AN ADAPTIVE OPERATIONAL WATER RESOURCES MANAGEMENT FRAMEWORK TO FACILITATE EFFECTIVE OPERATIONAL RIVER MANAGEMENT ON THE CROCODILE RIVER

1. OPERATIONAL WATER RESOURCES MANAGEMENT (OWRM)

Water resources systems have diverse social, technological, ecological, economic and political (STEEP) characteristics and processes that 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. Semi-arid run-of-river dominated basins1 exacerbate and enhance the difficulty in achieving IWRM within this complexity. These types of river systems are especially sensitive and susceptible to degradation in closing river basins2 due to the intrinsic uncertainty and complexity associated with high variability in runoff and lack of storage to manage it with. There is little evidence to show that current institutional arrangements for water resource management have been able to deal with the issues of basin closure.

Typically, studies on IWRM, complexity, adaptive management and basin closure, highlight the current gaps to their fulfilment, but fall short of indicating the further need to improve the short term operations of semi-arid run-of-river dominated catchments, and concentrate more on water resources planning interventions. Although water resource managers are required to perform tasks for both water resources planning and operations, water resource modelling for planning is widely practiced in South Arica, but the use of water resources modelling for operations appears to be less widely practiced. This is an area that requires further development and implementation (Clark and Smithers, 2013).

2. IMPORTANCE OF MAKING OWRM ADAPTABLE

The dual learning pathways of science and management are equally important for water resources management, and need to be applied in a social learning context to achieve concerted action in complex and uncertain contexts and situations (Ison and Watson, 2007).

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[1] 8River systems 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 system can be defined as a river system that has no or little in stream storage available for the management of runoff and is thus dependent on rainfall for runoff generation

[2] Basins 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 basin and at the river mouth, for part or all of the year, (Falkenmark and Molden, 2008; Molle, Wester and Hirsch, 2009).

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, 2000). IWRM, including OWRM should thus be developed and implemented in an ”adaptive manner” that stimulates scientists and practitioners through the philosophy of “learn by doing” i.e. being informed by practice. The corollary is that in complex systems, the users must be also part of deriving management solutions since this is where and how they learn (Pollard and Du Toit, 2008). If they are excluded, the ‘system’ does not learn and hence adapt to change and surprise. Traditionally where systems of governance and management meet they generally do not effectively accommodate the diversity of legitimate stakeholder needs and value-sets.

The ICMA has thus expressly acknowledged that it is a learning organisation that has embraced SAM and that it must be able to modify its behaviour to reflect new knowledge. The ICMA uses the SAM implementing framework developed for South Africa (Pollard and Du Toit 2007), which splits SAM into 3 key phases: adaptive planning; adaptive management; and adaptive evaluation. The adaptive planning phase has already been conducted by the ICMA during the development of its CMS and strategic plan, but the adaptive management and adaptive evaluation phases have yet to commence.

Water resource managers are required to perform tasks for both water resources planning and operational needs and it is important that these aspects are linked together under a single framework. According to the Global Water Partnership (2013) a DSS for IWRM typically includes a database and processing environment, a knowledge and information system, a modelling and analysis framework, a socioeconomic modelling and analysis framework, and a communication framework. As implied by Sawunyama et al., (2012) the management of scarce water resources requires that a DSS is both flexible and adaptable in design in order to provision accurate real time data, including the hydrological modelling associated with it. Such DSS’s provide the requisite level of information upon which OWRM has the ability to become adaptive, since:

- OWRM has historically been dealt with using management (tacit) knowledge rather than scientific knowledge, which implies that learning from management experience is important and that scientific knowledge in the area can be improved.
- River basin operational processes requires 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) – and thus adapt to changing conditions.
- Operational DSS’s require large amounts of real time data and physics based models 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). Modern technology allows for a high level of automation and sophistication in operational information technology.

- 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.

3. THE CROCODILE RIVER: A CASE STUDY FOR OPERATIONAL WATER RESOURCES MANAGEMENT

The Crocodile River is one of the main river catchments within the Inkomati WMA, is an excellent example of a semi-arid closing basin that is run-of-river dominated (IWAAS, 2010; Inkomati CMS, 2010b) for the following reasons:

- High water demand versus the available supply.
- Significant variability and seasonality in available water in both time and space.
- Low storage capacity in relation to the water demand in the catchment. The only dam on the main stem, Kwena Dam, only influences about 10% of the mean annual runoff.
- Rainfall areas and main irrigation demand areas are spatially disparate.
- It's a long river (length of approximately 250km), which makes it difficult to manage during low flow periods, when losses can be significant and unpredictable.
- International obligations for water sharing with Mozambique and Swaziland.
- It is ecologically important to the Kruger National Park yet the ecological flow requirements have yet to be implemented (the ICMA indicates that the implementation of the Reserve will result in decreased water availability as well as decreased assurances of supply).

3.1. Institutional Arrangements: Institutions, Responsibilities, and Communications

The NWA requires CMA's to establish catchment management committees to facilitate stakeholder engagement around IWRM at catchment level. The ICMA has already established a Crocodile River Forum in this regard and a more specific operational committee, the Crocodile River Operations Committee (CROCOC) was established to meet the institutional need in terms of OWRM. The CROCOC now meets quarterly[3]. The NWA also allows for the establishment of Water User Associations (WUA). WUA's are a key mechanism in the NWA for facilitating decentralisation of relevant powers and functions for IWRM to the local level and thus enable effective stakeholder engagement in IWRM at the local level. Within the Crocodile River, 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.

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[3] although the CROCOC can convene more frequently as the need arises.

The establishment of the CROCOC required the documentating of the institutional arrangements showing roles, responsibilities, forums, committees and decision and communication lines shown in Figure 1 below:

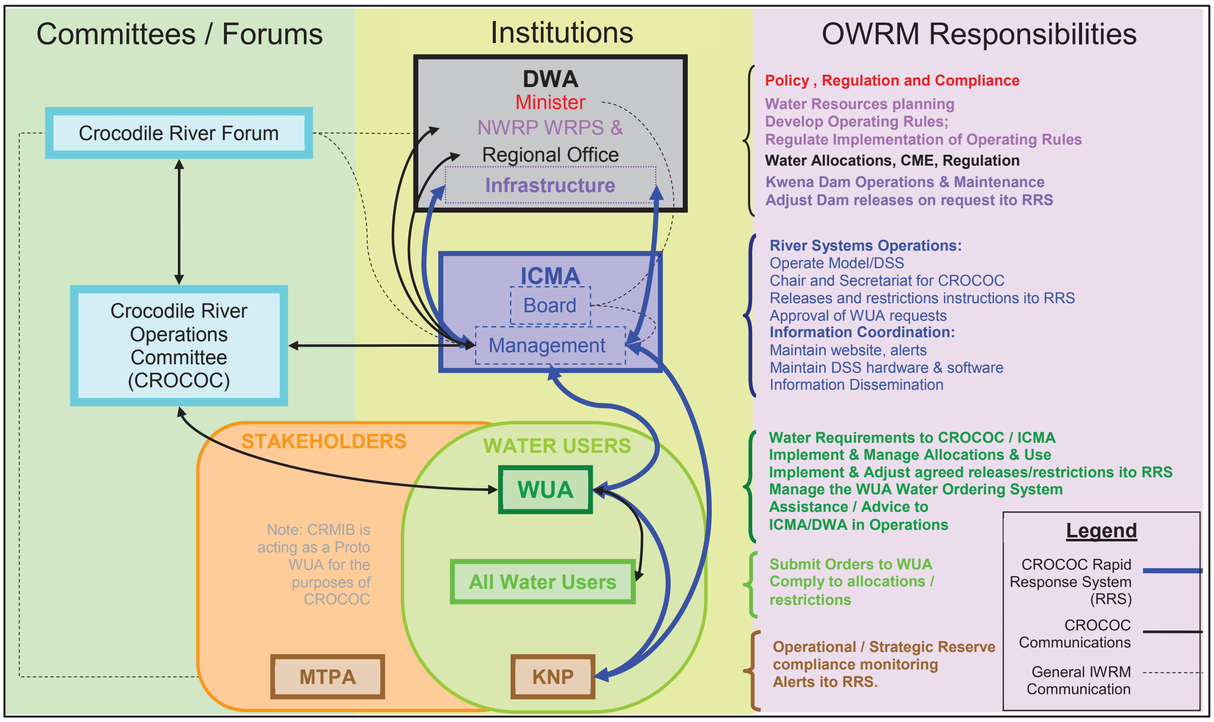

Figure 1: Institutional arrangements in the Crocodile River (DWA = Department of Water Affairs; ICMA = Inkomati Catchment Management Agency; NWRP = National Water Resource Planning; WRPS = Water Resource Planning Systems; DSS = Decision Support System; RRS = Rapid Response System; WUA = Water User Association; KNP = Kruger National Park; MTPA = Mpumalanga Tourism and Parks Agency; IWRM = Integrated Water Resource Management; CRMIB = Crocodile River Major Irrigation Board), adapted from ICMA (2010)

4. DEVELOPING AN ADAPTIVE OPERATIONAL WATER RESOURCES MANAGEMENT FRAMEWORK (AOWRMF)

The valuable guidance provided to the ICMA by Professor Kevin Rogers during the development of the CMS reinforced the importance and need for extensive stakeholder involvement and participatory decision in IWRM. His guidance also established the importance of a consensus based decision making system around IWRM with the ICMA. The CROCOC is perhaps one culmination of this endeavour since it was established to coordinate the stakeholder participation, decision making, action research and strategic adaptive management needs. This led to a vital sense of ownership of decisions and policies linking both technical DSS related data to the more complex social-ecological needs of the Crocodile river, ultimately leading to reduced resistance and even cooperation in implementing management action. The committee operates under a TOR that acts as the mutually acceptable ethical framework for Adaptive Operational Water Resources Management (AOWRMF) in the Crocodile River. The CROCOC has now established itself 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.

The knowledge required to implement an effective AOWRMF were analysed, evaluated, and adjusted (and documented) in the following hierarchy of categories:

<table>
<tr><td>• Institutional Arrangements</td><td rowspan="2">Social Scientific Learning</td><td rowspan="4">Management Learning</td></tr>
<tr><td>• Stakeholder Participation and Decision Making</td></tr>
<tr><td>• Data and Information</td><td rowspan="2">Technical Scientific Learning</td></tr>
<tr><td>• Modelling and Decision Support Systems</td></tr>
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The evaluation of the efficacy of the AOWRMF within this project had two outputs:

- assess how this is facilitated through the social learning of ICMA and CROCOC (social evaluation).
- assess the implementation of ecological reserve of the Crocodile River using real time operating rules (technical evaluation).

5. RESULTS OF THE AOWRMF DEVELOPMENT

The AOWRMF is thus the outcome of four years (Oct 2009 to Oct 2013) of deliberation, action research and development in collaboration with the CROCOC stakeholders, as documented in King and Pienaar, 2011; McLoughlin et al., 2011; and Pollard and Du Toit, 2011; Jackson et al., 2012. The vision, objectives and scoping management options (adaptive planning aspects of Pollard and du Toit, 2007) in the AOWRMF are shown in final form in Figure 2.

Figure 2: A pragmatic Adaptive Operational Water Resources Management Framework for the Crocodile River

5.1. A Rapid Response System

The Rapid Response System within the AOWRMF has evolved to cater for both operational water resources management and ecological flow implementation and incorporates various aspects of operational river management. It is the necessary prerequisite in which adaptive management is conducted in the Crocodile River and is also the key enabler of short term feedback loops (social transparency). In particular it has evolved to become a core enabler of openness and inclusivity for short term and near real time operations. This is because the CROCOC which meets quarterly thus cannot 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 rapid response system fills this gap.

The rapid response system includes the following aspects:

- Dissemination of real time rainfall, runoff and dam level information through emails and a web portal.
- Calculation and dissemination of short term forecasted rainfall, runoff and dam levels (weekly, but updated daily).
- Defined monthly alerts for river flows based on international obligations and historical statistics compared to current real time information.
- Defined worry levels around the reserve or ecological flows, linked to management actions.
- Calculation and dissemination of the weekly forecast ecological flows or reserve.
- 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.
- Linked to longer term aspects of the AOWRMF through the presentation of the logbook and short term monitoring results at CROCOC meetings.

5.2. Data, Information and dissemination

Water resource managers are required to perform tasks for both water resources planning and operations needs and it is important that these aspects are linked together under a single framework. According to the Global Water Partnership (2013) a DSS for IWRM typically includes a database and processing environment, a knowledge and information system, a modelling and analysis framework, a socioeconomic modelling and analysis framework, and a communication framework.

The DWA Project WP 9429: A Real-Time Operating Decision Support System (DSS) for the Crocodile East River System (Hallowes et al, 2007) and the Inkomati Water Availability Assessment Study (DWA, 2009) sourced the majority of the foundational information used in the Crocodile for water resources planning and operations. The information requirements relate to for instance: dam storages, landcover, hydrology, irrigation boards, WARMS (water use registration), climate forecasts, river health program data etc. A significant proportion of this data is used to drive the water resource DSS and combined modelling platform (Figure 3) upon which the CROCOC predicates it's decision making[4] further details of which can be found in Appendix 0.

Experience in the implementation of the AOWRMF has shown that the real time rainfall and stream flow loggers and water level probes require extensive maintenance. Staff was appointed at the ICMA and a technical support and maintenance contract with the service provider was put in place to ensure the continued reliable operations of the hardware.

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.

All of the above data and information is collected and disseminated to stakeholders through the rapid response system and the CROCOC via a combination of, e-mail, web portal and CROCOC presentations. This is managed by a water resources information management database running on the Mike customised DSS.

Whilst the hydrochemical and remote sensing data that was presented in section 2 has not been integrated with the DSS that the CROCOC uses, it nevertheless suggests that in the future this information will be extremely useful in these decision making frameworks in order to:

- provide a quantitative validity to hydrological data integration (particularly in terms of remote sensing data) in models at increasingly finer spatial and temporal resolutions – key to real-time water resources management
- provide qualitative baseline information for a broad array of stakeholders to understand catchment hydrodynamics (water pathways from hydrochemistry; land-use/topographic related water fluxes from remote sensing data), in order to elicit a robust conceptual hydrological platform upon which to predicate decisions at the operational level.

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[4] The TOR of the CROCOC summarises the main information and decision needs at various temporal scales required for operational water resources management of the Crocodile River.

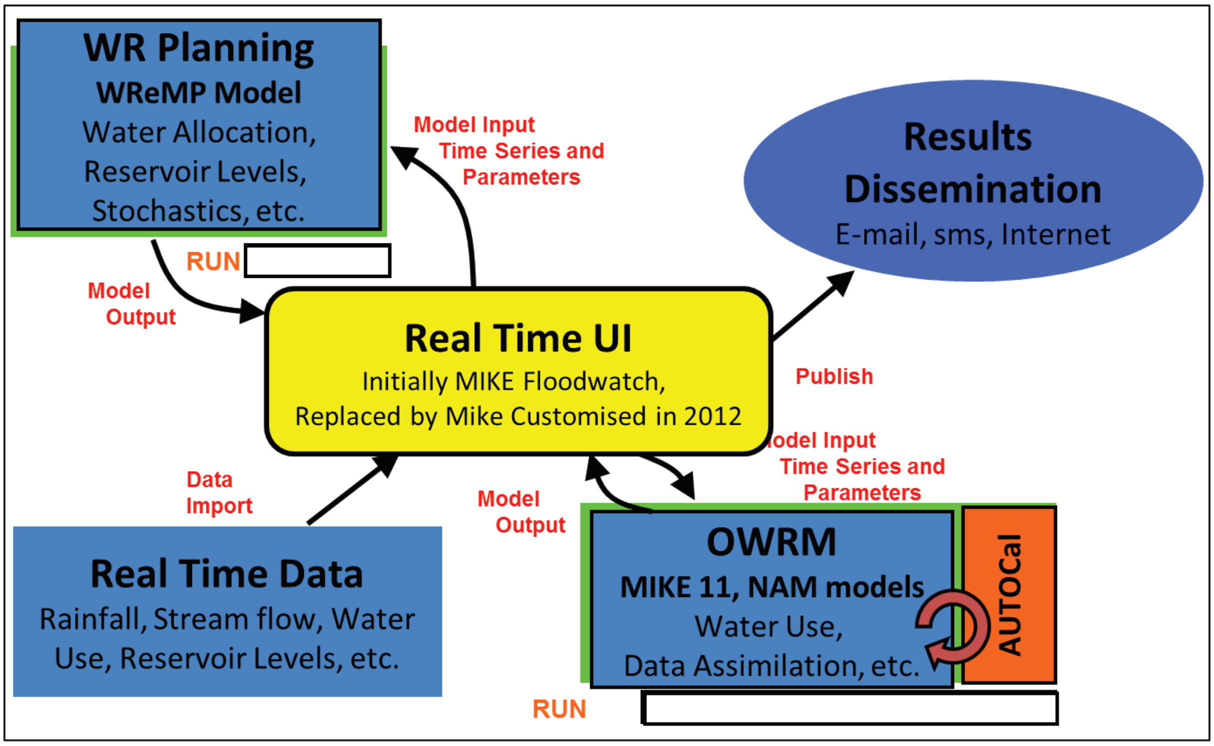

Figure 3: Conceptual Representation of the Operational Water Resources Management Decision Support System implemented in the Crocodile Catchment (Hallowes et al., 2007), where the WReMP is the long term water resources planning model and the MIKE suite of tools integrates this and other information for real-time operations for the Crocodile River

6. RESULTS OF THE AOWRMF IMPLEMENTATION

6.1. Social Evaluation: Stakeholder Participation in Decision Making

The CROCOC enabled the researcher to form bridges across the domains of science, management, and societal values and investigate the lived complexity between scientific, social and management disciplines.

The extensive discussions over the technical implementation of the ecological flows at the CROCOC are 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, it has also shown that frequent, focused discussions amongst relevant stakeholders can facilitate sufficient understanding and enable effective implementation of AOWRM.

The social learning outcomes from the questionnaire are summarised in Table 3.1 (Details of which may be found in Appendix 0). Users 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. An average score of higher than three (3) indicates that users are in general agreement, while a minimum score below three (3) indicates that some users do not agree with the general consensus. The results indicate that social learning is fairly well established in the AOWRM of the Crocodile River. The average scores of the questionnaire respondents indicate a high level of agreement. 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 contended here that its existence and effective functioning is critical to effective AOWRM.

The results 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. Although at present the drawbacks identified were: the absence of certain sectors, chiefly the municipalities, representatives from Mozambique and emerging farmers, were highlighted as issues of concern that must be addressed. The absence of water use information from the irrigation board was another cause of concern.

Table 1: Social Learning Evaluation of Stakeholder Engagement and Participatory Decision Making associated with implementing AOWRM through the CROCOC.

Key Capacities for Social Learning

Criteria	Users Scores									Statistics	
	AV	CM	ED	ER	JV	NV	RP	SM	TS	Min	Avg
FAIRNESS:	4	4	4	4	5	5	5	4	3	3	4.2
WISDOM: Competent Decisions	4	3	4	4	5	5	4	4	4	3	4.1
WISDOM: Consensus	5	4	5	5	4	4	5	4	5	4	4.6
STABILITY: decisions not opposed	4	3	4	3	2	4	3	4	4	2	3.4
SENSE OF OWNERSHIP:	4	4	5	5	5	4	4	4	5	4	4.4
CAPACITY BUILDING / LEARNING: Sufficient?	2	3	5	4	4	5	4	3	5	2	3.9
CAPACITY BUILDING / LEARNING: Other perspectives allowed?	4	4	4	5	4	5	4	4	4	4	4.2
AWARENESS: Good awareness	3	3	4	4	5	5	4	3	5	3	4.0
AWARENESS OF SYSTEM COMPLEXITY:	4	4	3	4	3	5	3	5	5	3	4.0
SHARED PROBLEM IDENTIFICATION:	4	3	5	4	3	4	3	4	5	2.5	3.8
INTERDEPENDANCE BETWEEN STAKEHOLDERS: D	2	4	5	3	4	4	4	3	3	2	3.6
LEARNING TO WORK TOGETHER:	3	4	5	5	5	5	4	4	4	3	4.2
RELATIONSHIPS: Formal relationships established?	3	4	4	4	4	4	4	4	3	3	3.8
RELATIONSHIPS: Informal relationships established?	4	3	4	4	3	4	4	3	4	3	3.7
TRUST:	4	4	5	4	5	5	4	4	3	3	4.2

Key Fostering Factors for Social Learning

Criteria	Users Scores									Statistics	
	AV	CM	ED	ER	JV	NV	RP	SM	TS	Min	Avg
ONGOING HIGH MOTIVATION: Amongst the stakeholders?	3	3	4	5	5	4	3	4	5	3	4.0
INDEPENDENT TECHNICAL MEDIATOR: ICMA a good independent technical Mediator?	5	5	5	5	5	5	5	4	4	4	4.8
HIGH COMMITMENT OF LEADERS: Responsible authorities highly committed?	4	4	5	4	5	5	3	3	4	3	4.1
LEGITIMACY: ICMA?	5	5	5	5	5	5	5	5	5	5	5.0
EXCHANGE OF INFORMATION: Good access to and exchange?	3	4	4	4	5	4	4	3	5	3	4.0
INCLUSIVITY (ABILITY TO CONTRIBUTE?): All stakeholders are able to effectively contribute?	5	4	5	2	5	5	4	3	3	2	4.0
DELEGATED LEADERSHIP: Sufficient delegation?	4	3	4	3	5	4	4	4	5	3	4.0
NUMBER OF PARTICIPANTS: Limited participants enables improved deliberations?	5	4	4	4	3	4	3	4	4	3	3.9
FREQUENT, FOCUSED DISCUSSION: Sufficiently frequent, and focused discussion?	3	3	4	3	3	5	4	3	5	3	3.7
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	3	4.1

Key Hindering Factors for Social Learning

Criteria	Users Scores									Statistics	
	AV	CM	ED	ER	JV	NV	RP	SM	TS	Min	Avg
INADEQUATE TIME AND RESOURCES:	3	3	5	5	4	3	3	4	5	3	3.9
LACK OF FEEDBACK OF OUTCOMES:	4	4	4	5	5	4	4	4	4	4	4.2
RELATIONSHIP BETWEEN STAKEHOLDERS AND TECHNICAL TEAMS:	3	5	5	5	5	4	3	4	4	3	4.2
OVERLY TECHNICAL LANGUAGE:	2	3	4	4	2	3	2	2	5	2	3.0
LACK OF CLARITY ON PROJECT AIMS:	5	4	4	4	3	4	3	4	5	3	4.0
CONFLICT IN SCALE OF PROJECT AND STAKEHOLDER INTEREST:	3	5	5	5	4	4	4	3	4	3	4.1

LACK OF OPENNESS:	4	4	4	4	5	4	4	4	4	4	4.1

Consensus Based Decision Making

Criteria	Users Scores									Statistics	
	AV	CM	ED	ER	JV	NV	RP	SM	TS	Min	Avg
PURPOSE DRIVEN:	5	4	5	5	5	5	4	4	5	4	4.7
INCLUSIVE:	4	4	5	3	5	4	4	4	4	3	4.1
VOLUNTARY PARTICIPATION:	4	4	5	5	3	5	3	4	5	3	4.2
SELF DESIGN:	5	2	5	3	3	4	4	3	3	2	3.6
FLEXIBILITY:	4	3	4	4	3	5	4	3	4	3	3.8
EQUAL OPPORTUNITY:	4	4	5	3	4	4	4	4	4	3	4.0
RESPECT FOR DIVERSE INTERESTS:	2	4	5	5	3	4	4	4	3	2	3.8
ACCOUNTABILITY:	4	4	4	3	5	4	3	3	5	3	3.8
REALISTIC DEADLINES:	4	4	4	5	4	4	4	4	5	4	4.2
IMPLEMENTATION	4	4	5	5	5	4	4	4	5	3.5	4.4

6.2. Real Time Implementation of the Ecological Water Requirements (Reserve)

Much research has also been done into the state-of-art of the development of ecological flows but general research has shown that ensuring that ecological flows are implemented in practice has received relatively little attention (Mallory, 2012). It has been shown that ecological flows cannot be implemented without implementing real time or near real time operations (McLoughlin et al, 2011), especially in semi-arid run-of-river dominated closing basins.

The first few meetings of the CROCOC clearly showed that the effective determination and implementation of the ecological flow requirements were the main concern and source of conflict amongst the stakeholders. 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.

It took 2 years of rigorous and frequent discussions at the CROCOC meetings from October 2009 until October 2011 before an effective and trusted real time ecological water requirement determination method and related decision making process was finally implemented at the ICMA. This 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 the result is much improved trust and ability to implement decisions.

6.2.1. Technical Aspects

Some of the technical issues related to the ecological water requirements present at the initiation of this AOWRMF in 2009 included:

- Ecological water 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 reserve requirements.
- The lack of consideration of the operational realities in the comprehensive reserve 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 only 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 reserve flow for the present day. This is especially troublesome if the ecological flows are required to be determined in support of operational near real time water resources management when forecasted natural flow is required, as is the case here. None of the above processing was in place in October 2009, when the AOWRMF was first introduced.
- In South Africa, the ecological reserve is 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). Methods developed and applied to date in Southern Africa entail 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).
- At the final steering committee meeting of the DWA reserve study, it was decided to maintain the present day flow regime in the Crocodile River and not to implement the recommended reserve class. What "present day flow" actually meant on a daily basis was not determined.

As a result of these issues, and due to insistence stemming from the CROCOC meetings, it was necessary to develop an effective methodology to calculate the ecological reserve in near real time. A method to compute real time naturalisation and ecological flow requirements without the need for accurate real time rainfall data was developed by Mallory (2010), on request of the ICMA. 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:

$$NF_t = OF_t + \Sigma WU_t + \Delta S$$

Where: NF is natural flows; OF is observed flows; WU is water use; S is storage; and t refers to a time interval. The method is described in detail by Mallory (2010).

The "present day flows" described in the DWA comprehensive reserve determination project also required determination and operationalisation (Mallory, 2010). These "present day flows" were compared to the original C-Class reserve requirements stemming from the DWA project and presented to the CROCOC stakeholders for discussion and adoption. Discussions over the final ecological flows to be used took place over many months at the CROCOC. The calculated "present day flows" included high flow requirements while the C-class reserve from the DWA project was only determined for low flow ecological requirements. Consensus was eventually reached on the use of a new recommended ecological flow requirement that is the lower of the "present day flow" and the DWA C-class reserve as shown in Figure 4.

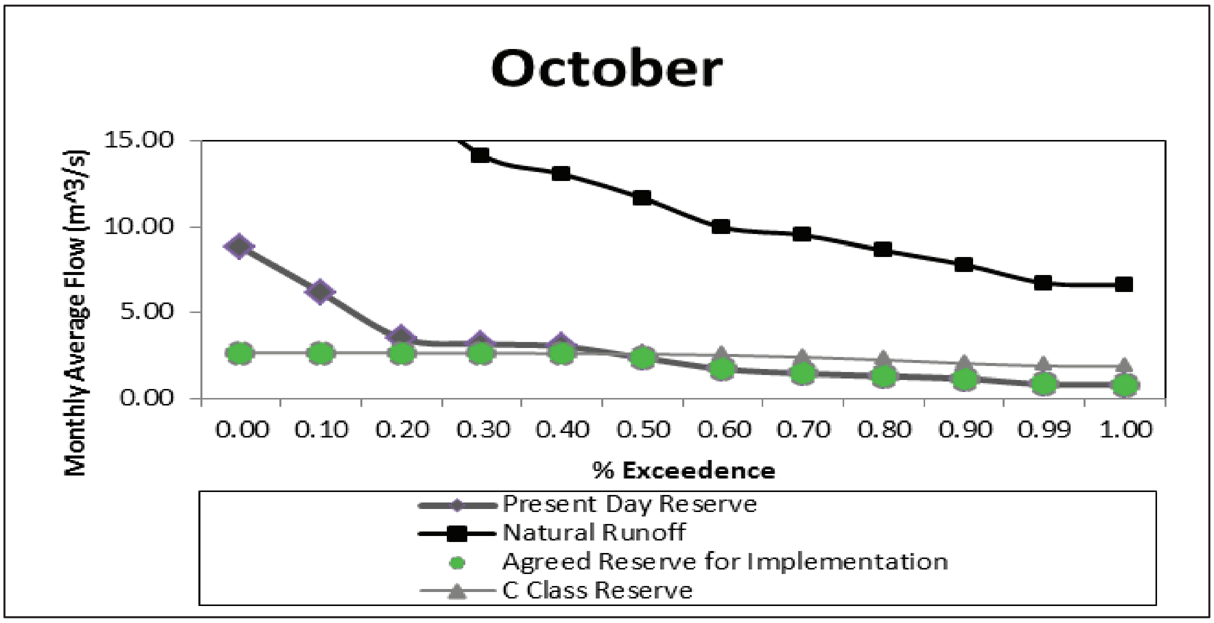

Fig 4: Present Day Flows vs. C Class Reserve and Natural Flow for October

Consensus was also reached on the implementation of the ecological reserve at the downstream end of the catchment near the DWA X2H016 (Tenbosch) flow gauge only. This decision was based on the assumption that if the downstream ecological flows were met then the upstream sites would also be met.

The model is run on a weekly basis. The model determines the real time natural flow and then calculates the agreed "present day flow" 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 outputs from the WReMP model used to calculate weekly ecological reserve flows at the Tenbosch gauge are sent to all relevant CROCOC stakeholders as a spreadsheet shown in Figure 5. This spreadsheet forms a critical aspect of the rapid response system and feedback loops of the AOWRMF 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 implementation and efficacy of the rapid response system and feedback loops associated with the ecological reserve is thus reliant on the short term operations aspects of the AOWRMF and the Mike Customised DSS.

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

Fig 5: Extract of the Weekly Ecological Reserve Spreadsheet emailed to all Relevant CROCOC Stakeholders

6.2.2. Evaluation

The compliance to the ecological reserve has been used as the main means of evaluating the efficacy of the AOWRMF, along with the social learning outcomes. This is apt as the ecological flows 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 methodology of Riddell et al (2014), to evaluate the compliance with the ecological flow requirements has been used in this project to ensure consistency with the research and monitoring of compliance previously conducted in the Crocodile River. The methodology determines the extent of non-compliance in terms of four categories: % time non-compliant, the number non-compliant months per year, seasonality of compliance, and magnitude and contiguity of compliance.

The DWA C-Class reserve has been used in accordance with Riddell et al (2014), although a more lenient “present day flow” requirement has been implemented since October 2009. The non-compliance before and after the implementation of the AOWRMF in 2010 is shown in Figure 6.

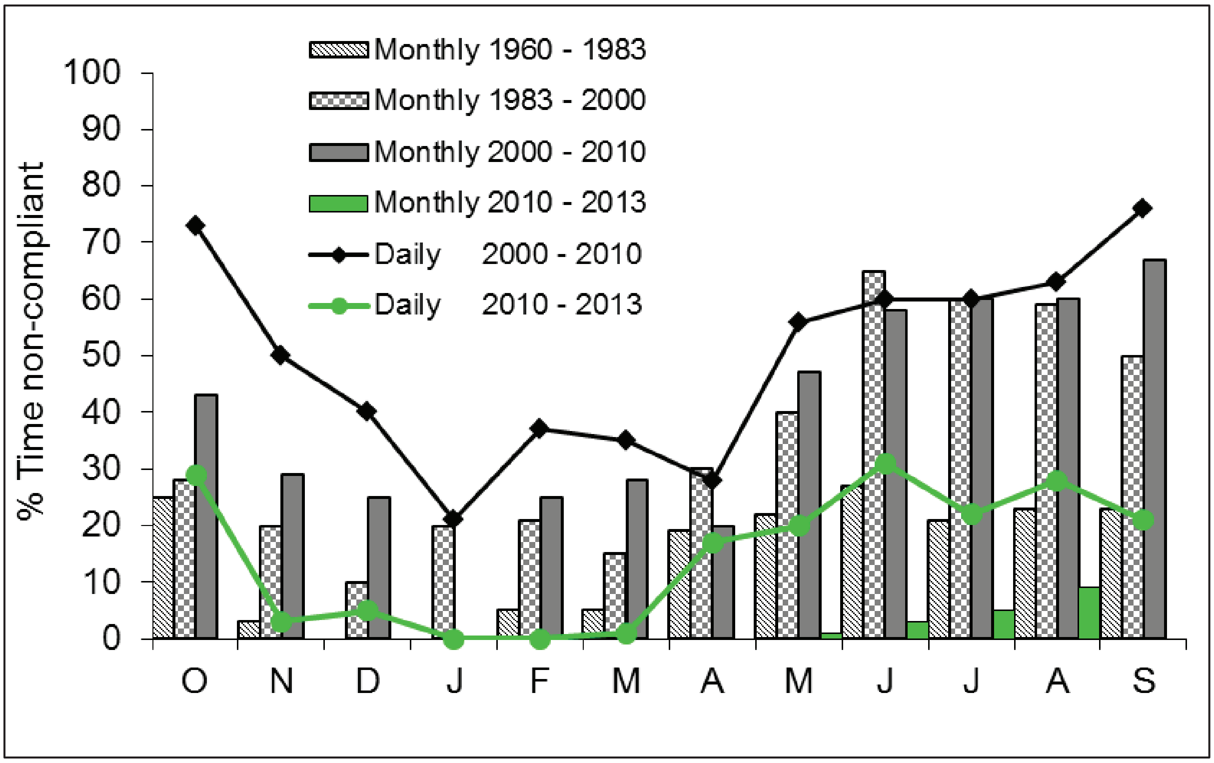

Fig 6: Percentage of Time for Monthly Ecological Flow Compliance before and after the implementation of the AOWRMF (green)

The average incidence of failure across all months since 2010 is only 2% with the maximum being 9% during August. Although not all categories are shown here, the percentage time, magnitude and contiguity of non-compliance to the ecological flow requirements have all drastically 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 efficacy in implementing OWRM. This has been achieved through the sharing and learning from information through consensus, that allows real-time adaptive decisions to effect change.

7. CONCLUSIONS

The results presented under the four categories of the adaptive operational water resources management framework (AOWRMF) clearly demonstrate that an AOWRMF can be effective in implementing operational water resources management in semi-arid, closing and run-of-river dominated catchments. The social learning questionnaire outcomes and the huge improvements in the compliance with the ecological flow requirements are the chief indicators supporting this statement.

Important overarching aspects of an effective AOWRMF for semi-arid, closing and run-of-river dominated catchments stemming from this research include:

- It is developed through a grounded action research methodology with strong stakeholder involvement, cognisant of both scientific and management learning.
- A broad scope of research is necessary to explore the many relevant aspects and levels of the concept and practice of operational water resources management. This includes both social and technical science.
- The AOWRMF is cognisant of requisite simplicity.
- The setting up and use of an operations committee with a defined TOR – developed in collaboration with the stakeholders - to provide the mutually acceptable ethical framework for the action research is crucial.
- It is based on Strategic Adaptive Management principles.
- It includes both water resources planning and operations aspects, links them together in one framework and does not concentrate on the implementation of the operations aspects in isolation.
- A rapid response system incorporating aspects from all four categories the AOWRMF is effective in implementing and facilitating the short term 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.
- The AOWRM process is continually being refined through continued input from stakeholders and managers. This should help the ICMA towards achieving two of their objectives viz, (i) ensure Effective, Efficient and Sustainable Management of Water Resources, and (ii) ensure collaborative and co-ordinated IWRM for wise socio-economic Development.
- It must be noted that a drought has not occurred since October 2009, when the implementation of AOWRMF commenced and the success of the AOWRMF can thus only be truly known by re-evaluating its performance through the next drought. /continued evaluation is thus recommended.

Importantly of course the results of operational practice need to speak to the governance goals of the ICMA also. It is necessary to provide an example of this at this juncture. Using this metric of progressively realising the implementation of an ecological water requirement (reserve) over the short period of four years in a complex river system is a key performance indicator of achieving some level of water resources sustainability (e.g. the "E" in STEEP). Since reserve implementation is a key criteria as described in the CMS (ICMA, 2010) for achieving the stakeholder derived vision for the Inkomati water management area, the steady approaching of those 'goals' in a part of that of WMA should be viewed as a positive, or a step in the right direction (e.g. a green traffic light). Whilst the detail of how this positive direction is being achieved may be cumbersome it is necessary to make such outcomes less cryptic, more so where there are a large variety of complex performance indicators. This is a prime example of important information that must not evade those that guide the ICMA at a governance level.