	SAWS	STOLZNEK
Not Real Time	SAWS	MBYAMITI
Not Real Time	SAWS	UITSOEK BOS
Not Real Time	SAWS	BROOKLANDS BOS
Not Real Time	SAWS	WITKLIP-BOS
Not Real Time	SAWS	HENDRIKSDAL
Not Real Time	SAWS	HENDRIKSDAL
Not Real Time	SAWS	SPITSKOP BOS
Not Real Time	SAWS	SABIE
Not Real Time	SAWS	BERGVLIET BOS
Not Real Time	SAWS	TWEEFONTEIN BOS
Not Real Time	SAWS	SABIE KLIPKRAAL
Not Real Time	SAWS	WELKOM
Not Real Time	SAWS	RIETSPRUIT
Not Real Time	SAWS	RIETSPRUIT
Not Real Time	SAWS	WILGEBOOM - BOS
Not Real Time	SAWS	DUNNOTTAR
Not Real Time	SAWS	ONVERWAG - BOS
Not Real Time	SAWS	ONVERWAG - BOS
Not Real Time	SAWS	TSHOKWANE
Not Real Time	SAWS	WELGEVONDEN - BOS
Not Real Time	SAWS	HEBRON - BOS

Not Real Time	SAWS	NWANEDZI
Not Real Time	SAWS	BERG-EN-DAL
Not Real Time	SAWS	SONGIMVELO
Not Real Time	SAWS	TALAMATI

APPENDIX M

MOA BETWEEN ICMA RAINFALL GAUGE HOSTS

MEMORANDUM OF AGREEMENT

ENTERED INTO BY AND BETWEEN

(Herein after referred to as the Grantor)

And

The Inkomati Catchment Management Agency

Herein represented by Brian Richard Jackson

In his / her capacity as acting Chief Executive Officer of the Catchment Management Agency duly authorised thereto

(Herein after referred to as the ICMA)

Whereas the ICMA has the need for an appropriate area of space to accommodate a rainfall gauging station as part of its water resource management functions in terms of the National Water Act, Act 36 of 1998 (the Act), and functions delegated to it by the Minister of Water and Environmental Affairs and the Grantor has on his / her / its property such area of space available and is willing to make it available.

THE PARTIES TO THIS AGREEMENT AGREE AS FOLLOWS:

1. The Grantor hereby authorises the ICMA to erect on a portion of his / her / its property with description …………………………………………………………………………………………………… ……………………………………………… …………………………………………………………………………………………………… ……………………………………………… …………………………………………………………………………………………………… ……………………………………………,

at a location agreed upon by the parties with coordinates:

....S; :..E and in accordance with the attached sketch plan attached as Annexure A, a rainfall gauging station. (The sketch plan indicates the site plan, including surrounding structures and vegetation and layout of the gauging station)

2. The portion of land (site) on the Grantor's property shall be clear of any obstructions that may influence the natural rainfall falling on the rainfall gauging station site at all times and shall be suitable for an area of 3 x 3 meters to be properly fenced off by the ICMA with an access gate.

3. The Grantor shall have access to the rainfall gauging station and the right of access to the data captured through the rainfall gauging station and may use such data in the management of the water resources on his / her / its property.

4. The Grantor undertakes to look after and take care of the rainfall gauging station to the extent that the fenced off area will be kept clear and clean and to check for any defects to the rainfall gauging station equipment and if any defects are found the Grantor will report such defects without any delay to the ICMA for the necessary repair.

5. The Grantor undertakes not to interfere with the proper operation of the rainfall gauging station and to endeavour to ensure that no human or fauna or flora or physical structure or object interferes with the proper operation of the rainfall gauging station at all times.

6. The Grantor authorises access to the rainfall gauging station by authorised ICMA staff who will be identified in writing to the Grantor for the purposes of any necessary work, inspections and maintenance to be done at the rainfall gauging station.

7. No compensation is payable for the land made available to the ICMA for the rainfall gauging station.

8. The ICMA staff and maintenance service providers must at all times when visiting the property of the Grantor comply with the arrangements and rules by the Grantor to manage his / her / its property and shall not create any unnecessary interference with the operations of the Grantor.

9. The parties choose the following addresses as *domicilium citandi et executandi*:

    a. The Grantor:

    b. The ICMA:

    3rd Floor Caltex Building
    32 Bell Street
    Nelspruit
    Fax: (013) 753 2786
    E-mail: jacksonb@inkomaticma.co.za or magagulas@inkomaticma.co.za

    Should the *domicilium citandi et executandi* of either party change then they shall notify the other party in writing without delay and indicate the new *domicilium citandi et executandi.*

10. This agreement is the full agreement between the parties and can be amended only by means of a written addendum duly signed by both parties.

THUS ENTERED INTO AND SIGNED AT .... ON THE .... DAY

OF .... 20..........

GRANTOR

WITNESSES: 1.

2.

THUS ENTERED INTO AND SIGNED AT .... ON THE .... DAY

OF .... 20..........

ICMA

WITNESSES: 1.

2.

APPENDIX N

EQUIPMENT AND COSTS TO MAINTAIN ICMA RAINFALL GAUGES

Raingauges unit rates						Remarks
	New value	1	un	R 12,200	R 12,200	
	Installation per day	1	day	R 3,000	R 3,000	no external people needed
	SIM cards per card per month	1	SIM/month	R 10	R 10	
	Webservice fee	1	year/station			more than 10 stations in one account is now for free
Recommended Spare parts to have in stock						
B900	Battery small - 6 Volt - 4AH Battery	2	un	R 400	R 800	
SP005	0,6 Watt iMetos Solarpanel	2	un	R 927	R 1,854	
101335	iMetos re-programming unit (both systems - Telit/Wavecom) with adapter	2	un	R 980	R 1,960	
10133-6	Motherboard for iMetos ECO	1	un	R 4,130	R 4,130	
10134-1	Quadband Modem for iMetos Sierra Wireless inclusive board	1	un	R 2,730	R 2,730	
IM523M	Rain Gauge mechanism (without plastic holder)	1	un	R 1,400	R 1,400	
IM5231	Rain Gauge Plastic with screws	1	un	R 1,460	R 1,460	
B923	Battery cable set for iMetos	1	l.s	R 237	R 237	
BS0015	5,5 mm Tool for	1				

	modem					
BS0016	PG 7 Tool for mounting of PG connectors	1				
				Total	R 14,571	
		14	units			
Annual cost		4	days	R 3,000	R 12,000	4 times per year preventive maintenance (Sipho)
Number of rain gauges in operation		25%	of spares	R 14,571	R 3,643	
	Regular maintenance	14	un	R 120	R 1,680	
	Spare parts	2	un	R 12,200	R 24,400	
	SIM Cards	1	l.s.	R 5,000	R 5,000	estimated cost of IT person to work on interfaces and integration
	Replacement of stolen stations					
	Keeping interface up to date			Total	R 46,723	

APPENDIX O

DEVELOPMENT OF LONG TERM OPERATING RULES

Extracted from Mallory, 2007.

Development of Long-Term Operating Rules

Introduction

In arid countries such as South Africa, it is not economical to always plan to supply all users with all the water they require all the time. In most systems restrictions are introduced to limit supply during droughts in order to achieve a sustainable supply over a prolonged drought period without failure of dam. Irrigators making use of their own water sources, such as streams rising on their properties or farm dams are often at liberty to make their own choice as to whether to abstract a small amount with no risk of experiencing shortages later, or targeting a larger abstraction in the knowledge that shortages will be experienced later. Users who are at liberty to make their own choices will tend to converge toward an economic optimum through trial and error, while users supplied from large systems, or users sharing a system, rely on water resource engineers to advise them on what is the best option.

The maximum abstraction rate targeted by users is dependent on the level of assurance that users in the systems are prepared to accept. If the water resource was sufficient for all users to obtain all their requirements all the time, this would of course be the ideal situation, but in most parts of the Crocodile river catchment we already know that this is not the case. Determining the maximum abstraction rate is therefore an iterative process, described in the following steps:

- Step 1: Agree on a target assurance of supply and level of restriction to be imposed for each user sector. Assurance in this context is the proportion of time that a user does not receive his full allocation.
- Step 2: Set up a water resources model with all the natural hydrology, evaporation, rainfall, dams, afforestation, ecological Reserves and international requirements. Include all users in the system with their target demands.
- Step 3: Identify the operating rules relevant to each catchment. This step answers the question; where are users being supplied from and what are the priorities of supply?
- Step 4: Run the model and check whether the water supply to the various users can be met at the target assurance. If not, develop restriction rules which restrict the supply of water to users under certain conditions (usually linked to the water level of a dam).

Assurances and restrictions

For modelling and presentation purposes it is convenient to present the combination of restrictions and assurances graphically as a restriction frequency diagram, examples of which is presented in *Figure* to *Figure*. The commonly used term 'assurance of supply' is represented by the points on the graph at which users no longer obtain their full supply, for example 60% in the case of citrus irrigators and 90% in the case of industrial users. Assurance of supply indicates how often a user will not receive all the water he requires but does not indicate the level of restriction that a user might experience. Arguably, the level of restriction is more important to most users than the frequency of restriction. For example, it is very difficult for a municipal manager to implement a restriction of much above 25% while for a citrus farmer the maximum restriction will be dictated by the minimum amount of water that the trees can survive on during an extreme drought. An opportunistic irrigator, on the other hand, accepts that in some years there will be no water available for irrigation and that if he plants crops he runs a significant risk of losing it completely.

Restriction rules have been refined to meet user requirements in the Crocodile river catchment in consultation with users. The user groups in the Crocodile, for which each has a unique target curtailment frequency, have been identified as follows:

- Strategic
- Industrial
- Domestic
- Irrigation: High value crops which includes citrus, nuts and tropical fruit
- Irrigation: Sugar cane
- Irrigation: Cash crops such as vegetables
- Irrigation: Maize

In the Crocodile River catchment, Maize is viewed as an opportunistic crop since production can be achieved in most cases without irrigation. Irrigating when water is available only improves the yield of the crop.

Note that no restriction is required for international requirements, basic human needs or ecological requirements since these must be fully supplied at all times. However, currently the reserve is not being implemented in the Catchment, therefore, effectively is being restricted.

Set up a water resources model

The Water Resources Modelling Platform (WReMP) has been set up for the Crocodile river catchment at quinary catchment scale. A system diagram of the model is attached in Appendix D while summaries of the mean annual water requirements and the hydrology used in the model are attached as Appendix E.

Determine restriction rules

Restrictions were applied on a trial and error basis to the various user sectors in the catchment until a solution was found, i.e. the maximum possible supply without the dam quite failing. The proposed restriction rules for each group are provided in the graphs that follow.

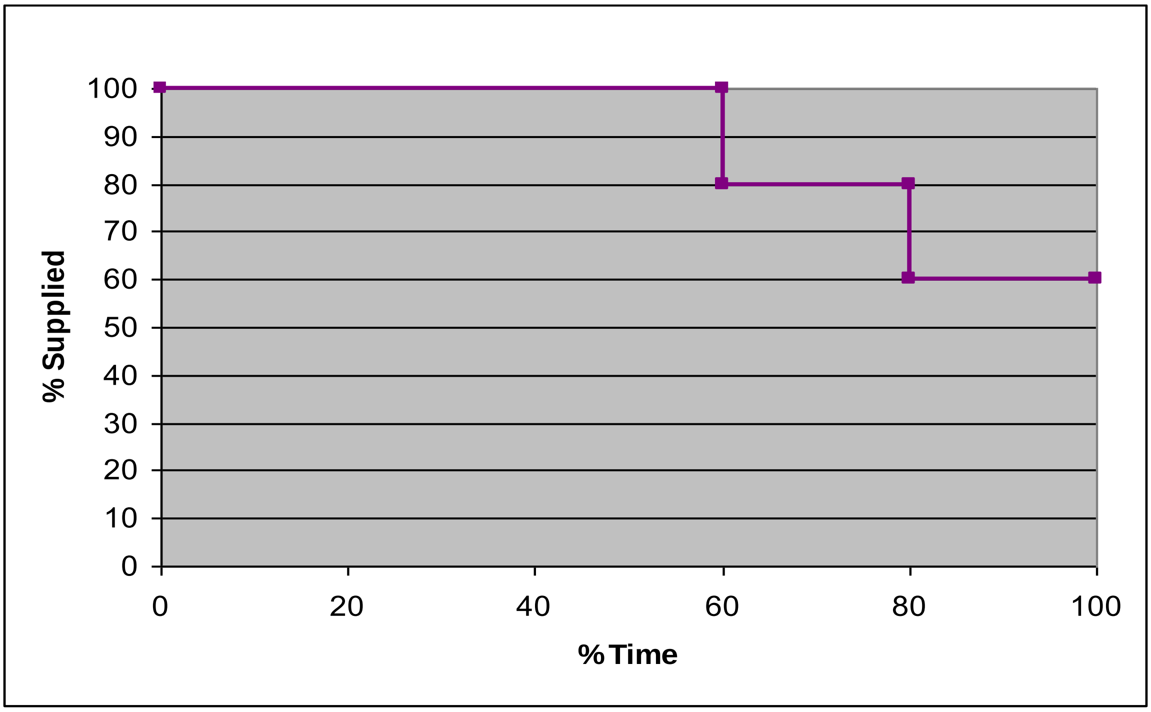

Figure 0.1: Proposed target restriction frequency for citrus

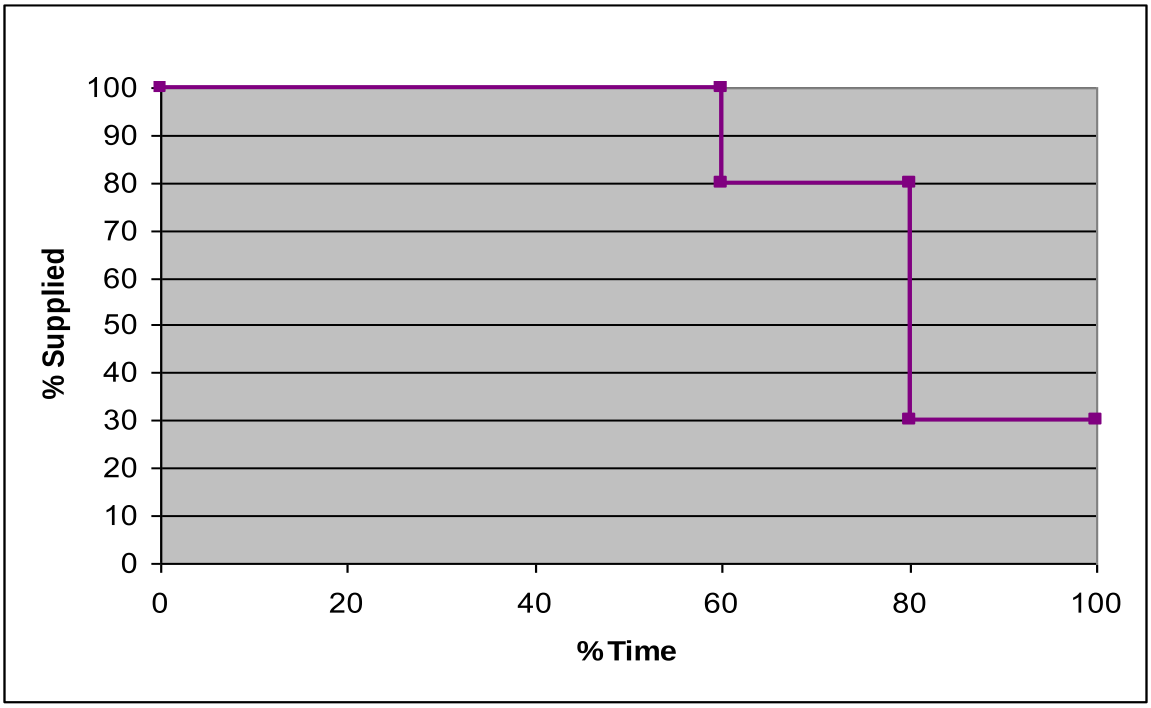

Figure 0.2: Proposed target restriction frequency for sugarcane

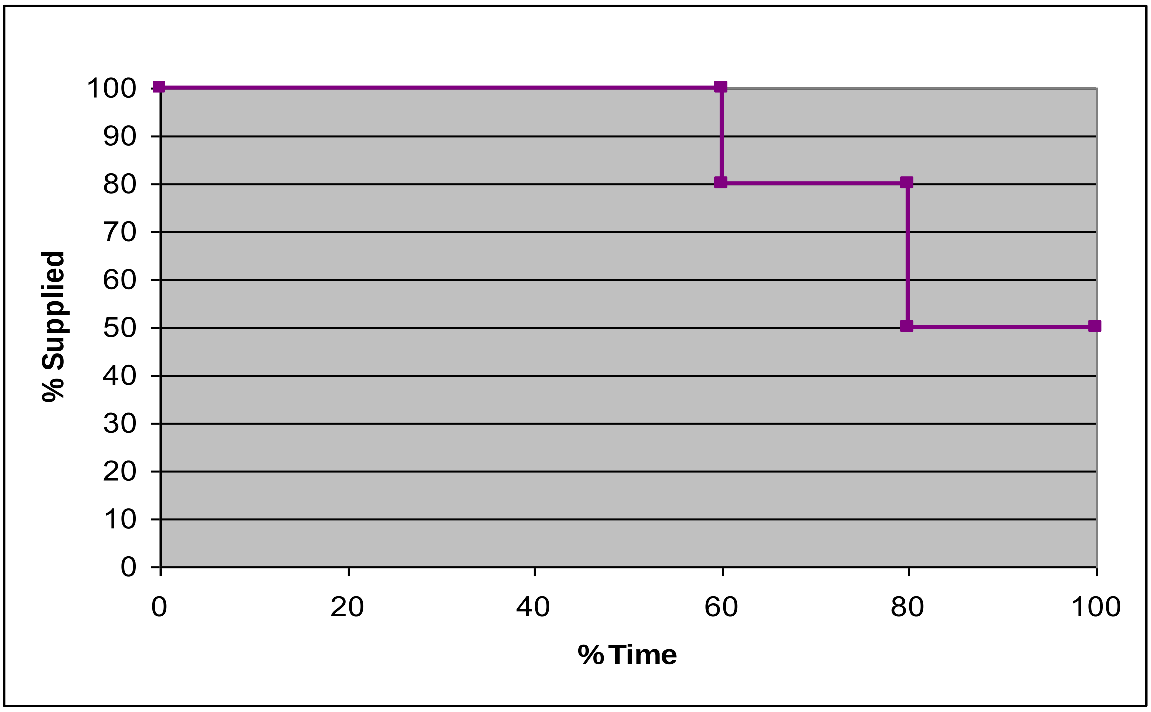

Figure 0.3: Proposed target restriction frequency for sugarcane

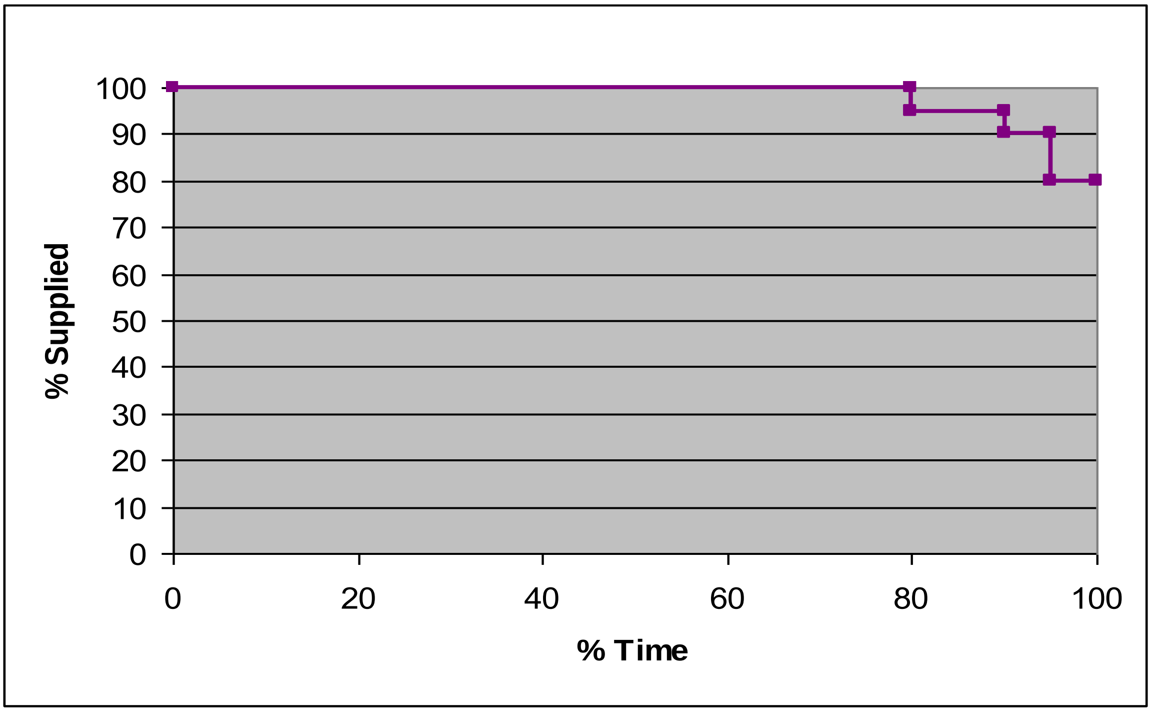

Figure 0.4: Proposed target restriction frequency for urban use

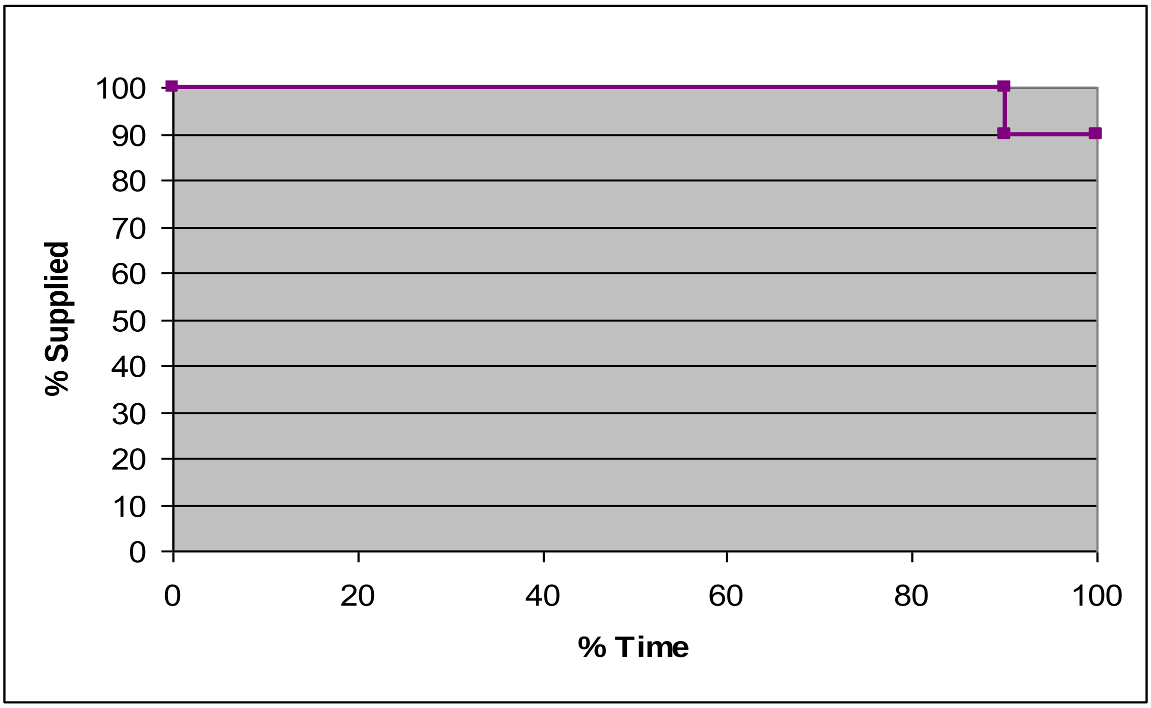

Figure 0.5: Proposed target restriction frequency industrial use

Dam operating rules

Through trial and error, the water levels in the Kwena Dam at which restrictions need to be imposed on the various user groups were determined, and these are indicated in *Figure* to *Figure*.

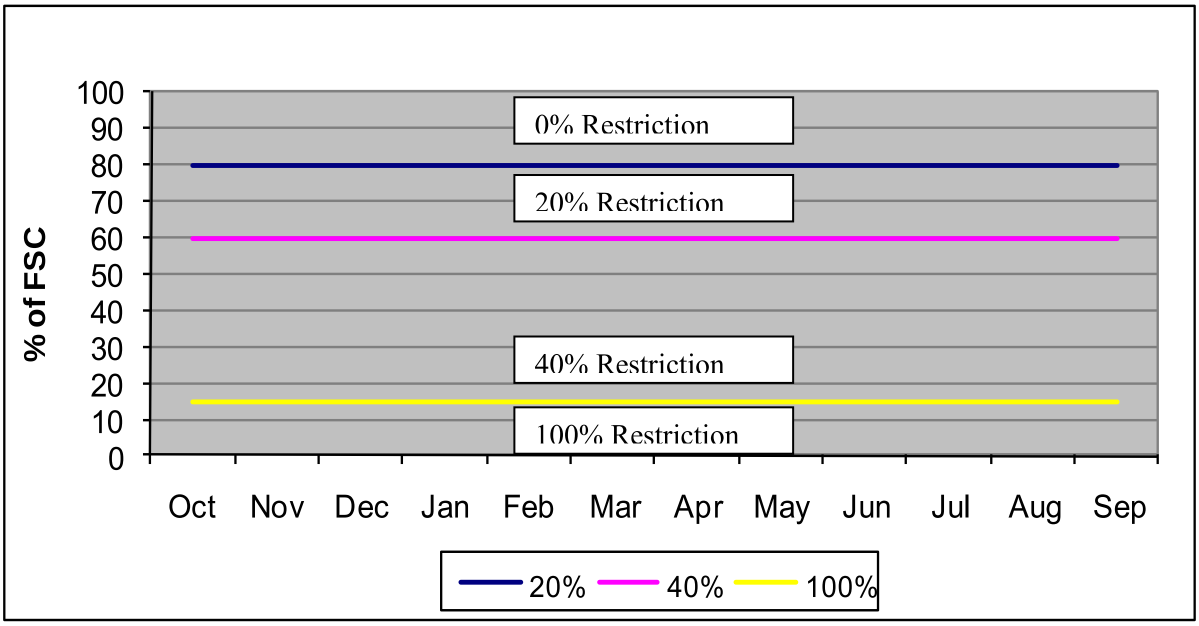

Figure 0.6: Operating rule curve for Kwena Dam: Restriction levels for Citrus irrigators

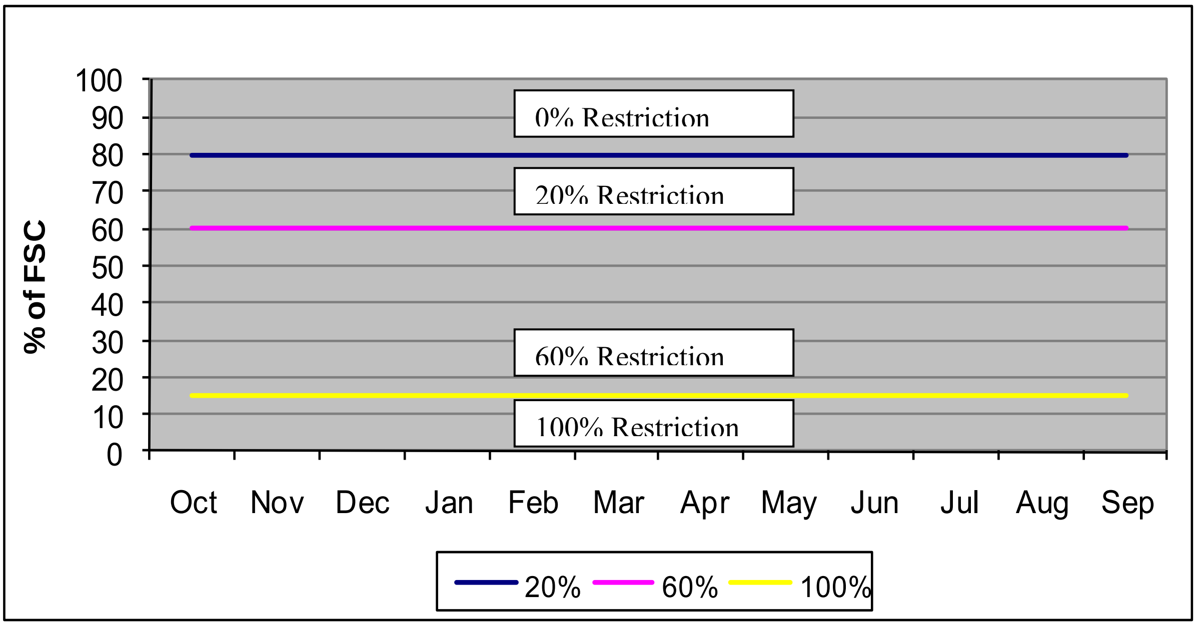

Figure 0.7: Operating rule curve for Kwena Dam: Restriction levels for sugar cane irrigators

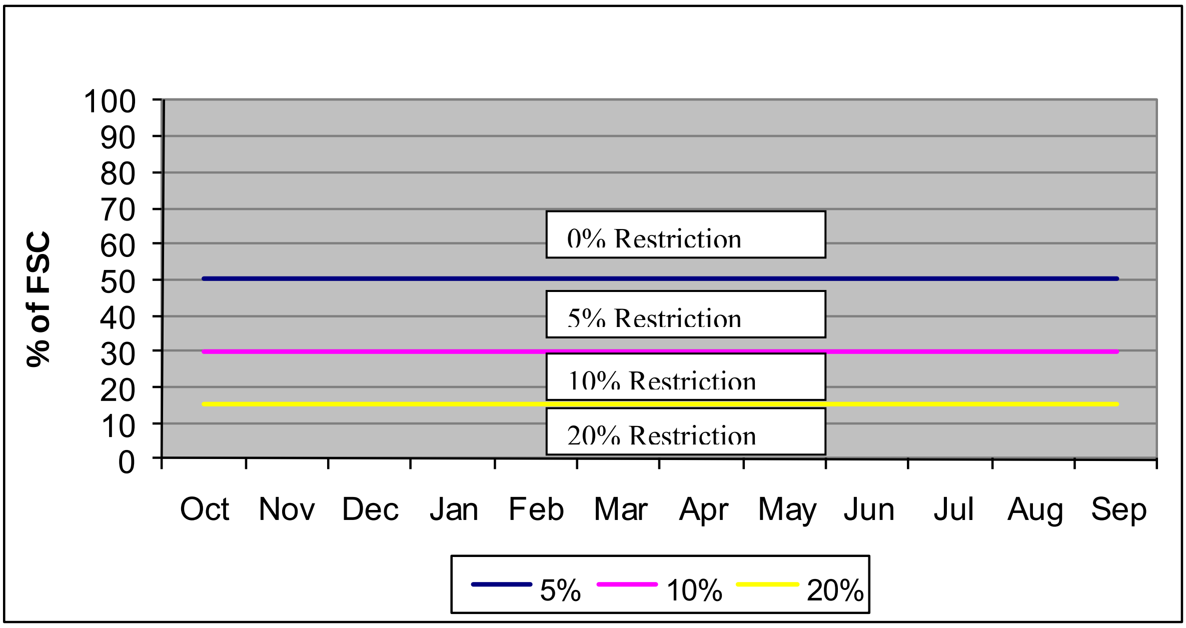

Figure 0.8: Operating rule curve for Kwena Dam: Restriction levels for urban users

APPENDIX P

STOCHASTIC MODELLING IN WREMP

Extracted from Mallory, 2007.

Stochastic Modelling

Introduction

The stochastic model used together with the Water Resources Yield Model is an Auto Regressive Moving Average model (ARMA) which selects annual flows and estimates monthly flows from disaggregation. While this model has served DWAF well, it has the following short-comings:

- Since it is an annual model, it requires dams with greater than annual carryover storage. The model is not appropriate of run-of-river situations.
- The starting monthly flow is determined through disaggregation and this is not an input parameter that the user can set. In many catchments within South Africa there is a strong correlation between the flow at the end of the rainy season (be this summer or winter) and the flow that for the remainder of the dry season. This correlation is not captured by an annual ARMA model.

The approach adopted by this study was therefore to use a monthly stochastic model which is able to predict flows through the dry winter months given the flow at the end of summer. This type of model is not new, having been developed by Sellick and Bonthuys as part of a DWAF project to develop operating rules for the Sabie River catchment. Mathematically the model is described as follows:

$Flow_{i+1} = f(_{Flow\ i})$ (1)

The flow next month is a function of this flow measured this month. This function is especially relevant from the month March through to October. During the wetter summer months there is a great deal of scatter but nevertheless, a probabilistic relationship can be established.

The relationship given in 1 was determined by, for the entire historical time series, pairs of values consisting of $Flow_i$ and $Flow_{i+1}$ - $Flow_i$. Plotting these values with $Flow_i$ on the x-axis and $Flow_{i+1}$ - $Flow_i$. on the Y- axis results in a graph that typically looks like Figure during the winter months and Figure in the summer months when the correlation is weak. The graphs for the remaining months are presented in Appendix A.

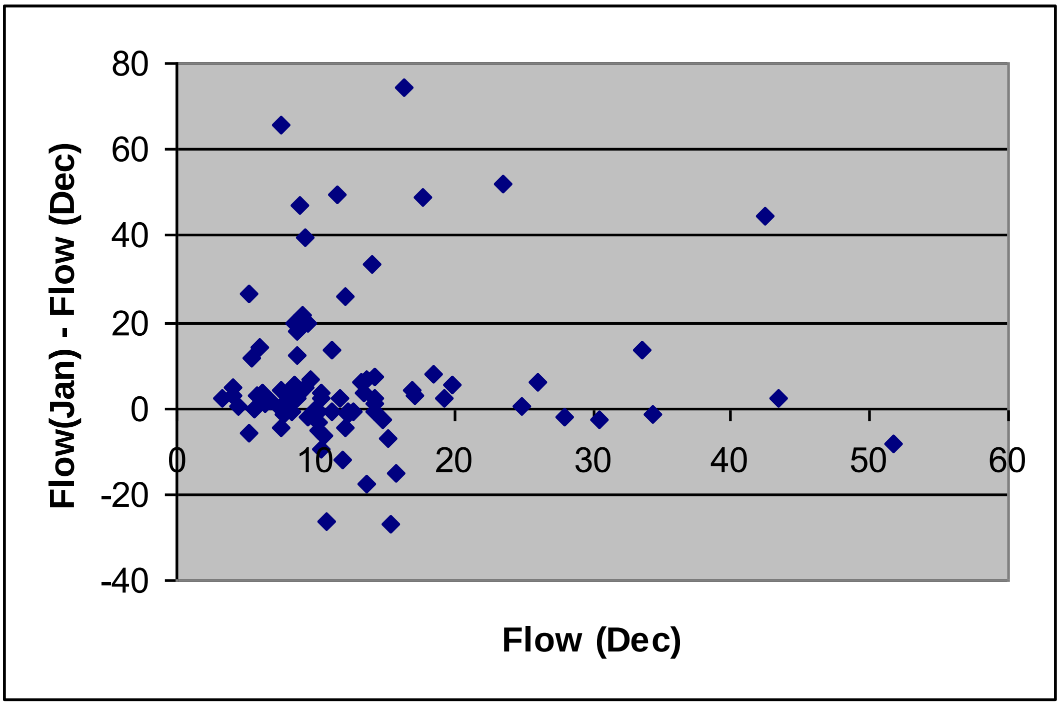

Figure 0.1: Relationship between flow in December and flow in January (summer month)

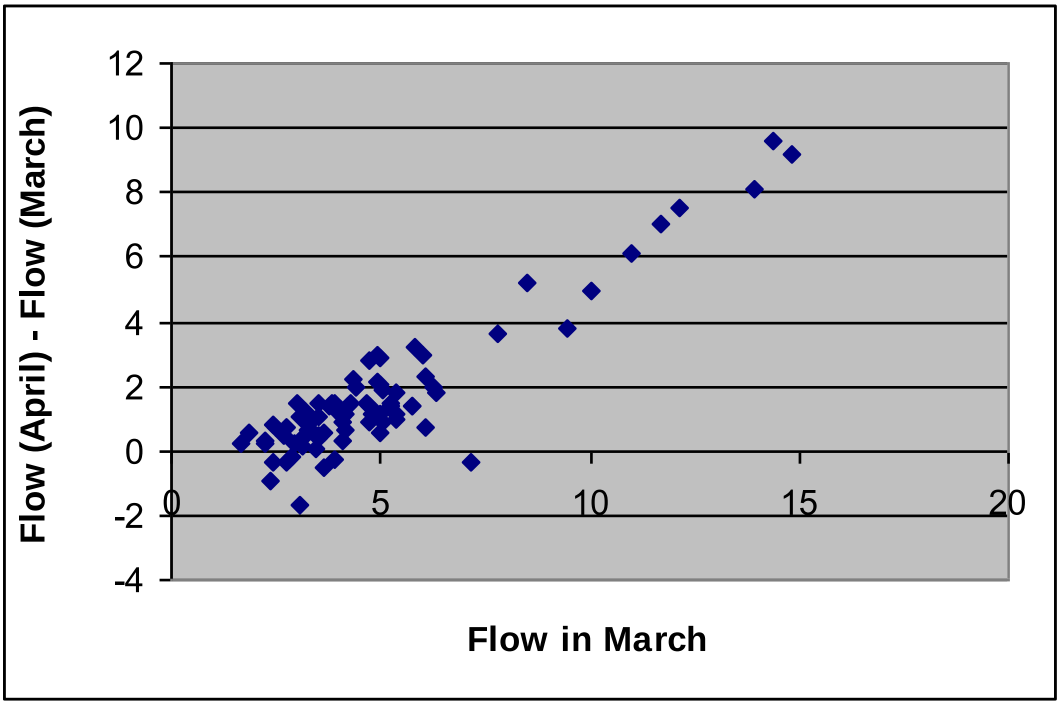

Figure 0.2: Relationship between flow in March and flow in April (end of summer)

The conclusion that can be drawn from Figure and Figure is that, given the flow in a particular month, there is possible range of likely flow in the following month. In the summer months when the range of possible rainfall event is much greater that in winter, there is obviously a wide range of possible events. In the winter months when rainfall is unlikely, the flow in the following month can be predicted with more confidence.

The method used in this stochastic model was derived from work carried out by Bonthuys and Sellick for DWAF (DWAF, 2003) and entails simply setting a range in which future flows can be selected based on the current flow. This range is not known and was set by trial and error. B & S arbitrarily assumed a range of 18% on either side of the flow in month under consideration. In this model, the approach taken was to allow a selection of 11 values from the following month, 5 values higher, 5 lower and one at the same % exceedance. See the example below (Table). To ensure that the mode retains some variability and randomness, the selection of the flow in the following month is based on a random selection of the 11 values within the prescribed range.

Table3.1: Table showing process of determining flow from one month to another

Ranked flows		Possible flows in March	
Februrary	February - March	Proportion	Million m^3
103.56	-12.2		
60.63	-13.09		
42.31	-9.6		
41.43	-42.31		
34.23	-8.78		
30.31	-16.84		
22.11	-15.22		
18.83	-6.48		
17.78	-34.23	3.25	49.45
16.84	-16.13	2.12	30.5
16.13	-8.36	1.64	21.48
16.03	-60.63	5.63	73.72
15.29	-15.29	2.19	28.13
15.22	-18.83	2.54	31.03
14.37	-22.11	2.96	33.4
13.12	-14.37	2.28	25.59

13.09	-17.78	2.59	28.96
12.84	-16.03	2.63	25.86
12.2	-11.22	2.17	20.82
11.29	-6.79		
11.22	-103.56		
11.18	-41.43		
9.83	-11.18		
9.6	-30.31		
9.44	-13.12		
8.78	-9.44		
8.36	-12.84		
6.79	-11.29		
6.48	-9.83		

Testing and Verification

Stochastic model

There are numerous tests for a stochastic model, the most basic and essential being to check the mean and standard deviation of the natural and stochastically generated flows are the same, or at least similar within a reasonable tolerance. Other more complex tests involve checking whether the yield generated using the stochastic hydrology sequences and the natural hydrology are similar. The STOMSA model (WRC, 2001) has been used to carry out such a test but the routines to carry out these tests is not readily available outside of the STOMSA modeling package. DWAF are developing a suite of test applications which should be available before the end of February 2010 and these applications will be used to carry out further more detailed statistical tests on the stochastically generated flows sequences.

Table5.1: Comparison of natural and simulated means at Kwena Dam

Mean	Simulated	Natural
Oct	3.23	4.72
Nov	7.66	10.61

Dec	12.15	13.28
Jan	18.84	20.31
Feb	20.86	21.24
Mar	15.87	15.59
April	10.76	10.41
May	6.99	6.79
June	4.89	4.77
Jul	4.13	4.06
Aug	3.47	3.44
Sep	3.26	3.23
Annual	112.11	118.45

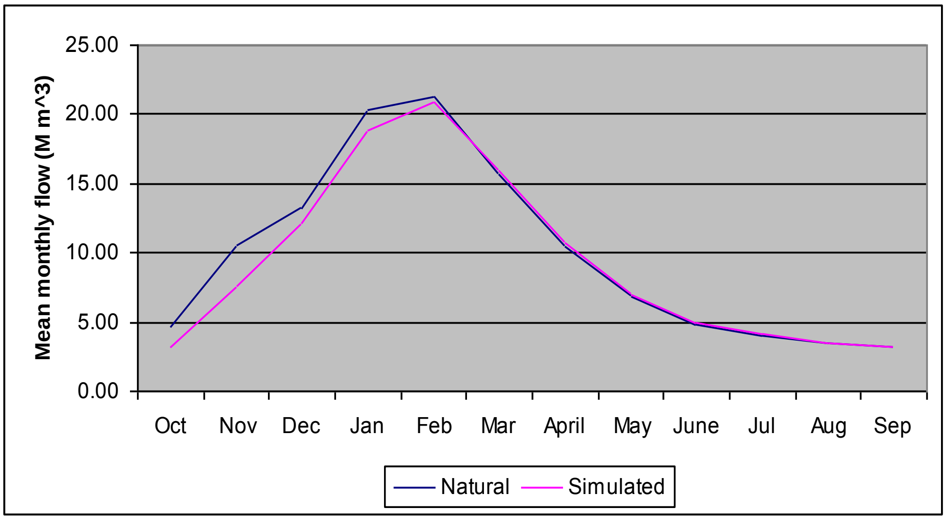

Figure 0.3 Comparison of natural and simulated monthly means based on 101 stochastically generated flow sequences at the key gauge (Kwena Dam)

Table 5.2: Comparison of natural and simulated means for the whole crocodile catchment

Mean	Simulated	Natural
Oct	38.6	38.56
Nov	74.41	75.56

Dec	121.52	119.96
Jan	167.12	168.41
Feb	207.65	211.42
Mar	175.75	184.83
Apr	111.52	111.8
May	65.66	66.67
Jun	47.51	47.12
Jul	38.16	38.64
Aug	33.04	32.98
Sep	30.34	30.42
Annual	1111.29	1126.35

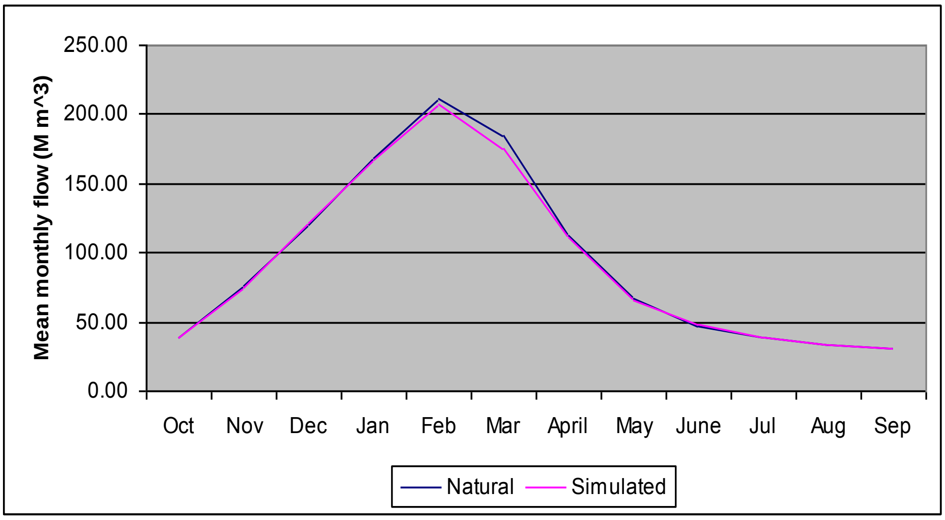

Figure 0.4: Comparison of natural and simulated monthly means based on 101 stochastically generated flow sequences summed for all quinary catchments

Table 5.3: Comparison of simulated and natural standard deviations at the key gauge

Mean	Simulated	Natural
Oct	1.56	2.27
Nov	6.44	10.48

Dec	9.05	8.9
Jan	17.43	18.38
Feb	20.36	21.12
Mar	9.12	8.48
April	4.36	3.81
May	2.72	2.44
June	1.66	1.54
Jul	1.25	1.18
Aug	1.07	1.07
Sep	1.33	1.34

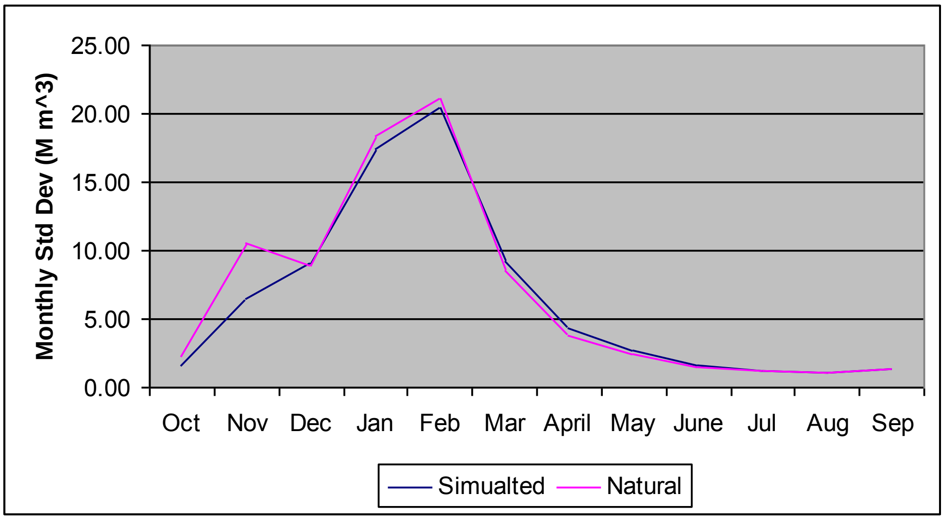

Figure 0.5: Comparison of simulated and natural standard deviations at the key gauge

Appendix A: Relationship between Flow in Month i to Flow in Month i+1

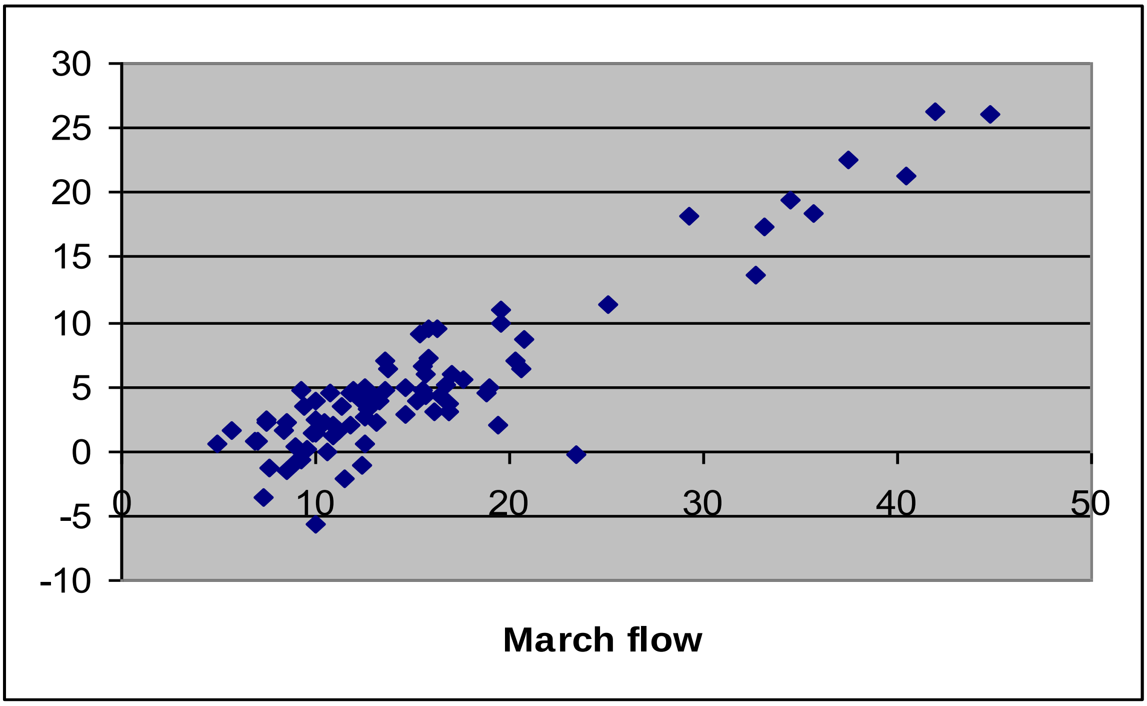

Figure 0.6 Relationship between flow in March and flow in April

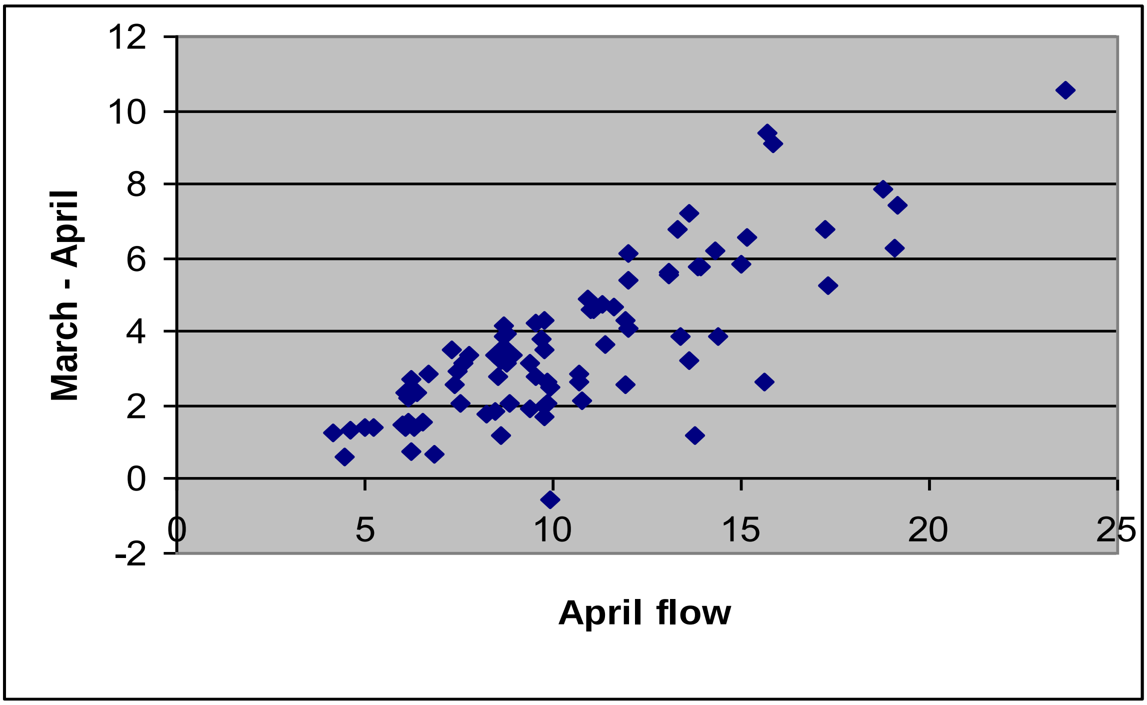

Figure 0.7: Relationship between flow in April and flow in May

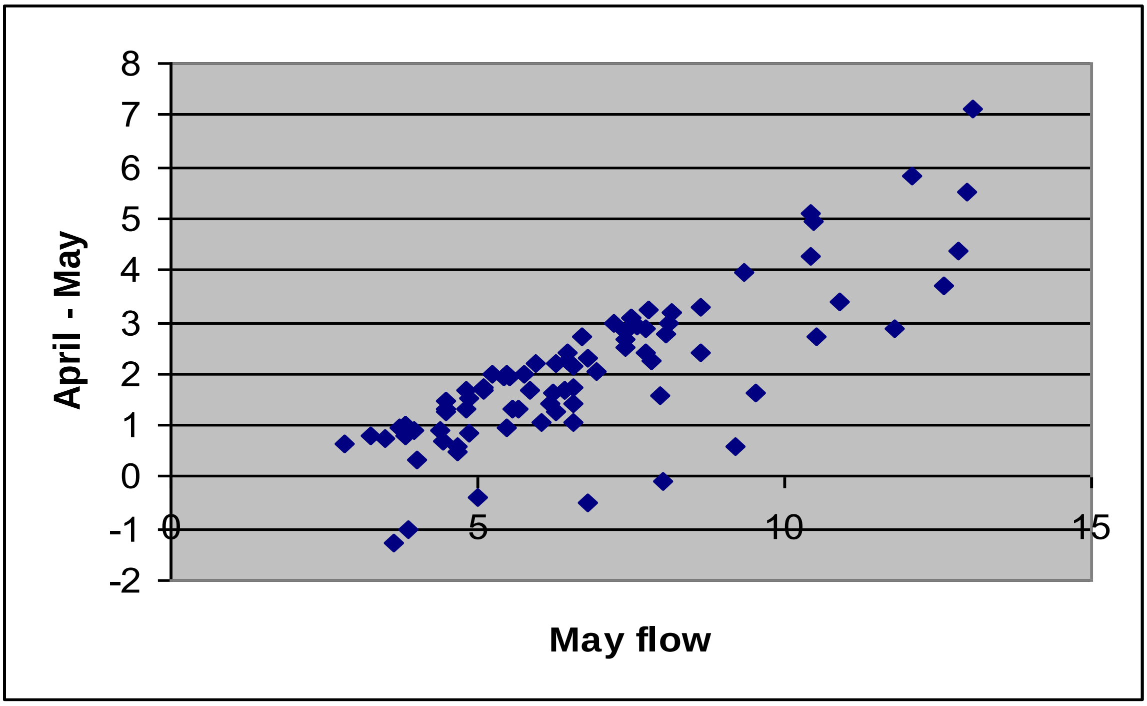

Figure 0.8: Relationship between flow in May and flow in June

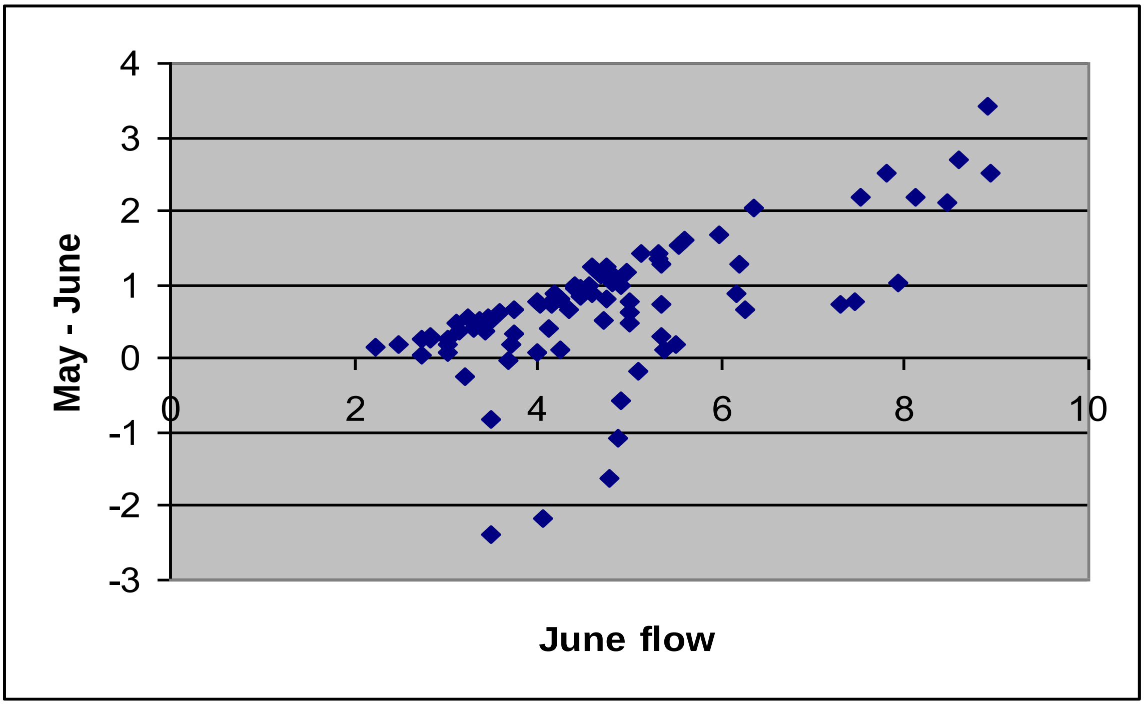

Figure 0.9: Relationship between flow in June and flow in July

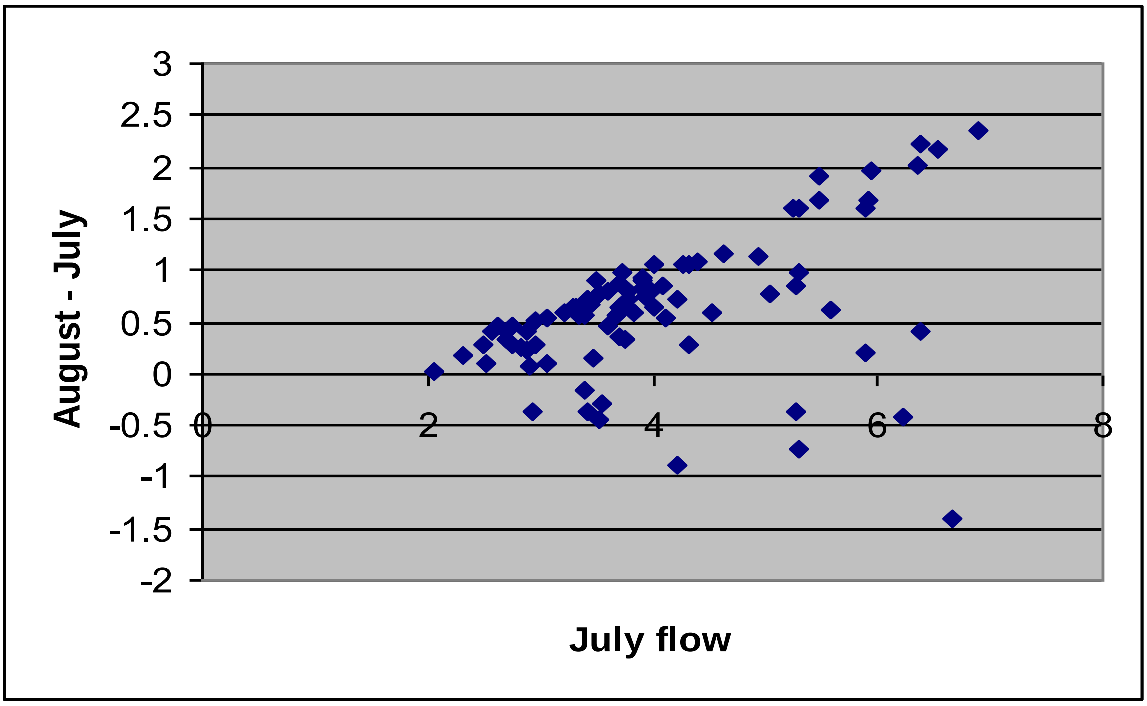

Figure 0.10: Relationship between flow in July and flow in August

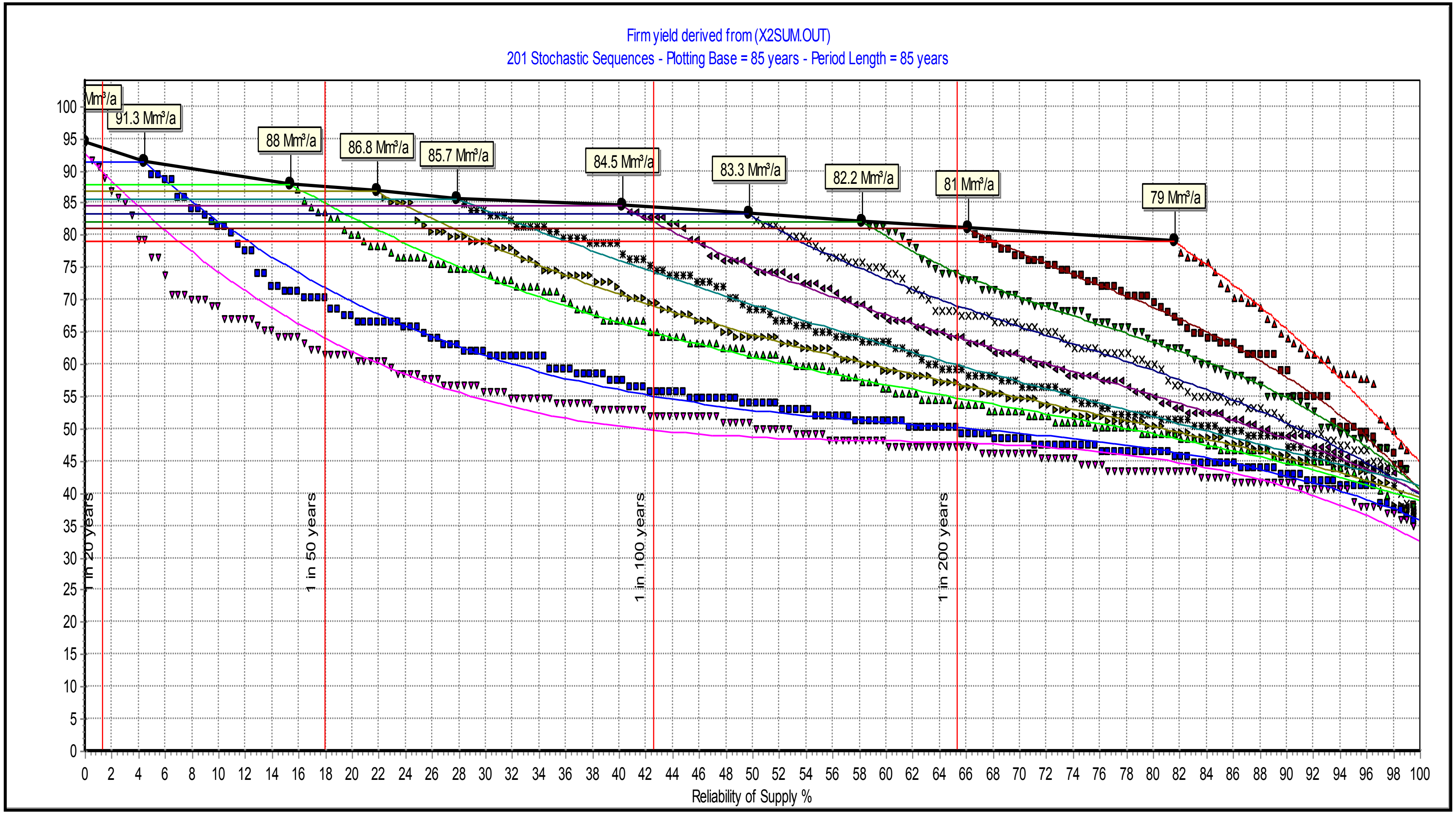

Figure: 0.11: Yield Curves for Kwena Dam

APPENDIX Q

MIKE 11 HYDRODYNAMIC MODELLING

Extracted from Jackson et al., 2012

MIKE 11 HYDRODYNAMIC MODEL

Model Setup

The main model objective can be divided into three smaller specific objectives:

1. ensuring that water in the right quantity is delivered when required using as little water as possible.
2. ensuring that the downstream minimum flow requirement is satisfied.
3. ensuring that real time measurements are assimilated into the model results before making forecast for the release hydrograph from the reservoir.

Data assimilation is used to make sure that forecasted model results are as accurate as possible. This procedure was first implemented in South Africa by Pedersen *et al.* (2007) on the Orange-Fish-Sundays scheme in the Eastern Cape. Pedersen *et al.* (2007) state that in order to optimize accurately forecasted dam releases in the shorter term, the state of the hydrological, hydraulic and environmental system needs to reflect the physics at the time of forecast. These system status parameters are updated within the model using a data assimilation procedure embedded within MIKE 11. Once the state of the river system is known at the time of forecast, with available real-time data, the optimisation-simulation framework is applied to determine an optimal dam release time series for the near future. This forecast lead period is usually in the order of a few days. As soon as more real-time observed data becomes available, the process is repeated and a new forecast release is generated based on observed conditions.

In terms of the optimisation, a three step procedure has been adopted to solve the problem:

1. An initial simulation with the model of the Crocodile River covering both the hind-cast and the forecast period is carried out. During hindcast, measurements of the water level and discharge is assimilated (as previously described) into the model results. In this way the best estimate of the situation at the time of forecast is achieved. During the forecast period an initial solution to the optimisation problem is found. This solution will suggest a hydrograph for the Kwena Dam.
2. Based on the results from the first initial simulation a new simulation of the Crocodile River model is performed. This time a correction to the release hydrograph is made. This correction will aim at increasing supply in situations where the demands are not met in the first simulation.
3. Based on the corrected initial solution an optimisation is now made. This optimisation is performed for the forecast period only. The optimisation will then try to improve the initial solution by adding/subtracting changes to the first solution.

Calibration

The main objective of the MIKE 11 calibrations was to ensure that the timing (or lagging) of water through the model was correct. Due to the lack of accurate cross sections, it was not possible to work on calibrations for model water levels. The low flow model calibration period was from 25th January 2007 to 21st October 2007. The high flow model calibration period was from 20th February 2009 to 30th June 2009. The same roughness coefficients that were used for the low flow check, as those that were found for high flow. The Manning's roughness coefficient values for the calibration period that were decided are depicted in Table 1.

Table 1 Manning's roughness coefficient (n) in the Crocodile MIKE 11 Model

Calibration Section	Chainage start / end	Chainage (m)	Manning n	Gauge Check
Kwena Dam to Montrose Weir	Start Chainage	0.0	0.065	Montrose (X2H013)
	End Chainage	57,500.	0.065	
Montrose Weir to top of Gorge	Start Chainage	58,000.0	0.055	Karino (X2H006)
	End Chainage	129,000.0	0.055	
Top of Gorge to Bottom of Gorge	Start Chainage	129,500.0	0.055	N/A
	End Chainage	145,000.0	0.055	
Bottom of Gorge to Riverside Weir	Start Chainage	145,500.0	0.055	Riverside (X2H046)
	End Chainage	186,500.0	0.055	
Riverside Weir to Komati Confluence	Start Chainage	187,000.0	0.070	Tenbosch (X2H016)
	End Chainage	270,000.0	0.070	

Calibration results of simulated versus observed flow values, for both high flow and low flow conditions are presented for two of the four gauging locations were the analysis was completed. These are shown for X2H006 - Karino (low flow in Fig , high flow in Fig) and for X2H016 – Tenbosch (low flow in Fig, high flow in Fig). From the figures it can be seen that good calibrations in terms of the timing of flow peaks was observed. However, the mass balance was difficult to simulate accurately, and some significant differences can be observed at the downstream gauging locations, where the impact of uncertain water abstractions by irrigators, and river losses to evaporation can also be large and highly variable.

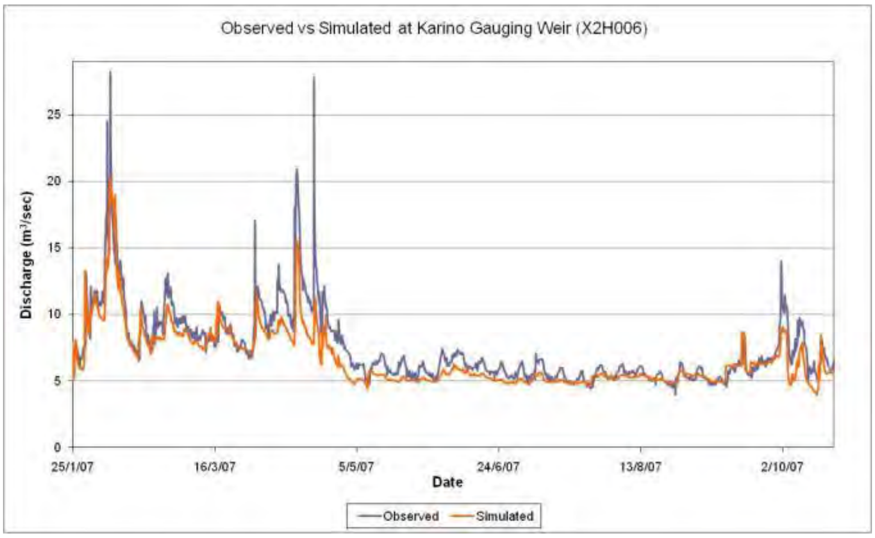

Figure 5: Low flow Calibration plot for Crocodile River at Karino

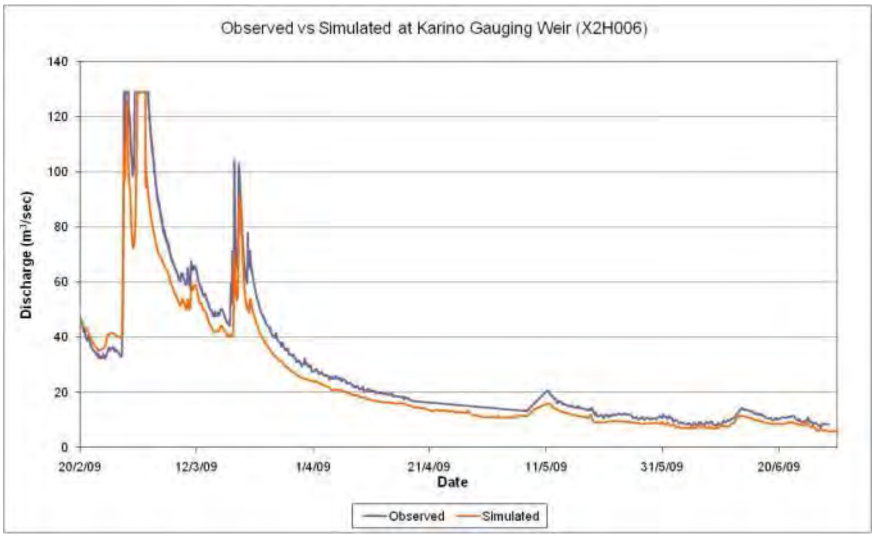

Figure 6: High flow calibration plot for Crocodile River at Karino

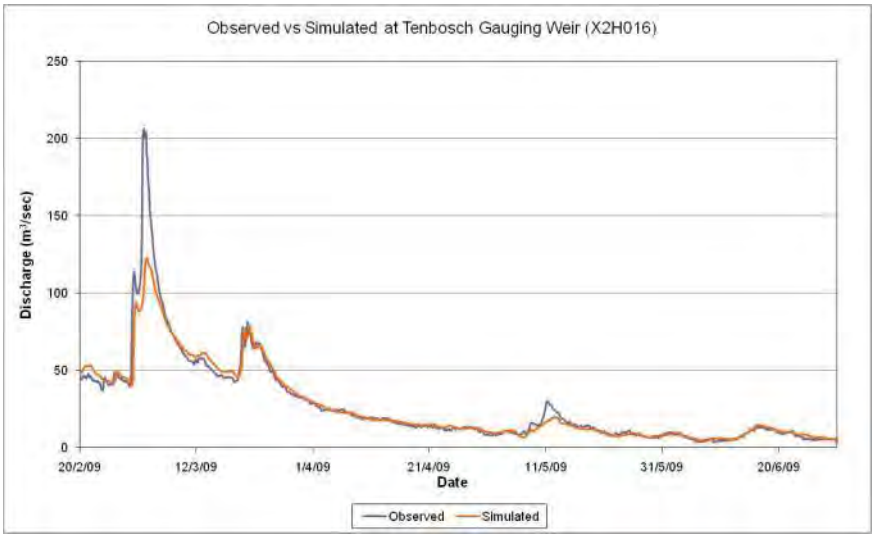

Figure 7: High flow calibration example plot for Crocodile River at Tenbosch

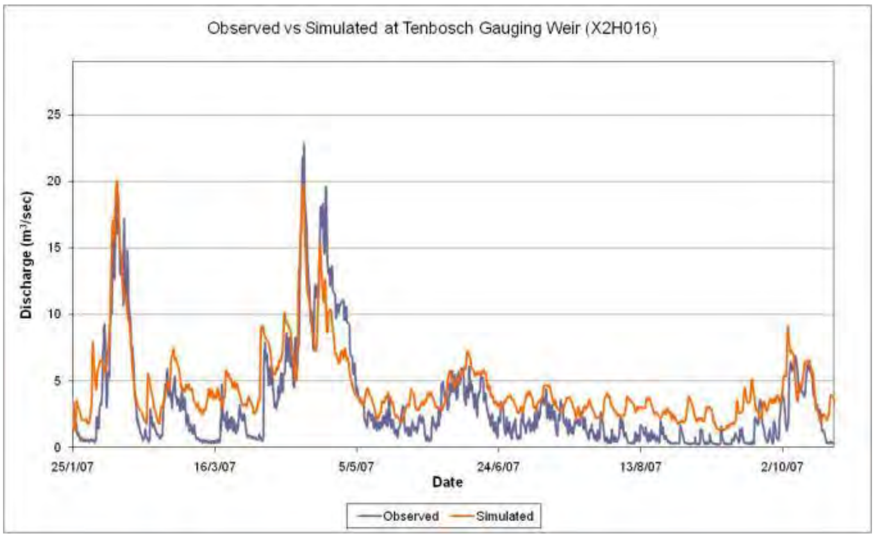

Figure 8: Low flow calibration example plot for Crocodile River at Tenbosch

The main objective of the calibration for the MIKE 11 model was met for both low flow and high flow conditions at all four of the gauging locations in the river where such analyses where possible. These results were presented in this section. It should be noted that that the volume differences between observed and simulated flows were large at certain gauges. This was most obvious under very low flow conditions. This volume error should improve as the model is used in an operational context and the water use data improves as a result of the water meter project initiated by the Crocodile River Major Irrigation Board. The hydrological model, could also have been a source of the volume error.

APPENDIX R

TOR FOR THE PROVISION OF TECHNICAL AND MAINTENANCE SUPPORT FOR REAL TIME OPERATIONAL WATER RESOURCES INFORMATION MANAGEMENT SYSTEM AND SHORT TERM OPERATIONAL MODELING REQUIREMENTS FOR THE INKOMATI WMA

The Maxsa Building ,13 Streak Street, 8th Floor, Suite 801
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INKOMATI
CATCHMENT MANAGEMENT AGENCY

Terms of Reference for the provision of Technical and Maintenance Support for Real Time Operational Water Resources Information Management System and Short Term Operational Modeling Requirements for the Inkomati WMA

BACKGROUND

The previous ICMA Contract with DHI South Africa "ICMA/WRP&P/Model Support-Short Term/2010: THE TECHNICAL SUPPORT AND MAINTENANCE OF THE CROCODILE RIVER DECISION SUPPORT SYSTEM REAL TIME FRAMEWORK AND SHORT TERM MODEL" expired on 31 March 2012

That project provided technical support and training to the short term models in the crocodile decision support system(DSS) including Mike Flood Watch and Mike 11 over the 18 month period of the contract. The contract also commenced the following two major components following request to do so by the IMCA:

- The installation and development of a real time and historical, processed water resource information management system for the Inkomati catchment and the dissemination of relevant information through the web to different stakeholders of the inkomati catchment to support river operations data management and dissemination in the entire Inkomati WMA. This DSS has been installed.
- Development of the Kaap River operating Rules. The data gathering and stakeholder engagement process was completed. However, the model set up and final operating rules were not completed.

The Department of Water Affairs has also commenced with the development of a DSS for the Sabie / Sand River Catchment that must be implemented at the ICMA during 2012.

"Consolidated Systems for Integrated Planning and Operations of River Systems" is one of the priority Strategic Actions identified by the ICMA for implementation in the Catchment Management Strategy. The crocodile DSS comprised the initial prioritised implementation of the strategic action. The commencement of the Sabie DSS project, along with the installation and development of the water resource information management system for the Inkomati catchment during 2011 have resulted in an expanded mandate for the ICMA in terms of this strategic action to manage the integrated planning and operations of River Systems for the entire Inkomati WMA.

The aspect of this priority strategic action relevant to this TOR is that of operations of river systems. Specifically, Water Resources Information Management and Short Term Operational Modelling.

DELIVERABLES AND TASKS

This Terms of Reference covers the required technical support, maintenance and capacity building to enable the ICMA to effectively implement its expanded mandate – explained above - in terms of the water resources information management system and short term operational modelling requirements related to DHI software solutions used by the ICMA.

The duties and tasks will include Inter Alia:

1. Support required to ensure continued deployment of the ICMA operational water resources information management system

The installed server based water resources information management system consists of both a DHI DSS platform to access information, and a web based application to allow for dissemination to a wider audience and to summarize key information indicators. The DHI DSS and associated web based system were installed onto 2 dedicated servers at the ICMA, which were purchased specifically for the purpose of collecting, storing, analyzing, managing and disseminating water resources information.

The main outcome of this task is to ensure that the installed DHI DSS and associated web based system, data acquisition, model simulations and all associated publications continue to run on a daily basis to provide the real time and historical data collections, storing, analysing, managing and disseminating needs for the river systems operations requirements of the ICMA and all of the related water resources modelling and hydrological modeling systems used by the ICMA for this purpose.

This task must be performed on request of and under the supervision of the Manager: River systems operations.

This would involve inter alia the following aspects:

- 1.1. Configuration of data into the DSS and associated data brokers and processing methods for existing data
- 1.2. On- Going Maintenance Support; DHI DSS: Maintenance of the DHI DSS itself and associated website and all data inputs and outputs associated to ensure the continued successful deployment of the DHI DSS and associated dashboard website. A time expenditure that may be foreseen is for 2.5 days of support per month.
- 1.3. Inclusion of new data sources:
  - 1.3.1. Incorporation of any remote sensing or related raster information requirements
  - 1.3.2. There will be several data sources identified in the user requirement survey that are likely to be required for effective operational water resources management
- 1.4. Any other relevant ad hoc support and maintenance requests of the ICMA

This support must also include attendance of the various ICMA river operations committee meetings and presentations to the meeting when requested.

2. Short Term Operational Modeling Requirements

Technical support to the ICMA is required on short term operational modelling related to DHI software products installed at the ICMA. This includes:

2.1 On- Going Maintenance and technical Support for CROC Floodwatch: Support the ICMA to continue to deploy the original CROC MIKE floodwatch framework until it is replaced by the new DHI DSS. For this purpose, and estimated time expenditure of 0.5 days of support per month until early 2013 is envisaged.
2.2 On- Going Maintenance and technical Support; Mike Basin: Support the ICMA continue to deploy the Mike Basin model setups installed at the ICMA. This includes the Kaap River DSS, Crocodile Mike Basin Setup and any other Mike Basin installations that may be installed at the ICMA during the period of this contract.
2.3 Technical Support related to the use and incorporation of hydrological models currently in development into the ICMA short term river operations modeling setups. This could include MIKE SHE, NAM, ACRU and PYTOPKAPI hydrological models.
2.4 White River Operating Rules: Technical input and assistance into the development and implementation of Operating Rules for the White River Catchment from a short term river operations perspective.
2.5 Groundwater / Surface Water interactions related to short term river operations including the determination and incorporation of soil moisture into the ICMA short term river operations where possible.
2.6 Ad hoc Maintenance and Technical Support to the ICMA related to short term operational modeling functions of the ICMA that utilise DHI products on request from the ICMA and which may arise from the User Requirement Survey.

3 User Requirement and Specification

In order to provide a water resources information management system that meets the needs of our stakeholders, the ICMA would like to conduct a User Requirements Survey and document the findings. The second component would be the technical specification of any IT related system that is hypothesized to meet the needs identified in the requirements survey:

3.1 User Requirements Survey and Document: investigate the water resources related information requirements in the Water Resources Planning and Operations section of the ICMA,. The Deliverable of the task is a requirements document which would need to be signed off by the ICMA, and which would then form the basis for the Technical Specification document.
3.2 On completion of the user requirements survey and document, the ICMA would need to specify, with help from DHI, the technical specifications for any further DSS and / or Dashboard developments. The technical specification document would then form the basis of any further development work that is required from DHI for the ICMA under item 4.4 below.
3.3 Report detailing the further development work recommended emanating out of tasks .1 and 3.2 above.

4 DHI DSS and DHI Model upgrades and Improvements

Any model upgrades and improvements, and any new observed data locations, which are possible within the existing implemented DHI DSS framework without having to write new programs or code, or without having to change model input and output adapters is required to be performed when required as part of this maintenance contract. This also includes the associated website publications within the existing website structure.

Major model upgrades and improvements, which involve changes to model calibrations, model input and output structures, as well as major changes to website structure and associated publications must be addressed as part of this contract as and when requested by the ICMA. The following major upgrades and improvements are required as part of this contract:

4.1 Migration of the existing Mike 11 Real Time and Mike Floodwatch software applications being implemented by the ICMA into the DHI DSS:

4.1.1 The DHI software solution known as MIKE 11 Real-Time, which is an integration of the MIKE 11 model and the GIS based forecasting framework MIKE Floodwatch, is currently being used for the basis of 2 water resources management DSS's in the ICMA operational area. However, the MIKE Floodwatch forecasting framework is no longer going to be a supported component of DHI's software from early 2013. The new DHI DSS framework is the follow on platform for MIKE Floodwatch and these existing systems must be fully integrated onto the newly installed DHI DSS platform.

4.2 Migration of all existing water resources management information needs of all other water resources modeling and hydrological modeling systems used by the ICMA onto the DHI DSS, where possible.

4.3 Upgrade and amendments to DHI DSS: implementation of identified short comings of the DHI DSS information management system as per the technical review document and which may result from other operational research in the Inkomati WMA including inter alia the RISKOMAN and WATPLAN projects; Integrated Modeling for Water Resource Planning and Operational Management WRC Project; and the remote sensing cooperation between the ICMA and Waterschap Groot Salland.

4.4 Other major DHI DSS and short term modeling upgrades, amendments and improvements that may arise: When requested to do so, the service provider must submit a proposal for provision of the requested service including an estimated cost, list of personal rates and project deliverables to be approved by ICMA before commencement of the relevant major upgrade or improvement can commence. No upgrade may commence if the estimated cost will exceed the budget allowed for in the contract.

5 Training and Capacity Building

Ideally, the support tasks described in 1 and 2 above should be completed by responsible persons at the ICMA without the assistance of a DHI consultant. In order to capacitate these persons at the ICMA so that they could achieve this level of competence, training and capacity building support is required as follows:

5.1 On- Going Maintenance Support: Via remote desktop connections and Skype

5.2 While much can be achieved via online interactions and training, trips by a DHI consultant to the ICMA in Nelspruit to perform on site maintenance and training when required and requested must be accomodated. These trips should be arranged to coincide with the monthly CROC meetings if possible.

5.3 Detailed Training Session on DHI DSS. a further 7 days of user training for the DHI DSS. This will be at the level of the advanced user and will deal specifically at using the DSS interface and tools to make analyses of data that is stored in the database

5.4 User manuals and training material must be updated as and when required. New training materials and manuals must also be developed as and when required to enable the ICMA to better implement the various tasks included in this TOR.

6 Execution, Supervision and Control

6.1 The ICMA must formally approve any work completed on the DHI DSS to ensure that any work undertaken by DHI is fully endorsed by the ICMA.

6.2 The administrative and contractual matters of the project will be done by the ICMA through a Project Manager. The ICMA Project Manager will be the Manager: River Systems Operations.

6.3 All requests for work by the ICMA mentioned in this TOR must be in writing from the Manager: River systems operations.

6.4 The Project Manager will maintain strict control over the performance of the proposed activities, and payment will be dependent on acceptable progress. The Manager: River Systems Operations shall certify invoices and a project progress sheet must be attached for his information.

6.5 A close Client – PSP relationship must be maintained during the execution of the study.

6.6 The PSP shall nominate a contract leader representing the PSP in execution of the contract and in dealing with the Client. The PSP's contract leader shall ensure that his/her team members regularly report back to him/her on progress made and on any findings that may either influence the progress of the contract or adversely affect the outcome or the budget of the contract. The contract leader shall convey that information without any delay to the Project Manager of the Client. If deemed necessary a special meeting will be arranged to discuss a way forward.

6.7 The study proposal and budget must allow for at least three scheduled project management meetings for the duration of the study. The PSP will arrange / schedule these meetings in accordance with the study programme. The PSP shall compile and circulate agendas and minutes, provide updated expenditure programmes, keep a record of decisions, make presentation on the work done and any problems experienced, etc.

APPENDIX S

MEMORANDUM OF AGREEMENT BETWEEN ICMA AND SANPARKS

MEMORANDUM OF AGREEMENT

ENTERED INTO BY AND BETWEEN

INKOMATI CATCHMENT MANAGEMENT AGENCY

Herein represented by Brian Jackson in his capacity as Acting Chief Executive officer

duly authorised thereto

(Here after referred to as "the ICMA")

And

SOUTH AFRICAN NATIONAL PARKS

Herein represented by .... in his/her capacity as ....

Duly authorised thereto

(here after referred to as "SANParks")

Whereas giving effect to the ecological reserve is an obligation of water management institutions and organs of state in terms of section 18 of the National Water Act 36 of 1998 the ICMA and SANParks is monitoring the implementation of the ecological reserve as well as performing bio-monitoring of the rivers within the Kruger National Park as part of their powers and functions.

Whereas SANParks is willing to make their staff available for Exploring Critical Feedback Components of a Strategic Adaptive Management System Associated with giving effect to the Ecological Reserve in the Inkomati Catchment and to provide all reports, deliverables and data obtained from the programme to the ICMA; and

Whereas the ICMA and SANParks have previously entered into a contract during the 2011/12 financial year that ended on 31 March 2012 for the first year of the project Exploring Critical Feedback Components of a Strategic Adaptive Management System Associated with giving effect to the Ecological Reserve in the Inkomati Catchment that has the scene for this cooperation and have made provision in their respective budgets for the progressive realisation of the ecological reserve and bio-monitoring of the Rivers within the Inkomati Management Area.

THE PARTIES TO THIS AGREEMENT AGREE AS FOLLOWS:

1. The ICMA and the SANParks joining resources to continue the exploration of Critical Feedback Components of a Strategic Adaptive Management System Associated with giving effect to the Ecological Reserve within the Inkomati Water Management Area as detailed in the terms of reference attached hereto as Annexure "TOR"
2. The work for the 2012/13 financial year shall be performed by SANParks employees in accordance with the budget attached hereto as Annexure "BUDGET" to be financed by the ICMA
3. The costs in respect of actual expenditure that shall be borne by the ICMA in terms of clause 1 shall not exceed the unspent portion (R162 495) of the previous project budget left over from the 2011/12 financial year and in the next financial years the costs that will be borne by the ICMA shall not exceed the budget amount by the ICMA for that specific financial year and the claiming procedures by the SANParks shall remain the same.
4. The SANParks shall bear all risks in respect of their employees and equipment in respect of this project.
5. Any dispute that may arise out of this agreement must first be referred to mediation and the mediator shall be appointed by agreement between the parties and if mediation is not completed and done within 90 days from the date of written notice of the dispute by one party to the other, any party may refer the dispute to a competent court or tribunal for relief.
6. The parties choose respectively the following addresses as *domicilium citandi et executandi* for the purpose of receiving notices and documents resulting from breaches and disputes arising from this agreement:

For the ICMA:	For the SANParks:
8th Floor Maxsa Building	Scientific Services
13 Streak Street	Conservation Building
Nelspruit	Kruger National Park
Tel: (013) 753 9000	Skukuza
Fax: (013) 753 2786	Tel / Fax: +27 13 735 4192
E-mail: jacksonb@inkomaticma.co.za	E-mail: stef.freitag @sanparks.org

7. The domicilium citandi et executandi must be changed by written notice within 10 days from the date of change of the physical business address of a party.
8. This agreement is the whole agreement between the parties and may be changed or amended only by means of an addendum properly signed by both parties.

THUS ENTERED INTO AND SIGNED AT NELSPRUIT ON THE ……………… DAY OF …………………………………..… 2011

……………………………………. WITNESS: 1.
…………………………………….

ICMA

2

…………………………………….

THUS ENTERED INTO AND SIGNED AT NELSPRUIT ON THE ……………… DAY OF ………………………………..… 2011

……………………………………. WITNESS: 1.

…………………………………….

SANPARKS

2

…………………………………….

ANNEXURE "TOR"

Terms of Reference

AIMS

The main aim of this study is to investigate, within a SAM framework, application of river bio-physical information to enhance catchment level stakeholder-centred decision making processes for water resource protection, associated with achieving sustainability goals under the NWA. Specifically, within the Inkomati Water Management Area, to:

1. Explore feasibility and recommend relevant and existing monitoring methodologies and decision support systems to test effectiveness of the Ecological Reserve.

2. Test the scenario planning role of ecological modelling platforms to support catchment level decision making associated with giving effect to the Ecological Reserve, i.e. testing the suitability of hydrological flow regimes, to meet river sustainability objectives.(Separate funding and not included as part of this contract)

3. Investigate and instigate appropriate ways to apply information from (1) and (2), in pertinent organizational and stakeholder feedback situations, with ongoing river flow monitoring initiatives.

ABRIDGED METHODOLOGY

1. Monitoring methodologies - Implementation, feasibility and recommendations (Aim 1)

Explore implementation and feasibility of two sets of methodologies under the SAM approach to test effectiveness of river flows upon giving effect to the Ecological Reserve: a) Rapid Habitat Assessment Method (RHAM), including integration with the River Health Program biotic indices; and b) geomorphology TPCs that were tested and implemented along the Crocodile River during WRC K5/1797 – this may not be pertinent thus excluded, subsequent to the large floods that occurred in January 2012.

2. Testing the scenario planning role of ecological models within a SAM framework (Aim2) (to be funded by SANPark)

Currently, catchment scenario planning exercises tend to use hydrological inputs and outputs at specific points in time (e.g. dam level changes, water restrictions etc); to make relevant decisions associated with giving effect to Ecological Reserve and water allocations. Longer-term modelling indicating consequences for the ecosystem are largely absent, but should form part of a wider SAM system, particularly when appropriateness of management actions in meeting sustainability and other biodiversity goals needs consideration. To test this, the project will employ the Breonadia TPC model developed for the Sabie River during the Kruger National Park Rivers Research Program of the 1990s.

2012-13 financial year: Strengthen the sediment dynamics module in the Breonadia TPC model; integration of the Breonadia model with hydrological modelling currently under way by IWR Water Resources (Stephen Mallory and Tendai Sawunyama) within the Sabie River sub-catchment (dependant on extended funding [consultancy] for sediment modelling from the Water Research Commission K5/1979 project);

2013-14 financial year: Use the Breonadia TPC model to assess biodiversity outcomes in the Sabie River, based on the ecological Reserve set for the Recommended Ecological State and alternate scenarios from the Reserve determination process. This work will also provide the necessary information to meet Aim 3 of the project.

3. Stakeholder engagement and feedback sessions (Aim 3)

The project is taking an "action research" based approach, where improved understanding about feedbacks of information within the SAM system will coincide with change in the way information is used, to enhance stakeholder environments for learning. Stakeholders will be included in the process from the beginning. The key focus areas are the Sabie River and Crocodile River sub-catchments (operations committees and other stakeholder forums).

DELIVERABLES: 2012-13 FINANCIAL YEAR

1. Report: Annual data collection, analysis, auditing and reporting associated with RHAM/RHP TPC related monitoring along the Sabie and Crocodile Rivers within KNP.
2. Report on the integration of the strengthened Breonadia model with the IWR hydrological model.
3. Presentations: Adaptive Reflection sessions associated with Deliverable (1), for catchment-scale Strategic Adaptive Management associated with giving effect to ecological Reserve - feedbacks to Crocodile and Sabie River (if pertinent) catchment stakeholder forums

ANNEXURE "BUDGET"

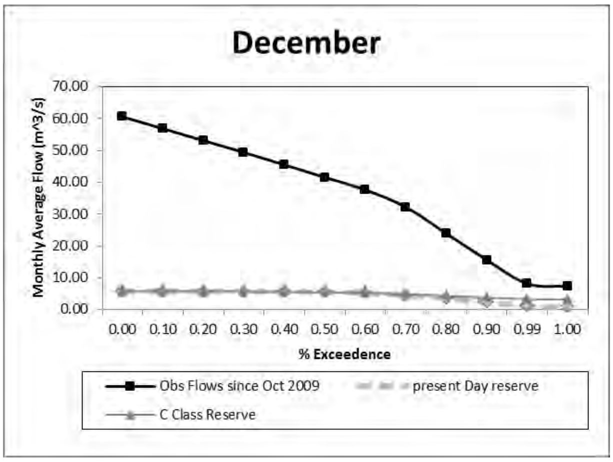
TASK	DESCRIPTION	BUDGET
1.	Habitat assessment along rivers in the KNP	R63 600
2.	*Breonadia* research and integration with hydrological model	(Funded by SANParks)
3.	Stakeholder consultation	R19 600
	Reimbursable Expenses	R53 120
	Sub-Total VAT	R136 320 R 19 085
	Total(incl VAT)	R155 405

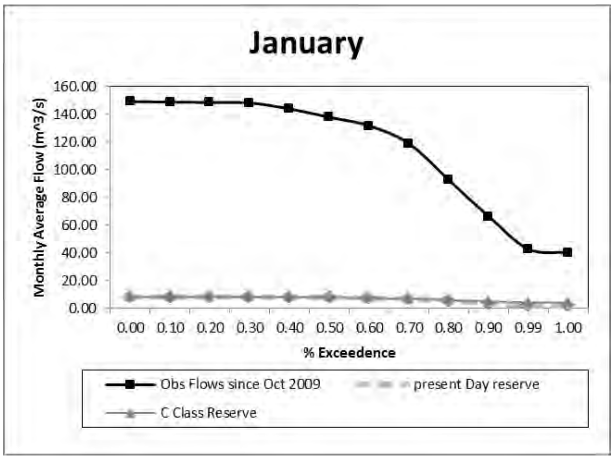
The time rate (VAT excl.) for members of the Project Team at the time of signing the Contract shall be as tabulated below.

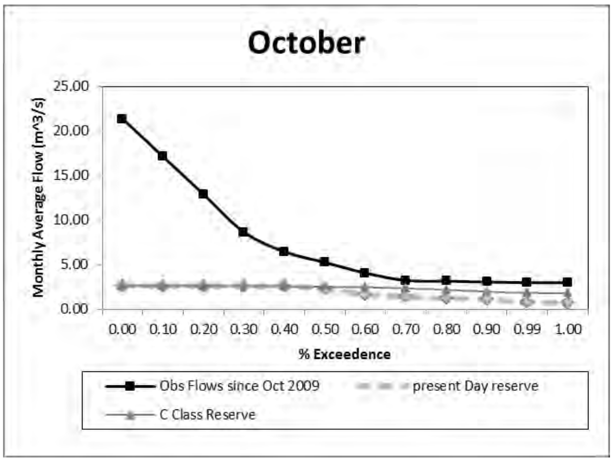
HUMAN RESOURCE	HOURLY RATE (R)	DAILY RATE (R)
Craig McLoughlin	350.00	2 800.00
James MacKenzie	350.00	2 800.00
A Deacon	400.00	200.00

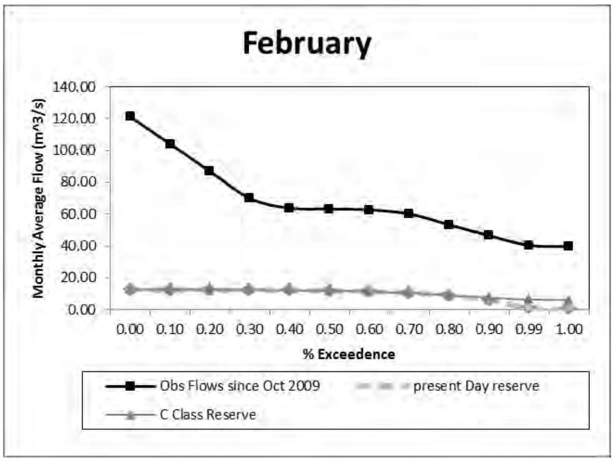
APPENDIX T

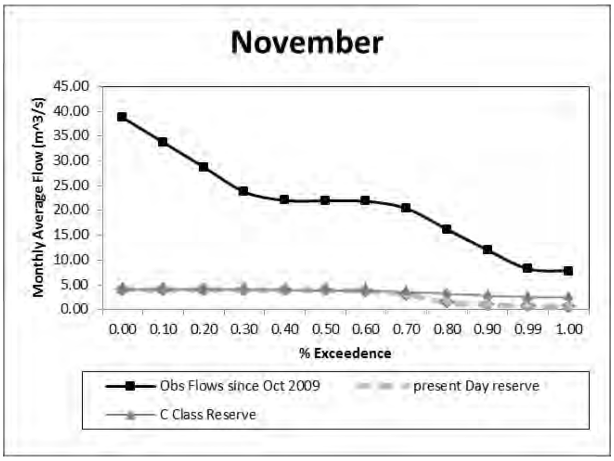
FLOW DURATION ANALYSIS BETWEEN THE OBSERVED FLOW AND ECOLOGICAL FLOW REQUIREMENT

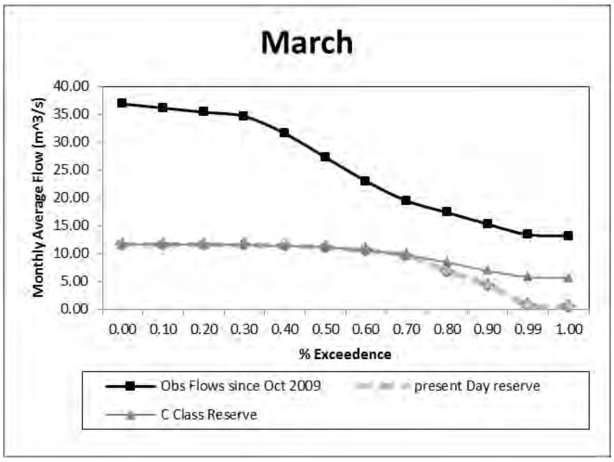


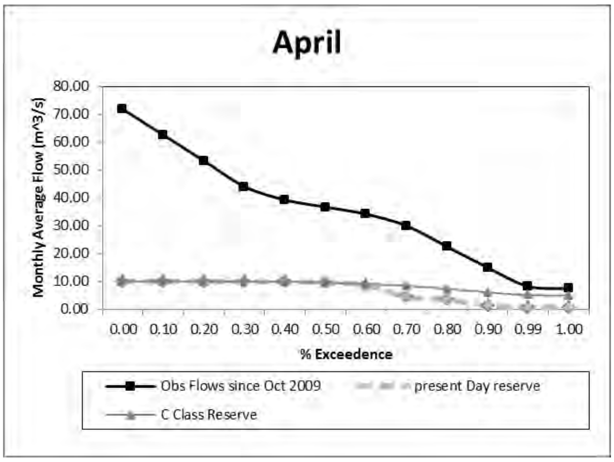


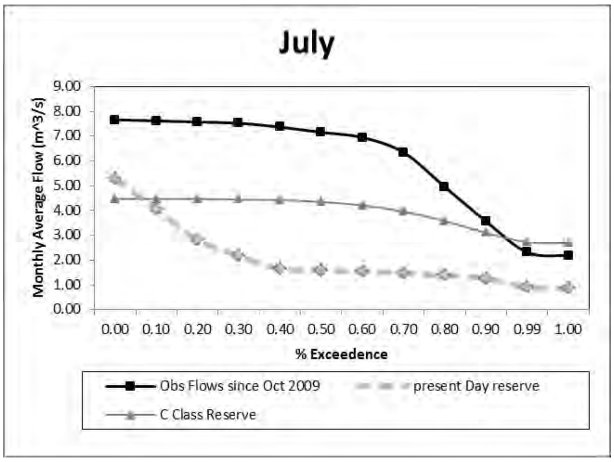


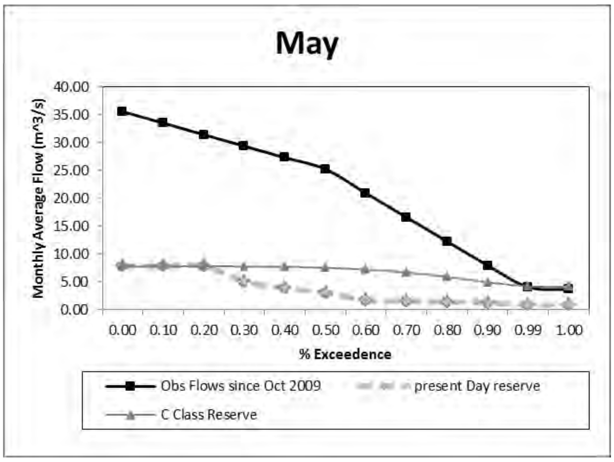


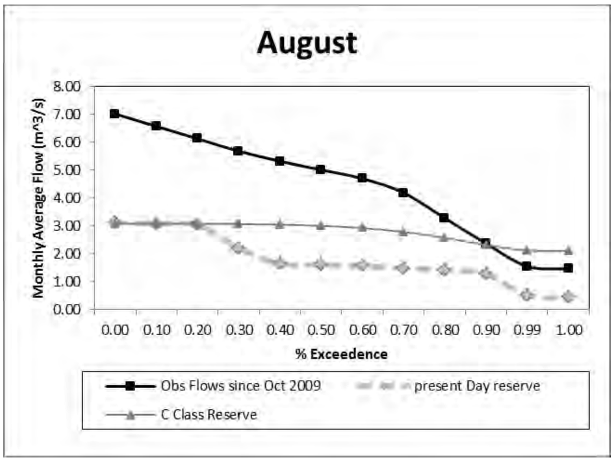


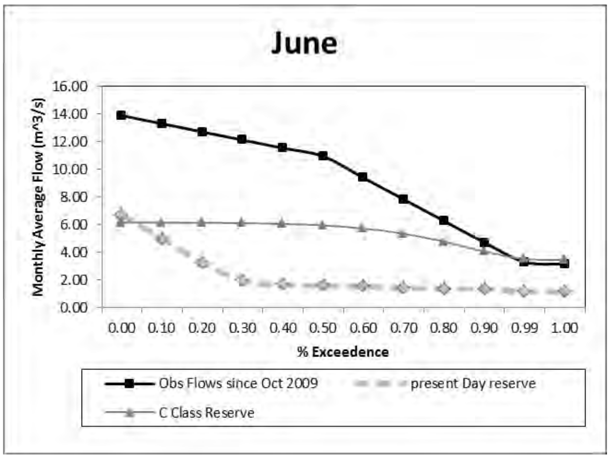


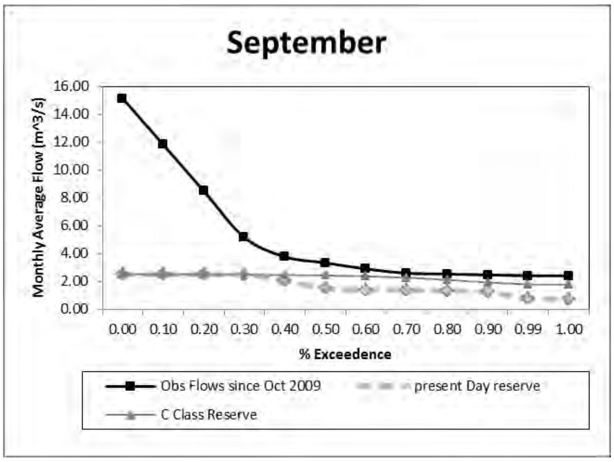

April
Monthly Average Flow (m^3/s)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 0.99 1.00
% Exceedence
Obs Flows since Oct 2009
present Day reserve
C Class Reserve


July
Monthly Average Flow (m^3/s)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 0.99 1.00
% Exceedence
Obs Flows since Oct 2009
present Day reserve
C Class Reserve


May
Monthly Average Flow (m^3/s)
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 0.99 1.00
% Exceedence
Obs Flows since Oct 2009
present Day reserve
C Class Reserve


August
Monthly Average Flow (m^3/s)
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 0.99 1.00
% Exceedence
Obs Flows since Oct 2009
present Day reserve
C Class Reserve


June
Monthly Average Flow (m^3/s)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 0.99 1.00
% Exceedence
Obs Flows since Oct 2009
present Day reserve
C Class Reserve


September
Monthly Average Flow (m^3/s)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 0.99 1.00
% Exceedence
Obs Flows since Oct 2009
present Day reserve
C Class Reserve