

**Comprehensive Reserve Determination Study  
for Selected Water Resources  
(Rivers, Groundwater and Wetlands)  
in the INKOMATI WATER MANAGEMENT AREA,  
MPUMALANGA**

**PROJECT NO: WP 9133**

**ECOLOGICAL, GOODS & SERVICES AND  
SOCIO-ECONOMIC CONSEQUENCES  
OF VARIOUS OPERATIONAL SCENARIOS**

**Volume 1: Description of Operational Scenarios**

**Volume 2: Ecological and Goods  
& Services Consequences**

**Volume 3: Macro-Economic Consequences**

**INKOMATI**

**MARCH 2010**

**REPORT NO.: 26/8/3/10/12/011**



**water affairs**

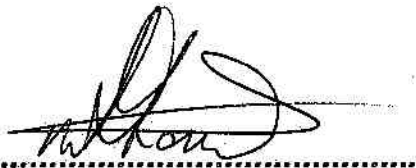
Department:  
Water Affairs  
REPUBLIC OF SOUTH AFRICA

**COMPREHENSIVE RESERVE DETERMINATION STUDY  
FOR SELECTED WATER RESOURCES (RIVERS,  
GROUNDWATER AND WETLANDS) IN THE INKOMATI  
WATER MANAGEMENT AREA. MPUMALANGA**

**SABIE AND CROCODILE RIVER SYSTEMS :  
OPERATIONAL SCENARIOS AND CONSEQUENCES REPORT:  
VOLUMES 1 – 3**

---

**Approved for Rivers for Africa by:**



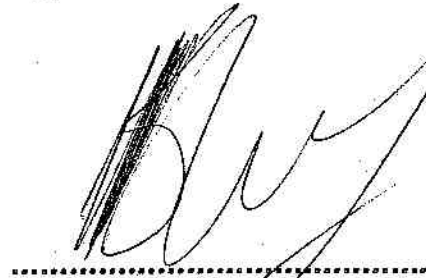
**Delana Louw  
Technical Project Manager**



**Adhishri Singh  
Administrative Project Manager**

---

**Approved for the Chief Directorate: Resource Directed Measures by:**



**Barbara Weston  
Study Manager**

## **PREFACE**

---

### **BACKGROUND**

The CD:RDM identified the Inkomati Water Management Area (WMA) as requiring a comprehensive Reserve assessment in light of the initiation of the Compulsory Licensing Process in the WMA and the proposed Montrose and Mountain View Dams. These studies require higher levels of confidence in the Reserve determination results as is currently available in certain of the catchments, such as the Sabie-Sand and Crocodile River catchments. This will assist the DWAF to make informed decisions regarding the authorisation of future water use and the magnitude of the impacts of the present and proposed developments.

The Reserve studies that were previously conducted for the Crocodile and Sabie-Sand river catchments consist of:

- An Intermediate Ecological Reserve study was undertaken during 2002 (Godfrey, 2002) for the Crocodile System. This study will update and refine the Intermediate Ecological Reserve study. The same study sites will be used, but more updated methodologies applied where necessary.
- An Intermediate Ecological Reserve was undertaken during 1996 (Tharme, 1997) for the Sabie-Sand system. Many of the methods now in place were not available at that stage and to complicate matters further, the large floods of 2001 (biggest floods on record) resulted in most of the physical site specific data not being applicable. Where applicable, the same study sites were used, but resurveyed and all historical information was also used within this updated study.

### **STUDY AREA AND STUDY SITES**

The Inkomati WMA is largely located within the Mpumalanga Province. It can be considered to consist of three largely independent catchments, the Komati, Crocodile (East) and Sabie–Sand River catchments. All these rivers drain the WMA and confluence to form the Incomati River in Mozambique which flows into the Indian Ocean.

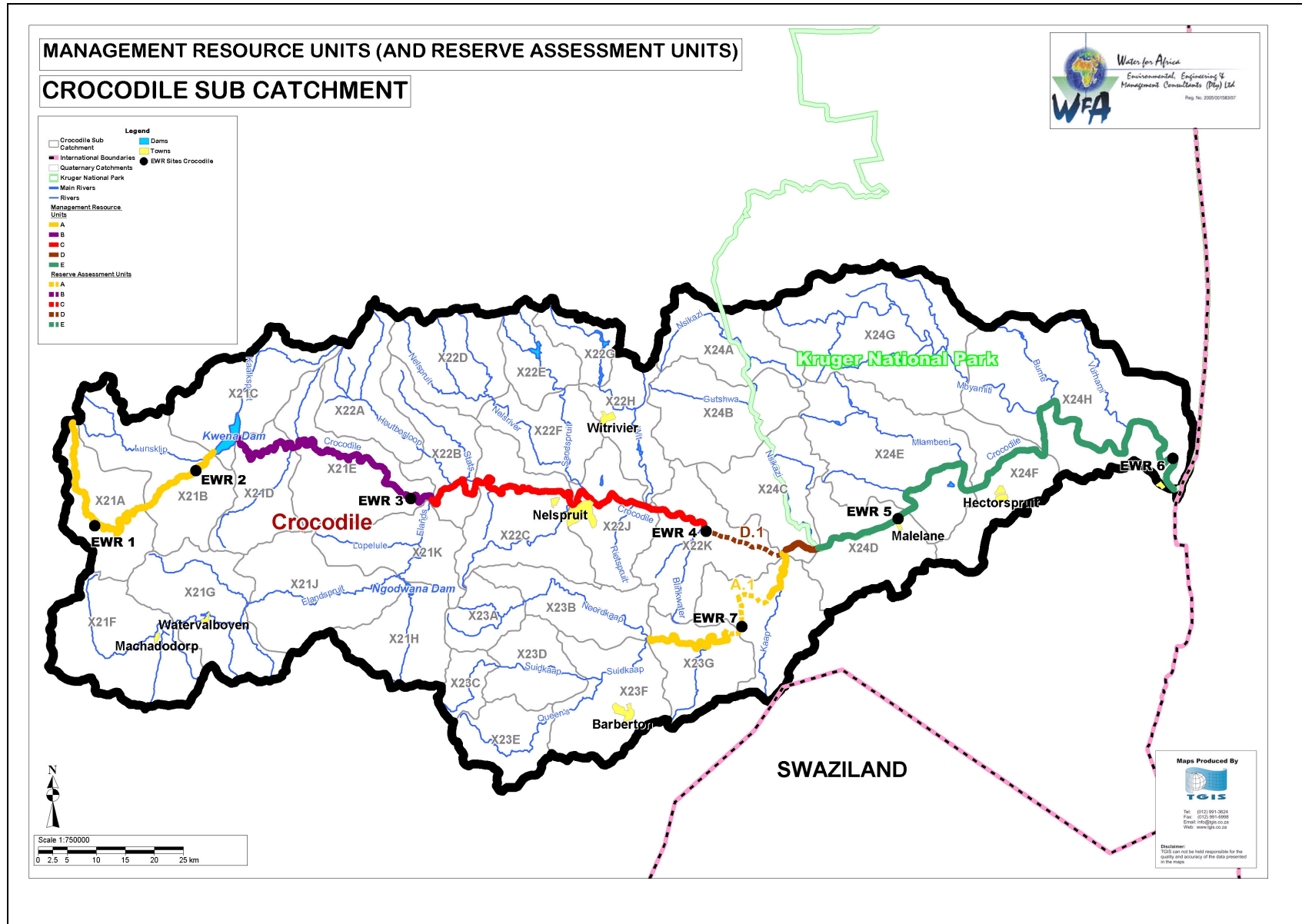
The Reserve requirements for the Komati River system (the remaining major river system in WMA 5) was determined and approved in 2003, the results of which are at a high confidence and are still relevant for use and implementation by the DWA. As such it was deemed unnecessary to include this system in the study area. The focus of this study therefore is only on the Crocodile (X2) and Sabie-Sand (X3) catchments. The locality and characteristics of the EWR sites in the Sabie-Sand and Crocodile River catchments are provided in the table below and following two figures. Information on site selection and the Management Resource Units (MRUs) in which they fall are provided in RDM Report 26/8/3/10/12/006 (DWAF, 2008).

## Locality of EWR sites for the Inkomati River System

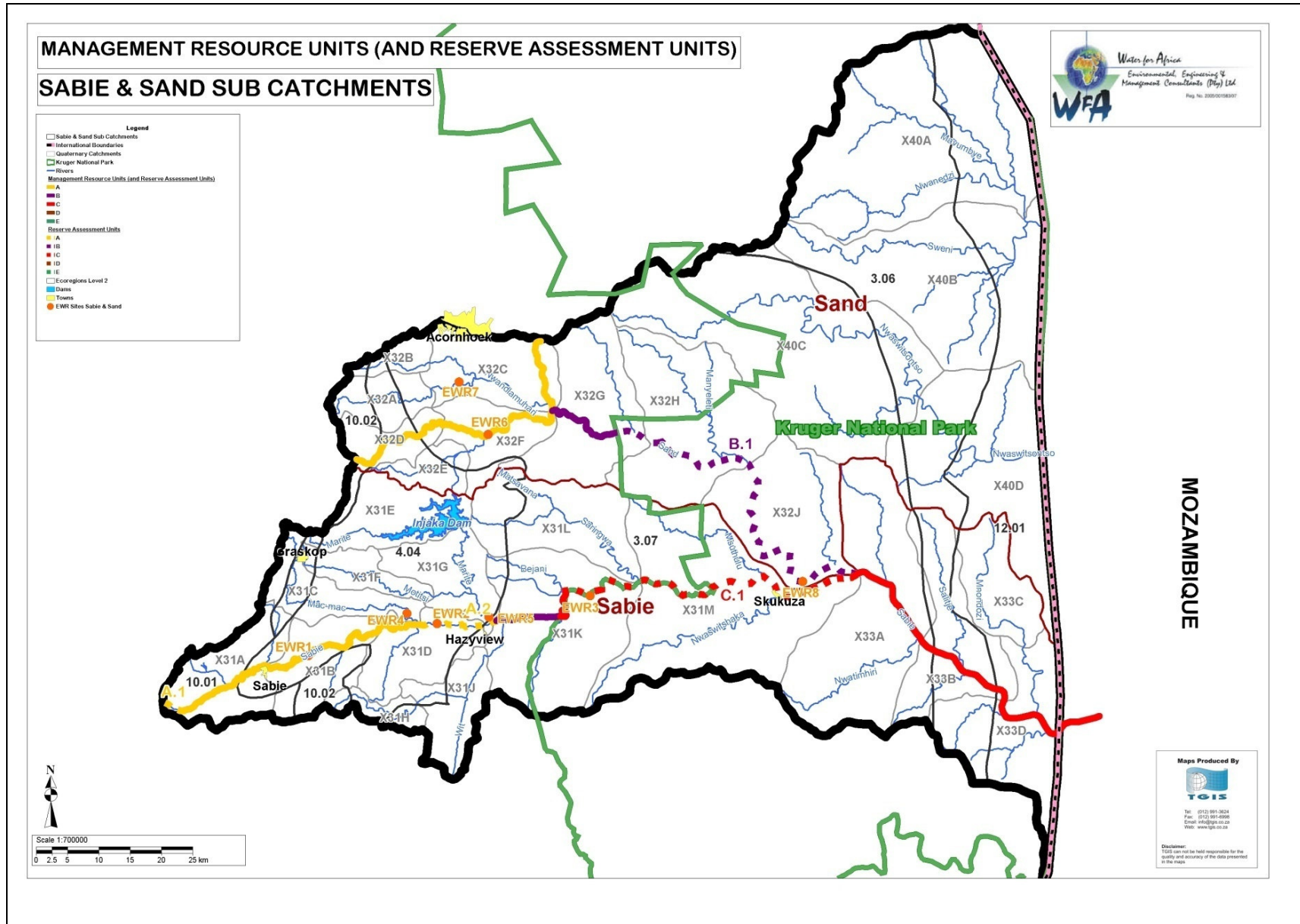
EWR site no	EWR site name	River	Coordinates		EcoRegion <sup>1</sup> (Level 2)	Geomorphic Zone	Quat <sup>2</sup>
			Latitude	Longitude			
<b>CROCODILE SYSTEM</b>							
EWR 1	Valeyspruit	Crocodile River	S25 29.647	E30 08.656	9.02	Upper Foothills	X21A
EWR 2	Goedehoop	Crocodile River	S25 24.555	E30 18.955	9.04	Upper Foothills	X21B
EWR 3	Poplar Creek	Crocodile River	S25 27.127	E30 40.865	10.02	Lower Foothills	X21E
EWR 4	KaNyamazane	Crocodile River	S25 30.146	E31 10.919	4.04	Lower Foothills	X22K
EWR 5	Malelane	Crocodile River	S25 28.972	E31 30.464	3.07	Lower Foothills	X24D
EWR 6	Nkongoma	Crocodile River	S25 23.430	E31 58.467	12.01	Lower Foothills	X24H
EWR 7	Honeybird	Kaap River	S25 38.968	E31 14.572	4.04	Upper Foothills	X23H
<b>SABIE SYSTEM</b>							
EWR 1	Upper Sabie	Sabie River	S25 04.424	E30 50.924	4.04	Upper Foothills	X31B
EWR 2	Aan de Vliet	Sabie River	S25 01.675	E31 03.099	4.04	Lower Foothills	X31D
EWR 3	Kidney	Sabie River	S24 59.256	E31 17.572	3.07	Lower Foothills	X31K
EWR 4	MacMac	Mac Mac River	S25 00.800	E31 00.243	4.04	Upper Foothills	X31C
EWR 5	Marite	Marite River	S25 01.077	E31 07.997	4.04	Upper Foothills	X31G
EWR 6	Mutlumuvi	Mutlumuvi River	S24 45.352	E31 07.923	3.07	Upper Foothills	X32F
EWR 7	Tlulandziteka	Tlulandziteka River	S24 40.829	E31 05.188	3.07	Lower Foothills	X32C
EWR 8	Sand	Sand River	S24 58.045	E31 37.641	3.07	Lower Foothills	X32J

<sup>1</sup> Refer to Kleynhans *et al.* (2007) for EcoRegion description.

<sup>2</sup> Quaternary catchment



Crocodile River catchment and locality of EWR sites



Sabie-Sand River catchment and locality of EWR sites

**THIS REPORT**

This report consists of three separate standalone volumes which each provide a summary of the methods followed and the results. To ensure that a logical process could be followed in any one of the reports, this combined executive summary was provided in each report. This provides the context of all the work undertaken for Step 5 of the Ecological Reserve study.

The report consists of three volumes as follows:

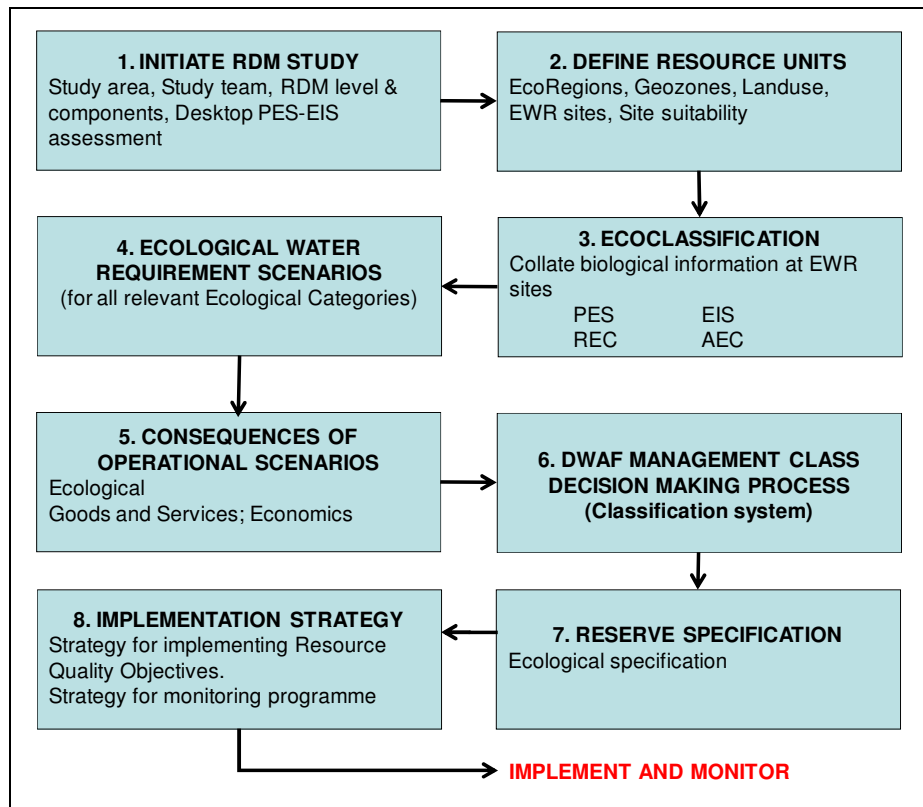
- Volume one: Description of the operational scenarios.
- Volume two: Ecological and G&S consequences of the operational scenarios.
- Volume three: Macro Economic consequences of the operational scenarios.

**EVALUATION OF OPERATIONAL SCENARIOS**

During this part of an Ecological Reserve study, aspects other than ecology are also considered for the evaluation of various operational flow scenarios and/or future development scenarios. The purpose of this is to provide the decision-maker with sufficient information to make informed decisions regarding the implications of the flow scenario and the Ecological Category which will be signed off as the Ecological Reserve. This will in future form part of the Classification System.

Operational scenarios are any flow scenario other than the present which could be implemented in future.

The Comprehensive Ecological Reserve Methodology was followed within the 8 - step Ecological Reserve process (refer to figure below). This section summarizes step 5 of the Ecological Reserve process that was followed during this study.



**The 8-step Ecological Reserve procedure (adapted from DWAF, 1999)**

Step 5 refers to the ecological consequences of operational scenarios. However, as part and parcel of the Ecological Reserve approach, this step has been extended since the early 2000s to include the Goods and Services (G&S) and macro economic consequences. In the absence of a Classification system, this was specifically to provide DWA with a greater understanding of the consequences of decisions to either protect or use the water resources in the Crocodile, Sabie and Sand River catchments.

The objective of this Reserve step is therefore to provide sufficient information to the decision maker regarding the operational scenarios and the consequences of these in terms of:

- Ecology
- Goods and Services (G&S)
- Socio Economics

This should then allow for informed decision-making regarding which Ecological Category and Reserve should be signed off.

### ***INFORMATION REQUIRED PRIOR TO THIS STEP***

#### ***Reserve Step 3: EcoClassification***

EcoClassification determines the Present Ecological State (PES) and identifies the changes (from natural) that have taken place resulting in the PES. A Recommended Ecological Category (REC) based on the Ecological Importance and Sensitivity (EIS) is also identified as well as the issues that will have to be addressed to achieve this REC (if different from the PES).

A suite of models is used to determine the EcoClassification. This process has to be in place and finalised prior to step 5. Ecological consequences are described in terms of changes in Ecological Category from the PES, and a good understanding of the PES is therefore required. The models are used in a predictive fashion to estimate what the resulting EC will be for each operational scenario.

#### ***Reserve Step 4: EWR scenarios***

The term EWR scenario refers to flow regimes set for a range of ECs. The resulting flow regimes, serve as a baseline against which to measure the consequences on the PES of the flow regimes associated with the various operational flow scenarios.

This information is also used during the design of the operational scenario phase to assess the implications of the Reserve and can guide the design of the operational scenarios.

#### ***Goods and Services***

The consequences of operational scenarios on the G&S must be assessed. It is therefore required to identify the relevant G&S as well as to estimate a value of the G&S. This serves as the baseline and changes based on the different operational scenarios are measured against this. The focus is on G&S that will change due to changes in flow and the associated responses of the other physical drivers and biota.

#### ***Socio Economics***

The economic impact of the proposed operational scenarios is measured against the deviation from the current economic activities. This entails that a detailed analysis of the current activities of water use are performed and expressed in terms of Gross Domestic Product (GDP), Employment

and impact on households and specifically on Low Income Households. The parameters are expressed in terms of direct, indirect and induced impacts.

If a specific scenario is by implication causing a curtailment in the volume of available water the impact of the lower volume is calculated and expressed. The curtailment of a specific activity takes place against a number of assumptions. It is assumed that domestic and industrial water will be provided within an active Water Conservation and Demand Management program. This does not apply for irrigation water and is it mostly the irrigation activities that are curtailed.

In the case of a volume curtailment it is accepted that the area is reduced. When decreasing "Assurance of Supply" the long term average production yield is lowered. In the case of curtailment, the low value crops are reduced first, followed by the higher value crops. In the final instance the macro economic impacts of the different scenarios are presented to assist in the final decision making process.

## **STEP 5: DETERMINING CONSEQUENCES TO OPERATIONAL SCENARIOS**

### ***Identifying and determining operational scenarios***

The operational scenarios mostly focus on different flow scenarios. There are two types of operational flow scenarios:

- a) Changes in the present operation in terms of flow.
- b) Future development scenarios (which will result in different operational flow scenarios).

The Reserve team is dependent on the client supplying the operational scenarios. Usually, the Reserve team and the managing client body, in this case DWA and specifically the Project Management Team, will facilitate the process. Various meetings were held to present findings, discuss preliminary results, and to agree on a final range of the most likely and realistic scenarios to be provided for assessing consequences.

Part and parcel of this process is yield modelling. The flow time series at various points in the catchment were provided through a water resources systems model in terms of natural and present day flows. A monthly time step was used in all these simulations. Prior to identifying the operational scenarios, the EWR scenarios for different ECs was run through the yield model to identify whether the EWR scenarios could be met and, if not, how much could be met and where (in terms of seasons etc.) the problems lie.

This information can then provide guidance for identifying operational scenarios. Three hypothetical examples of the rationale and type for different scenarios are provided:

- If it is identified that the Reserve can mostly be met except during the dry season in very dry years, the EWR drought flows can be decreased by an estimated percentage and this will serve as one of the scenarios. The EWR specialists will then assess what the implications are of the decreased flows in terms of EC.
- Another example could be that a new irrigation development is being planned and an existing dam has to supply the water for this irrigation development. The yield modelling process will include this future irrigation development and then assess the resulting flows at each EWR site. The EWR specialist will again assess the consequences on EC.
- Future development scenarios could consist of a new dam and transfer scheme. These kinds of scenarios are complicated as each future development scenario consists of its own range of scenarios, which is dependent on how the system will be operated.

Once all the scenarios are identified, the output from the yield model is provided in the required format for consequences assessment. Volume 1 in this report series documents the operational scenarios that were modelled and the consequence of these scenarios on system yield.

***Assessing consequences of operational scenarios***

*a) Ecological consequences*

Detail is provided in Volume 2 regarding this process. In summary, the flow regime at each EWR site and for each scenario is provided as a flow duration table. This information is used either in this format, or converted to ecological stress. Where necessary, the response of the fluvial geomorphology, physico-chemical variables and biota, is modelled to assess the EC for each operational flow scenario.

*b) Goods and Services*

Detail is provided in Volume 2 regarding this process. In summary, the ecological specialists evaluate whether the identified Goods and Services will change in terms of order of magnitude for each operational scenario.

*c) Socio-economics*

Detail is provided in Volume 3 regarding this process. The economic baseline of irrigation agriculture water use was established per allocation zone and the value of water was expressed in terms of the contribution to Gross Domestic Production (GDP), Employment and Low Income Households. The changed due to each operational scenario as well as the EWR scenarios are determined.

---

## ACRONYMS AND ABBREVIATIONS

AEC	Alternative Ecological Category
CD: RDM	Chief Directorate: Resource Directed Measures
CD:RDM	Chief Directorate: Resource Directed Measures
COMBUD	Computer Based Budgets
D:RQS	Directorate: Resource Quality Services
DWA	Department of Water Affairs (Name change 2009)
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirements
EZ	Economic Zone
FDI	Flow dependent macroinvertebrate
FFHA	Fish Flow Habitat Assessment
FRAI	Fish Response Assessment Index
FROC	Fish Frequency of Occurrence
FV	Future value
GDP	Gross Domestic Product
G&S	Goods and Services
GAI	Geomorphology Assessment Index
HFSR	Habitat Flow Stressor Response
LSR	Large semi-rheophilic fish
MAR	Mean Annual Runoff
MCM	Million Cubic Metres
MCM/annum	Million Cubic Metres per annum
MIRAI	Macroinvertebrate Assessment Index
MRU	Management Resource Unit
MVI	Marginal vegetation macroinvertebrate
PAI	Physico-chemical Assessment Index
PD	Present Day
PDH	Present Day Hydrology
PES	Present Ecological State
Quat	Quaternary catchment
REC	Recommended Ecological Category
SAM	Social Accounting Matrix
Sc	Scenario
SR	Small rheophilic fish
VEGRAI	Riparian Vegetation Response Assessment Index
WIM	Water Impact Model
WMA	Water Management Area

## Reports as part of this project:

Report no	Report title
26/8/3/10/12/001	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Inception report
26/8/3/10/12/002	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Desktop EcoClassification report
26/8/3/10/12/003	Newsletters
26/8/3/10/12/004	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Basic Human Needs Reserve report
26/8/3/10/12/005	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Groundwater report
26/8/3/10/12/006	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Resource Unit report
26/8/3/10/12/007	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Desktop Estimation report
26/8/3/10/12/008	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Wetland report
26/8/3/10/12/009	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: EcoClassification report
26/8/3/10/12/010	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: EWR scenario report
<b>26/8/3/10/12/011</b>	<b>Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Operation Scenarios and Consequences report. Operation Scenarios and Consequences report</b>
26/8/3/10/12/012	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: EcoSpecs report
26/8/3/10/12/013	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Socio Economic Present State Evaluation Report
26/8/3/10/12/014	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Training audit and report
26/8/3/10/12/015	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Main report
26/8/3/10/12/016	Comprehensive Reserve Determination Study for selected water resources in the Inkomati WMA, Mpumalanga: Electronic information and data

**Bold** indicates this report which consists of Volume 1 of a 3 part series of reports used to describe the operational scenarios that were evaluated and their ecological goods and services and macro-economic consequences.

## **THIS REPORT SHOULD BE REFERENCED AS:**

---

Department of Water Affairs, South Africa. 2010. Comprehensive Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Inkomati Water Management Area, Mpumalanga. Crocodile River and Sabie-sand system: Operation Scenarios and Consequences Report. Volume 1: Description of Operational Scenarios. Authored by Mallory, SJL for Rivers for Africa. Edited by Louw, MD and Koekemoer, S. RDM Report no 26/8/3/10/12/011.

## **ACKNOWLEDGEMENTS**

---

### **Other contributors through personal communication with the author:**

Mr Brian Jackson, Incomati Catchment Management Agency

### **Trainees:**

The following trainees assisted with the analyses and report writing:

Mr Desai, Ahmed (Hydraulics and Systems Analysis)

## EXECUTIVE SUMMARY

### VOLUME 1: THE DESIGN OF OPERATIONAL SCENARIOS

#### **CROCODILE SUB-SYSTEM GROUP 1: EWR DEMANDS EXCLUDED**

**Scenarios C1 to C6: A combination of operating rules, restrictions, and/or curtailments applied:** The scenarios related mainly to the option to either introduce curtailments to water users (by means of compulsory licensing) or to introduce harsher restrictions than assumed in the Base Scenario. While a wide range of possible options have been modelled, the river flow is very similar for many of the scenarios. Under Sc C3 and Sc C6 the water saved by the restrictions of irrigation resulted in increased yield of Kwena Dam and two additional scenarios, Sc C3.1 and C6.1 were modelled and the ecological consequences were determined. Under these scenarios the increased yield was released down the river to determine how much of the additional yield would supply the EWRs.

**Scenario C7: New dam at Montrose:** A new dam will be constructed at the Montrose site which is located just downstream of the confluence of the Crocodile and Elands Rivers. In order to keep this analysis uncomplicated, the following assumptions were made:

- The Montrose Dam would replace the Kwena Dam as being the main regulator of flow in the Crocodile River. Kwena Dam would supplement the Montrose Dam by making releases when the storage in Montrose Dam drops to below 10% of its full supply capacity.
- Montrose Dam would not contribute to the ecological flow requirements of the Crocodile River (in this scenario).
- The water abstracted from the Montrose Dam (i.e. yield) was supplied directly from the dam and not released into the Crocodile River to supplement downstream users. No restriction was imposed on the yield i.e. it was the historic firm yield of the dam.
- The Base Scenario restriction rules were applied to existing users in the catchment.

**Scenario C8: New dam at Mountain View:** This scenario consisted of the Mountain View site which is located a few kilometres upstream of the confluence of the Kaap and Crocodile Rivers. The same assumptions as for Montrose Dam were made.

**Scenario C9: New dams at Montrose and Mountain View:** In this scenario it was assumed that new dams would be constructed at the Mountain View and Montrose site.

**Scenario C11: No cross-border flows:** One of the main drivers of the low-flow under current operating conditions is the cross-border flows. As the lower Crocodile River has in the past flowed at very low flows, it was requested that the scenario of not supplying these minimum flows be modelled.

#### **CROCODILE SUB-SYSTEM GROUP 2 SCENARIOS: EWR DEMANDS INCLUDED**

The scenarios presented in this section pertain specifically to implementing the EWR for the Recommended Ecological Category (REC) and the Present Ecological State (PES) (basically EWR scenarios). Operating rules which entailed a range of restrictions and curtailments were developed to meet the EWR scenarios.

**Scenario C10 and C12: *Reduced releases from Kwena Dam to meet the PES (Sc C10) and REC (Sc C12) EWR at EWR 3:*** Under the current operation of the Crocodile system water is released out of the Kwena Dam into the Crocodile River to supplement the water supply to irrigators riparian to the river. Due to the large irrigation water demands throughout winter, the flow in the Crocodile River at EWR 3 is often higher than natural during the winter. As summer releases are often not made due to sufficient inflow from tributaries to supply irrigation requirements, the low flows in summer are abnormally low, resulting in a seasonal reversal. In order to assess the economic impact of avoiding this unseasonal flow, this scenario modelled releases into the Crocodile River only to meet the EWR 3 requirements. Although the total supply to the irrigation sector remained relatively high, the irrigators located near the end of the Crocodile River would experience very low assurance of supply. Also, the international requirements would not be met.

**Scenario C13: *Meet the Present Ecological status at EWR 6: The PES would be maintained with PRESENT DAY HYDROLOGY, i.e., the Base Scenario.*** A PES EWR scenario was also generated which resulted in a higher requirement than the present day hydrology.

**THEREFORE, the PES EWR had to be seen as one scenario in a range of flows that would meet the PES but would result in a higher PES than the present hydrology. The PES EWR was therefore a scenario of a flow regime that would also maintain the PES. This flow scenario would imply a decreased risk of the river degrading from the PES, whereas the risk of degradation associated with the present day flows was higher.**

In order to meet the PES EWR scenario (see above), irrigators would need to be curtailed by 25%. Given this curtailment, a restriction rule was developed to meet the PES at EWR 7 located on the Kaap River. Note that the restriction rule applied to irrigators in Zone 2 (Kaap River) was a function of the natural flow at EWR 7 and not the state of storage in the Kwena Dam as assumed in the Group 1 scenarios.

**Scenario C14: *Meet the REC at EWR 6:*** In order to meet the EWR for the REC, irrigators would need to be curtailed by 50%.

### **SABIE RIVER SUBSYSTEM**

Eight hypothetical scenarios were modelled in the Sabie River catchment. These scenarios entailed increasing the current irrigation requirements in steps up to 30 million m<sup>3</sup>/annum. In addition, varying levels of water restriction were imposed on users.

### **SAND RIVER CATCHMENT**

Four abstraction weirs (*viz.* Champagne, Dingleydale, New Forest, Edinburgh) in the Upper Sand exist but are not operating correctly. All the water (i.e.100%) is diverted and only the high flow spills continue downstream. There are also leaks from canals and the weirs that will trickle at places in the river. The Sand scenarios were based on the assumption that these four abstraction weirs would be rehabilitated, thus improving the flow downstream.

Scenarios consisting of combinations of weir improvement, curtailment and restrictions were simulated. The scenarios selected for evaluation are listed below (highlighted).

Scenario	Improvement to downstream flow at abstraction weirs	Curtailments (%)	Restriction Level
<b>Sc 1 (Sellick Rule)</b>	<b>See description below</b>		
Sc 2	0	0	None
Sc 3	50	0	None
Sc 4	50	0	R5
<b>Sc 5</b>	<b>50</b>	<b>20</b>	<b>None</b>
Sc 6	75	0	None
Sc 7	75	20	None
Sc 8	75	0	R5
<b>Sc 9</b>	<b>75</b>	<b>20</b>	<b>R5</b>

### **Sellick Rule**

In accordance with the Sabie River Catchment Operating Rules (DWAF, 2003), a proportion of the flow in the river is supposed to be allowed to flow past the abstraction points down the river in order to meet the EWR. This proportion varies from one abstraction site to the next depending on its location within the catchment. This rule, referred to here as the Sellick rule (after Charles Sellick) only comes into effect when the river flow drops to a certain level.

### **SUMMARY OF RESULTS**

The results of the various scenarios modelled are summarised in terms of demand, supply and assurance of supply in the tables below.

#### **Results of all Crocodile Group 1 Scenarios (No EWR demand)**

Crocodile Scenarios	Description	Zone 1			Zone 2			Additional Yield*#
		Demand*	Supplied*	Assurance of supply (%)	Demand*	Supplied*	Assurance of supply (%)	
C1	C <sup>1</sup> : Zero; R <sup>2</sup> = 35%	400	344	72	77	67	65	
C2	C: 15%; R = 35%	340	315	90	66	62	87	
C3	C: 30%; R = 35%	280	265	97	54	53	96	
C4	C: 15%; R = 0%	340	322	97	66	62	87	
C5	C: 15%; R = 0%	280	266	98	54	53	95	
C6	C: 15%; R = 0%	220	211	98	42	42	98	
C7	Montrose Dam	400	357	76	77	67	65	88
C8	Mountain View Dam	400	338	62	77	67	68	55
C9	Both dams	400	356	86	77	67	65	129
C11	Cross-border = 0;	400	344	74	77	73	84	

\* Demand, supply and additional yield units are in million m<sup>3</sup>/annum.

# Additional yield is expressed as historic firm yield supplied directly out of the proposed dams.

1 Curtailment

2 Restriction

**Results of all Crocodile Group 2 Scenarios (EWRs met)**

Crocodile Scenarios	Description	Zone 1			Zone 2		
		Demand*	Supplied*	Assurance of supply (%)	Demand	Supplied	Assurance of supply (%)
C10	Reduce releases from Kwena to meet PES at EWR 3	400	344	74%	77	72	84%
C12	Reduce releases from Kwena to meet REC at EWR 3	400	365	88%	77	72	84%
C13	Meet PES	300	251	70%	58	52	77%
C14	Meet REC	200	173	70%	39	34	75%

\*Demand and supply units are in million m<sup>3</sup>/annum

**Results of all Sabie Scenarios**

Sabie Scenarios	Description	Demand*	Supplied*	Assurance of supply (%)
Sabie1	Base	80.3	70.7	62
Sabie5	+25 - No Restriction	105.3	95.7	71
Sabie6	+30 - No Restriction	110.3	100.7	72
Sabie7	+30 - R2 Restriction	110.3	79.8	80
Sabie8	+30 - R5 Restriction	110.3	53.1	89

\* Demand and supply units are in MCM/a

**Results of all Sand Scenarios**

Sand Scenarios	Description	Demand*	Supplied*	Assurance of supply (%)
Sellick	Sellick proportional flow rule	23.6	19.0	78
Sand2	+50 improvement, 20% Curt, R2 Restriction	27.4	21.3	71
Sand3	+75 improvement, 20% Curt, R5 Restriction	17.9	8.1	77

\* Demand and supply units are in MCM/a

**VOLUME 2: ECOLOGICAL CONSEQUENCES**

The purpose of this task is to predict the driver and biota responses to each operational scenario and derive the Ecological Category (EC) for the riverine EWR site and Management Resource Unit (MRU).

All information used during the EcoClassification step (the suite of EcoClassification models set up for different ECs) (DWA, 2009a) and the Ecological Water Requirement (EWR) scenario step (DWA, 2010) is used as baseline for this assessment.

The following steps were required to determine the ecological consequences of the flow scenarios.

- The operational scenarios (Volume 1) were modelled and a time series was provided for each scenario at each EWR site.
- The time series was converted to a flow duration table and both was provided to the physico chemical and geomorphology specialist.
- These specialists had to provide a conclusion and resulting EC of the operational scenario assessed at the EWR to the biological responses team.
- These specialists completed the Physico-chemical Assessment Index (PAI) and Geomorphology Assessment Index (GAI) models to predict the driver EC.
- The riparian vegetation specialist then assessed the response on the marginal and other riparian zones and supplied this information to the instream biota specialists. This was

done prior to the instream biota assessment as riparian vegetation is a driver in terms of important habitat for the instream biota.

- Where required, the riparian vegetation specialist ran the Vegetation Response Assessment Index (VEGRAI) model to predict the EC for the operational scenario.

Assessment of the economic impacts of the various scenarios essentially identifies the direction of change (either positive or negative), and estimates the magnitude of the change in benefits and costs that may be experienced within the River System. The process adopted was the analysis of potential economic changes based on a valuation of the status quo, that is, the value of the Goods and Services (G&S) currently provided by the water in River systems, identifying the potential change that each of the key G&S may undergo in each of the scenario clusters. And where required the current value of G&S was then multiplied by these factors for each scenario, to provide an indication of the potential future value of the Goods and Services. The change in value was thus measured.

### **ECOLOGICAL CONSEQUENCES RESULTS**

Results are summarised according to whether the scenarios meet the REC or not, and if not, to what degree. Colour coding and symbols should be interpreted as follows:

- ✓ REC EcoStatus or REC instream IS met.
- X REC EcoStatus or REC instream is NOT met.

Light green with black ✓:	Meets REC EcoStatus including all components.
Light green with red ✓:	Meets REC instream, but not riparian vegetation (this is usually because the vegetation REC cannot be met due to non-flow related problems).
Dark Green with black ✓:	Meets the REC EcoStatus, but not all the components.
Turquoise with X:	The scenario is an improvement of the PES but does not meet any of the REC versions as in green above.
Orange with X:	The scenario does not meet REC requirements but meets the PES.
Purple with X:	The scenario results in an EC below the PES, but still above a E EC.
Red with X:	The results are below a E EC.

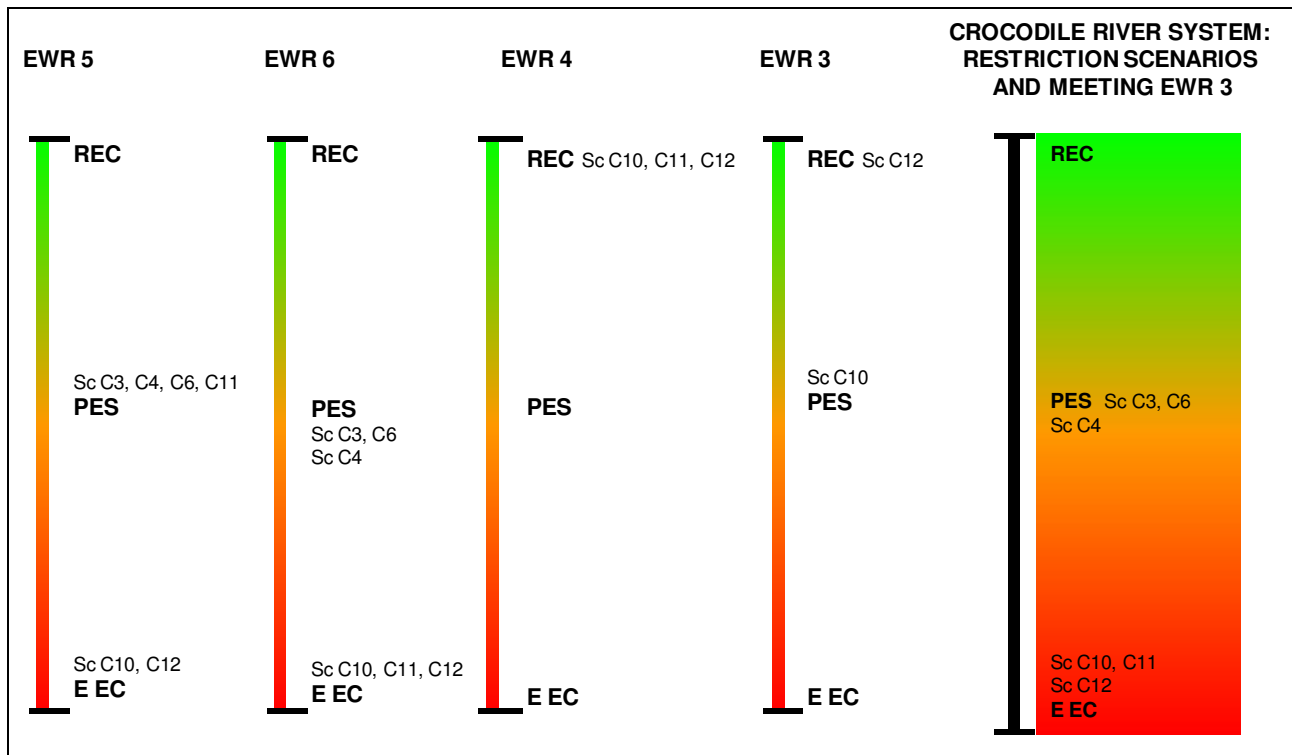
### **Crocodile Sub-system: Curtailment and restriction irrigation scenarios**

An overall assessment was undertaken for the various sub-systems for scenarios of the same type. The table below provides a summary of the results at each EWR site. The overall evaluation usually reflects the results at the site which is least likely to meet the REC. The reasoning is that even if you meet the REC at other EWR sites, the scenario fails within a system context if it does not meet the REC at one of the sites.

EWR SITE	SC 3	SC 4	SC 6	SC 10	SC 11	SC 12
EWR 5	X	X	X	X	X	X
EWR 6	X	X	X	X	X	X
EWR 4				✓	✓	✓
EWR 3				X		✓
OVERALL	X	X	X	X	X	X

The results provided in the table are ranked and illustrated on a scale from good (REC) to ‘bad’ (an E EC) where in this case the PES has been placed in the middle. This provides an indication of the DEGREE to which the scenarios do not meet the REC and takes into consideration the more detailed assessment on which the summaries are based.

Within a system context none of the scenarios meet the REC at any of the EWR sites. The PES is maintained under Sc C3 and C6. Scenario C4 met the PES EcoStatus; the fish component however deteriorated to an unacceptable level and therefore the overall PES requirement are not met and was ranked below the PES in the figure below. Scenario C10 – C12 resulted in a deterioration of the PES EcoStatus. The overall assessment is provided as the traffic diagram on the right.

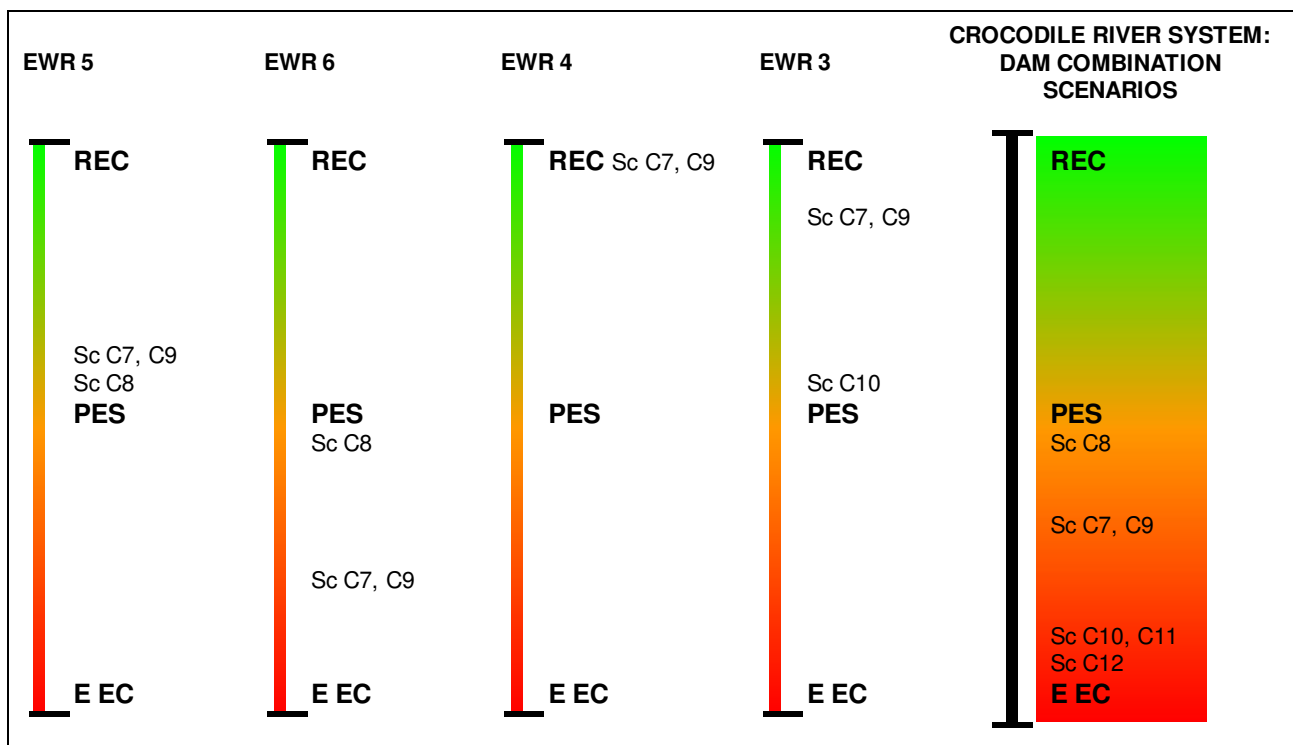


**Crocodile Sub-system: Development (new dam) scenarios**

These scenarios were not evaluated in detail as each dam and combination will require a whole range of different operating rules for useful comparison. The results are provided below.

EWR SITE	Sc C7	Sc C8	Sc C9
EWR 5	X	X	X
EWR 6	X	X	X
EWR 4	✓		✓
EWR 3	X		X
OVERALL	X	X	X
EWR 7		X	X

Scenario C7 – C9 did not maintain the PES at EWR 6. Scenario C8 maintains the PES EcoStatus but does not maintain the riparian vegetation and geomorphology PES. Scenario C8 was therefore ranked lower than the PES (figure below) at EWR 6. Looking at EWR 7 in isolation, the scenarios with Mountain View Dam and the no releases downstream of the dam resulted in an unacceptable condition. The overall assessment is provided as the traffic diagram on the right.



**Crocodile River: Additional scenarios evaluated at EWR 6**

Two optimised scenarios were developed for additional screening, Sc C3.1 and Sc C6.1. Both were evaluated at EWR 6 as the key site. Sc C6.1 achieved the REC and Sc C3.1 improved the PES. The comparison is provided in the figure below.

Driver Components	PES	REC	Sc C3	Sc C4	Sc C6	Sc C10-C12	Sc C3.1	Sc C6.1
HYDROLOGY	D	B						B
WATER QUALITY	C	B	C	D	C	D/E	C	B
GEOMORPHOLOGY	C	C	C	C	C	C	C	C
Response Components	PES	REC	Sc C3	Sc C4	Sc C6	Sc C10-C12	Sc C3.1	Sc C6.1
FISH	C	B	D	D/E	D	D	B/C	B
MACRO INVERTEBRATES	C	B	C	C	C	D/E	C	B
INSTREAM	C	B	C	D	C	D	B/C	B
RIPARIAN VEGETATION	C	B	B/C	B/C	B	D	B/C	B
ECOSTATUS	C	B	C	C	C	D	B/C	B

**REC** Sc C6.1

Sc C3.1

**PES**  
Sc C3, C6  
Sc C4

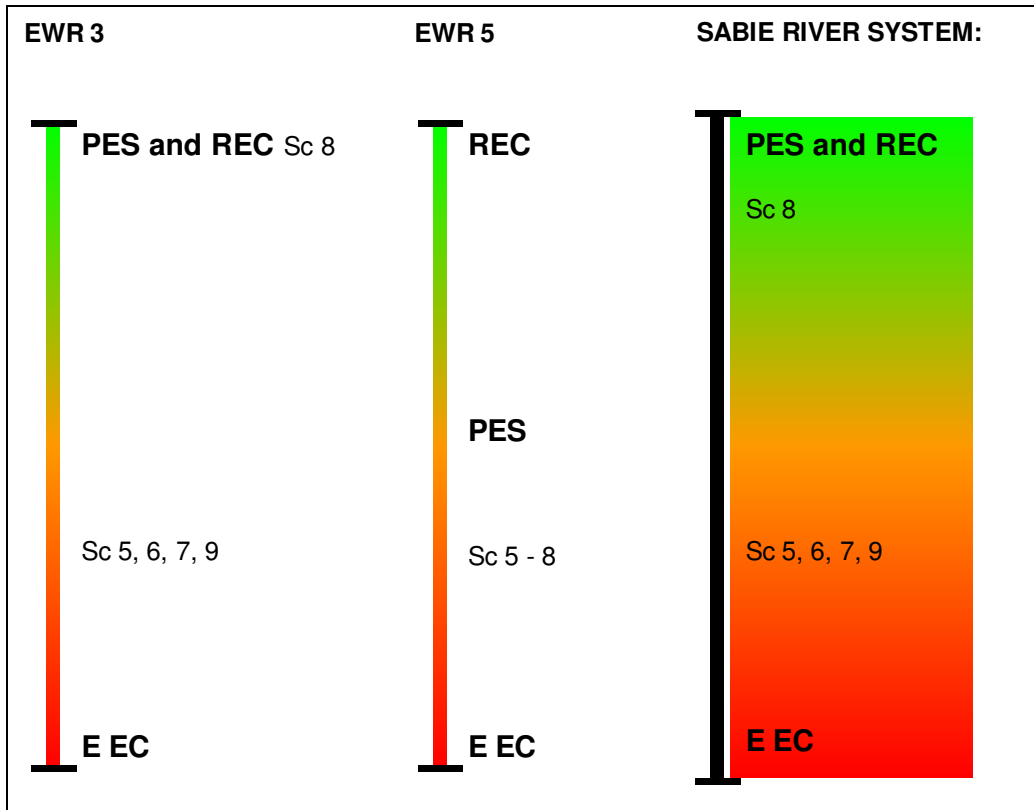
Sc C10, C11, C12  
**E EC**

CROCODILE RIVER SYSTEM								
EWR SITE	Sc C3	Sc C4	Sc C6	Sc C10	Sc C11	Sc C12	Sc C3.1	Sc C6.1
EWR 6	X	X	X	X	X	X	X	✓

**Ecological consequences of the Sabie Sub-system**

The table and figure below provides a summary of the results at each EWR site. Sc 8 achieves the objectives at EWR 3 in KNP but not at Marite (EWR 5). Therefore it is significantly better than the other scenarios which are at both sites lower than the PES.

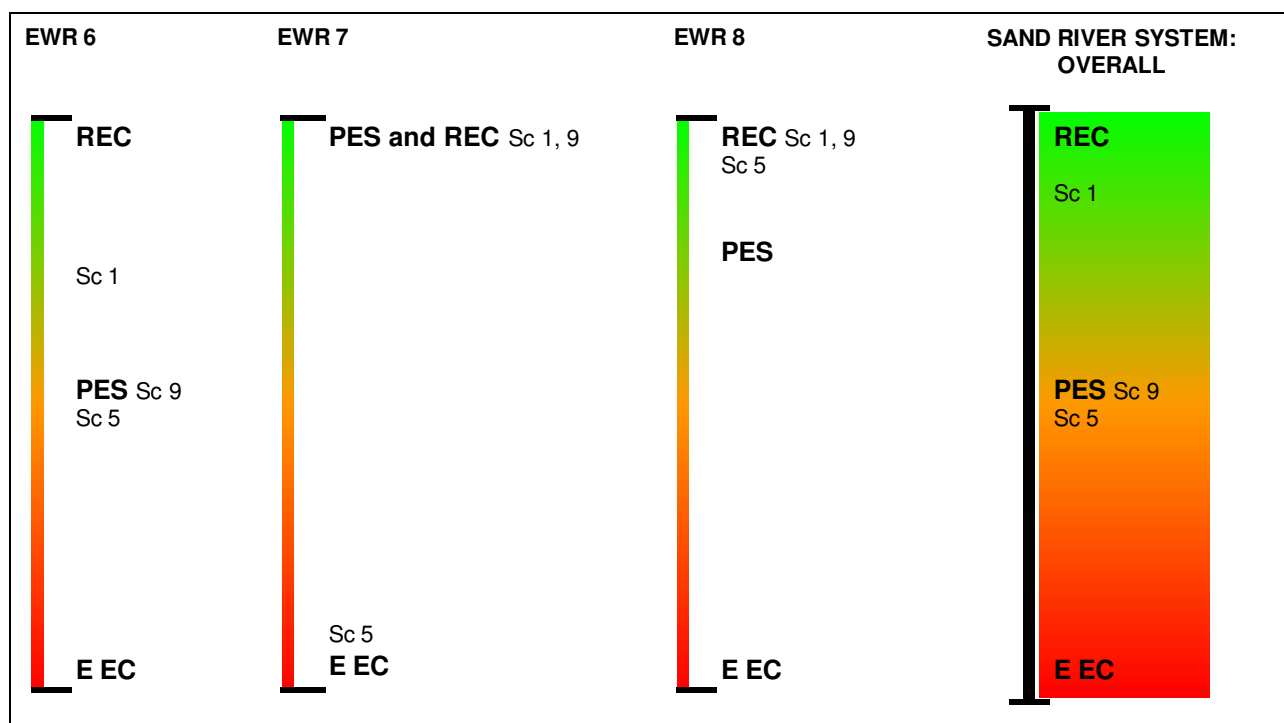
SABIE RIVER SYSTEM				
EWR SITE	Sc 5	Sc 6	Sc 7	Sc 8
EWR 3	X	X	X	✓
EWR 5	X	X	X	X
OVERALL	X	X	X	X



**Ecological consequences of Sand sub-system**

The table provides a summary of the results at each EWR site. Scenario 1 is an improvement of the PES at EWR 6 and meets the REC at EWR 7 and 8. It is a better scenario than Sc 9 which only meets the PES at EWR 6 and does not improve it as is the case with Sc 1. Scenario 5 is the worst scenario as it does not meet the PES/REC at EWR 7.

SAND RIVER SYSTEM			
	Sc 1	Sc 5	Sc 9
EWR 6	X	X	X
EWR 7	✓	X	✓
EWR 8	✓	✓	✓
OVERALL	X	X	X



**GOODS AND SERVICES SUMMARY OF RESULTS**

The following represents a summary of scenarios by economic zone: Those in green are positive and relates to the scenario providing increased resources for the utilization of goods and services; negative (shaded red) relates to a decrease in resources. Those scenarios shaded in yellow are neutral and indicates either (a) no change in resources and will be the same as present or (b) some G&S will be positively affected and some will be negatively affected but overall there is no driving indicator that would suggest either a positive or a negative overall outcome.

Economic Zone	EWR Site	Scenarios							
<b>Crocodile-East sub-catchment</b>									
Upper Crocodile	EWR 1, 2	None							
Elands		None							
Lower Kwena	EWR 3	3	7	10	12				
Middle Crocodile	EWR 4	7	9	10	11	12			
Kaap	EWR 7	8	9						
White River		None							
Lower Crocodile	EWR 5, 6	3	4	6	7	8	9	10	12
<b>Sabie-Sand sub-catchment</b>									
Sabie	EWR 1, 2, 4	None							
Maritsane/Inyaka	EWR 3, 5	5							
Sand	EWR 6 - 8	1	5	9					

**RECOMMENDATIONS**

**Crocodile Sub-system**

Of all the scenarios evaluated in the Crocodile River system the optimization scenarios (Sc C3.1 and C6.1) are the best scenarios from an ecological and G&S viewpoint. Scenario C6.1 meets the REC requirement at EWR 6 (critical site in the Crocodile River system) while Sc C3.1 results in an improvement of the PES at this site.

Due to the socio economic impact of Sc C6.1 it is acknowledged that it is unlikely to be considered. Therefore Sc C3.1 is therefore a better option, although the potential socio-economic consideration can be significant. However; considering the position of the Kruger National Park in the system, and the general High to Very High EIS of the system, it would be irresponsible not to make some attempt to meet Sc C3.1, or investigate further optimization options to determine other scenario options. As Sc C3.1 results in the improvement of the PES, the risk associated with the PES not degrading further will be minimised and, more important, considering the resolution which one is dealing with in terms of ecological and hydrological results, it is even possible that one could reach the B REC (for EWR 6 in the lower Crocodile River). From an ecological and G&S point of view, this would be the recommended scenario.

There are also options to investigate the daily operation of the system which, due to the abstraction regime, results in extreme localised changes in hydrology and impacts negatively on the ecological health of the system. There might be options to recommend a change in the manner of abstraction which could improve the system.

### ***Sabie Sand Sub-system***

No operational scenarios were required for evaluation in the Sabie System. Theoretical scenarios that consist of different levels of irrigation restrictions to meet increasing irrigation requirements were investigated. These represent increased flows to various degrees at EWR 5 (Marite) and decreased flows at EWR 3 (Kidney). Scenario 8 is the only scenario that still meets the PES and REC at EWR 3 in the KNP. The Marite REC was not achieved. The present flow regime results in the same situation and it is therefore recommended that the status quo is maintained. If increased flow for irrigation is ever required, Sc 8 would be the recommended option.

The scenarios in the Sand system are all based on improving the irrigation supply structures (small dams, canals, weirs) in the system. Scenario 1, the original Sellick Rule set up to operate the system will be the best scenario as this scenario improves the PES at EWR 6 and meets the REC requirements at EWR 7 and 8. Scenario 1 is therefore recommended from the ecological and G&S viewpoint.

## ***VOLUME 3: ECONOMIC CONSEQUENCES***

### ***INTRODUCTION***

Changes in water volume have an effect on the economics of a catchment e.g. change in supply to farmers will affect activity per hectare and therefore affect the Gross Domestic product (GDP) and employment opportunities. Assurance also reflects long-term water availability which influences GDP and employment opportunities, but only for the harvesting cost. This implies that if assurance increases, job opportunities will increase during harvesting. Therefore, water volumes were transformed with the use of the WIM model to determine total GDP, total number of employment opportunities and the distribution towards the low income households in Zone 1. All the scenarios were based upon the Base (Current State).

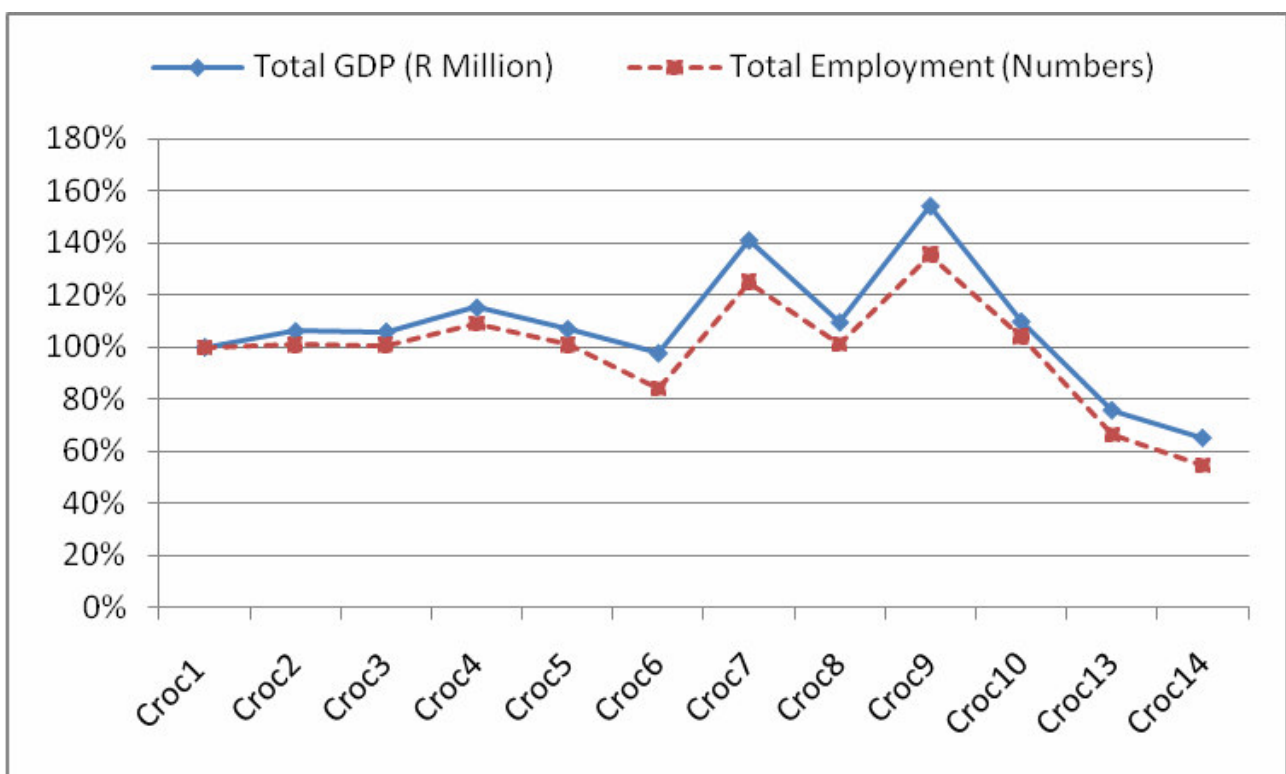
The Sabie scenarios were not further evaluated as all scenarios related to an improved assurance and supply to agriculture.

The Sand system was not further evaluated as all scenarios included the improvement of the current irrigation system and structures which would maintain or improve the current irrigation activities, as well as improve the runoff in the river system.

**CROCODILE RIVER CATCHMENT RESULTS**

The figure below reflects that Sc C7 and C9 are the best economic impact performers when analysing the scenarios. These economic impacts are expressed in total GDP, total number of employment opportunities as well as the distribution towards Low Income Households. Low income households follow mostly the trend of GDP and are therefore not included in the graph.

When the scenarios involving dams and international flow are excluded, Scenario C4 reflects the best economic performance.

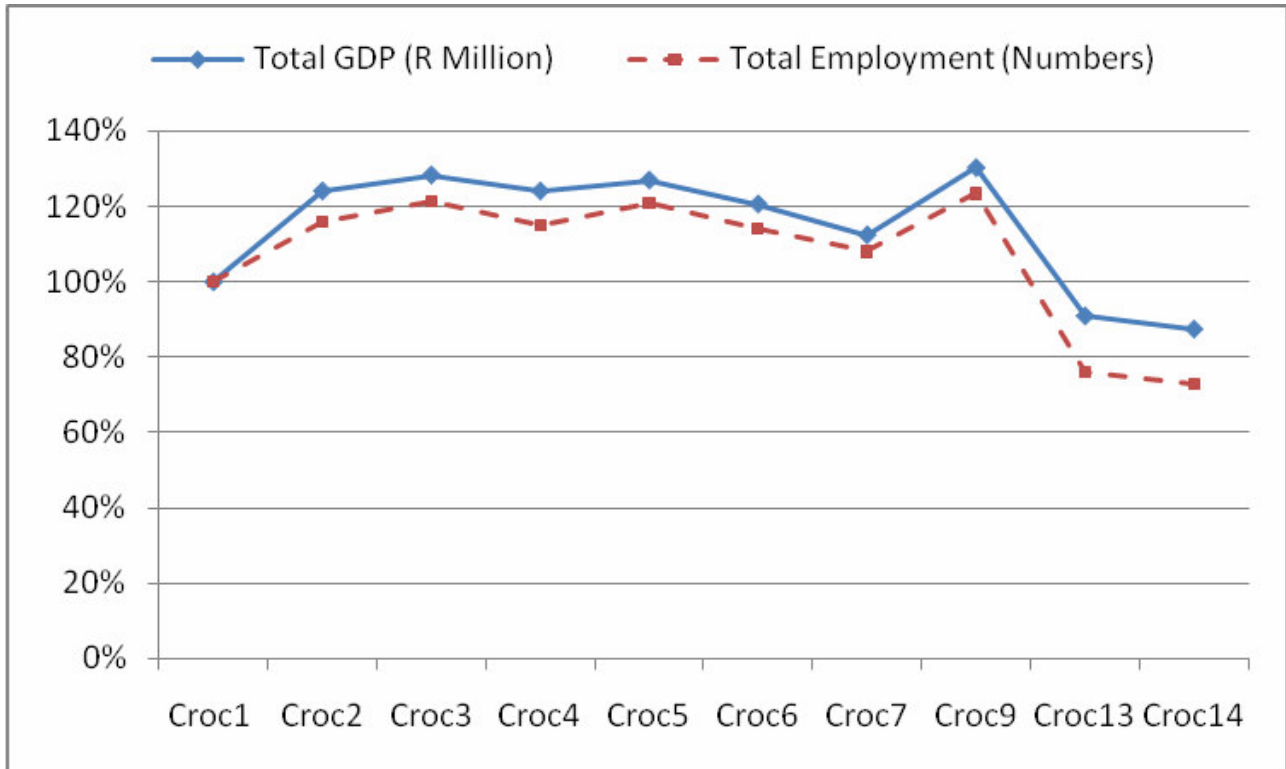


In summary, if the development scenarios (Sc C7 – C9) are excluded from the assessment, Sc C2 to 6 all give a positive deviation compared to Sc 1 (Present Day), with Sc 4 being the best of these scenarios in terms of GDP and total employment. Scenario C9 is the best scenario (most positive GDP impact) and total employment when analysing all the impacts.

It must be noted (refer to Volume 1): The Present Ecological State will be maintained by Sc C1, i.e. the way the system is presently being operated. Scenario C13 (PES), refers to an additional flow scenario which will also maintain the PES and consists of higher flow requirements than present day in certain months. This scenario will include a lower risk of failure of the PES and further degradation of the river to a lower category. The economic consequences associated with this PES EWR scenario must NOT be confused with the consequences of maintaining the river in its present state, as that is being achieved by Sc C1, or the baseline (present operation of the system).

**KAAP RIVER CATCHMENT RESULTS**

The macro economic impacts of the scenarios on Zone 2 are provided in the figure below. The results reflect that Sc C9 is the best economic impact performer. These economic impacts are expressed in total GDP, total number of employment opportunities as well as the distribution towards Low Income Households. If the development scenarios are excluded, Sc C3 is the most recommended scenario in terms of GDP and employment.



Based on the results all the scenarios have a positive deviation from the GDP, except for Sc C13. Scenario C3 is the best scenario if the development scenarios (Sc C7 – C9) are excluded.

## TABLE OF CONTENTS

<b>1.</b>	<b>INTRODUCTION.....</b>	<b>1-1</b>
1.1.	STUDY AREA.....	1-1
1.2.	PURPOSE OF THE REPORT .....	1-1
1.3.	OUTLINE OF THE REPORT .....	1-1
1.3.1.	Chapter 1: Introduction.....	1-1
1.3.2.	Chapter 2: Operational scenario results.....	1-1
1.3.3.	Chapter 3: Scenario description .....	1-1
1.3.4.	Chapter 4: Operational scenario results.....	1-1
1.3.5.	Chapter 5: References .....	1-2
1.3.6.	Appendix A: Short notes from Scenario development meeting .....	1-2
1.3.7.	Appendix B: Detailed results of scenarios.....	1-2
<b>2.</b>	<b>PRESENT OPERATION OF THE SYSTEM.....</b>	<b>2-1</b>
2.1.	CROCODILE RIVER CATCHMENT .....	2-1
2.1.1.	Sabie River catchment .....	2-2
2.1.2.	Sand River catchment .....	2-2
<b>3.</b>	<b>SCENARIO DESCRIPTION.....</b>	<b>3-1</b>
3.1.	BACKGROUND AND APPROACH.....	3-1
3.2.	ZONE 1: CROCODILE RIVER CATCHMENT.....	3-2
3.2.1.	Group 1: EWR demands excluded .....	3-2
3.2.2.	Group 2 Scenarios: EWR demands included.....	3-3
3.3.	SABIE RIVER CATCHMENT .....	3-6
3.4.	SAND RIVER CATCHMENT.....	3-6
3.4.1.	Sellick Rule .....	3-8
<b>4.</b>	<b>OPERATIONAL SCENARIO RESULTS .....</b>	<b>4-1</b>
4.1.	CROCODILE RIVER.....	4-1
4.1.1.	Group 1 scenarios.....	4-1
4.1.2.	Group 2 scenarios: Meeting a PES EWR scenario and REC by applying curtailments.....	4-1
4.2.	SABIE RIVER .....	4-2
4.3.	SAND RIVER.....	4-2
<b>5.</b>	<b>REFERENCES.....</b>	<b>5-1</b>

### LIST OF TABLES

Table 2.1	Base scenario (PD) restriction rule	2-1
Table 2.2	Water demand and supply under the Crocodile PD scenario restriction rule	2-2
Table 2.3	Water demand and supply for the Sabie River PD scenario	2-2
Table 2.4	Water demand and supply under the Sand River Base scenario	2-3
Table 3.1	Description of Group 1 Scenarios	3-2
Table 3.2	Group 1: Scenario rule applied to the irrigation sector	3-2
Table 3.2	Group 2: Scenario restriction rules for the irrigation sector (typical)	3-4
Table 3.4	EWR categories and file names	3-5
Table 3.5	List of scenarios modelled for the Sabie River system	3-6
Table 3.6	Restriction rules applied in the Sabie River catchment	3-6
Table 3.7	Sand River operational scenarios: River levels and restrictions imposed	3-7
Table 3.8	List of scenarios modelled for the Sand River system	3-8

Table 3.8	Proportions of water released at certain river flows in the Sand River	3-8
Table 4.1	Results of all Crocodile Group 1 Scenarios	4-1
Table 4.2	Results of all Crocodile Group 2 Scenarios	4-1
Table 4.3	Results of all Sabie Scenarios	4-2
Table 4.4	Results of all Sand Scenarios	4-2

### LIST OF FIGURES

Figure 3-1	Duration for a typical low-flow month.....	3-5
Figure 3-2	Location of the Champagne, Dingleydale, New Forest and Edinburgh canals (courtesy of B Jackson).....	3-7

### LIST OF APPENDICES

<b>APPENDIX A:</b> Short notes from Scenario development meeting .....	1-4
<b>APPENDIX B:</b> Detailed results of scenarios .....	5-10

## **1. INTRODUCTION**

---

### **1.1. STUDY AREA**

The study area for this Ecological Reserve study consists of the catchments of the Crocodile and Sabie rivers in the Mpumalanga province. Both these rivers rise on the escarpment which separates the Highveld and Lowveld and are characterised by high rainfall at and near the source in the West with decreasing rainfall to the East. The Crocodile River rises near the town of Belfast, flows through the town of Nelspruit and exits the catchment at the town of Komatipoort where it joins the Komati River before flowing into Mozambique. The Sabie River rises near the town of Graskop and flows through the Kruger National Park into Mozambique. The Sand River, a much drier tributary of the Sabie River, joins the Sabie River in the Kruger National Park near the Skukuza Rest Camp. Refer to study area map provided in preface of this report.

### **1.2. PURPOSE OF THE REPORT**

This report (Volume 1) serves to document the operational scenarios that were modelled and the consequence of these scenarios on system yield. The output from the yield model is used to determine the ecological, goods and services and socio-economic consequences of the operational scenarios.

### **1.3. OUTLINE OF THE REPORT**

The consequences of the operational scenarios, RDM Report 26/8/3/10/12/011, consist of a three volume report series which is outlined below:

- **Volume one: (This report) Description of Operational Scenarios.**
- Volume two: Ecological and Goods and Services Consequences.
- Volume three: Macro Economic Consequences.

The report structure of Volume one is provided below.

#### **1.3.1. Chapter 1: Introduction**

This chapter.

#### **1.3.2. Chapter 2: Operational scenario results**

Changes in water availability to water users within the system are provided in terms of curtailments, restrictions, current demand and resulting supply.

#### **1.3.3. Chapter 3: Scenario description**

This chapter provides a description of the scenarios and details regarding the rationale behind the scenario modelling within the catchment context.

#### **1.3.4. Chapter 4: Operational scenario results**

Changes in water availability to water users within the system are provided in terms of curtailments, restrictions, current demand and resulting supply.

**1.3.5. Chapter 5: References**

**1.3.6. Appendix A: Short notes from Scenario development meeting**

Important notes taken during 17 March 2009 regarding the approach to scenario modelling are provided.

**1.3.7. Appendix B: Detailed results of scenarios**

The water demand and supply to all the major sectors in the Crocodile River catchment under the various scenarios are provided.

---

## 2. PRESENT OPERATION OF THE SYSTEM

### 2.1. CROCODILE RIVER CATCHMENT

By far the largest water user in the Crocodile River catchment is the irrigation sector. This water use is largely unmeasured and hence in order to estimate how much is actually being used and at what level of assurance, a water resources model is required. Various models were set up as part of other studies (DWAF, 2009b-f; DWAF, 2007) but the most recent and relevant model is that being utilised on the recently completed project to develop a real-time operational system for the Crocodile River system (Mallory *et al.*, 2008). This model, referred to as the Water Resources Modelling Platform, and extensions thereof into the Sabie and Sand River catchment, was therefore used during the Comprehensive Reserve study.

The present day situation is based on a model simulation and is presented in Table 2.1, 2.2 and 2.3.

International requirements, or cross-border flows, are in a state of flux with the generally accepted Pigss Peak agreement of 1991 requiring a minimum flow of 0,9 m<sup>3</sup>/s from the Crocodile River catchment while the more recent IncoMaputo Water Use Agreement requires at least 1.17 m<sup>3</sup>/s but possibly as much as 1.63 m<sup>3</sup>/s depending on how the agreement is interpreted. When carrying out this baseline assessment a figure of 46 million m<sup>3</sup>/annum was accepted as a realistic present day cross-border flow.

Industrial use consist of water supplied to the SAPPI paper mill from the Ngwodwana Dam and water supplied to the TSB sugar mill in Malelane from the Crocodile River (supported by releases from the Kwena Dam). The supply to SAPPI is at 100% assurance while TSB can theoretically be restricted during severe droughts.

Domestic use is mostly abstracted from the Crocodile River with large abstraction works located in Nelspruit and at KaNyamazane. Water is also transferred to the villages referred to as Nsikasi North from the Sabie River catchment and to Barbeton from the Lomati River. These transfers are assumed to be at 100% assurance. Current problems being experienced with the water supply to Nsikasi North are operational and not related to the water resource.

The bulk of the irrigation water use is also abstracted from the Crocodile River although there are also a number of farm dams which are used to supply irrigators. In this Present Day (PD) Scenario it was assumed that all users in the system are subjected to restrictions based on the state of storage in the Kwena Dam, although it is debatable as to how much control the irrigation board has over the small private farmers located in tributaries of the Crocodile River. The restriction rule is shown in Table 2.1. Note that the Base Scenario refers to Present Day (PD).

**Table 2.1 Base scenario (PD) restriction rule**

Storage in Kwena Dam	Restriction (% of demand)		
(% of full supply capacity)	Industrial	Urban	Irrigation
> 55		0	0
55 to 20		5	
55 to 10			25

Storage in Kwena Dam	Restriction (% of demand)		
20 to 10		10	
< 10	10	20	65

Based in the restriction rules shown in Table 2.1, the estimated demands, supply and assurance of supply are shown in Table 2.2. Zone 1 refers to the Economic delineation which includes the Crocodile River catchment. Zone 2 refers to the Kaap River (refer to Section 3 and Volume 3 in this report series for more information).

**Table 2.2 Water demand and supply under the Crocodile PD scenario restriction rule**

Zone 1: Crocodile River catchment	Demand (million m <sup>3</sup> /annum)	Supply (million m <sup>3</sup> /annum)	Assurance
Cross border flows	46.0	46.0	100.0%
Industrial	23.5	23.4	98.6%
Domestic	48.0	46.6	72.0%
Irrigation	400.0	344.3	68.0%
<b>Total</b>	<b>517.5</b>	<b>460.3</b>	
Zone 2: Kaap River			
Cross border flows	0.0	0.0	N/A
Industrial	0.0	0.0	N/A
Domestic	3.8	3.8	100.0%
Irrigation	77.0	67.3	65.0%
<b>Total</b>	<b>80.8</b>	<b>71.1</b>	

### 2.1.1. Sabie River catchment

The international agreements require a cross border flow from the Sabie River expressed only as an annual average flow catchment. This is currently being met and there is therefore no operating rule which imposes a minimum flow.

Although operating rules were developed for the Sabie River catchment, these were never applied in practice. The system was therefore modelled on a location-priority basis in which upstream users have priority over downstream users. This results in a relatively low assurance of supply to irrigators along the lower Sabie River (Table 2.3).

**Table 2.3 Water demand and supply for the Sabie River PD scenario**

User Sector	Demand (million m <sup>3</sup> /annum)	Supply (million m <sup>3</sup> /annum)	Assurance
Cross border flows	0	0	N/A
Industrial	0	0	N/A
Domestic	10.2	10.2	100.0%
Irrigation	80.3	70.7	62.0%
<b>Total</b>	<b>90.5</b>	<b>80.9</b>	

### 2.1.2. Sand River catchment

Similar to the Sabie River, there are no formal operating rules currently in place within the Sand River catchment. However, a so-called proportional allocation rule was developed to allow only a fixed proportion of flow to be diverted out of the river at diversions works. This rule, which was

applied by means of carefully designed diversion works were however never successfully applied because irrigators in the catchment vandalised the diversion works and for many years have been diverting the flow at the maximum capacity of the distribution canals. Hence the irrigation 'demand' stated in the Table 2.4 should not be confused with the irrigation requirement, which is usually determined with the aid of theoretical models. The demand in this context relates to these current operational practices within the Sand River catchment.

**Table 2.4 Water demand and supply under the Sand River Base scenario**

User Sector	Demand (million m <sup>3</sup> /annum)	Supply (million m <sup>3</sup> /annum)	Assurance
Cross border flows	0.0	0.0	N/A
Industrial	0.0	0.0	N/A
Domestic	6.1	5.5	90%
Irrigation	60.1	43.0	25.7%
<b>Total</b>	<b>66.2</b>		

### 3. SCENARIO DESCRIPTION

---

#### 3.1. BACKGROUND AND APPROACH

At a meeting held on 17 March 2009, several scenarios relating to possible development options were identified with key stakeholders. The concluding notes derived from this meeting are attached as Appendix A. At this meeting it was decided to distinguish between operational scenarios that entail imposing curtailments and/or restrictions on water users, and scenarios that entail development options, which in this case is the construction of new dams. These scenarios were expanded upon to include a range of flows for the ecologists to assess.

***For reporting purposes, the scenarios have been subdivided into those scenarios in which the Ecological Reserve is not met, referred to below as Group 1, and those in which it is met, referred to as Group 2. The final scenarios are described in detail below.***

The comparison of one scenario versus another was carried out by comparing water availability under Present Day (PD) conditions versus that of the scenario in question, where water availability is expressed as the average annual volume of water supplied to each sector, as well as the assurance of supply to each sector. Assurance of supply in this context is defined as the percentage of time that a user obtains his full demand.

Ultimately, the implementation of the Ecological Water Requirements (EWR) at the Recommended Ecological Category (REC) will require restrictions (and possibly curtailments) to be imposed on users in the system. These rules will not necessarily be the same throughout the catchment. During scenario modelling it was found that while one set of rules satisfied the EWR on the main stem of the Crocodile River, a second set of rules was required for the Kaap River in order to meet the EWR at site 7. Hence the system was divided in two zones, referred to further in this report as Zone 1 and Zone 2.

**Zone 1:** The majority of water users within the Crocodile River catchment abstract water directly from the river, and this is supplemented when required by releases from the Kwena Dam. Restrictions are imposed on users in this zone based on the water level in the Kwena Dam. The restriction rule that was assumed for in the Base Scenario was that being used at the time that the PD scenario was modelled and is given in Table 3.2. Note that this rule has recently changed since Mallory *et al.* (2008).

**Zone 2:** Water users in the Kaap River catchment do not benefit from releases from the Kwena Dam and only have access to run-of-river flow in the Kaap River, with the exception of irrigators in the Louws Creek irrigation Board, who are supplied from the Shiyalongobu Dam, located on a tributary of the Lomati River, and the town of Barbeton which received most of its water from the Lomati Dam. The restriction rules developed for this zone were based on the natural flow at the EWR 7.

## 3.2. ZONE 1: CROCODILE RIVER CATCHMENT

### 3.2.1. Group 1: EWR demands excluded

**Scenarios C1 to C6: A combination of operating rules, restrictions, and/or curtailments applied.**

A range of plausible operational scenarios were modelled and the scenario flow at each EWR site provided for the determination of ecological consequences. The scenarios related mainly to the option to either introduce curtailments to water users (by means of compulsory licensing) or to introduce harsher restrictions than assumed in the Base scenario. While a wide range of possible options have been modelled, the river flow is very similar for many of the scenarios. For economic purposes, therefore, the range of combinations was thus narrowed to only six, namely three levels of curtailment and two levels of restrictions (Table 3.1). The two restriction rules used are given in Table 3.2. Note that the '35 Rule' is the same as the Base scenario rule (Table 2.1).

**Table 3.1 Description of Group 1 Scenarios**

Scenario	Restriction Rule (refer to Table 2.1)	Curtailment
C1	35% Rule	Zero
C2	35% Rule	15%
C3	35% Rule	30%
C4	Zero Rule	15%
C5	Zero Rule	30%
C6	Zero Rule	45%

**Table 3.2 Group 1: Scenario rule applied to the irrigation sector**

Storage in Kwena Dam (% of full supply capacity)	Percentage of full demand supplied	
	35% Rule	Zero Rule
> 70	100%	100%
70 to 55	100%	65%
55 to 10	75%	40%
< 10	35%	0%

Two additional scenarios were evaluated at a later stage for ecological consequences evaluation. These are referred to as Sc 3.1 and Sc 6.1. Sc C3 and Sc C6 result in increased yield of Kwena Dam. Effectively, the water saved by the restrictions of irrigation results in increased yield of Kwena Dam. For Sc 3.1 and 6.1, the increased yield was released down the river to determine how much that would supply in terms of EWRs. This results in an improved assurance of supply to users and increased flow at all EWR sites 3, 4, 5 and 6. No further mention of these scenarios is made in this report as this was a test as part of an attempt to optimise the scenarios. The ecological consequences of these two optimization scenarios are provided in Volume 2 of this report series.

#### **Scenario C7: New dam at Montrose**

In this scenario it is assumed that a new dam will be constructed at the Montrose site which is located just downstream of the confluence of the Crocodile and Elands Rivers. The assumed physical characteristics of the dam are as follows:

- Full supply capacity: 254 MCM
- Full supply area: 10.3 km<sup>2</sup>
- Dead storage: 5 MCM

- Area/capacity relationship:  $\text{Area} = 0.49 \times \text{Storage}^{0.55}$

The additional yield that can be made available from the dam depends on a large number of factors, probably the most important being where in the system the intended new users of this dam are to be located. In order to keep this analysis uncomplicated, the following assumptions were made:

- The Montrose Dam will replace the Kwena Dam as being the main regulator of flow in the Crocodile River. Kwena Dam will supplement the Montrose Dam by making releases when the storage in Montrose Dam drops to below 10% of its full supply capacity.
- Montrose Dam will not contribute to the ecological flow requirements of the Crocodile River (in this scenario).
- The water abstracted from the Montrose Dam (i.e. yield) is supplied directly from the dam and not released into the Crocodile River to supplement downstream users. No restriction is imposed on the yield i.e. it is the historic firm yield of the dam.
- The Base Scenario restriction rules were applied to existing users in the catchment.

### **Scenario C8: New dam at Mountain View**

It was assumed when modelling this scenario that a new dam is to be constructed at the Mountain View site which is located a few kilometres upstream of the confluence of the Kaap and Crocodile Rivers. The assumed physical characteristics of the dam are as follows:

- Full supply capacity: 187 MCM
- Full supply area: 7.3 km<sup>2</sup>
- Dead storage: 5 MCM
- Area/capacity relationship:  $\text{Area} = 0.41 \times \text{Storage}^{0.77}$

As in the case of the Montrose Dam, the additional yield made available from the dam depends on a large number of factors and the same assumptions made for the Montrose Dam were applied to the Mountain View Dam.

### **Scenario C9: New dams at Montrose and Mountain View**

In this scenario it was assumed that new dams will be constructed at the Mountain View and Montrose site. Details of these dams and the assumptions made regarding their operation and additional yield are discussed under Scenario C7 and C8.

### **Scenario C11: No cross-border flows**

One of the main drivers of the low-flow under current operating conditions is the cross-border flows. As the lower Crocodile River has in the past flowed at very low flows, it was requested that the scenario of not supplying these minimum flows be modelled.

### **3.2.2. Group 2 Scenarios: EWR demands included**

The scenarios presented in this section pertain specifically to implementing the EWR for the REC and the Present Ecological State (PES) (basically EWR scenarios). The operating rules that were developed to meet the EWR scenarios entailed a combination of restrictions and curtailments. In order to limit the number of operational scenarios to be evaluated from an economic point of view, the latest restriction rule that is being used to operate the system (see Table 3.3) was applied to irrigators in Zone 1, while a separate restriction rule was developed for Zone 2.

Note however that small adjustments were required to the level in the Kwena Dam at which this first restriction is applied in order to maintain the assurance of supply at 70%, which was assumed to be the target assurance for the irrigation sector. If the restriction rule alone did not result in the EWR scenarios being met (which is always the case), a curtailment was applied by reducing irrigated areas across the whole catchment. These scenarios are therefore similar to scenarios 1, 2 and 3 with the difference that the EWR scenarios are supplied as a first priority user and that the latest restriction rule has been used which differs to the present day restriction rule applied in the Group 1 scenarios (Table 3.1). Note that this latest restriction rule was only tabled very recently at the Crocodile River Operation forum and therefore represents the most likely restriction rule to be applied into the future.

**Table 3.3 Group 2: Scenario restriction rules for the irrigation sector (typical)**

Storage in Kwena Dam (% of full supply capacity)	Restriction (% of demand)
> 65	100%
55 to 30	35%
30 to 10	60%
< 10	0%

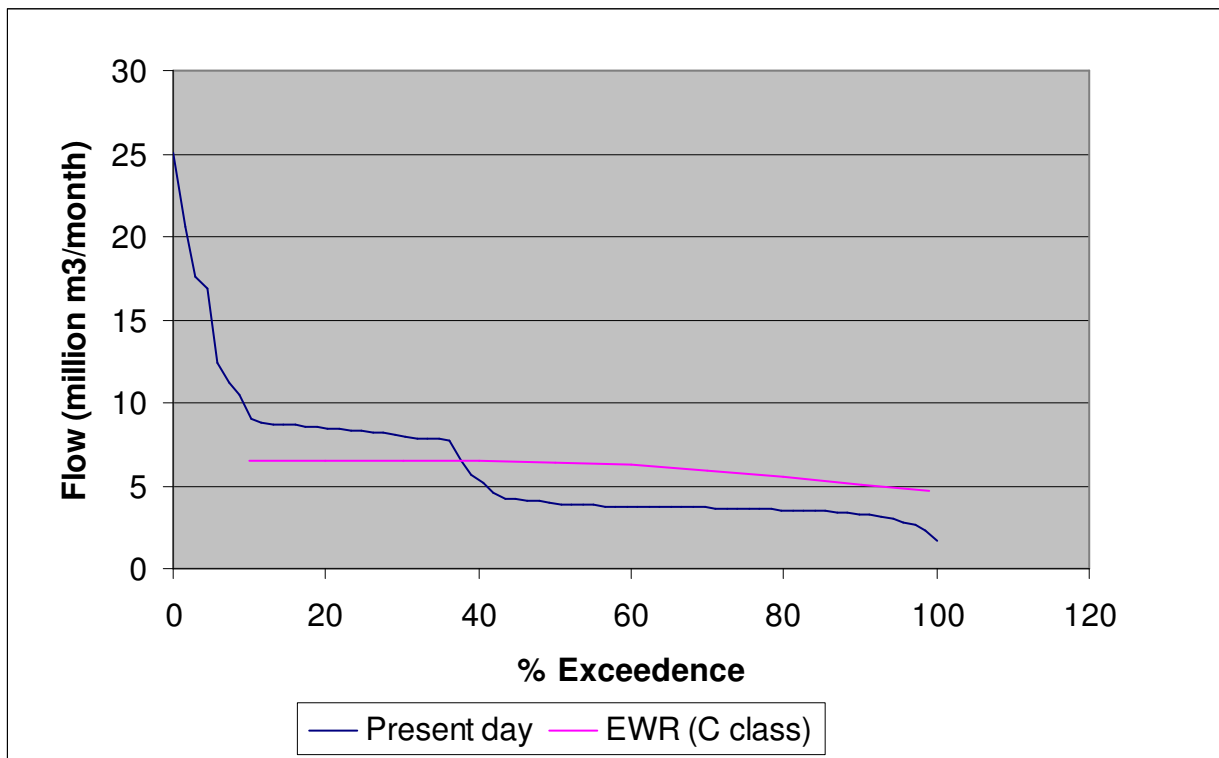
### **Scenario C10 and C12: Reduced releases from Kwena Dam to meet the PES (Sc C10) and REC (Sc C12) EWR at EWR 3**

Under the current operation of the Crocodile system water is released out of the Kwena Dam into the Crocodile River to supplement the water supply to irrigators riparian to the river. Due to the large irrigation water demands throughout winter, the flow in the Crocodile River at EWR 3 is often **higher than natural during the winter**. As summer releases are often not made due to sufficient inflow from tributaries to supply irrigation requirements, the **low flows in summer is abnormally low**, resulting in a seasonal reversal. In order to assess the economic impact of avoiding this unseasonal flow, this scenario modelled releases into the Crocodile River only to meet the EWR 3 requirements. Although the total supply to the irrigation sector remains relatively high, the irrigators located near the end of the Crocodile River will experience very low assurance of supply. Also, the international requirements will not be met.

### **Scenario C13: Meet the Present Ecological Status at EWR 6**

The PES will be maintained with PRESENT DAY HYDROLOGY, i.e. the Base Scenario. A PES EWR scenario was also generated which results in a higher requirement than the present day hydrology. This is due to the following:

- The PES biotic stress requirements are very close to and lower than present day hydrology in the key months required.
- However, in some of the other months, it is slightly higher. Slightly higher in terms of stress, is significantly different in terms of flow volumes.
- Additionally, the present day hydrology has minimal variability within months (i.e., a flat line in terms of a flow duration graph). The EWR will be generated for the months following the natural variability, thereby exceeding the present day flows (Figure 3-1).



**Figure 3-1 Duration for a typical low-flow month**

THEREFORE, the PES EWR must be seen as a range of flows that will meet the PES but would result in a higher PES than the present hydrology. The PES EWR is therefore a scenario of a flow regime that would also maintain the PES. This flow scenario would imply a decreased risk of the river degrading from the PES, whereas the risk of degradation associated with the present day flows is higher.

In order to meet the PES EWR, irrigators will need to be curtailed by 25%. Given this curtailment, a restriction rule was developed to meet the PES at EWR7 located on the Kaap River. Note that the restriction rule applied to irrigators in Zone 2 (Kaap River) is a function of the natural flow at EWR 7 and not the state of storage in the Kwena Dam as assumed in the Group 1 scenarios. This restriction rule is more complex than the one applied to releases out of Kwena Dam since it consists of a different rule for every month. See Appendix A.

**Scenario C14: Meet the REC of EWR 6**

In order to meet the EWR for the REC, irrigators will need to be curtailed by 50%. The restriction rule to meet EWR 7 is more complicated that applied in Zone 1 since the restriction applied varies from month to month. The Zone 2 restriction rule is attached as Appendix A2.2.

The EWR Rule curves used in the Group 2 analyses are as indicated in Table 3.4. This data is included in DWA (2010b).

**Table 3.4 EWR categories and file names**

EWR Site	PES		REC	
1	A/B	CE1_AB.rul (low flows)	A/B	CE1_AB.rul (low flows)
2	B	CE2_B.rul (low flows)	B	CE2_B.rul (low flows)
3	B/C	CE3_BC.rul (low flows)	B	Rul curve could not be provided
4	C	CE4_C.rul (low flows)	B	CE4_C.rul (low flows)

EWR Site	PES		REC	
5	C	CE5__new.rul (low flows)	B	CE5__new.rul (low flows)
6	C	CE6__new.rul (low flows)	B	CE6__new.rul (low flows)
7	C	CE7_C.rul (low flows)	B	CE7_C.rul (low flows)

### 3.3. SABIE RIVER CATCHMENT

Eight hypothetical scenarios were modelled in the Sabie River catchment. These scenarios entailed increasing the current irrigation requirements in steps up to 30 MCM/annum (MCM/a). In addition, varying levels of water restriction were imposed on users. Table 3.5 below presents the range of additional water requirement and the restriction levels applied during the modelling of the scenarios.

**Table 3.5 List of scenarios modelled for the Sabie River system**

Scenario	Additional User Requirements (MCM/a)	Restriction Rule
1	0	None
2	10	None
3	10	Rule 1
4	10	Rule 2
5	25	None
6	30	None
7	30	Rule 1
8	30	Rule 2

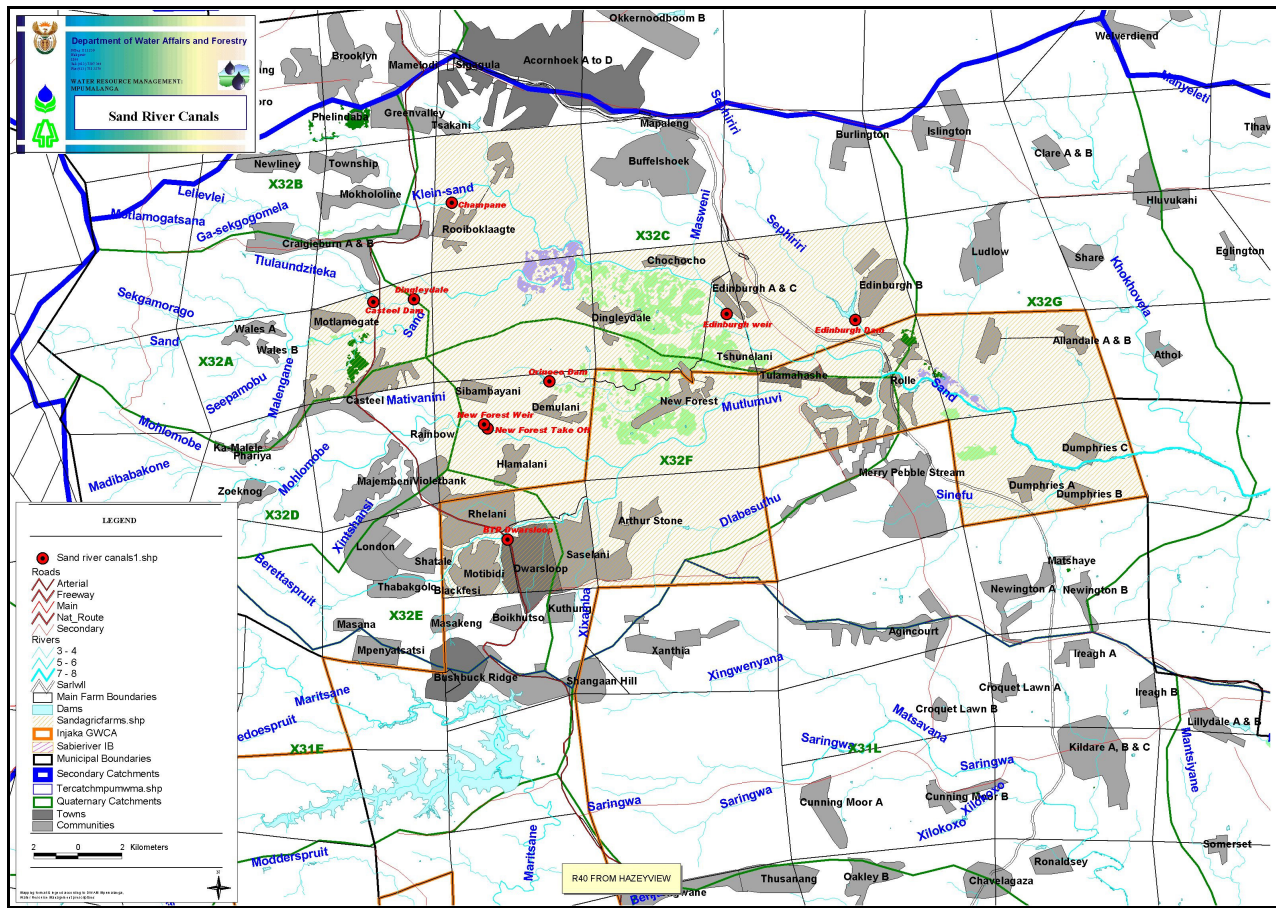
Restriction Rule 1 and 2 are described in Table 3.6.

**Table 3.6 Restriction rules applied in the Sabie River catchment**

Natural flow at EWR 3	Rule 1	Rule 2
	Demand restricted by (% of full demand)	Demand restricted by (% of full demand)
10	60%	30%
55	60%	30%
70	50%	20%
100	50%	20%

### 3.4. SAND RIVER CATCHMENT

Four abstraction weirs (*viz.* Champagne, Dingleydale, New Forest, and Edinburgh) in the Upper Sand River exist but are not operating correctly. All the water (i.e.100%) is diverted for use by the local irrigators and only the high flow spills continue downstream (Figure 3-2).



**Figure 3-2 Location of the Champagne, Dingleydale, New Forest and Edinburgh canals (courtesy of B Jackson)**

The scenarios were based on the assumption that the four abstraction weirs in the upper Sand River would be rehabilitated, thus improving the flow downstream. Scenario modelling included:

- The amount of water that each abstraction weir diverted was reduced to 50% and 25% (i.e. an improvement of 50% and 75% of downstream flow).
- Curtailments of 20% were imposed on the irrigators in the Sand River system.
- Restriction levels (R5) were imposed upon the irrigators in the Sand River system. The restrictions were based upon the natural river flow i.e. when the level of the river drops to a certain point, a restriction is imposed upon the users. The levels of the river and the respective restrictions are tabulated in Table 3.7.

**Table 3.7 Sand River operational scenarios: River levels and restrictions imposed**

Natural River Flow Level (%)	Restriction: R5
	Assurance (%) [Restriction (%)]
0	40 [60]
10	40 [60]
55	50 [50]
70	50 [50]
100	100 [0]

Scenarios consisting of combinations of weir improvement, curtailment and restrictions were simulated and listed in Table 3.8.

**Table 3.8 List of scenarios modelled for the Sand River system**

Scenario	Improvement to downstream flow at abstraction weirs	Curtailments (%)	Restriction Level
<b>Sc 1 (Sellick Rule)</b>	<b>See description below</b>		
Sc 2	0	0	None
Sc 3	50	0	None
Sc 4	50	0	R5
<b>Sc 5</b>	<b>50</b>	<b>20</b>	<b>None</b>
Sc 6	75	0	None
Sc 7	75	20	None
Sc 8	75	0	R5
<b>Sc 9</b>	<b>75</b>	<b>20</b>	<b>R5</b>

The scenarios were compared to the EWR requirements for a range of Ecological Categories (EC) and those requirements sufficiently different from the range of ECs requirements were selected to determine the ecological consequences. The scenarios selected are those highlighted in the above table.

### 3.4.1. Sellick Rule

In accordance with the Sabie River Catchment Operating Rules (DWAF, 2003), a proportion of the flow in the river is supposed to be allowed to flow past the abstraction points down the river in order to meet the EWR. This proportion varies from one abstraction site to the next depending on its location within the catchment (See Table 3.8). This rule, referred to here as the Sellick rule (after Charles Sellick) only comes into effect when the river flow drops to the level indicated under "River Flow" and the capacity of these canals is based on the percentage of off-take at this flow threshold.

**Table 3.9 Proportions of water released at certain river flows in the Sand River**

Canal	Capacity (m <sup>3</sup> /s)	% Releases	River Flow (m <sup>3</sup> /s)
Champagne	0.127	35%	0.1954
Dingleydale	0.962	35%	1.48
New Forest	0.283	50%	0.566
Edinburgh	1.150	65%	3.28

## 4. OPERATIONAL SCENARIO RESULTS

### 4.1. CROCODILE RIVER

#### 4.1.1. Group 1 scenarios

The supply to the domestic and industrial sectors does not vary much from one scenario to the next, hence the scenario results given in this main body of the report have been simplified to show only the impact on the irrigation sectors. The complete results showing all sectors are attached as Appendix B. Group 1 results are provided in Table 4.1.

**Table 4.1 Results of all Crocodile Group 1 Scenarios**

Crocodile Scenarios	Description	Zone 1			Zone 2			Additional Yield**
		Demand*	Supplied*	Assurance of supply (%)	Demand	Supplied	Assurance of supply (%)	
C1	C: Zero; R = 35%	400	344	72	77	67	65	
C2	C: 15%; R = 35%	340	315	90	66	62	87	
C3	C: 30%; R = 35%	280	265	97	54	53	96	
C4	C: 15%; R = 0%	340	322	97	66	62	87	
C5	C: 15%; R = 0%	280	266	98	54	53	95	
C6	C: 15%; R = 0%	220	211	98	42	42	98	
C7	Montrose Dam	400	357	76	77	67	65	88
C8	Mountain View Dam	400	338	62	77	67	68	55
C9	Both dams	400	356	86	77	67	65	129
C11	Cross-border = 0;	400	344	74	77	73	84	

\* Demand, supply and additional yield units are in million m<sup>3</sup>/annum.

# Additional yield is expressed as historic firm yield supplied directly out of the proposed dams.

#### 4.1.2. Group 2 scenarios: Meeting a PES EWR scenario and REC by applying curtailments

Table 4.2 summarises the results for the Group 2 Crocodile River scenarios.

**Table 4.2 Results of all Crocodile Group 2 Scenarios**

Crocodile Scenarios	Description	Zone 1			Zone 2		
		Demand*	Supplied*	Assurance of supply (%)	Demand	Supplied	Assurance of supply (%)
C10	Reduce releases from Kwena to meet PES at EWR 3	400	344	74%	77	72	84%
C12	Reduce releases from Kwena to meet REC at EWR 3	400	365	88%	77	72	84%
C13	Meet PES	300	251	70%	58	52	77%
C14	Meet REC	200	173	70%	39	34	75%

\* Demand and supply units are in MCM/a.

## 4.2. SABIE RIVER

Table 4.3 summarises the results for the Sabie River catchment.

**Table 4.3 Results of all Sabie Scenarios**

Sabie Scenarios	Description	Demand*	Supplied*	Assurance of supply (%)
Sabie1	Base	80.3	70.7	62
Sabie5	+25 - No Restriction	105.3	95.7	71
Sabie6	+30 - No Restriction	110.3	100.7	72
Sabie7	+30 - R2 Restriction	110.3	79.8	80
Sabie8	+30 - R5 Restriction	110.3	53.1	89

\* Demand and supply units are in MCM/a.

## 4.3. SAND RIVER

Table 4.4 summarises the results for the Sand River catchment.

**Table 4.4 Results of all Sand Scenarios**

Sand Scenarios	Description	Demand*	Supplied*	Assurance of supply (%)
Sellick	Sellick proportional flow rule	23.6	19.0	78
Sand2	+50 improvement, 20% Curt, R2 Restriction	27.4	21.3	71
Sand3	+75 improvement, 20% Curt, R5 Restriction	17.9	8.1	77

\* Demand and supply units are in MCM/a.

## 5. REFERENCES

---

Department of Water Affairs and Forestry, South Africa (DWA). 1999. Resource directed measures for the protection of water resources. Volume 3: River ecosystems, version 1.0.

Department of Water Affairs and Forestry (DWA). 2003. Sabie River catchment: Operating Rules and Decision Support Models for Management of the Surface Water Resources

Department of Water Affairs and Forestry, South Africa. 2008. Comprehensive Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Inkomati Water Management Area, Mpumalanga. Sabie and Crocodile Systems: Resource Unit Delineation: Prepared by Water for Africa, authored by Louw, MD. Report no. 26/8/3/10/12/006.

Department of Water Affairs, South Africa (DWA). 2009a. Comprehensive Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Inkomati Water Management Area, Mpumalanga. Sabie and Crocodile Systems: EcoClassification Report - Volume 1. Prepared by Water for Africa, edited by Louw, MD and Koekemoer, S. RDM Report no 26/8/3/10/12/009.

Department of Water Affairs and Forestry (DWA). 2009b. Inkomati Water Availability Assessment: Main Report. Report no. PWMA 05/X22/00/0808.

Department of Water Affairs and Forestry (DWA). 2009c. Inkomati Water Availability Assessment: Water Requirements. Report no. PWMA 05/X22/00/0908.

Department of Water Affairs and Forestry (DWA). 2009d. Inkomati Water Availability Assessment: Hydrology of the Crocodile River. Report no. PWMA 05/X22/00/1508.

Department of Water Affairs and Forestry (DWA). 2009e. Inkomati Water Availability Assessment: Hydrology of the Sabie River. Report no. PWMA 05/X22/00/1608.

Department of Water Affairs and Forestry (DWA). 2009f. Inkomati Water Availability Assessment: Yield Modelling. Report no. PWMA 05/X22/00/1708.

Department of Water Affairs, South Africa (DWA). 2010a. Comprehensive Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Inkomati Water Management Area, Mpumalanga. Sabie and Crocodile River Systems: Sabie-Sand River System: EWR Scenario Report - Volume 1. Prepared by Rivers for Africa, edited by Louw, MD and Koekemoer, S. RDM Report no 26/8/3/10/12/010.

Department of Water Affairs, South Africa (DWA). 2010b. Comprehensive Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Inkomati Water Management Area, Mpumalanga. Sabie and Crocodile Systems: Electronic information and data. RDM Report no 26/8/3/10/12/016.

Godfrey, L. (Ed), 2002. Ecological Reserve Determination for the Crocodile River Catchment, Incomati System, Mpumalanga. Technical Report for the Department of Water Affairs and Forestry, by the Division of Water Environment and Forestry Technology, CSIR, Pretoria. Report No. ENV-P-C 2001. iii + 70 pp.

Kleynhans, C.J., Thirion, C., Moolman, J. and Gaulana, L. 2007a. A Level II River Ecoregion classification System for South Africa, Lesotho and Swaziland. Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

Mallory SJL, Odendaal P, Desai A. 2008. The Water Resources Modelling Platform User's Guide. Version 3. [www.waterresources.co.za](http://www.waterresources.co.za)

Tripartite Permanent Technical Committee. 2002. Interim IncoMaputo Water Use Agreement.

Tharme, R. 1997. Sabie-Sand River System: In-stream Flow Requirements. Proceedings of the IFR workshop. Report to the Department of Water Affairs and Forestry. Southern Waters Ecological Research and Consulting cc, Freshwater research unit, University of Cape Town, Rondebosch.

---

**APPENDIX A: CROCODILE AND SABIE-SAND COMPREHENSIVE EWR ASSESSMENT -  
DESIGNING OF OPERATIONAL SCENARIOS FOR EVALUATION OF ECOLOGICAL,  
GOODS AND SERVICES AND SOCIO-ECONOMIC CONSEQUENCES**

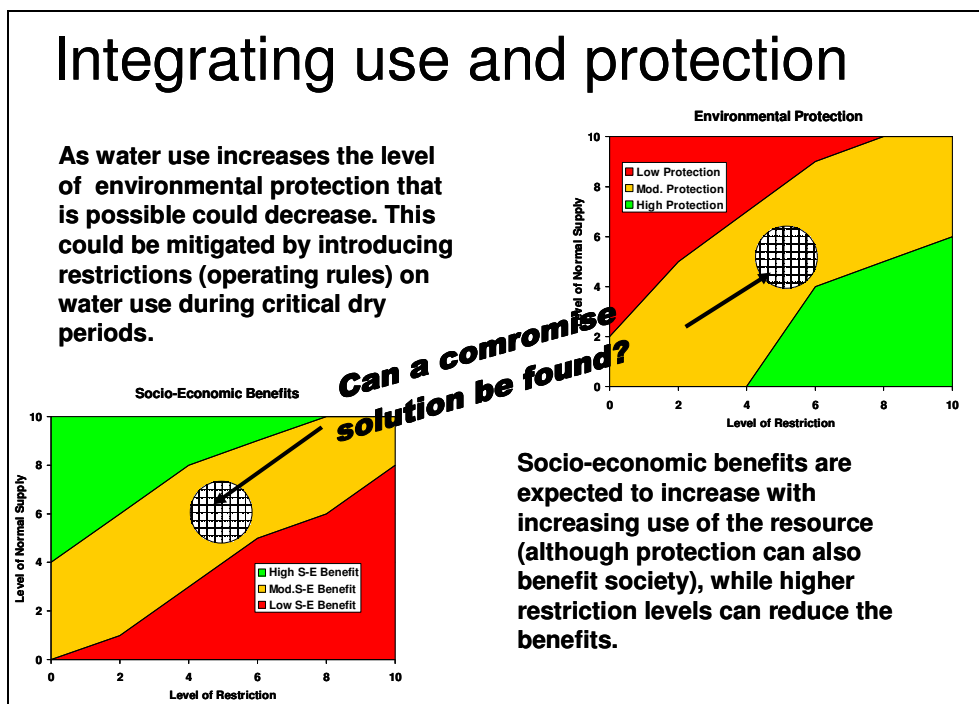
**Attendance:**

Delana Louw	Rivers for Africa
Ahmed Desai	Rivers for Africa
Denis Hughes	Institute for Water Research
Stephen Mallory	IWR Water Resources
Niel van Wyk	DWA
Rongqiv Cai	DWA
Brian Jackson	Inkomati CMA
Sharon Pollard	AWARD
Jan-Willem ?	AWARD
Tolmay Hopkins	DWA
Geert Grobler	DWA
Magezi (Kenny) Mabaso	DWA
Marcus Selepe	Inkomati CMA
Morteza Fayazi	DWA
Geraldine Klarenberg	Mvula Trust
Jonathan Swart	Sabie Sand
Zimkitha Peteni-Kave	DWA

## A1 SHORT NOTES ON THE MEETING

### A1.1 WAY OF PRESENTING SCENARIOS

A format for providing the information of the scenario evaluation phase to decision-makers was developed and used to determine the range of scenarios. A slide from a presentation illustrating the process is provided below.



### A1.2 FINAL SCENARIOS TO BE ASSESSED

Presentation of preliminary scenarios and discussion resulted in agreement of the following scenarios to be assessed:

#### A1.2.1 Crocodile River

Sc 1: Curtailment versus restrictions changes to result in different ECs. Complete – update with changed Reserve requirements for EWR 6 and 5.

Sc 2: As for Sc 1 with Montrose Dam: EWR 5 and 6

Sc 3: As for Sc 1 with Mountain view: EWR 7 (move to DS of dam and upstream of dam), EWR 5 and 6.

Sc 4: As for Sc 1 with both dams: EWR 5, 6 and 7.

Sc 5: Decrease releases from Kwena Dam to meet EWR 3 in the dry season and increase releases to meet EWR in the wet season. This will impact on all the downstream sites. Test and evaluate at EWR4, 5, 6 to test implications.

### **A1.2.2 Sabie - Sand River:**

Sc 1: SABIE: Curtailment-restriction graph: No EWRs as a demand: Need results at EWR 3 and 5. Evaluate scenarios by increasing use thereby having less water available for the Reserve. Test at EWR 3. Check base flow increases at EWR 5 as well as impact on spillage.

SAND:

Sc 2: No transfer from Inyaka. Update the user requirements. No agricultural rule (Sellick)

Sc 3: Full transfer with the agricultural rule (Sellick). Forestry that has been removed must be included.

Other scenarios will be done for Brian Jackson but these will not be reported on as part of this Reserve study.

---

**APPENDIX B: DETAILED SCENARIO RESULTS**

**Table B1 Water demand and supply under Croc Scenario 1**

Zone	Demand (MCM/a)	Supply (MCM/a)	Assurance
<b>Zone 1</b>			
Cross border flows	46.0	46.0	100.0%
Industrial	23.5	23.4	98.6%
Domestic	48.0	46.6	72.0%
Irrigation	400.0	344.3	68.0%
<b>Total</b>	<b>517.5</b>	<b>460.3</b>	
<b>Zone 2</b>			
Cross border flows	0.0	0.0	N/A
Industrial	0.0	0.0	N/A
Domestic	3.8	3.8	100.0%
Irrigation	77.0	67.3	65.0%
<b>Total</b>	<b>80.8</b>	<b>71.1</b>	

**Table B2 Water demand and supply under Croc Scenario 2**

Zone	Demand (MCM/a)		Supply (MCM/a)	Assurance
	Current	Adjusted		
<b>Zone 1</b>				
Cross border flows	46.00	46.00	46.00	100.0%
Industrial	23.50	23.50	23.49	99.7%
Domestic	48.00	48.10	47.46	93.3%
Irrigation	400.00	339.60	314.85	90.0%
<b>Total</b>	<b>517.50</b>	<b>457.20</b>	<b>431.65</b>	
<b>Zone 2</b>				
Cross border flows	0.00	0.00	0.00	N/A
Industrial	0.00	0.00	0.00	N/A
Domestic	3.80	3.80	3.80	100.0%
Irrigation	77.00	65.46	61.92	87.0%
<b>Total</b>	<b>80.80</b>	<b>127.84</b>	<b>65.72</b>	

**Table B3 Water demand and supply under Croc Scenario 3**

Zone	Demand (MCM/a)		Supply (MCM/a)	Assurance
	Current	Adjusted		
<b>Zone 1</b>				
Cross border flows	46.00	46.00	46.00	100.0%
Industrial	23.50	23.50	23.50	100.0%
Domestic	48.00	48.10	47.66	98.3%
Irrigation	400.00	279.67	265.09	97.0%
<b>Total</b>	<b>517.50</b>	<b>397.27</b>	<b>382.25</b>	
<b>Zone 2</b>				
Cross border flows	0.00	0.00	0.00	N/A
Industrial	0.00	0.00	0.00	N/A
Domestic	3.80	3.80	3.80	100.0%
Irrigation	77.00	53.91	52.59	96.0%
<b>Total</b>	<b>80.80</b>	<b>57.71</b>	<b>56.39</b>	

**Table B4 Water demand and supply under Croc Scenario 4**

Zone	Demand (MCM/a)		Supply (MCM/a)	Assurance
	Current	Adjusted		
<b>Zone 1</b>				
Cross border flows	46.00	46.00	46.00	100.0%
Industrial	23.50	23.50	23.48	100.1%
Domestic	48.00	48.10	47.42	98.6%
Irrigation	400.00	339.60	321.48	97.4%
<b>Total</b>	<b>517.50</b>	<b>457.20</b>	<b>438.10</b>	
<b>Zone 2</b>				
Cross border flows	0.00	0.00	0.00	N/A
Industrial	0.00	0.00	0.00	N/A
Domestic	3.80	3.80	0.00	100.0%
Irrigation	77.00	65.46	61.92	87.0%
<b>Total</b>	<b>80.80</b>	<b>127.84</b>	<b>65.72</b>	

**Table B5 Water demand and supply under Croc Scenario 5**

Zone	Demand (MCM/a)		Supply (MCM/a)	Assurance
	Current	Adjusted		
<b>Zone 1</b>				
Cross border flows	46.00	46.00	46.00	100.0%
Industrial	23.50	23.50	23.50	100.0%
Domestic	48.00	48.10	47.66	100.0%
Irrigation	400.00	279.67	266.41	97.9%
<b>Total</b>	<b>517.50</b>	<b>397.27</b>	<b>383.50</b>	
<b>Zone 2</b>				
Cross border flows	0.00	0.00	0.00	100.0%
Industrial	0.00	0.00	0.00	100.0%
Domestic	3.80	3.80	3.80	100.0%
Irrigation	77.00	53.91	52.85	95.1%
<b>Total</b>	<b>80.80</b>	<b>57.71</b>	<b>56.65</b>	

**Table B6 Water demand and supply under Croc Scenario 6**

Zone	Demand (MCM/a)		Supply (MCM/a)	Assurance
	Current	Adjusted		
<b>Zone 1</b>				
Cross border flows	46.00	46.00	46.00	100.0%
Industrial	23.50	23.50	23.50	100.0%
Domestic	48.00	48.10	47.69	100.0%
Irrigation	400.00	219.74	210.59	98.0%
<b>Total</b>	<b>517.50</b>	<b>337.34</b>	<b>327.74</b>	
<b>Zone 2</b>				
Cross border flows	0.00	0.00	0.00	100.0%
Industrial	0.00	0.00	0.00	100.0%
Domestic	3.80	1.19	3.80	100.0%
Irrigation	77.00	42.36	41.90	97.7%
<b>Total</b>	<b>80.80</b>	<b>43.55</b>	<b>45.70</b>	

**Table B7 Water demand and supply under Croc Scenario 7**

Zone	Demand (MCM/a)		Supply (MCM/a)	Assurance
	Current	Adjusted		
<b>Zone 1</b>				
Cross border flows	46.00	46.00	46.00	100.0%
Industrial	23.50	23.50	23.42	98.3%
Domestic	48.00	48.10	40.99	80.0%
Irrigation	400.00	400.00	355.57	76.0%
Additional yield	88.00		88.0	100.0%
<b>Total</b>	<b>607.50</b>	<b>517.13</b>	<b>465.98</b>	
<b>Zone 2</b>				
Cross border flows				
Industrial	0.00	0.00	0.00	N/A
Domestic	3.8	3.8	3.8	100.0%
Irrigation	77.0	77.0	67.3	65.0%
<b>Total</b>	<b>80.8</b>	<b>80.8</b>	<b>71.1</b>	<b>67.0%</b>

**Table B8 Water demand and supply under Croc Scenario 8**

Zone	Demand (MCM/a)		Supply (MCM/a)	Assurance
	Current	Adjusted		
<b>Zone 1</b>				
Cross border flows	46.00	46.00	46.00	100.0%
Industrial	23.50	23.50	23.36	98.3%
Domestic	48.00	48.10	46.42	68.0%
Irrigation	400.00	399.53	338.31	62.0%
<b>Total</b>	<b>517.50</b>	<b>517.13</b>	<b>453.49</b>	
<b>Zone 2</b>				
Cross border flows	0.00	0.00	0.00	n/a
Industrial	0.00	0.00	0.00	n/a
Domestic	3.80	3.80	3.80	100.0%
Irrigation	77.00	77.00	67.13	65.0%
Additional yield	55.00	55.00	55.00	100.0%
<b>Total</b>	<b>135.80</b>	<b>135.80</b>	<b>125.93</b>	

**Table B9 Water demand and supply under Croc Scenario 9**

Zone	Demand (MCM/a)		Supply (MCM/a)	Assurance
	Current	Adjusted		
<b>Zone 1</b>				
Cross border flows	46.00	46.00	46.00	100.0%
Industrial	23.50	23.50	23.43	98.3%
Domestic	48.00	48.10	41.04	82.0%
Irrigation	400.00	399.53	356.29	86.0%
Additional yield	74.00	74.00	74.00	100.0%
<b>Total</b>	<b>517.50</b>	<b>517.13</b>	<b>465.91</b>	
<b>Zone 2</b>				
Cross border flows	0.00	0.00	0.00	N/A
Industrial	0.00	0.00	0.00	N/a
Domestic	3.80	3.80	3.80	100.0%
Irrigation	77.00	77.00	67.10	65.0%
Additional yield	55.00	55.00	55.00	100.0%
<b>Total</b>	<b>135.80</b>	<b>190.81</b>	<b>128.79</b>	

**Table B10 Water demand and supply under Croc Scenario 10**

Zone	Demand (MCM/a)		Supply (MCM/a)	Assurance
	Current	Adjusted		
<b>Zone 1</b>				
Cross border flows	46.00	46.00	46.00	100.0%
Industrial	23.50	23.50	23.48	98.2%
Domestic	48.00	48.10	47.40	98.0%
Irrigation	400.00	399.53	343.88	74.2%
<b>Total</b>	<b>517.50</b>	<b>471.13</b>	<b>443.86</b>	
<b>Zone 2</b>				
Cross border flows	0.00	0.00	0.00	N/A
Industrial	0.00	0.00	0.00	N/A
Domestic	3.80	3.80	3.80	100.0%
Irrigation	77.00	77.01	72.47	83.7%
<b>Total</b>	<b>126.80</b>	<b>127.84</b>	<b>105.37</b>	

**Table B11 Water demand and supply under Croc Scenario 11**

Zone	Demand (MCM/a)		Supply (MCM/a)	Assurance
	Current	Adjusted		
<b>Zone 1</b>				
Cross border flows	46.00	46.00	46.00	N/A
Industrial	23.50	23.50	23.47	98.2%
Domestic	48.00	48.10	47.33	90.0%
Irrigation	400.00	399.53	364.99	88.0%
<b>Total</b>	<b>517.50</b>	<b>471.13</b>	<b>435.79</b>	
<b>Zone 2</b>				
Industrial	0.00	0.00	0.00	N/A
Domestic	0.00	0.00	0.00	N/A
Irrigation	3.80	3.80	3.80	100.0%
<b>Total</b>	<b>77.00</b>	<b>77.01</b>	<b>70.82</b>	<b>82.0%</b>

**Table B12 Water demand and supply under Croc Scenario 12**

Zone	Demand (MCM/a)		Supply (MCM/a)	Assurance
	Current	Adjusted		
<b>Zone 1</b>				
Cross border flows	46.00	46.00	46.00	100.0%
Industrial	23.50	23.50	23.45	99.0%
Domestic	48.00	48.10	47.17	85.0%
Irrigation	400.00	299.64	250.61	70.0%
<b>Total</b>	<b>517.50</b>	<b>417.25</b>	<b>367.22</b>	
<b>Zone 2</b>				
Cross border flows	0.00	0.00	0.00	N/A
Industrial	0.00	0.00	0.00	N/A
Domestic	3.80	3.80	3.80	100.0%
Irrigation	77.00	57.76	52.24	77.0%
<b>Total</b>	<b>80.80</b>	<b>127.84</b>	<b>56.04</b>	

**Table B13 Water demand and supply under Croc Scenario 13**

Zone	Demand (MCM/a)		Supply (MCM/a)	Assurance
	Current	Adjusted		
<b>Zone 1</b>				
Cross border flows	46.00	46.00	46.00	100.0%
Industrial	23.50	23.50	23.49	99.3%
Domestic	48.00	48.10	47.38	88.0%
Irrigation	400.00	199.76	172.84	70.0%
<b>Total</b>	<b>517.50</b>	<b>317.37</b>	<b>289.72</b>	
<b>Zone 2</b>				
Cross border flows	0.00	0.00	0.00	N/A
Industrial	0.00	0.00	0.00	N/A
Domestic	3.80	3.80	3.80	100.0%
Irrigation	77.00	38.50	33.61	75.0%
<b>Total</b>	<b>80.80</b>	<b>42.30</b>	<b>37.41</b>	