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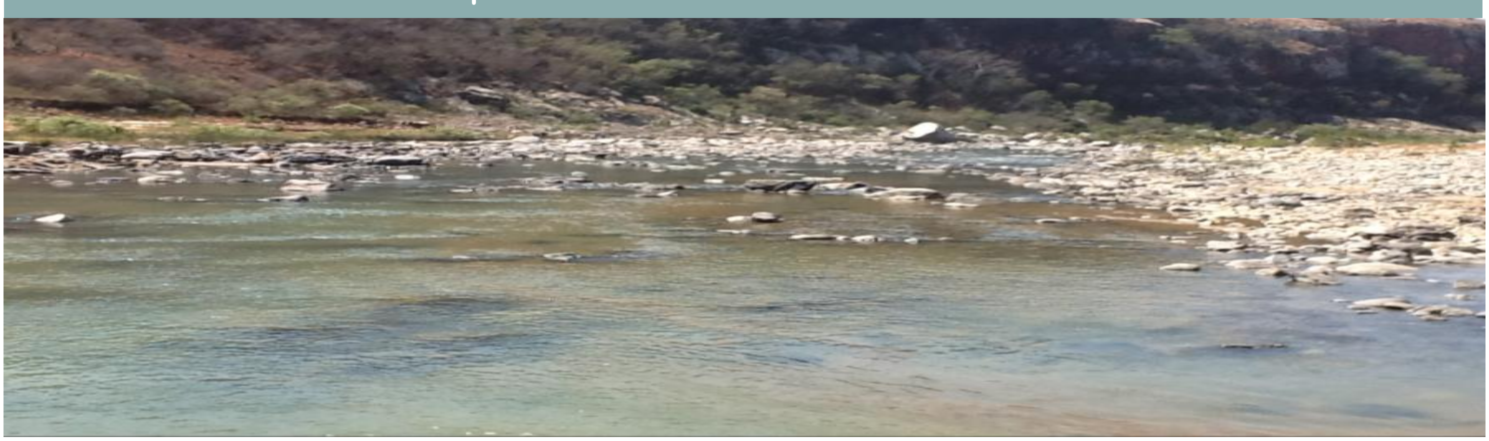
RESERVE DETERMINATION STUDIES FOR SELECTED SURFACE WATER, GROUNDWATER, ESTUARIES AND WETLANDS IN THE USUTU/MHLATUZE WATER MANAGEMENT AREA
WP 10544

HYDROLOGY SPECIALIST REPORT

FINAL

JUNE 2015
Report No. RDM/WMA6/CON/COMP/1013



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Department:
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DEPARTMENT OF WATER AND SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEMS

CONTRACT NO. WP 10544

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Contract Title:	Reserve determination studies for selected surface water, groundwater, estuaries and wetlands in the Usutu/Mhlathuze Water Management Area
Report Title	Hydrology Specialist Report
Authors	André Görgens, Gerald Howard and Anton Sparks, Aurecon South Africa (Pty) Ltd

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Consultants: Tlou Consulting (Pty) Ltd and Aurecon

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Chief Director: Water Ecosystems

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Project Team members:

Gerald Howard	Aurecon
Anton Sparks	Aurecon

EXECUTIVE SUMMARY

Introduction

In early 2014 the Department of Water and Sanitation (DWS), through its Directorate: Resource Directed Measures, commissioned Tlou Consulting (Pty) Ltd, to conduct studies to determine the Preliminary Reserve for selected surface water sources, groundwater sources, estuaries and wetlands in the Usutu/Mhlathuze Water Management Area.

During July 2014 Tlou Consulting contracted Aurecon South Africa (Pty) Ltd to conduct a range of hydrological modelling studies to support the above Reserve studies.

The Study Area for the purposes of this Report comprises all or parts of the catchments of the Usutu, Pongola, Mkuze, Hluhluwe, Msinene, Nyalazi, Mfolozi, Mhlatuze and Matigulu Rivers, as well as of Lake St Lucia and the Kosi Bay Estuary.

Objective and scope of hydrology study

The objective of the hydrology study was to support the above Preliminary Reserve studies in terms of all their requirements for hydrological information and/or related catchment and systems modelling.

The scope of the hydrology study was to provide the above Preliminary Reserve studies with daily and/or monthly streamflow sequences for natural, present-day and various future scenario catchment development conditions for nine environmental water requirement (EWR) river and floodplain sites and as inflows to Lake St Lucia and Kosi Bay. Additionally, natural monthly streamflow sequences were determined at 50 individual river sites (known as extrapolation nodes) across the Study Area.

General approach to the hydrology study

Given the challenging timeframe for the execution of this hydrology study, our brief was restricted to utilising existing model configurations for natural and present-day conditions, including their input data, in all the study catchments. Consequently, we initially expected that no new hydro-meteorological, land-use and water demand data needed to be assembled. HoThe existing model configurations sourced for this work comprised a mix of monthly and daily models.

The prior or current studies from which existing model configurations were sourced are as follows:

- *Develop Integrated Water Resource Management Strategies (IWRMS) and Plans for the Incomati and Maputo River Basins for the PRIMA Programme.* Completed: 2012. Client: The National Directorate of Water Affairs (DNA), Mozambique.
- *Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system*. Completed: 2014. Client: iSimangaliso Wetland Park Authority.
- *Mhlathuze water availability assessment study (WAAS).* Completed: 2008. Client: RSA Department of Water Affairs.

- *Water Resources of South Africa, 2012 Study (WR2012).* Completed: 2016. Client: Water Research Commission.

The models whose existing configurations were sourced from the aforementioned studies are as follows:

- WRYM Monthly System Yield Model (DWAF, 2009)
- WR2012 Pitman Monthly Catchment Modelling System (WRC, 2016) (previously known as WRSM2000)
- *ACRU* Daily Agrohydrological Modelling System (Schulze, 1995)
- MODSIM-DSS Daily River Basin Decision Support System (Lambadie, 2012).

Table E1 outlines the sourcing of model configurations and their related input files from prior or current studies for the individual catchments/systems constituting the Study Area.

Table E1: Model configurations implemented and studies from which the configurations were sourced

River EWR Site Catchment / Estuary Inflowing Catchment	Existing Model Configuration	Prior/Current Study
Assegai River	WRYM (monthly)	Incomati-Maputo IWRMS - PRIMA
Upper Pongola River	WRYM (monthly)	Incomati-Maputo IWRMS - PRIMA
Lower Pongola River	MODSIM+WRYM (daily and monthly)	Incomati-Maputo IWRMS - PRIMA
Mkuze River	Provisional: *ACRU* (monthly). Final: *ACRU* (daily)	Lake St Lucia - iSimangaliso
Hluhluwe, Msinene, Nyalazi Rivers	Provisional: Pitman WR2012 (monthly). Final ACRU (daily)	Lake St Lucia - iSimangaliso
Mfolozi River	Provisional: *ACRU* (monthly). Final *ACRU* (daily)	Lake St Lucia - iSimangaliso
Nseleni River	WRYM (monthly) &	Mhlathuze WAAS

River EWR Site Catchment / Estuary Inflowing Catchment	Existing Model Configuration	Prior/Current Study
	ACRU (daily)	
Matigulu River	Pitman 2012 (monthly)	WR2012
Kosi Bay Catchment	Pitman 2012 (monthly)	WR2012

Scenarios Modelled

Details of the future development scenarios which were super-imposed on the above model configurations were extracted from a draft Scenario Report which had been prepared prior to the start of this study. The scenarios comprise aspects such as future increases in water demands by the domestic and industrial sectors and introduction of new dams, as well as mitigating measures such as changes in operating rules of existing dams, reduction of afforestation, reduction of water losses in the domestic and irrigation sectors, etc. **Table E2** summarises the scope of both the provisional and final scenario analyses.

NB: It should be noted that a number of scenarios were added or changed during the course of the study.

Table E2: Number of scenarios modelled per EWR Site or estuary inflowing river

River EWR Site / Estuary Inflowing River	Model	Number of Scenarios Modelled (Including Natural)	Time Resolution of Streamflow Series Provided to Ecology Team
Assegai – AS1	WRYM (monthly) (+ disaggregation)	10	Daily
Upper Pongola – UP1	WRYM (monthly) (+ disaggregation)	6	Daily
Lower Pongola – LP1	MODSIM+WRYM (daily and monthly) (+ disaggregation)	6	Daily
Mkuze – MK1	*ACRU* (daily)	6	Daily
Black Mfolozi – BM1	*ACRU* (daily)	5	Daily
Black Mfolozi – BM2	*ACRU* (daily)	7	Daily
White Mfolozi – WM1	*ACRU* (daily)	7	Daily

River EWR Site / Estuary Inflowing River	Model	Number of Scenarios Modelled (Including Natural)	Time Resolution of Streamflow Series Provided to Ecology Team
Matigulu – MA1	Pitman 2012 (monthly) (+ disaggregation)	5	Daily
Nseleni – NS1	*ACRU* + WRYM (daily and monthly)	3	Daily
Mfolozi – Full Catchment	*ACRU* (monthly and daily)	11	Daily
Hluhluwe – Full Catchment	Provisional: Pitman WR2012 (monthly). Final *ACRU* (daily)	6	Daily
Msinene and Nyalazi – Full Catchments	Provisional: Pitman WR2012 (monthly). Final *ACRU* (daily)	2	Daily
Mkuze – Full Catchment	*ACRU* (monthly & daily)	6	Daily
Kosi Bay Catchment	Pitman 2012 (monthly)	5	Monthly

The aquatic ecology team required streamflow sequences at the river EWR sites at a daily time resolution. Consequently, at the river sites where the scenarios were modelled with a monthly model (AS1, UP1, LP1, NS1 and MA1), the resulting simulated monthly flow sequences were disaggregated by means of observed daily flow sequences in the nearby tributaries or neighbouring rivers. The natural monthly streamflow sequence at each of the 50 extrapolation nodes across the Study Area was determined by means of the model configuration in which that specific node happened to fall.

Support to the river and estuary ecology teams

The hydrology team provided all the aforementioned streamflow sequences electronically to the river ecology team in a format suitable for input to the software which the river ecology team uses for the determination of both river EWRs and estuary EWRs. Leading up to and during the course of the EWR-related workshops, the hydrology team provided "on-standby" support to the river and estuary ecology teams - for example, by re-modelling certain modified baseline or future scenarios at their request, or providing detailed feed-back on certain aspects of some of the configurations, etc.

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ABBREVIATIONS AND ACRONYMS

DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EWR	Environmental water requirements
IAP	Invasive alien plants
MAP	Mean annual precipitation
MAR	Mean annual runoff
PSC	Project Steering Committee
WDM	Water conservation and demand management
WRYM	Water resources yield model
WR2012	Water Resources of South Africa Study - 2012

1 INTRODUCTION

1.1 Background

In early 2014 the Department of Water and Sanitation (DWS), through its Directorate: Resource Directed Measures, commissioned Tlou Consulting (Pty) Ltd, to conduct studies to determine the Preliminary Reserve for selected surface water sources, groundwater sources, estuaries and wetlands in the Usutu/Mhlathuze Water Management Area.

During July 2014 Tlou Consulting contracted Aurecon South Africa to conduct a range of hydrological modelling studies to support the above Reserve studies.

1.2 Objective and scope of hydrology study

The objective of the hydrology study was to support the above Preliminary Reserve studies in terms of all their requirements for hydrological information and/or related catchment and systems modelling.

The scope of the hydrology study was to provide the above Preliminary Reserve studies with daily and/or monthly streamflow sequences for natural, present-day and various future scenario catchment development conditions for a range of rivers and estuary inflows in the Usutu/Mhlathuze Water Management Area. Particular attention was paid to representative environmental flow requirement (EWR) sites in various rivers as well as to selected lakes and estuaries.

1.3 Study area

1.3.1 Study catchments

The Study Area for the purposes of this Report comprises all or parts of the catchments of the Usutu, Pongola, Mkuze, Hluhluwe, Msinene, Nyalazi, Mfolozi, Mhlatuze and Matigulu Rivers, as well as of the Mfolozi, Lake St Lucia and the Kosi Bay Estuaries. The wider catchment boundaries as well as the EWR sites are depicted in **Figure 1-1**.

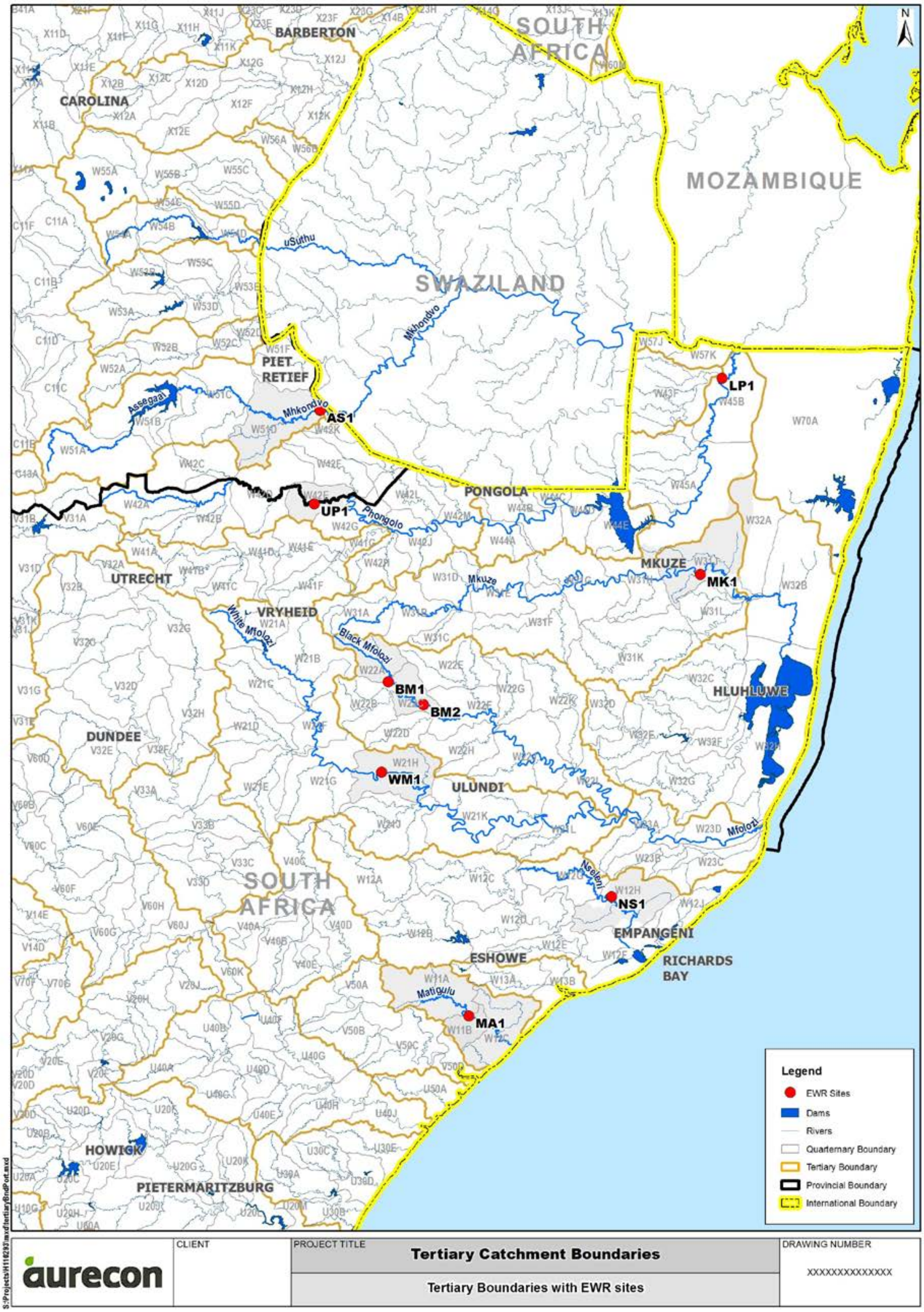

Figure 1-1: Map of study catchment boundaries and river EWR sites

1.3.2 Climate

The climate of the study area comprises wet, hot summers and dry winters which cause icy temperatures in the western mountainous regions, easing to progressively milder temperatures in the easterly subtropical regions approaching the Indian Ocean. Mean annual rainfall varies considerably across the study area from above 1150 mm in some regions to lower than 550 mm in other regions, as is depicted in **Figure 1-2**. Rain-causing mechanisms vary from convective storms to coastal fronts to cyclones.

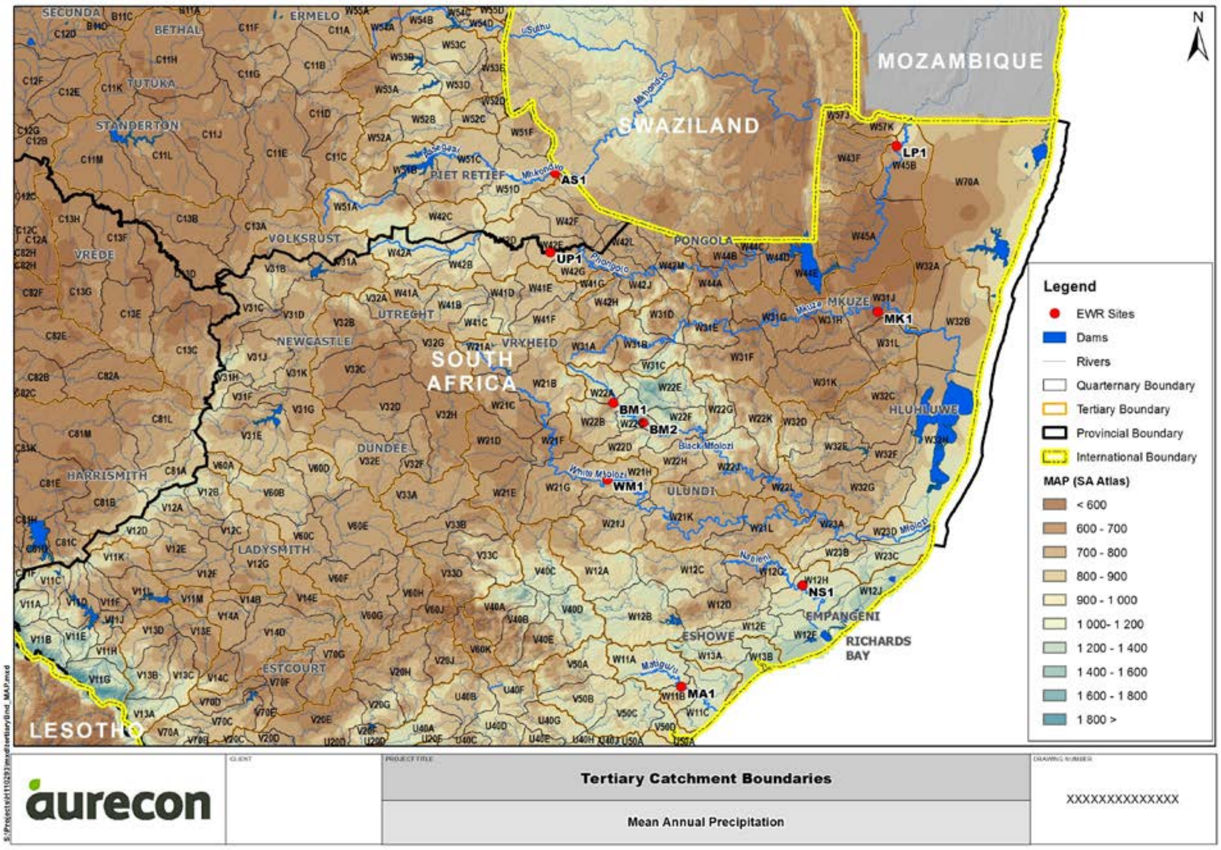

Figure 1-2: Mean annual precipitation (MAP) (mm/a)

1.4 EWR sites: rivers, lakes and estuaries

Table 1-1 presents the coordinates of the eight EWR sites in selected river reaches identified by the aquatic ecology team in the early part of this project. The site locations are presented in **Figure 1-1.** A ninth EWR site, LP1, was identified in the floodplain of the Lower Pongola (in Quaternary Catchment W43F).

Table 1-1: Coordinates of river EWR sites

Quaternary Catchment	River	Site Name	Latitude	Longitude
W51D	Assegaai	EWR Site AS1	27°3'44.28"S	30°59'19.68"E
W42E	Upper Pongola	EWR Site UP1	27°21'50.88"S	30°58'10.62"E
W31J	Mkuze	EWR Site MK1	27°35'31.56"S	32°13'4.80"E
W22C	Black Mfolozi	EWR Site BM1	27°56'20.04"S	31°12'37.08"E
W22C	Black Mfolozi	EWR Site BM2	28°0'50.04"S	31°19'27.48"E
W21H	White Mfolozi	EWR Site WM1	28°13'53.24"S	31°11'17.97"E
W12H	Nseleni	EWR Site NS1	28°38'2.76"S	31°55'51.24"E
W11B	Matigulu	EWR Site MA1	29°1'12.36"S	31°28'13.44"E

The lakes and estuaries of interest are Lake St Lucia and Kosi Bay.

1.5 General approach to this hydrology study

1.5.1 Overview

Given the challenging timeframe for the execution of this hydrology study, our brief was restricted to utilising existing model configurations for natural and present-day conditions, including their input data, in all the study catchments. Consequently, we initially expected that no new hydro-meteorological, land-use and water demand data needed to be assembled. HoThe existing model configurations sourced for this work comprised a mix of monthly and daily models, as described in the following sub-section.

1.5.2 Model configurations sourced from prior or current studies

The prior or current studies from which existing model configurations were sourced are as follows:

- *Develop Integrated Water Resource Management Strategies (IWRMS) and plans for the Incomati and Maputo River Basins for the PRIMA Programme.* Completed: 2012. Client: The National Directorate of Water Affairs (DNA), Mozambique.
- *Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system*. Completed: 2014. Client: iSimangaliso Wetland Park Authority.
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The models whose existing configurations were sourced from the aforementioned studies are as follows:

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- *ACRU* Daily Agrohydrological Modelling System (Schulze, 1995)
- MODSIM-DSS Daily River Basin Decision Support System (Lambadie, 2012).

Table 1-2 presents the details of the sourcing of model configurations and their related input files from prior or current studies for the individual catchments/systems constituting the Study Area.

Table 1-2: Models implemented and studies from which the models were sourced

River EWR Site Catchment / Estuary Inflowing Catchment	Existing Model Configuration	Prior/Current Study
Assegai River	WRYM (monthly)	Incomati-Maputo IWRMS - PRIMA
Upper Pongola River	WRYM (monthly)	Incomati-Maputo IWRMS - PRIMA
Lower Pongola River	MODSIM+WRYM (daily and monthly)	Incomati-Maputo IWRMS - PRIMA
Mkuze River	Provisional: *ACRU*	Lake St Lucia -

River EWR Site Catchment / Estuary Inflowing Catchment	Existing Model Configuration	Prior/Current Study
	(monthly). Final: *ACRU* (daily)	iSimangaliso
Hluhluwe, Msinene, Nyalazi Rivers	Provisional: Pitman WR2012 (monthly). Final: ACRU (daily)	Lake St Lucia - iSimangaliso
Mfolozi River	Provisional: *ACRU* (monthly). Final: *ACRU* (daily)	Lake St Lucia - iSimangaliso
Nseleni River	WRYM (monthly) & *ACRU* (daily)	Mhlathuze WAAS
Matigulu River	Pitman 2012 (monthly)	WR2012
Kosi Bay Catchment	Pitman 2012 (monthly)	WR2012

NB: It should be noted that the aquatic ecology team required streamflow sequences at the river EWR sites at a daily time resolution. Consequently, at the river sites where the scenarios were modelled with a monthly model (AS1, UP1, LP1 and MA1), the resulting simulated monthly flow sequences were disaggregated by means of observed daily flow sequences in nearby tributaries or neighbouring rivers. The natural monthly streamflow sequence at each of the 50 extrapolation nodes across the Study Area was determined by means of the model configuration in which that specific node happened to fall.

1.6 Scenario formulation

River EWRs are usually determined by the aquatic ecology team by means of the so-called DRIFT process. During a follow-up process the potential impacts of various future development or operational scenarios in the study catchments on a range of ecosystem components are assessed in order to evaluate whether the EWRs would need to be modified so that the preliminary Ecological Reserve might reflect projected future changes or operational limitations.

For the Preliminary Reserve assessments of the lakes and estuaries in the system a similar evaluation of the potential impacts of various future development or operational scenarios in the study catchments on a range of estuarine ecosystem components are undertaken.

The hydrology study included superposition on the model configurations of a range of future development or operational scenarios (see Table 1-3) formulated in a previous stage of the

Reserve Determination study, sourced from a final draft report by Tlou Consulting to the then DWA (2014), as well as some more recent proposals by DWS.

Table 1-3: Number of scenarios modelled per EWR Site or estuary inflowing river

River EWR Site / Estuary Inflowing River	Model	Number of Scenarios Modelled (Including Natural)	Time Resolution of Streamflow Series Provided to Ecology Team
Assegai – AS1	WRYM (monthly + disaggregation)	10	Daily
Upper Pongola – UP1	WRYM (monthly + disaggregation)	6	Daily
Lower Pongola – LP1	MODSIM+WRYM (daily and monthly + disaggregation)	6	Daily
Mkuze – MK1	*ACRU* (daily)	6	Daily
Black Mfolozi – BM1	*ACRU* (daily)	5	Daily
Black Mfolozi – BM2	*ACRU* (daily)	7	Daily
White Mfolozi – WM1	*ACRU* (daily)	7	Daily
Matigulu – MA1	Pitman 2012 (monthly + disaggregation)	5	Daily
Nseleni – NS1	*ACRU* + WRYM (daily and monthly)	3	Daily
Mfolozi – Full Catchment	*ACRU* (monthly and daily)	11	Daily
Hluhluwe – Full Catchment	Provisional: Pitman WR2012 (monthly). Final: *ACRU* (daily)	6	Daily
Msinene and Nyalazi – Full Catchments	Provisional: Pitman WR2012 (monthly). Final: *ACRU* (daily)	2	Daily
Mkuze – Full Catchment	*ACRU* (monthly & daily)	6	Daily

River EWR Site / Estuary Inflowing River	Model	Number of Scenarios Modelled (Including Natural)	Time Resolution of Streamflow Series Provided to Ecology Team
Kosi Bay Catchment	Pitman 2012 (monthly)	5	Monthly

NB: It should be noted that during this modelling process the hydrology team determined that a number of the scenario details of DWA (2014) needed to be modified for practical or modelling reasons. The final scenario details, as modelled, are presented in the chapters that follow.

1.7 Purpose and structure of the hydrology specialist report

This hydrology specialist report is a stand-alone document and serves to record most of the analyses that were undertaken to support the preliminary Ecological Reserve assessments as well as all relevant catchment information, model details and outcomes, and critical assumptions. The report structure comprises separate chapters dealing with analysis details and outcomes for each of the nine river/floodplain EWR cases and the two lake/estuary cases, respectively.

NB: It should be noted that, in order to meet both the contractually-specified modelling approaches for simulated scenario streamflows for the four inflowing rivers to Lake St Lucia and for the Mfolozi at its estuary, as well as related deliverable dates for this specialist report (September and October 2014, respectively), this document reflects firstly provisional scenario simulation outcomes for the four inflowing rivers to Lake St Lucia and for the Mfolozi at its estuary, which meet the both the above approaches and deadlines, as well as the final selected scenario outcomes, which followed some 15 months later.

2 ASSEGAI RIVER MODELLING: EWR SITE AS1

2.1 WRYM model configuration

The modelling of the scenarios for the Assegai River EWR Site AS1 was performed with the latest existing configuration of the WRYM model for the Usutu-Pongola System, inherited from the PRIMA IAAP 10 Study (TPTC, 2011).

2.2 Land-use and water demands

2.2.1 Baseline land-use and domestic demands

Table 2-1 presents the present-day land-use and water demands that were included in the aforementioned WRYM configuration and which constitute the Baseline Scenario AS1-1.

Table 2-1: Baseline land-use and water demands for Scenario AS1-1

Quaternary Catchment	Afforestation (km^2)	IAPs (km^2)	Irrigation Area (km^2)	Domestic Demands (10^6 m^3)	Inter-Basin Transfer for Eskom (10^6 m^3)	Dam Capacity (10^6 m^3)
W51A	52	8.8	16.8	0	0	3.8
W51B				1.42	64.2	454
W51C	430	0	3.9	0	0	0
W51D				3.1	0	1.16
Total	482	8.8	20.7	4.52	0	458.96

2.2.1 Scenario EWRs, domestic demands and land-use for AS1

Table 2-2 presents the main land-use, water demands and operational features of the scenarios for EWR Site AS1.

Table 2-2: Main land-use, water demands and operational features of AS1 scenarios

Item	Baseline		AS1-2	AS1-3	AS1-4	AS1-5	AS1-6	AS1-7	AS1-8
	AS1-1A	AS1-1B							
With EWRs	No	No	Baseflow only	Heyshope Dam release capped to 104 m^3/s	Full	Baseflow only	Baseflow only	Baseflow only	Baseflow only
Domestic demand	4.5	4.5	4.5	4.5	4.5	7.8 (2040)	6.1 (2040 with 21% WDM)	6.1	6.1

Item	Baseline		AS1-2	AS1-3	AS1-4	AS1-5	AS1-6	AS1-7	AS1-8
	AS1-1A	AS1-1B							
s (10^6 m^3/a)									
Domestic return	40	40	40	40	40	40	40	40	40

Item	Baseline		AS1-2	AS1-3	AS1-4	AS1-5	AS1-6	AS1-7	AS1-8
	AS1-1A	AS1-1B							
flows (%)									
Irrigation efficie	85	85	85	85	85	85	100	100	100

Item	Baseline		AS1-2	AS1-3	AS1-4	AS1-5	AS1-6	AS1-7	AS1-8
	AS1-1A	AS1-1B							
ncy									
Invasive Alien Plants (k	9	9	9	9	9	9	9	0	0

Item	Baseline		AS1-2	AS1-3	AS1-4	AS1-5	AS1-6	AS1-7	AS1-8
	AS1-1A	AS1-1B							
m²)									
Afforestation (km²)	482	482	482	482	482	482	482	482	300 (38% reduction)
Non	64.2	75.6	64	64	64	62.9	64.9	67.1	68.7

Item	Baseline		AS1-2	AS1-3	AS1-4	AS1-5	AS1-6	AS1-7	AS1-8
	AS1-1A	AS1-1B							
- Failure inter-basin transfer									

Item	Baseline		AS1-2	AS1-3	AS1-4	AS1-5	AS1-6	AS1-7	AS1-8
	AS1-1A	AS1-1B							
for Eskom (10^6 m^3/a)									
Releases	0.64 (PRIMA)	0.28 (Actual)	0.64	0.64	0.64	0.64	0.64	0.64	0.64

Item	Baseline		AS1-2	AS1-3	AS1-4	AS1-5	AS1-6	AS1-7	AS1-8
	AS1-1A	AS1-1B							
from Heyshope (m^3/s)									

2.3 Scenario impacts on streamflows

2.3.1 Impacts on MARs

Table 2-3 presents the MARs at EWR site AS1 for the various scenarios. It can be seen that the only scenarios that have a notable impact on the MAR are AS1-1B - increased inter-basin transfers for Eskom and reduced Heyshope Dam releases - and AS1-8 - reduction in afforestation.

Table 2-3: Mean annual runoff at AS1 for different scenarios

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
AS1_N	278.2	Oct 1951-Sep 2004
AS1-1A	133.4	
AS1-1B	122.0	
AS1-2	133.6	
AS1-3	133.6	
AS1-4	133.6	
AS1-5	132.7	
AS1-6	133.3	
AS1-7	133.6	
AS1-8	147.4	

2.3.2 Impacts on flow duration curves

Figure 2-1 presents the flow duration (percentile) curves for daily streamflows at EWR Site AS1 for different scenarios. The daily flow duration curves illustrate quite graphically the benefits to the streamflow regime of a reduction of afforested area of 38% (scenario AS1-8).

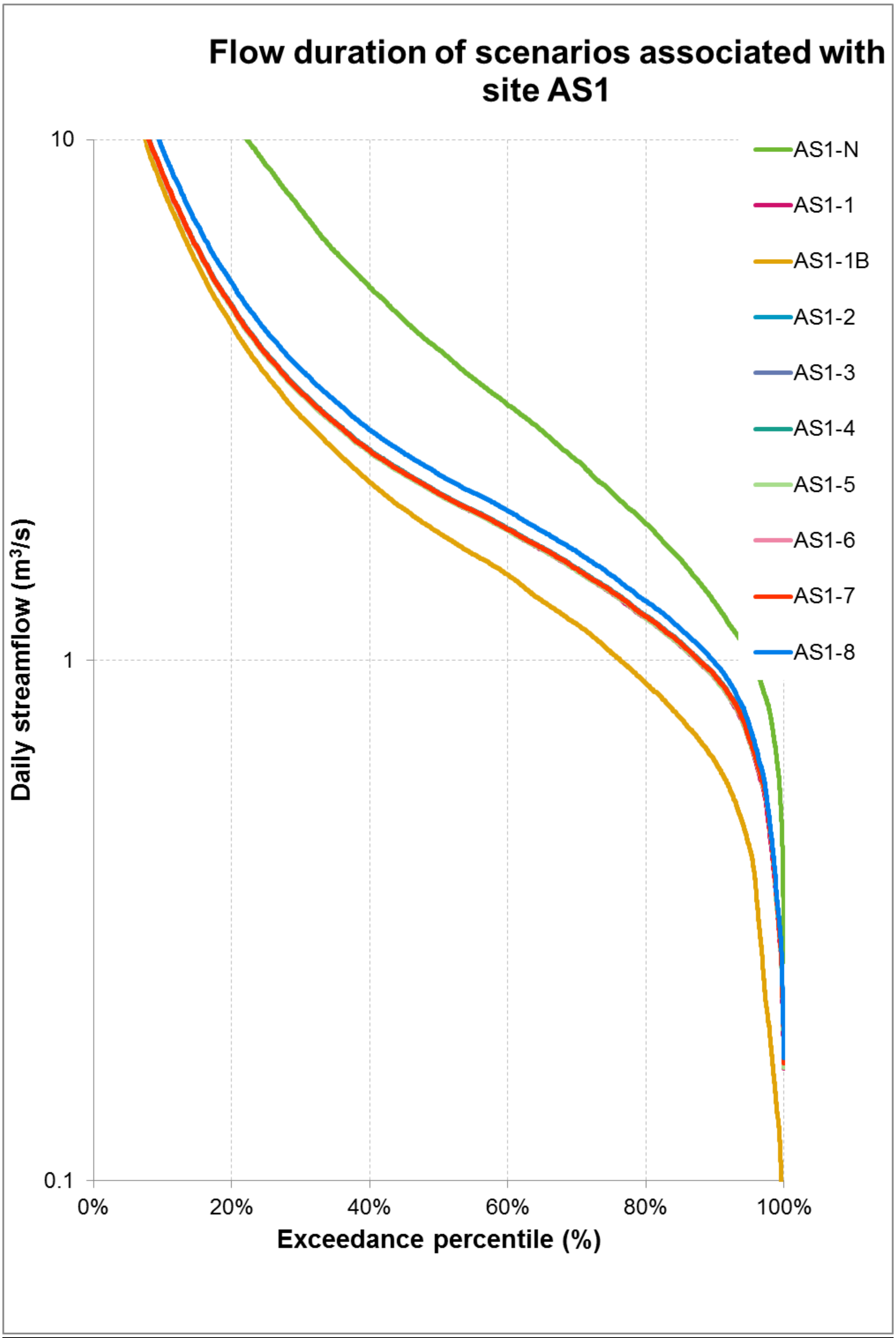


Figure 2-1: Daily flow duration curves at EWR Site AS1 for different scenarios

3 UPPER PONGOLA RIVER MODELLING: EWR SITE UP1

3.1 WRYM model configuration

The modelling of the scenarios for the Upper Pongola River EWR Site UP1 was performed with the latest existing configuration of the WRYM model for the Usutu-Pongola System, inherited from the PRIMA IAAP 10 Study (TPTC, 2011).

3.2 Land-use and water demands

3.2.1 Baseline land-use and domestic demands

Table 3-1 presents the present-day land-use and water demands that were included in the aforementioned WRYM configuration and which constitute the Baseline Scenario UP1-1.

Table 3-1: Baseline land-use and water demands for Scenario UP1-1

Quaternary Catchment	Afforestation (km^2)	IAPs (km^2)	Irrigation Area (km^2)	Domestic Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W42A	15.5	0.8	3.0	0	0
W42B	90.9	0.0	3.6	0	0
W42C	22.0	2.7	1.7	0	0
W42D	209.6	0.0	1.4	1.32	0
W42E u/s UP1	29.1	0.0	1.2	1.93	1.5
W42E d/s UP1	11.2	0.0	0.0	0	0

3.2.2 Scenario EWRs, domestic demands and land-use

Table 3-2 presents the main land-use, water demands and operational features of the scenarios for EWR Site UP1.

Table 3-2: Main land-use, water demands and operational features of UP1 scenarios

Item	Baseline UP1-1	UP1-2	UP1-3	UP1-4	UP1-5
With EWRs	No	No	No	No	No
Domestic demand (10^6 m^3)	3.3	8.4 (2040)	6.7 (2040 with 20% WDM)	6.7	6.7
Domestic return flows (%)	0	0	0	0	0
Irrigation efficiency (%)	85	85	100	100	100
Alien vegetation (km^2)	3.5	3.5	3.5	0	0
Afforestation (km^2)	367	367	367	367	220 (45% reduction)
Dam Capacity to meet domestic demand (10^6 m^3)	1.5	4.0	3.5	3.5	3.5

3.3 Scenario impacts on streamflows

3.3.1 Impacts on MARs

Table 3-3 presents the MARs at EWR site UP1 for the various scenarios. It can be seen that most scenarios have little impact on the MAR, with the 45% reduction in afforestation as the only notable (positive) impact.

Table 3-3: Mean annual runoff at UP1 for different scenarios

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
UP1_N	286.2	Oct 1950-Sep 2005
UP1-1	232.7	
UP1-2	227.2	
UP1-3	229.9	
UP1-4	234.6	
UP1-5	250.4	

3.3.2 Impacts on flow duration curves

Figure 3-1 presents the flow duration (percentile) curves for daily streamflows at EWR Site UP1 for different scenarios. The daily flow duration curves illustrate some benefit to the streamflow regime of a reduction of afforested area of 45% (scenario UP1-5).

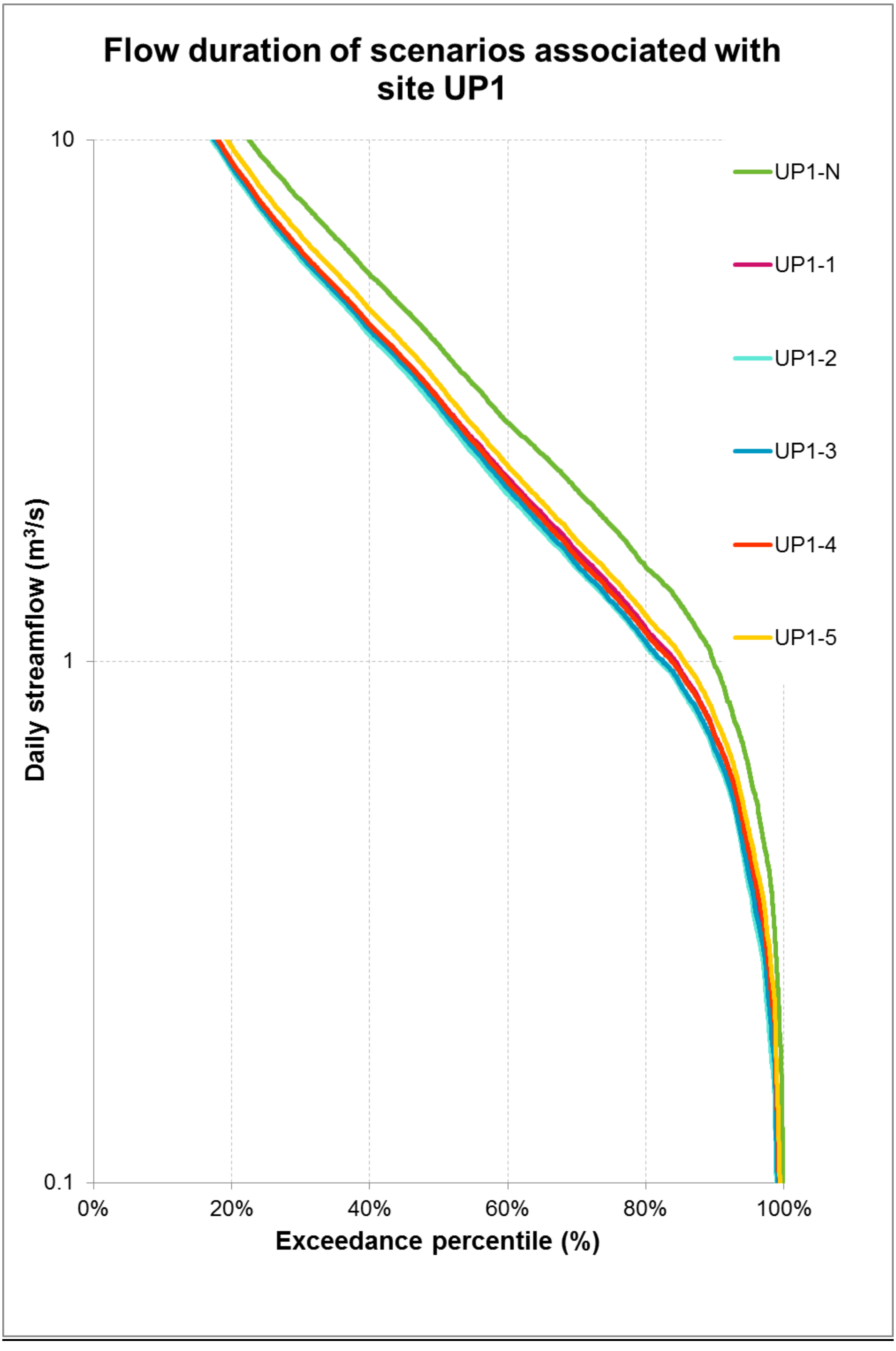


Figure 3-1: Daily flow duration curves at EWR Site UP1 for different scenarios

4 LOWER PONGOLA RIVER MODELLING: EWR SITE LP1

4.1 Modelling approach

The modelling of the scenarios for the Lower Pongola River EWR Site LP1 was performed, respectively, with the latest existing configuration of the WRYM model for the Usutu-Pongola System, inherited from the PRIMA IAAP 10 Study (TPTC, 2011), as well as with the MODSIM-DSS model (Lambadie, 2012) for simulation of daily operation of streamflow releases and accruals downstream of Pongolapoort Dam.

4.2 MODSIM-DSS configuration

MODSIM is a water resource modelling DSS which offers broadly similar functionalities to those of WRYM, but that operates on a daily time-step. As in WRYM, the system is configured as a network, while a framework of priorities (called “costs”) is used to rank which demands have the highest priority to receive any available water.

In the modelling of the operation of Pongolapoort Dam, the implementation of MODSIM enabled constraints on the daily releases to be simulated; given that the required annual October flood peak releases of 800m^3/s would not be possible if the dam storage level would be below RL126.4m.

In order to model the Pongolapoort Dam operations in MODSIM, the monthly WRYM inflows into Pongolapoort Dam were disaggregated to daily streamflows. The maximum releases possible for different storage elevations were input into MODSIM as part of the Pongolapoort Dam’s characteristics. The required annual October flood peak releases and other routine downstream demands were linked to the Dam via suitable settings in the model’s network configuration. For each day, the full downstream demands were supplied by MODSIM if sufficient maximum outflow capacity happened to be available. The WRYM inflows from the tributaries downstream of Pongolapoort Dam, primarily from the Ngwavuma River, were included in the configuration (after disaggregation) so that the model would generate the total inflows to the Pongola River upstream of EWR Site LP1.

4.3 Land-use and water demands

4.3.1 Baseline land-use and domestic demands

Table 4-1 presents the present-day land-use and water demands that were included in the abovementioned WRYM configuration and which constitute the Baseline Scenario LP1-1.

Table 4-1: Baseline land-use and water demands for Scenario LP1-1

Sub-System	Quaternary Catchment	Afforestation (km^2)	IAPs (km^2)	Irrigation Area (km^2)	Domestic Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
U/s Pongolapoort Dam	W41A-D	184.1	2.2	3.8		0.85
	W41E-G	19.2	1.3	0.0		113
	W42A-E (u/s of UP1)	367.1	3.4	10.9	3.25	1.5
	W42E (d/s of UP1) to W42M	145.1	10.3	12.2	3.23	0
	W44A-W44D	0.2	0.3	182.7		0
Controlled from Pongolapoort Dam	W44E	0.0	0.0	31.28		1587
	W45A	0.0	0.0	90.4	4.9	0
	W45B	0.0	0.0			0
Ngwavuma tributary	W43A-D	56.2	24.0	1.2		0
	W43E-F	0.0	0.0	0.0		0

4.3.2 Scenario EWRs, domestic demands and land-use

Table 4-2 presents the main land-use, water demands and operational features of the original scenarios for EWR Site LP1. In the EWR workshop, additional to the natural and baseline scenarios, altogether seven other future scenarios were evaluated for which we generated daily streamflows (releases and spills) downstream of the Dam. Four of these were variations on scenario LP1-3. Scenario LP1-2 was not used in the EWR workshop.

Table 4-2: Main land-use, water demands and operational features of original LP1 scenarios #

Item	Baseline (LP1-1)	LP1-2	LP1-3	LP1-4	LP1-5
October flood release: 200 million m^3	y	y	n	n	n
With EWR (baseflow)	y	y	y	y	y
With EWR (flood)	n	n	y	y	y
WDM scenario limited to adjusting demands controlled by Pongolapoort Dam					
Domestic Demand (10^6 m^3)	4.9	4.9	4.9	39.9	31.5
Irrigation efficiency (%)	85	85	85	85	100
Pongolapoort Dam – 70% FSC	y	y	y	y	y

Values provided by Mr Norman Ward of the DWS KwaZulu-Natal Regional Office.

4.4 Scenario impacts on streamflows

4.4.1 Impacts on MARs

Table 4-3 presents the estimated MARs at EWR site LP1 for the natural (LP1_N) and baseline (LP1-1) scenarios, as well as the future scenarios LP1-3, LP1-4 and LP1-5. It can be seen that inclusion of the flood EWR instead of the present-day practice of an October release of 200 million m^3 increases the MAR at LP1.

Table 4-3: Mean annual runoff at LP1 for different scenarios

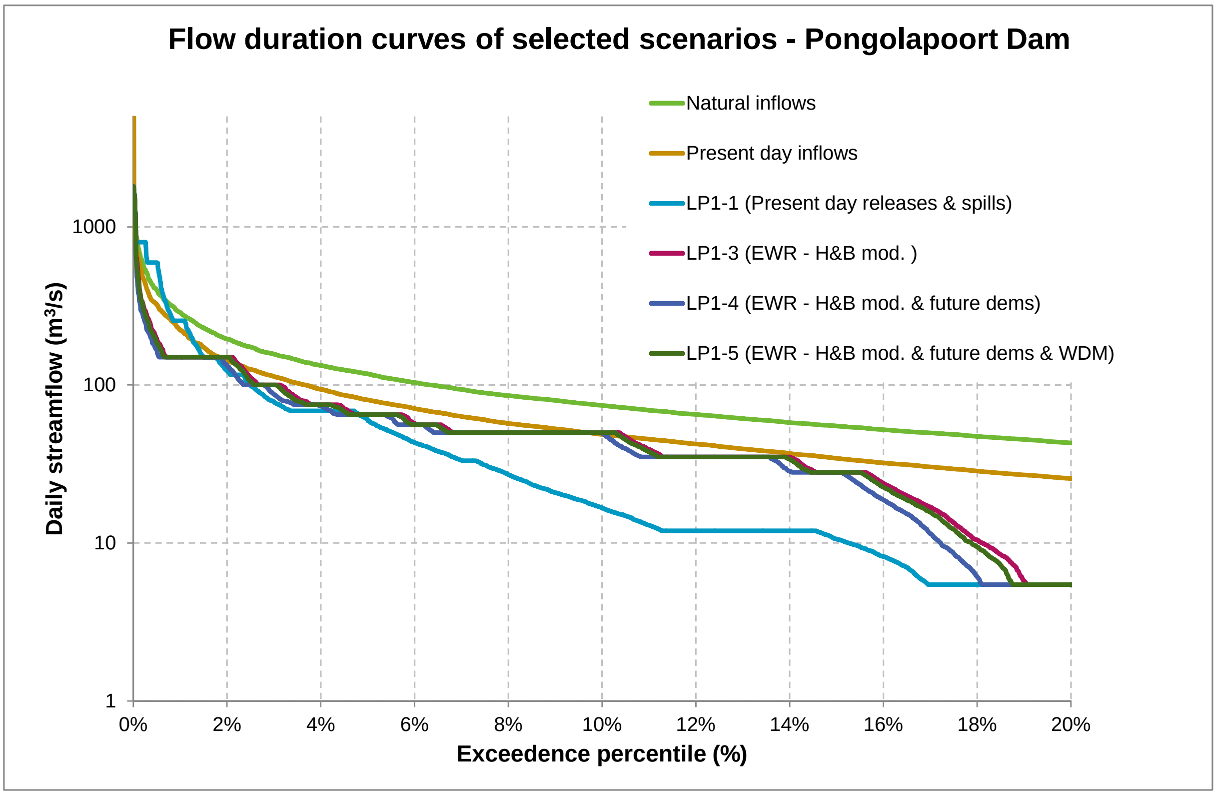
Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
LP1_N	1225.2	Oct 1951 – Sep 2004
LP1-1	806.4	
LP1-3	813.7	

Scenario	Mean Annual Runoff (Million m³/a)	Simulation Period
LP1-4	785.8	
LP1-5	805.9	

4.4.2 Impacts on flow duration curves

Figure 4-1 presents the flow duration (percentile) curves for daily streamflows downstream of the Dam for the primary scenarios evaluated in the EWR workshop. It can be seen that the flow duration curve for future scenario LP1-3 tracks that of the present day inflows for the upper 16% of daily streamflows markedly better than that of LP1-1 (present day releases and spills).

Figure 4-1: Daily flow duration curves downstream of Pongolapoort Dam for different scenarios



5 MKUZE RIVER MODELLING: EWR SITE MK1

5.1 *ACRU* model configuration and calibration

5.1.1 Configuration refinements

The *ACRU* configuration sourced from the iSimangaliso (GEF) study (Aurecon, 2014) was considerably refined for this hydrology study, as follows:

- The previously consolidated dam storages were fully disaggregated and their locations carefully placed in the configuration.
- Irrigation return flows were explicitly and dynamically modelled (including irrigation with imported Pongola water) whereas in the prior study irrigation return flows had been treated as a proportion of demand.
- Return flows from urban areas, ignored in the prior study, were included downstream of all urban water supply nodes.
- The existing built-in excessive runoff responses of degraded areas were significantly dampened.

5.1.2 Calibration

In the iSimangaliso study the default *ACRU* settings for the Mkuze and the other three contributing rivers to Lake St Lucia generated excessive inflows to the Lake – indicated by excessively low simulated salinities in the Lake. This was partially countered by increasing all soil depths in the model. However, ultimately the simulated inflows into the Lake had to be down-scaled by a power function.

In this study, we retained *ACRU*'s default soil depth settings (originally based on the Agricultural Research Council's national land-type maps) for the Mkuze. The mean annual rainfall was factored downwards until a reasonable correspondence between the simulated daily streamflows and the observed streamflow record at DWA gauging station W3H008 was reached. We preferred this approach, because, by reducing the rainfall inputs by a constant proportion rather than a power function-based reduction of the simulated streamflows as in the iSimangaliso study, the integrated hydrological response characteristics of the Mkuze catchment remained approximately preserved and it avoided distortions of the simulated hydrograph characteristics of floods, recessions, freshet and baseflows. For reliable river EWR determination, the latter requirement was highly significant.

The W3H008 record covered the period 1970 – 2010, but, given that the depth-discharge rating equation/table for this weir had a low limit of 23 m^3/s, resulting in a significant number of rating limit exceedences, viz. 718 days, the total observed MAR had to be estimated.

We estimated the rating limit exceedence part of the MAR as follows: Given that the observed record for this gauge included not only discharge, but also stage (water depth), we could calculate the mean of the water depths of all exceeded days. We then calculated the ratio of the depth limit of the rating equation/limit as a % of this mean water depth of exceeded days, i.e. 41.6%. This value was then powered by 1.5, which is a generally-used power value for a depth-discharge equation for a broad-crested weir such as W3H008. The result was a value of 268%, which indicated the approximate extent to which the recorded MAR of the 718 rating exceedence days should be increased to account for the under-measurement of flow on rating exceedence days The resulting 87 million m^3/a was then added to the under-recorded MAR of 91.6 million m^3/a, resulting in an estimated observed MAR of 178.6 million m^3/a (more than 20% of days with missing observations were removed from both sequences).

A limited iterative process converged on a rainfall reduction factor for the Mkuze River catchment of 0.78. In order to acceptably match the W3H008 observed recessions and baseflows, the *ACRU* default drainage rate from the root-zone to groundwater had to be markedly increased. We cross-checked our estimated observed MAR of 178.6 million m^3/a against the WR2012 current-day MAR of 159.6 million m^3/a at a site upstream of this gauge (note: for different periods). We believe the above calibration process achieved a pragmatic balance between the MAR and essential hydrograph characteristics by reducing the MAPs of the various modelling sub-catchments by the factor of 0.78. The final simulated MAR was 183.6 million m^3/a for the 1970 - 2010 period.

We accepted the small over-simulation of the MAR, given that the weir had had a low-flow by-pass caused by the 2000 floods which had not been corrected.

5.2 Land-use and water demands

5.2.1 Baseline land-use and domestic/ industrial demands

Table 5-1 presents the present-day land-use and water demands that were super-imposed on the natural *ACRU* configuration to form the Baseline Scenario MK1-1 (sourced from Aurecon, 2014).

Table 5-1: Baseline land-use and water demands for Scenario MK1-1

Quaternary Catchment	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic/Industrial Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W31A	51.1	3.22	2.33 (Industrial)	6.79
W31B	43.2	1.60	0	1.03
W31C	44.6	1.62	0	0

Quaternary Catchment	Afforestation and IAPs (km²)	Irrigation Area (km²)	Domestic/Industrial Demands (10^6 m³)	Dam Capacity (10^6 m³)
W31D	51.4	1.56	0	0.79
W31E	0	0.68	0	0
W31F	11.8	18.0	0	2.19
W31G	0	4.0	0	0.47
W31H	0	25.0	3.02 (Domestic)	3.75
W31J	0	1.0	0	0
Total	202.1	56.68	5.35	15.02

5.2.2 Scenario EWRs, domestic demands and land-use

Table 5-2 presents the main land-use, water demands and operational features of the *original* scenarios for EWR Site MK1. It should be noted that after discussion with the aquatic ecology team leader, the EWRs for scenarios MK1-2 and MK1-5 were not included in the analyses because these EWRs were not going to be available in time for the deadline of this report. That meant that scenarios MK1-4 and MK1-5 were identical and, therefore, MK1-5 fell away.

Table 5-2: Main land-use, water demands and operational features of MK1 scenarios

Item	Baseline MK1-1	MK1-2	MK1-3	MK1-4	MK1-5
With EWRs	No	Yes	No	No	Yes
Domestic demand (10^6 m³)	3.02	3.02	5.74 (2040)	5.74	5.74
Industrial demand (10^6 m³)	2.33	2.33	5.16 (2040)	4.02 (2040 with 22% WDM savings)	4.02
Afforestation (km²)	202.1	202.1	202.1	202.1	202.1
Domestic return flows	35	35	35	35	35

Item	Baseline MK1-1	MK1-2	MK1-3	MK1-4	MK1-5
(%)					
Irrigation (km^2)	56.8	48.76	56.8	56.8	56.8
Irrigation effic. (incl. distrib. losses) (%)	75	85	75	85	85

5.3 Scenario impacts on streamflows

5.3.1 Impacts on MARs

Table 5-3 presents the MARs at EWR site MK1 for the various scenarios. It can be seen that the respective future scenarios result in relatively minor differences in the MARs, with scenario MK1-2 (20% reduction in irrigation demand) being the most favourable.

Table 5-3: Mean annual runoff at MK1 for different scenarios

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
MK1_N	271.8	Oct 1959-Sep 2010
MK1-1	237.6	
MK1-2	245.8	
MK1-3	238.0	
MK1-4	241.2	

5.3.2 Impacts on flow duration curves

Figure 5-1 presents the flow duration (percentile) curves for daily streamflows at EWR Site MK1 for the various scenarios. It can be seen that the respective future scenarios result in relatively minor differences in the daily streamflow regimes.

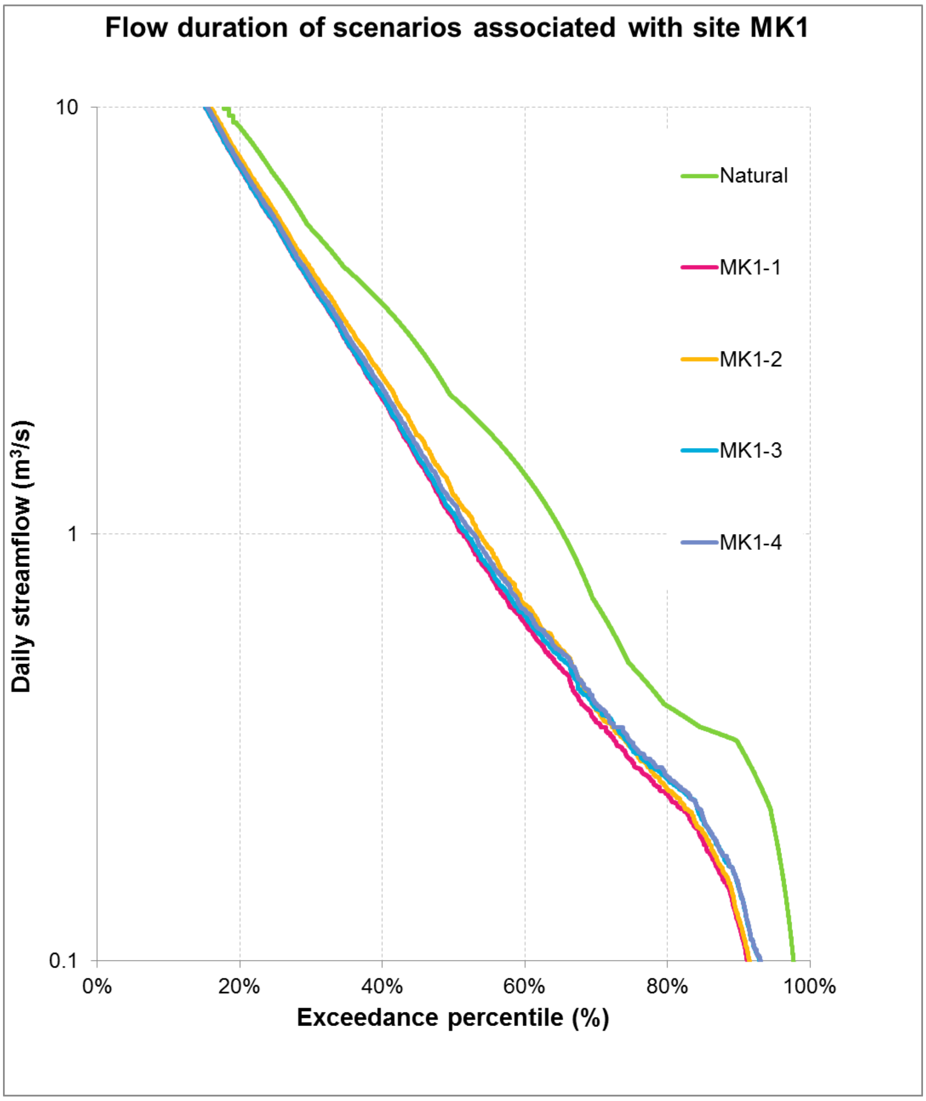


Figure 5-1: Daily flow duration curves at EWR Site MK1 for different scenarios

6 BLACK MFOLOZI RIVER MODELLING: EWR SITE BM1

6.1 *ACRU* model configuration and calibration

6.1.1 Configuration refinements

The *ACRU* configuration for the Black Mfolozi sourced from the iSimangaliso (GEF) study (Aurecon, 2014) was considerably refined for this hydrology study, as follows:

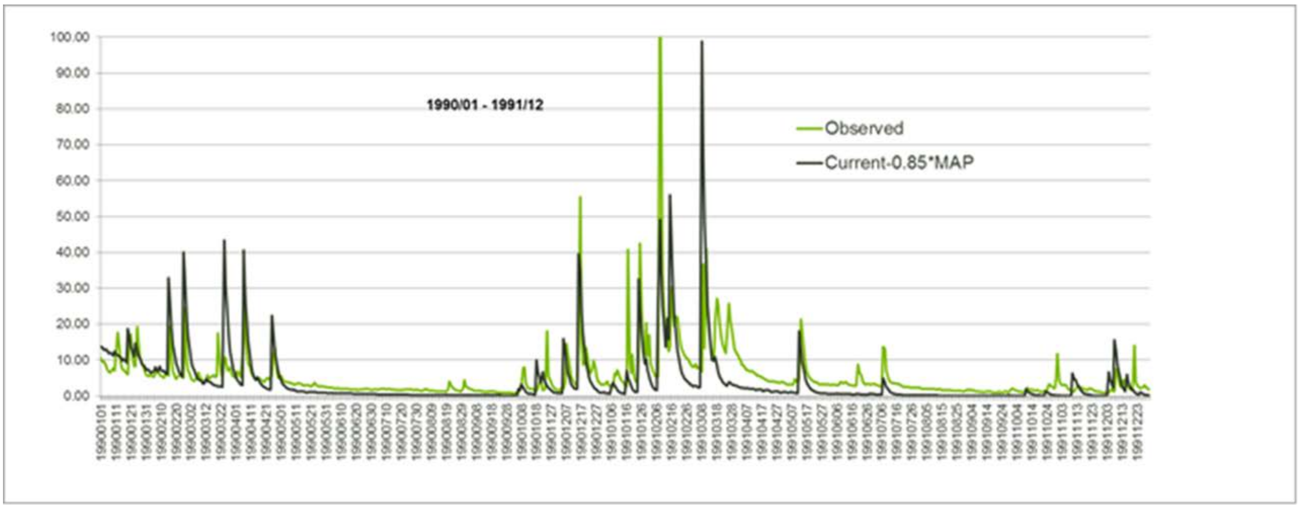
- Irrigation return flows were explicitly and dynamically modelled whereas in the prior study irrigation return flows had been treated as a proportion of demand.
- Return flows from urban areas, ignored in the prior study, were included downstream of all urban water supply nodes.
- The existing built-in excessive runoff responses of degraded areas were significantly dampened.

6.1.2 Calibration

In the iSimangaliso study the default *ACRU* settings for the Black Mfolozi seemed to generate excessive streamflows relative to the historical streamflow records at DWA streamflow gauging station W2H006, which we then partially countered by increasing all soil depths in the model. However, ultimately lower simulated streamflows in the Black Mfolozi had to be created by down-scaling the rainfall by a factor of 0.92.

In this hydrology study, we retained *ACRU*'s default soil depth settings (originally based on the Agricultural Research Council's national land-type maps) for the Mfolozi. As motivated above, the mean annual rainfall was factored downwards until a reasonable approximation was reached of the historical streamflow record at DWA streamflow gauging station W2H006. In order to acceptably match the observed recessions, the *ACRU* default drainage rate from the root-zone to groundwater had to be markedly increased.

A limited iterative process converged on a rainfall reduction factor for the Black Mfolozi catchment of 0.85. **Figure 6-1** presents typical comparisons of simulated and observed daily streamflows at gauge W2H006. It should be noted that the observed values are for historical land-use and water-use conditions, whereas the simulated values are for present-day land-use and water-use conditions. **Table 6-1** presents a comparison of the observed and simulated MARs at W2H006.



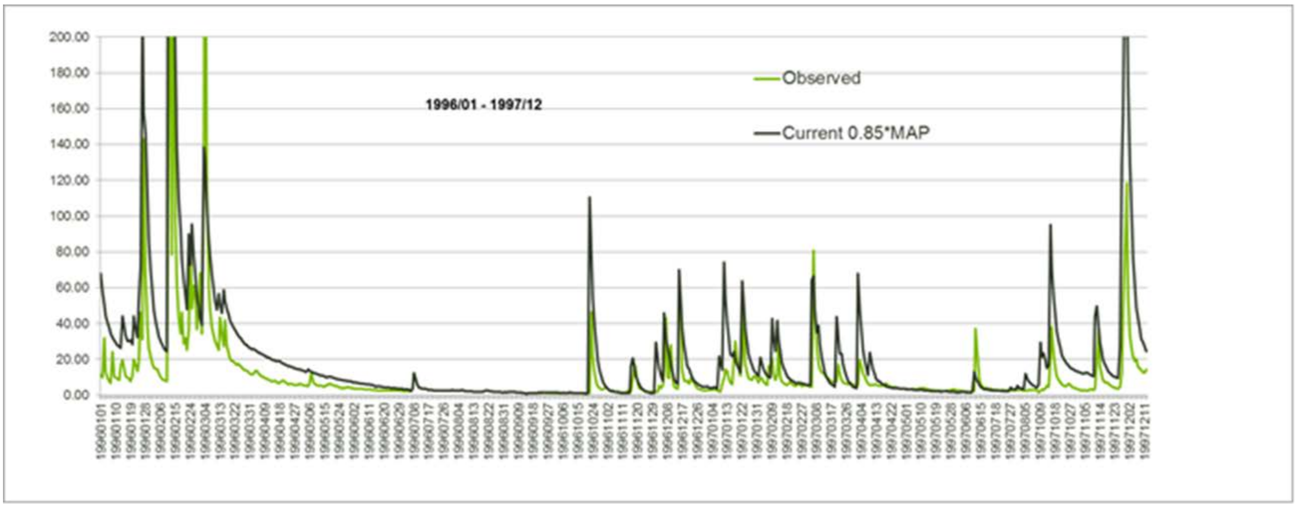


Figure 6-1: Typical correspondence of observed and simulated daily streamflows at W2H006 (m^3/s) for two randomly selected years

Table 6-1: Observed and simulated MARs for the period 1986 - 2010

Gauge (1986 – 2010)	Observed MAR (million m^3/a)	Simulated MAR (million m^3/a)
W2H006 (Black)	182	213
W2H005 (White)	255	315

The values in **Table 6-1** exclude all days with missing observed values and also account for rating curve exceedences in the observed record. Excessive numbers of simulated near-zero/zero flow days were empirically patched. We accepted over-simulation of MARs because further reduction of rainfall reduced simulated baseflows and freshets to unrealistic levels and introduced additional near-zero and zero flow days.

6.2 Land-use and water demands

6.2.1 Baseline land-use and domestic demands

Table 6-2 presents the present-day land-use and water demands that were super-imposed on the natural *ACRU* configuration to form the Baseline Scenario BM1-1 (sourced from Aurecon, 2014).

Table 6-2: Baseline land-use and water demands for Scenario BM1-1

Quaternary Catchment	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W22A	84.0	2.16	0.13	0.62

6.2.2 Scenario EWRs, domestic demands and land-use

Table 6-3 presents the main land-use, water demands and operational features of the *original* scenarios for EWR Site BM1. It should be noted that after discussion with the aquatic ecology team leader, the EWRs for scenarios BM1-2 and BM1-4 were not included in the analyses because the EWRs were not going to be available in time for the deadline of this report.

Table 6-3: Main land-use, water demands and operational features of BM1 scenarios

Item	Baseline BM1-1	BM1-2	BM1-3	BM1-4
With EWRs	No	Yes	No	Yes
Domestic demand (10^6 m^3)	0.13	0.091 (Curtailed to 70% as basic human needs)	0.31 (2040)	0.217 (2040 - Curtailed to 70% as basic human needs)
Afforestation (km^2)	84.0	84.0	84.0	84.0
Domestic return flows (%)	25	25	25	25
Irrigation efficiency (incl. distribution losses) (%)	75	85	75	85

6.3 Scenario impacts on streamflows

6.3.1 Impacts on MARs

Table 6-4 presents the MARs at EWR site BM1 for the various scenarios. It can be seen that the respective future scenarios cause relatively minor differences in the MARs.

Table 6-4: Mean annual runoff at BM1 for different scenarios

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
BM1_N	31.5	Oct 1959-Sep 2010
BM1-1	23.9	
BM1-2	24.4	
BM1-3	22.5	
BM1-4	23.3	

6.3.2 Impacts on flow duration curves

Figure 6-2 presents the daily flow duration curves at EWR site BM1 for low flows for the various scenarios. It can be seen that the respective future scenarios cause relatively minor differences in the daily low-flow regimes.

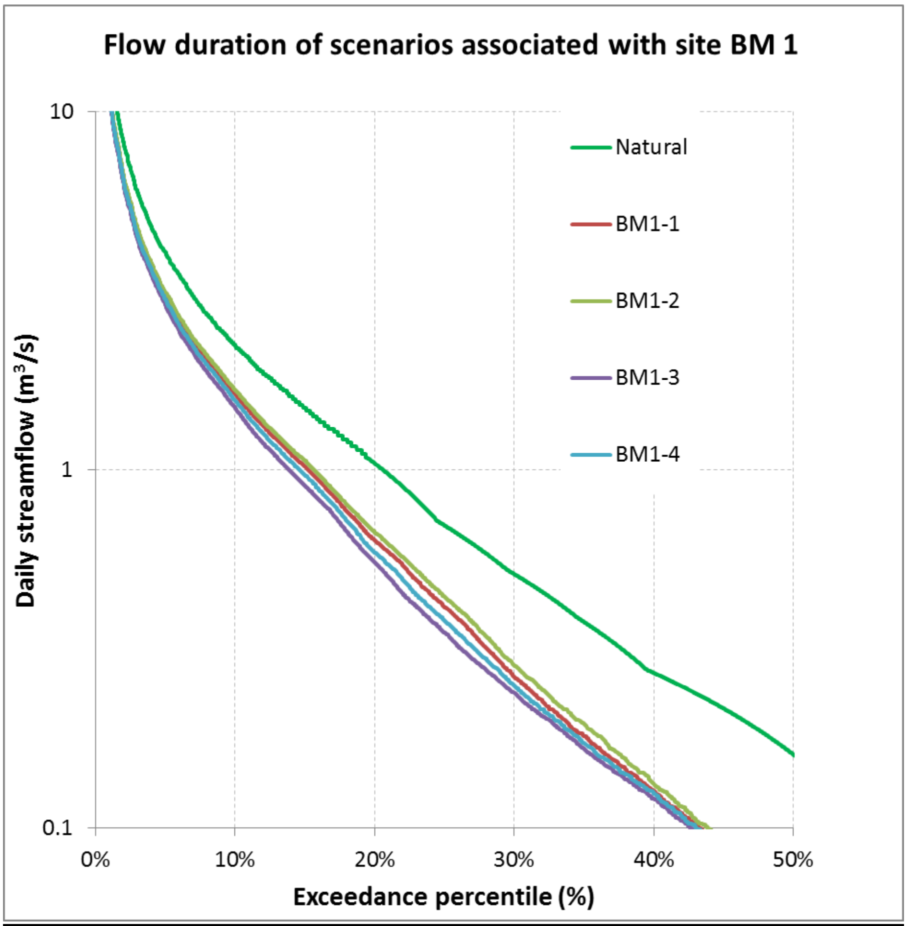


Figure 6-2: Daily flow duration curves at EWR Site BM1 for different scenarios

7 BLACK MFOLOZI RIVER MODELLING: EWR SITE BM2

7.1 *ACRU* model configuration and calibration

7.1.1 Configuration refinements

The *ACRU* configuration for the Black Mfolozi sourced from the iSimangaliso (GEF) study (Aurecon, 2014) was considerably refined for this hydrology study, as follows:

- Irrigation return flows were explicitly and dynamically modelled whereas in the prior study irrigation return flows had been treated as a proportion of demand.
- Return flows from urban areas, ignored in the prior study, were included downstream of all urban water supply nodes.
- The existing built-in excessive runoff responses of degraded areas were significantly dampened.

7.1.2 Calibration

In the iSimangaliso study the default *ACRU* settings for the Black Mfolozi seemed to generate excessive streamflows relative to the historical streamflow records at DWA streamflow gauging station W2H006, which was then partially countered by increasing all soil depths in the model. However, ultimately lower simulated streamflows in the Black Mfolozi had to be created by down-scaling the rainfall by a factor of 0.92.

In this study, we retained *ACRU*'s default soil depth settings (originally based on the Agricultural Research Council's national land-type maps) for the Mfolozi. As motivated above, the mean annual rainfall was factored downwards until a reasonable approximation was reached of the historical streamflow record at DWA streamflow gauging station W2H006. In order to acceptably match the observed recessions, the *ACRU* default drainage rate from the root-zone to groundwater had to be markedly increased.

A limited iterative process converged on a rainfall reduction factor for the Black Mfolozi catchment of 0.85. . **Figure 6-1** presents typical comparisons of simulated and observed daily streamflows at gauge W2H006. It should be noted that the observed values are for historical land-use and water-use conditions, whereas the simulated values are for present-day land-use and water-use conditions. **Table 6-1** presents a comparison of the observed and simulated MARs at W2H006. The values in **Table 6-1** exclude all days with missing observed values and also account for rating curve exceedences in the observed record. Excessive numbers of simulated near-zero/zero flow days were empirically patched. We accepted over-simulation of MARs because further reduction of rainfall reduced simulated baseflows and freshets to unrealistic levels and introduced additional near-zero and zero flow days.

7.2 Land-use and water demands

7.2.1 Baseline land-use and domestic demands

Table 7-1 presents the present-day land-use and water demands that were super-imposed on the natural *ACRU* configuration to form the Baseline Scenario BM2-1 (sourced from Aurecon, 2014).

Table 7-1: Baseline land-use and water demands for Scenario BM2-1

Quaternary Catchment	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W22A	84.0	2.16	0.13	0.62
W22B	19.4	0.41	0	0
W22C	12.7	4.77	0	1.3

Quaternary Catchment	Afforestation and IAPs (km²)	Irrigation Area (km²)	Domestic Demands (10^6 m³)	Dam Capacity (10^6 m³)
W22D	0	0	0	0
W22E	187.5	0	0	0
W22F	2.8	0	2.26 (Ceza)	0
W22G	0	0	3.23 (Nongoma)	6.0
Total	306.4	5.34	5.62	7.92

7.2.2 Scenario EWRs, domestic demands and land-use

Table 7-2 presents the main land-use, water demands and operational features of the original scenarios for EWR Site BM2. It should be noted that after discussion with the aquatic ecology team leader, the EWRs for scenario BM2-2 was not included in the analyses because these EWRs were not going to be available in time for the deadline of this report.

Table 7-2: Main land-use, water demands and operational features of BM2 scenarios

Item	Baseline BM2-1	BM2-2	BM2-3	BM2-4	BM2-5
With EWRs	No	Yes	No	No	No
Domestic demand (10^6 m³)	5.49 (Includes 22% excess losses)	3.85 (Basic human needs)	17.63 (2025 + 22% excess losses)	21.37 (2040 + 22% excess losses)	17.52 (2040 with 22% WDM savings)
Afforestation (km²)	306.4	153.2	306.4	306.4	306.4
Domestic return flows (%)	25	25	25	25	25
Irrigation effic. (incl. distrib. losses) (%)	75	85	75	85	85
Vukwana Dam capacity	6	6	20	0	0

Item	Baseline BM2-1	BM2-2	BM2-3	BM2-4	BM2-5
(10^6 m^3)					
New OCS capacity (10^6 m^3)	0	0	0	25	25

7.3 Scenario impacts on streamflows

7.3.1 Impacts on MARs

Table 7-3 presents the MARs at EWR site BM2 for the various scenarios. It can be seen that the respective future scenarios cause relatively minor differences in the MAR relative to the Baseline.

Table 7-3: Mean annual runoff at BM2 for different scenarios

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
BM2_N	95.1	Oct 1959-Sep 2010
BM2-1	85.0	
BM2-2	85.6	
BM2-3	81.4	
BM2-4	80.1	
BM2-5	81.1	

7.3.2 Impacts on flow duration curves

Figure 7-1 presents the daily flow duration curves for low flows at EWR site BM2 for the various scenarios. It can be seen that all the respective future scenarios cause a notable reduction in the daily flow regimes below a discharge of $10m^3/s$.

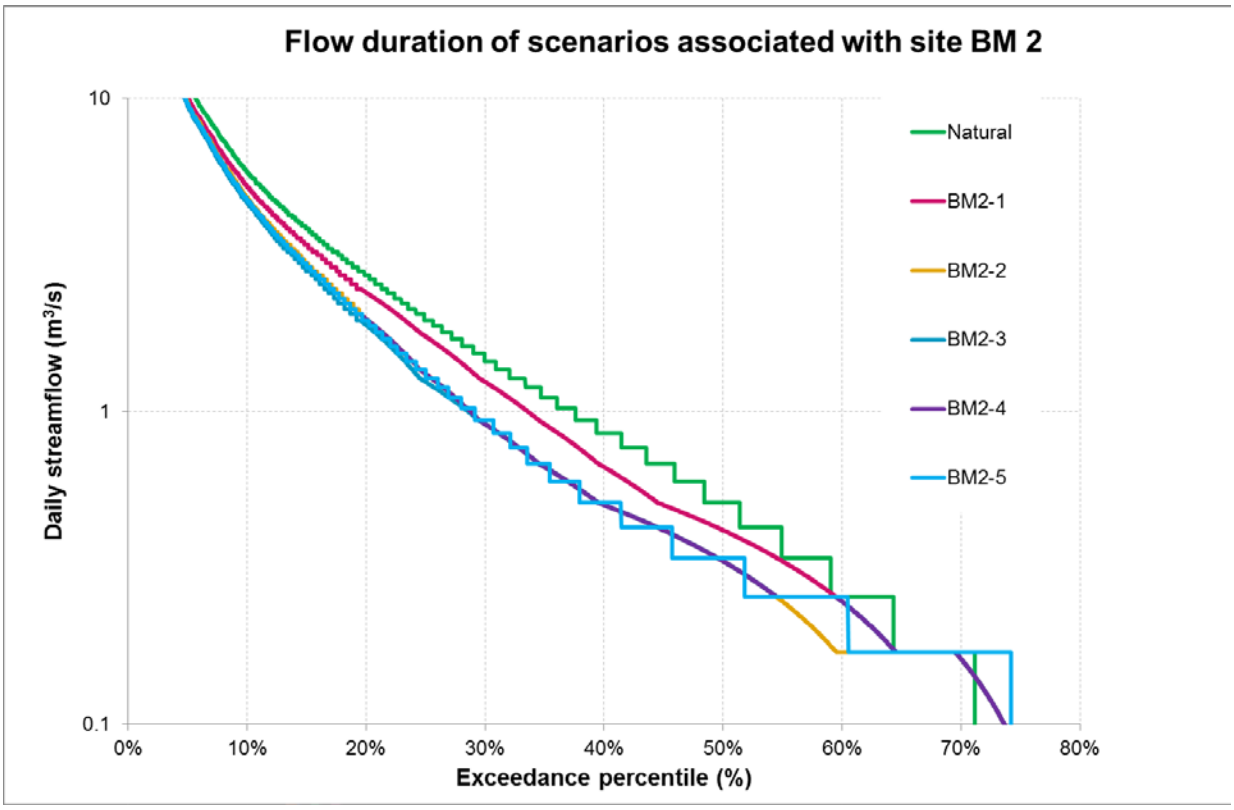


Figure 7-1: Daily low-flow duration curves at EWR Site BM2 for different scenarios

8 WHITE MFOLOZI RIVER MODELLING: EWR SITE WM1

8.1 *ACRU* model configuration and calibration

8.1.1 Configuration refinements

The *ACRU* configuration for the White Mfolozi sourced from the iSimangaliso (GEF) study (Aurecon, 2014) was considerably refined for this hydrology study, as follows:

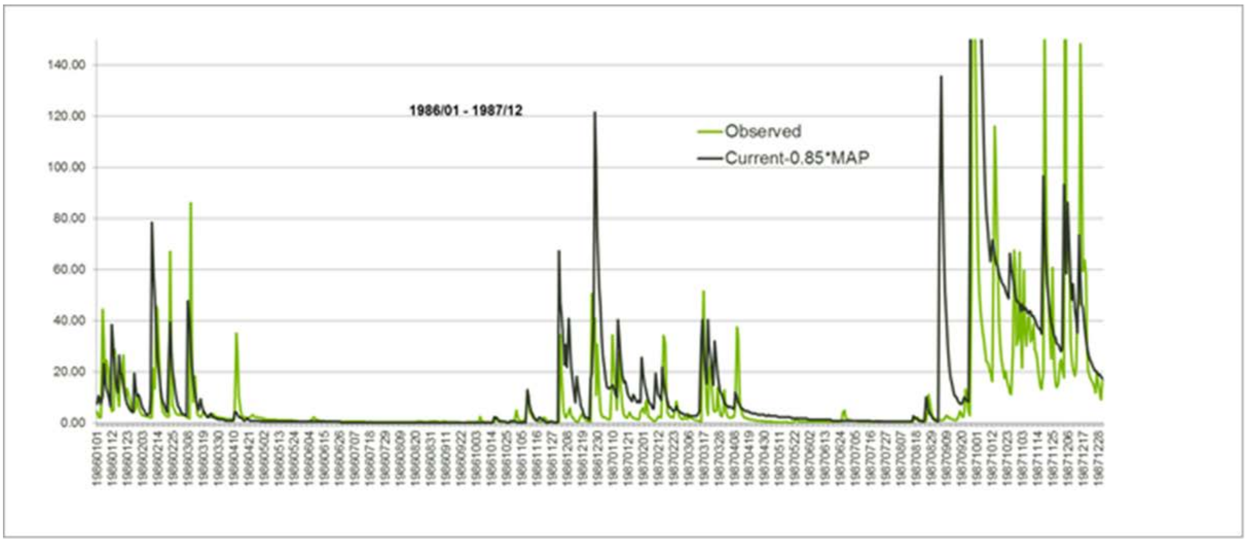
- Mvunyana Dam was included in the configuration.
- Irrigation return flows were explicitly and dynamically modelled whereas in the prior study irrigation return flows had been treated as a proportion of demand.
- Return flows from urban areas, ignored in the prior study, were included downstream of all urban water supply nodes.
- The existing built-in excessive runoff responses of degraded areas were significantly dampened.

8.1.2 Calibration

In the iSimangaliso study the default *ACRU* settings for the White Mfolozi seemed to generate excessive streamflows relative to the historical streamflow records at DWA streamflow gauging station W2H005, which was then partially countered by increasing all soil depths, but ultimately lower simulated streamflows in the White Mfolozi had to be created by down-scaling the rainfall by a factor of 0.92.

In this study, we retained *ACRU*'s default soil depth settings (originally based on the Agricultural Research Council's national land-type maps) for the Mfolozi. As motivated above, we factored the mean annual rainfall downwards until a reasonable approximation was reached of the historical streamflow record at DWA streamflow gauging station W2H005. In order to acceptably match the observed recessions, the *ACRU* default drainage rate from the root-zone to groundwater had to be markedly increased.

A limited iterative process converged on a rainfall reduction factor for the White Mfolozi catchment of 0.85. **Figure 8-1** presents typical comparisons of simulated and observed daily streamflows at gauge W2H005. It should be noted that the observed values are for historical land-use and water-use conditions, whereas the simulated values are for present-day land-use and water-use conditions. **Table 6-1** presents a comparison of the observed and simulated MARs at W2H005. The values in **Table 6-1** exclude all days with missing observed values and also account for rating curve exceedences in the observed record. Excessive numbers of simulated near-zero/zero flow days were empirically patched. We accepted over-simulation of MARs because further reduction of rainfall reduced simulated baseflows and freshets to unrealistic levels and introduced additional near-zero and zero flow days.



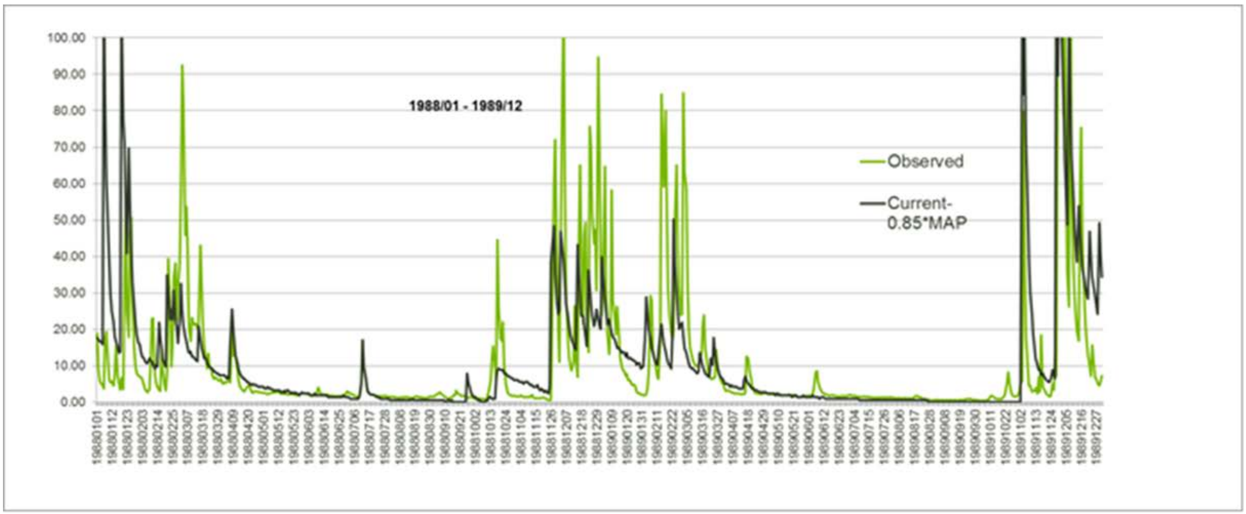


Figure 8-1: Typical correspondence of observed and simulated daily streamflows at W2H005 (m^3/s) for two randomly selected years

8.2 Land-use and water demands

8.2.1 Baseline land-use and domestic demands

Table 8-1 presents the present-day land-use and water demands that were super-imposed on the natural *ACRU* configuration to form the Baseline Scenario WM1-1 (sourced from Aurecon, 2014).

Table 8-1: Baseline land-use and water demands for Scenario WM1-1

Quaternary Catchment	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic Demands (10^6 m^3)	Dam Capacity (10^6 m^3)

Quaternary Catchment	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W21A	87.0	1.17	7.51	22.46
W21B	79.0	3.5	0	1.2
W21C	2.9	4.67	0	0.82
W21D	0.6	0	5.17	2.87
W21E	0.4	0	0	0
W21F	3.1	0.32	0	0
W21G	4.8	0	0	0
W21H	2.4	0	0.79	0
W21J	0	0	0	0
W21K	0	0	8.57	0
Total	180.2	8.66	22.04	27.35

8.2.2 Scenario EWRs, domestic demands and land-use

Table 8-2 presents the main land-use, water demands and operational features of the original scenarios for EWR Site WM1. It should be noted that after discussion with the aquatic ecology team leader, the EWRs for scenarios WM1-2 and WM1-3 were not included in the analyses because these EWRs were not going to be available in time for the deadline of this report.

Table 8-2: Main land-use, water demands and operational features of WM1 scenarios

Item	Baseline WM1-1	WM1-2	WM1-3	WM1-4	WM1-5	WM1-6
With EWRs	No	Yes	Yes	No	No	No
Domestic demand (10^6 m^3)	22.04	17.75 (Ulundi demand = 50%)	22.04 (Pipeline from Klipfontein Dam)	62.64 (2040) (No pipeline)	62.64 (2040) (No pipeline)	43.85 (2040 - Curtailed to basic human needs)
Dam storage	24.83	23.40 (Mvunyana	21.96 (Mvunyana	24.83	39.83 (Klipfontein	39.83 (Klipfontein

Item	Baseline WM1-1	WM1-2	WM1-3	WM1-4	WM1-5	WM1-6
($10^6.m^3$)		50% silted)	not used)		raised 4m)	raised 4m)
Domestic return flows (%)	25	25	25	25	25	25
Irrigation effic. (incl. distrib. losses) (%)	75	75	75	75	75	85
Gluckstadt I.S. (km^2)	2.5	1.25	0	2.5	2.5	0
New OCS capacity (10^6 m^3)	0	0	0	0	0	40

8.3 Scenario impacts on streamflows

8.3.1 Impacts on MARs

Table 8-3 presents the MARs at EWR site WM1 for the various scenarios. It can be seen that the respective future scenarios WM1-4, WM1-5 and WM1-6 result in marked reductions in the MAR.

Table 8-3: Mean annual runoff at WM1 for different scenarios

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
WM1_N	298.3	Oct 1959-Sep 2010
WM1-1	273.4	
WM1-2	277.1	
WM1-3	269.2	
WM1-4	252.8	
WM1-5	213.5	

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
WM1-6	220.9	

8.3.2 Impacts on flow duration curves

Figure 8-2 presents the daily flow duration curves at EWR site WM1 for the various scenarios. It can be seen that the respective future scenarios WM1-4, WM1-5 and WM1-6 have notably unfavourable impacts on the daily streamflow regime below a discharge of about $10m^3/s$.

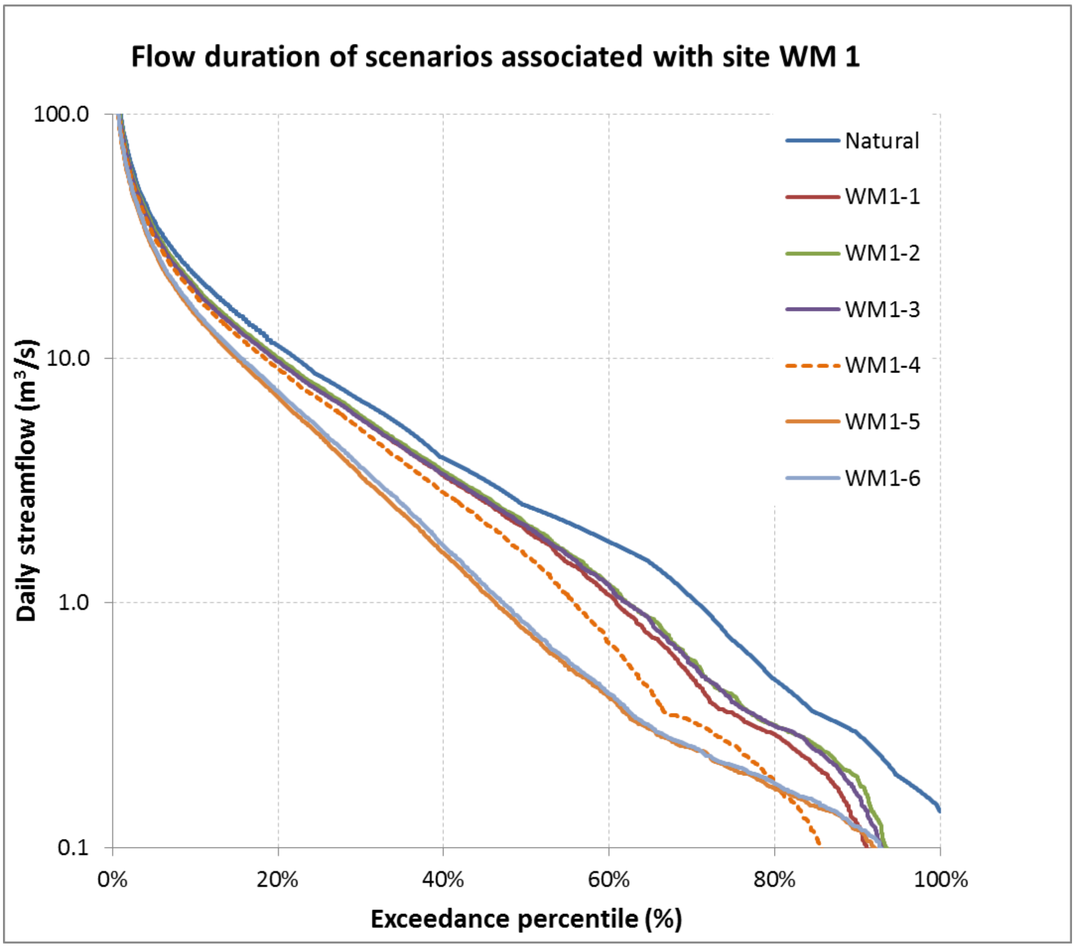


Figure 8-2: Daily flow duration curves at EWR Site WM1 for different scenarios

9 MATIGULU RIVER MODELLING: EWR SITE MA1

9.1 WR2012 Pitman model configuration

The scenario modelling for the Matigulu River EWR Site MA1 was performed by means of the WR2012 Pitman Model configuration obtained from the WR2012 study (WRC, 2014).

9.2 Land-use and water demands

9.2.1 Baseline land-use and domestic demands

Table 9-1 presents the present-day land-use and water demands that were super-imposed on the natural Pitman model configuration to form the Baseline Scenario MA1-1 (sourced from DWA, 2014).

Table 9-1: Baseline land-use and water demands for Scenario MA1-1

Quaternary Catchment	Afforestation (km^2)	IAPs (km^2)	Irrigation Area (km^2)	Domestic Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W11A	8.9	45.4	12	0.06	0.428
W11B	0	6.4	6.4	0	0.142
W11C	13.2	25.8	0	0.39	2.066

9.2.2 Scenario EWRs, domestic demands and land-use

Table 9-2 presents the main land-use, water demands and operational features of the scenarios for EWR Site MA1.

Table 9-2: Main land-use, water demands and operational features of MA1 scenarios

Item	Baseline (MA1-1)	MA1-2	MA1-3	MA1-4
With E	No	No	No	No

Item	Baseline (MA1-1)	MA1-2	MA1-3	MA1-4
WRs				
Domestic demand ($10^6 m^3$)	0.45	1.59 (2040)	1.26 (2040 with 21% WDM)	1.26
Domestic return flow	0	0	0	0

Item	Baseline (MA1-1)	MA1-2	MA1-3	MA1-4
s (%)				
Irrigation efficiency (%)	85	85	100	100
Alien vegetation	78	78	78	0

Item	Baseline (MA1-1)	MA1-2	MA1-3	MA1-4
(km^2)				
Afforestation (km^2)	22	22	22	22
Dam capacity to meet	2.64	3.0	2.7	2.7

Item	Baseline (MA1-1)	MA1-2	MA1-3	MA1-4
demands (10^6 m^3)				

9.3 Scenario impacts on streamflows

9.3.1 Impacts on MARs

Table 9-3 presents the MARs at EWR site MA1 for the various scenarios. It can be seen that the respective future scenarios cause relatively minor differences in the MARs.

Table 9-3: Mean annual runoff at MA1 for different scenarios

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
MA1_N	83.6	Oct 1950-Sep 2005
MA1-1	77.4	
MA1-2	76.9	
MA1-3	77.5	
MA1-4	78.4	

9.3.2 Impacts on flow duration curves

Figure 9-1 presents the daily flow duration curves at EWR site MA1 for the various scenarios. It can be seen that the respective future scenarios result in relatively minor impacts on the daily streamflow regime.

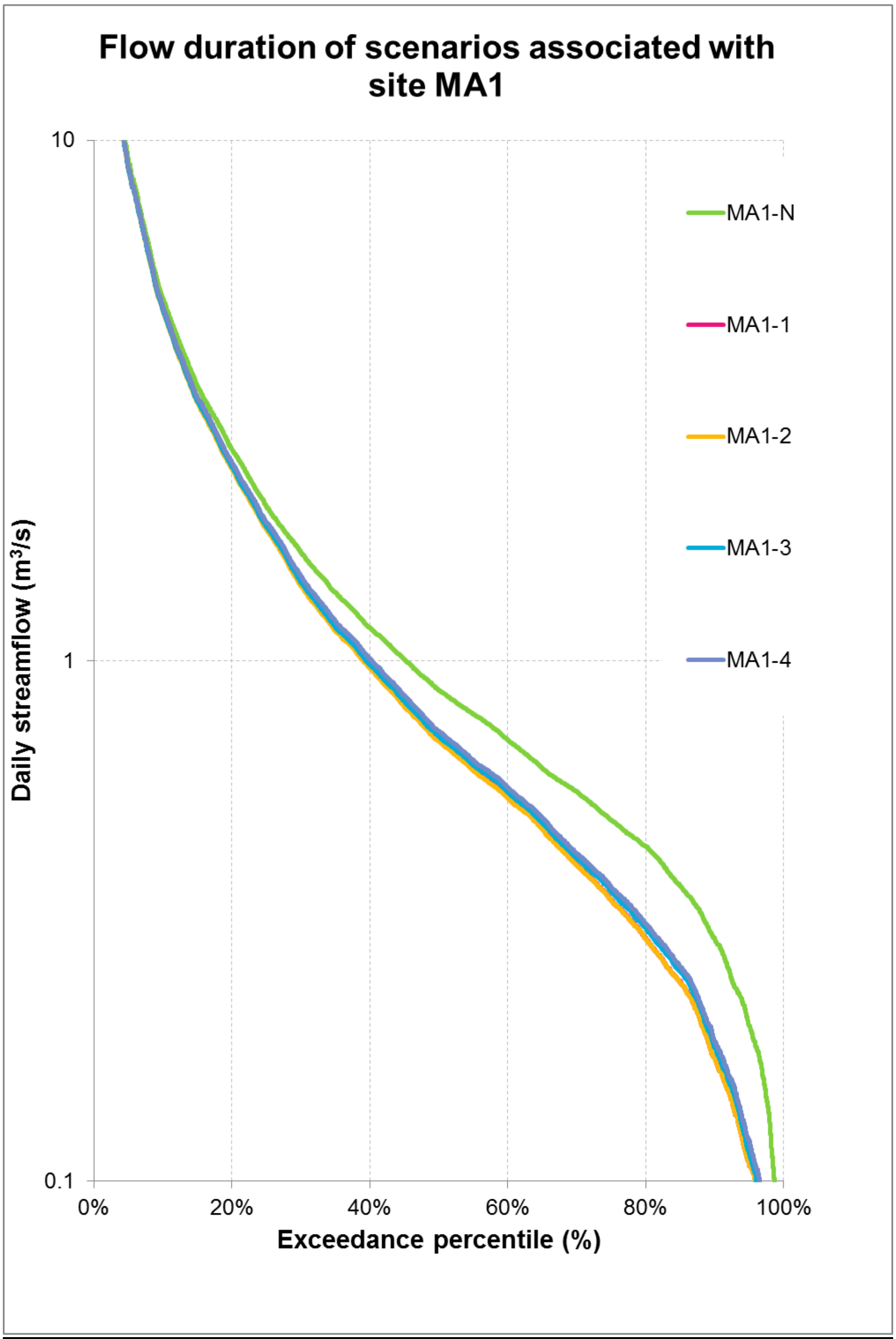


Figure 9-1: Daily flow duration curves at EWR Site MA1 for different scenarios

10 NSELENI RIVER MODELLING: EWR SITE NS1

10.1 WRYM configuration

In line with our contractual requirements, the catchment modelling for EWR Site NS1 on the Nseleni River was initially performed via the relevant sub-system of the existing WRYM model for the Mhlatuze System. However, the resulting WRYM model runs for natural and present-day scenarios produced seasonal distributions of mean monthly flows that seemed anomalous in comparison with both observed and simulated mean monthly distributions of neighbouring sub-catchments and catchments. We cross-checked the mean monthly distributions for the relevant quaternaries in the WR2005 database, and found that they showed a similar anomaly, the root of which appeared to be in the rainfall used.

10.2 *ACRU* model configuration

No historical streamflow records exist for the Nseleni River that could be used for verification of the WRYM results. Therefore, we decided to configure the *ACRU* model with default model parameter settings for the Nseleni and to simulate the daily natural and present-day flows after first confirming that the *ACRU* default input database contained significantly different rainfall station records to those in WRYM. The result was a simulated mean monthly distribution that was fully plausible, unlike the initial WRYM output. To align the scale of the *ACRU* flows with that of the original WRYM flows, the *ACRU* flows were scaled by the ratio of the natural MAR of the WRYM flows to the natural MAR of the *ACRU* flows.

The ACRU model configurations included the land-use and water demand information summarised in Section 10.3.

10.3 Land-use and water demands

10.3.1 Baseline land-use and domestic demands

Table 10-1 presents the present-day land-use and water demands that were super-imposed on the natural *ACRU* configuration to form the Baseline Scenario NS1-1 (sourced from DWA, 2014).

Table 10-1: Baseline land-use and water demands for Scenario NS1-1

Quaternary Catchment	Afforestation (km^2)	IAPs (km^2)	Irrigation Area (km^2)	Domestic Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W12G	0	21.2	7	0	1.2
W12H	134.4	35.7	21.92	0	6.08

10.3.2 Scenario EWRs, domestic demands and land-use

Table 10-2 presents the main land-use, water demands and operational features of the scenarios for EWR Site NS1.

Table 10-2: Main land-use, water demands and operational features of NS1 scenarios

Item	Baseline (NS1-1)	NS1-2
With EWRs	No	No
Domestic demand (10^6 m^3)	0	0
Domestic return flows (%)	0	0
Irrigation efficiency (%)	75	85
Alien vegetation (km^2)	56.9	0
Afforestation (km^2)	134.4	134.4

10.4 Scenario impacts on streamflows

10.4.1 Impacts on MARs

Table 10-3 presents the MARs at EWR site NS1 for the various scenarios. It can be seen that the respective future scenarios cause relatively minor differences in the MARs.

Table 10-3: Mean annual runoff at NS1 for different scenarios

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
NS1_N	34.1	Oct 1958-Sep 2009
NS1-1	23.4	
NS1-2	24.5	

10.4.2 Impacts on flow duration curves

Figure 10-1 presents the daily flow duration curves at EWR site NS1 for the various scenarios. It can be seen that the future scenario NS1-2 results in relatively minor impacts on the daily streamflow regime.

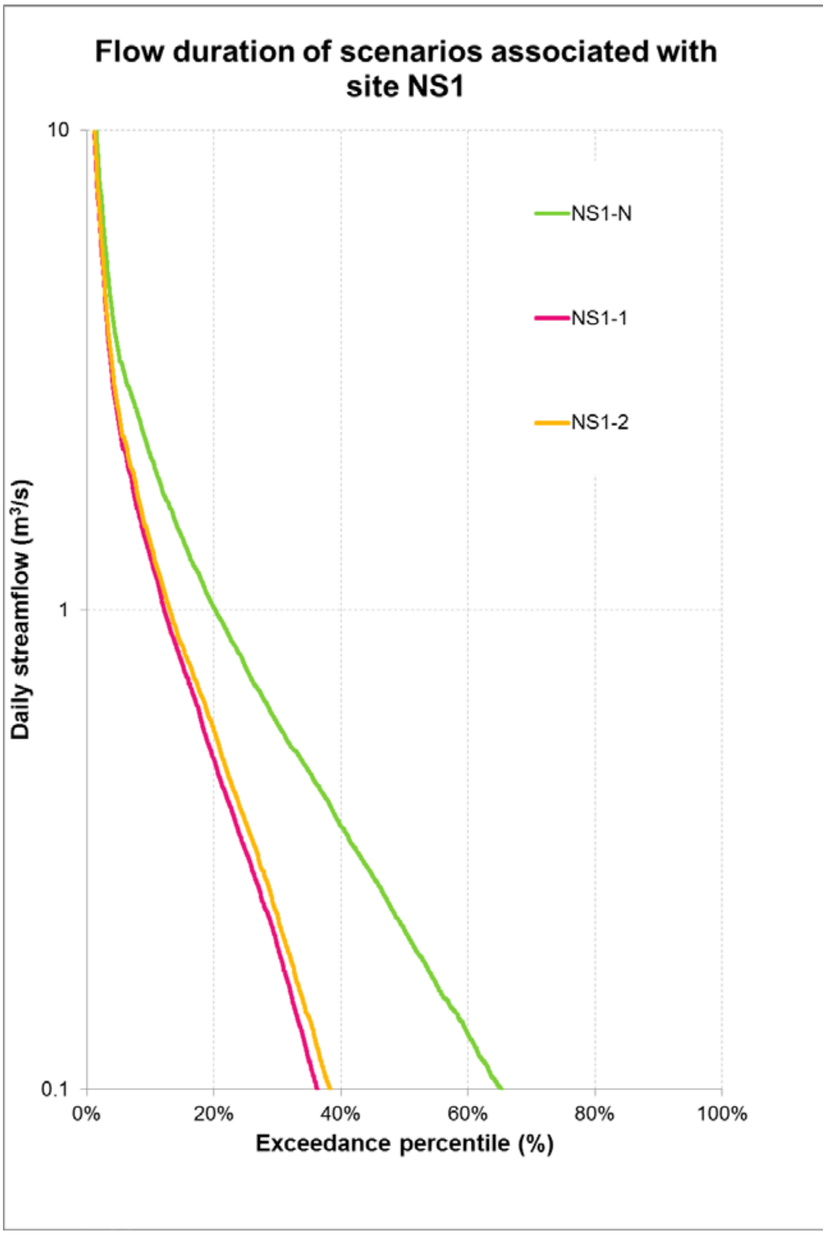


Figure 10-1: Daily flow duration curves at EWR Site NS1 for different scenarios

11 LAKE ST LUCIA: PROVISIONAL MFOLOZI CATCHMENT SCENARIO MODELLING

NB: It should be noted that this Section presents *provisional* scenario simulation outcomes, which were completed and written up in order to satisfy related deliverable dates for this specialist report - September 2014 for the estuary inflow sequences and October 2014 for the report. The models that were used and the monthly time-step of the estuary inflow sequences were contractually-specified. Simulation of the *final* selected scenarios followed more than a year later. These were modelled in the *ACRU* model and for these daily time-step estuary inflow sequences were prepared. The scenario outcomes are presented in Sections 16 and 17.

11.1 Provisional configuration and calibration of the *ACRU* model

Sections 6.1, 7.1 and 8.1 provide details of how, for the purposes of river EWR determination in this study, the ACRU configurations for the Black and White Mfolozi, sourced from the iSimangaliso (GEF) study (Aurecon, 2014), were refined and also "re-calibrated" against observed streamflows at DWS gauging stations. This was done by applying a reduction factor of 0.85 to the input rainfall sequences in those two configurations.

11.2 Land-use and water demands downstream of BM2 and WM1

11.2.1 Baseline land-use and domestic demands

Table 11-1 presents the present-day land-use and water demands downstream of EWR sites BM2 and WM1 that were super-imposed on the natural *ACRU* configuration to form the Baseline Scenario LMF1-1 (sourced from Aurecon, 2014).

Table 11-1: Baseline land-use and water demands for Scenario LMF1-1

Quaternary Catchment	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic/Industrial Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W21H	2.3	0	0	0
W21J	41.8	0	0	0
W21K	5.7	0.3	0	0
W21L	0	0	0	0
W22H	0	0	0	0

Quaternary Catchment	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic/Industrial Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W22J	0	0	0	0
W22K	0	0	0	0
W22L	0	0	0	0
W23A	0.2	0.5	4.4 (Domestic)	0
W23B	2.7	2.0	3.1 (Domestic)	0
W23C	7.9	8.0	0	0
W23D	4.4	28.2	11.0 (Industrial)	6.0
Total	65.0	39.0	18.5	6.0

11.2.2 *Original* scenario characteristics

Table 11-2 presents the main land-use, water demands and operational features of the *original* scenarios for Mfolozi downstream of EWR sites BM2 and WM1. It should be noted that after discussion with the aquatic ecology team leader scenarios LMF1-2 and LMF1-5 were not analysed at this provisional stage and were ultimately replaced by scenario LMF-EWR, which is described in Section 17.

Table 11-2: Main land-use, water demands and operational features of *original* LMF1 scenarios for Mfolozi downstream of EWR sites BM2 and WM1#

Item	Baseline (LMF1-1)	LMF1-2	LMF1-3	LMF1-4	LMF1-5	LMF1-6	LMF1-7
With EWRs	No	Yes	No	No	Yes	No	No
Domestic demand (10^6 m^3)	7.4	7.4	7.4	17.7 (2040)	17.7 (2040)	17.7 (2040)	17.7 (2040)
Industrial demand (10^6 m^3)	11.0	11.0	11.0	12.6 (2040)	12.6 (2040)	12.6 (2040)	25.0 (>2040)
Dam Capacity (10^6 m^3)	6.0 (Richards Bay Minerals)	6.0 (RBM)	6.0 (RBM)	6.0 (RBM) 7.5	6.0 (RBM) 7.5	6.0 (RBM)	10.0 (RBM) 7.5

Item	Baseline (LMF1-1)	LMF1-2	LMF1-3	LMF1-4	LMF1-5	LMF1-6	LMF1-7
				(OCS)	(OCS)		(OCS)
Afforestation (km^2)	65.0	65.0	49.8	65.0	65.0	65.0	65.0
Domestic return flows (%)	25	25	25	25	25	25	25
Irrigation (km^2)	39.0	39.0	39.0	39.0	39.0	39.0	39.0
Irrigation effic. and distribution losses (%)	75	75	75	75	75	75	75

#: It should be noted that the Baseline scenarios BM2-1 and WM1-1 were in place during the above LMF1 scenario modelling exercise.

11.3 Additional scenario characteristics

During early June 2015 DWS requested that three additional scenarios be analysed and their outcomes compared with the original scenarios outlined in **Table 11-2.** The characteristics of these additional scenarios are presented in **Table 11-3**. Because there was some urgency about having the above comparison available within a few days, we decided to analyse the three scenarios with the WR2012 Pitman Model, using the monthly streamflows generated for scenario LMF1-6 by the *ACRU* Model at the sites of interest.

Table 11-3: Additional LMF1 scenarios superimposed on scenario LMF1-6

Item	LMF1-6	LMF1-8	LMF1-9	LMF1-10
With EWRs	No	No	No	No
Domestic demand (10^6 m^3)	17.7 (2040)	17.7 (2040)	17.7 (2040)	20.0 (2040)
Industrial demand (10^6 m^3)	12.6 (2040)	12.6 (2040)	12.6 (2040)	12.6 (2040)
Dam Capacity (10^6m^3)	6.0 (RBM)	6.0 (RBM) 96.0 (Kwesibomvu)	6.0 (RBM)	6.0 (RBM)

Item	LMF1-6	LMF1-8	LMF1-9	LMF1-10
Afforestation (km^2)	65.0	65.0	65.0	65.0
Domestic return flows (%)	25	25	25	25
Irrigation (km^2)	39.0	39.0	39.0	39.0
Irrigation effic. and distribution losses (%)	75	75	75	75
Diversion (2.5 m^3/s) to new OCS	No	No	Yes	No

11.4 Provisional scenario impacts on Mfolozi estuary inflows

11.4.1 Provisional impacts on MARs

Table 11-4 presents the MARs at the Mfolozi estuary for the various scenarios. It can be seen that future scenarios LMF1-7, LMF1-8 and LMF1-9 result in notable reductions in the MAR, with LMF1-8 (in-channel Kwesibomvu Dam) being the most severe.

Table 11-4: Provisional MARs at LMF1 for different scenarios

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
LMF1_N	1054.4	Oct 1959-Sep 2010
LMF1-1	952.2	
LMF1-2	952.2	
LMF1-3	952.9	
LMF1-4	942.8	
LMF1-5	942.8	

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
LMF1-6	959.8	
LMF1-7	932.0	
LMF1-8	886.9	
LMF1-9	900.7	
LMF1-10	960.4	

11.4.2 Provisional impacts on flow duration curves

Figure 11-1 presents the provisional monthly flow duration curves at the Mfolozi estuary for the various scenarios. It can be seen that the future scenarios LMF1-7, LMF1-8, and LMF1-9 result in notably unfavourable impacts on the monthly streamflow regime below a monthly discharge of about 50 million m^3/month, with LMF1-8 (in-channel Kwesibomvu Dam) being the most severe.

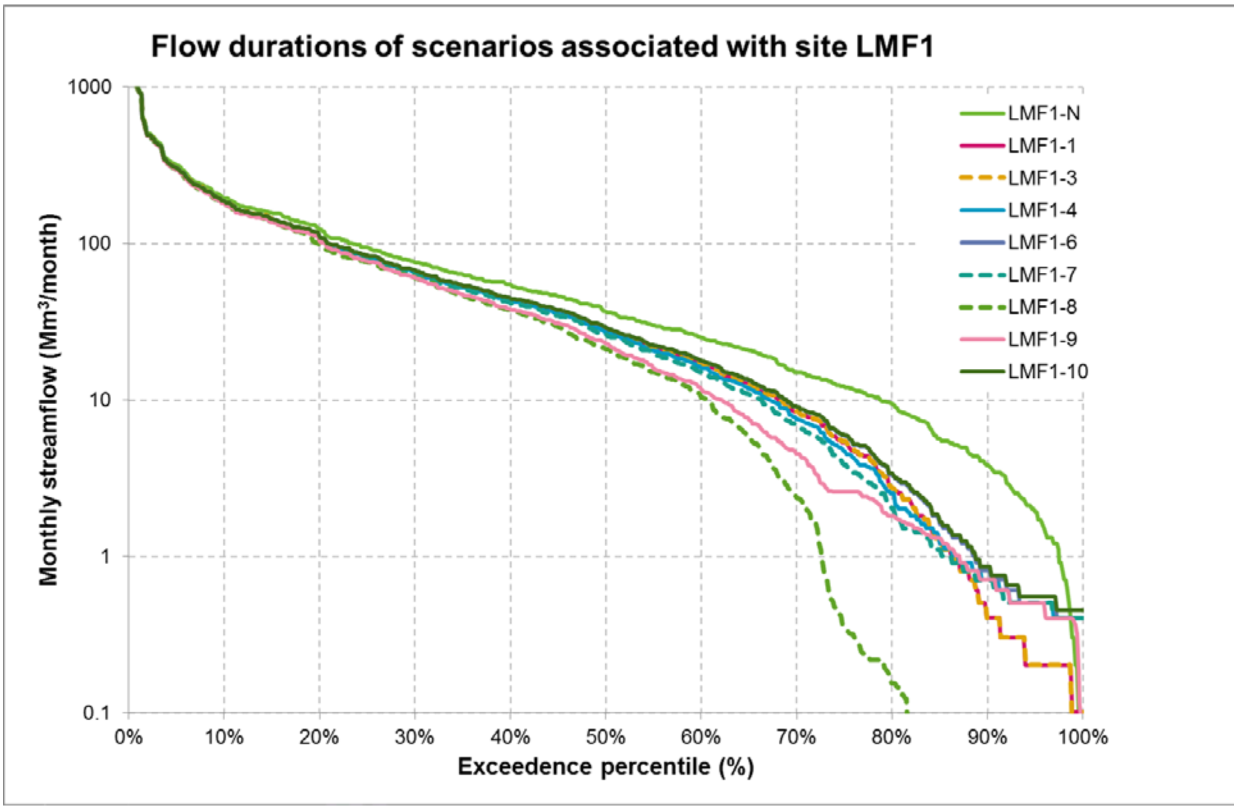


Figure 11-1: Provisional monthly flow duration curves at the Mfolozi estuary for different scenarios

12 LAKE ST LUCIA: PROVISIONAL HLUHLUWE (NZIMANE) CATCHMENT SCENARIO MODELLING

NB: It should be noted that this Section presents *provisional* scenario simulation outcomes, which were completed and written up in order to satisfy related deliverable dates for this specialist report - September 2014 for the estuary inflow sequences and October 2014 for the report. The models that were used and the monthly time-step of the estuary inflow sequences were contractually-specified. Simulation of the *final* selected scenarios followed more than a year later. These were modelled in the *ACRU* model and for these daily time-step estuary inflow sequences were prepared. The scenario outcomes are presented in Sections 16 and 17.

12.1 WR2012 Pitman model configuration

The provisional future scenario modelling for the Hluhluwe River catchment (also known as the Nzimane River) was performed by means of the WR2012 Pitman Model configuration obtained from the WR2012 study (WRC, 2014).

12.2 Land-use and water demands

12.2.1 Baseline land-use and domestic demands

Table 12-1 presents the present-day land-use and water demands as per the WR2012 study (WRC, 2014).

Table 12-1: Baseline land-use and water demands for Scenario HH1-1

Quaternary Catchment	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic/Industrial Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W32D	1.7	0	3.1 (Domestic)	0
W32E	3.7	0	0	25.9
W32F	8.5	13.8	0	0
TOTAL	13.9	13.8	3.1	25.9

12.2.2 Scenario EWRs, domestic demands and land-use

Table 12-2 presents the main land-use, water demands and operational features of the scenarios for the Hluhluwe catchment. It should be noted that Scenario HH1-3 was not analysed because the Estuary EWR Workshop post-dated the finalisation of this report.

Table 12-2: Main land-use, water demands and operational features of Hluhluwe scenarios

Item	Baseline HH1-1	HH1-2	HH1-3	HH1-4	HH1-5
With EWRs	No	No	Yes	No	No
Domestic demand (10^6 m^3)	3.1	3.1	3.1	6.02 (2040) (Transfer in = 6.10^6 m^3/a)	6.02 (2040) (Zero transfer in)
Afforestation (km^2)	13.9	0	0	13.9	0
Domestic return flows (%)	0	0	0	0	0
Irrigation (km^2)	13.8	13.8	13.8	13.8	13.8
Irrigation effic. and distrib. losses (%)	75	75	75	85	75

12.3 Provisional scenario impacts on estuary inflows

12.3.1 Provisional impacts on MARs

Table 12-3 presents the MARs of Hfor the various scenarios. It can be seen that the removal of afforestation, the import of water and higher irrigation, respectively, all benefit the MAR.

Table 12-3: Provisional MARs at Lake St Lucia for different scenarios

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
HH1_N	61.5	Oct 1959-Sep 2005
HH1-1	48.1	

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
HH1-2	50.8	
HH1-4	51.2	
HH1-5	47.2	

12.3.2 Provisional impacts on flow duration curves

Figure 12-1 presents the monthly flow duration curves of Hluhluwe inflows into Lake St Lucia for the various scenarios. It can be seen that the future scenarios HH1-2 (removal of afforestation) and HH1-4 (import of 6 million m^3/a and increased irrigation efficiencies) result in notably favourable impacts on the monthly low-flow regime below a monthly inflow of about 1 million m^3/m, whereas scenario HH1-5 (no water imports) has an unfavourable impact on the above low-flow regime.

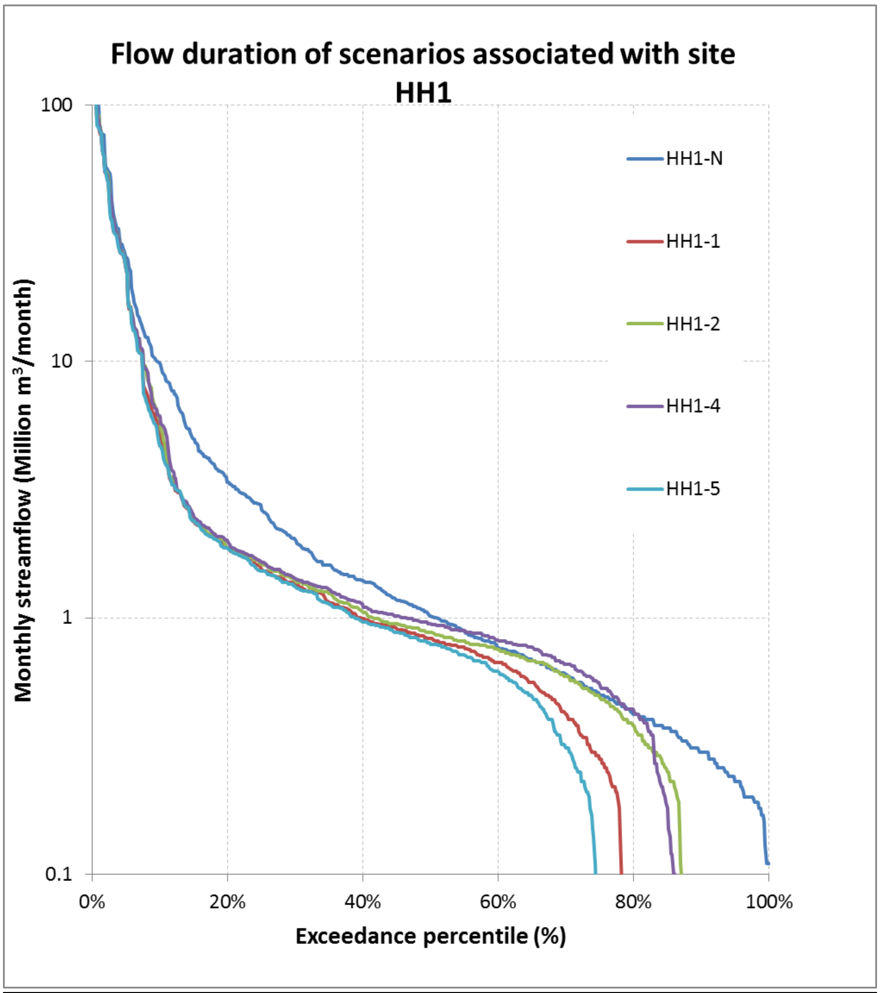


Figure 12-1: Provisional monthly flow duration curves of Hluhluwe inflows into Lake St Lucia for different scenarios

13 LAKE ST LUCIA: PROVISIONAL NYALAZI CATCHMENT SCENARIO MODELLING

NB: It should be noted that this Section presents *provisional* scenario simulation outcomes, which were completed and written up in order to satisfy related deliverable dates for this specialist report - September 2014 for the estuary inflow sequences and October 2014 for the report. The models that were used and the monthly time-step of the estuary inflow sequences were contractually-specified. Simulation of the *final* selected scenarios followed more than a year later. These were modelled in the *ACRU* model and for these daily time-step estuary inflow sequences were prepared. The scenario outcomes are presented in Sections 16 and 17.

13.1 WR2012 Pitman model configuration

The provisional scenario modelling for the Nyalazi River catchment was performed by means of the WR2012 Pitman Model configuration obtained from the WR2012 study (WRC, 2014). It should be noted that the WR2012 configuration includes the area of Lake St Lucia (350 km^2). For this hydrology study, this Lake area was omitted from the area of Quaternary Catchment W32H.

13.2 Land-use and water demands

13.2.1 Baseline land-use and domestic demands

Table 13-1 presents the present-day land-use and water demands as per the WR2012 study (WRC, 2014).

Table 13-1: Baseline land-use and water demands for Nyalazi Scenario NYAL-C

Quaternary Catchment	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic/Industrial Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W32G	105.6	6.7	0	0
W32H	145.7	0	0	0

13.2.2 Scenario EWRs, domestic demands and land-use

The Scenario Report (DWA, 2014) indicates no future scenarios for the Nyalazi catchment.

13.3 Provisional scenario impacts on estuary inflows

13.3.1 Provisional impacts on MARs

Table 13-2 presents the MARs of Nyalazi inflows into Lake St Lucia for the natural (NYAL-N) and present-day (NYAL–C) scenarios.

Table 13-2: Provisional MARs at Lake St Lucia for different scenarios

Scenario	Mean Annual Runoff (Million m³/a)	Simulation Period
NYAL-N	123.8	Oct 1959-Sep 2005
NYAL-C	102.6	

13.3.2 Provisional impacts on flow duration curves

Figure 13-1 presents the monthly flow duration curves of Nyalazi inflows into Lake St Lucia for natural and present-day scenarios.

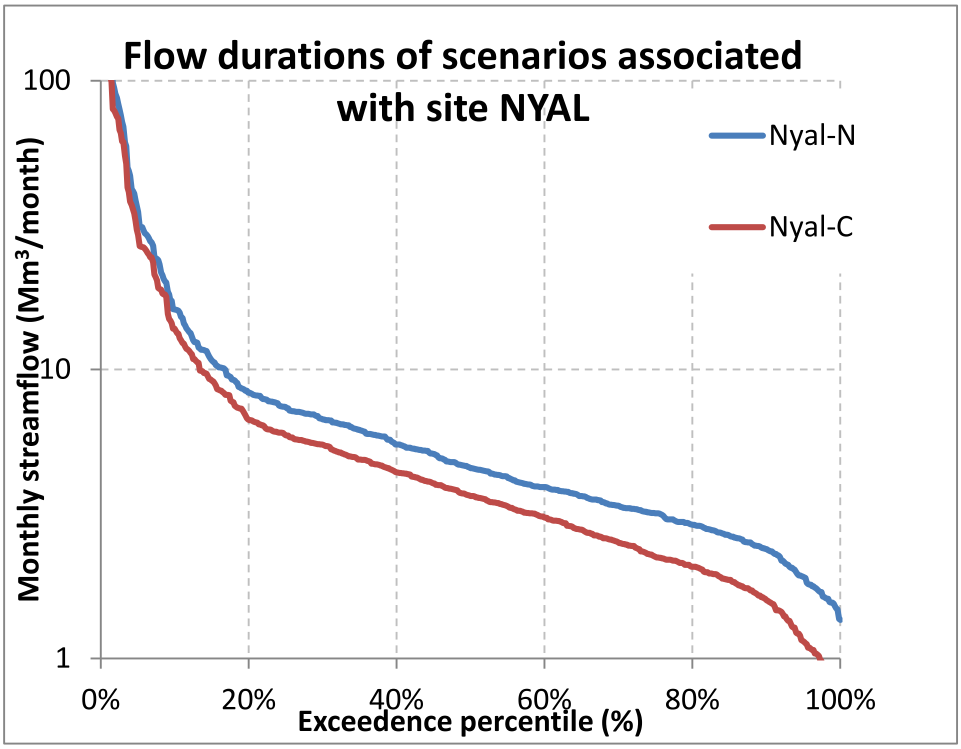


Figure 13-1: Provisional monthly flow duration curves of Nyalazi inflows into Lake St Lucia for natural and present-day scenarios

14 LAKE ST LUCIA: PROVISIONAL MSINENE CATCHMENT SCENARIO MODELLING

NB: It should be noted that this Section presents *provisional* scenario simulation outcomes, which were completed and written up in order to satisfy related deliverable dates for this specialist report - September 2014 for the estuary inflow sequences and October 2014 for the report. The models that were used and the monthly time-step of the estuary inflow sequences were contractually-specified. Simulation of the *final* selected scenarios followed more than a year later. These were modelled in the *ACRU* model and for these daily time-step estuary inflow sequences were prepared. The scenario outcomes are presented in Sections 16 and 17.

14.1 WR2012 Pitman model configuration

The scenario modelling for the Msinene River catchment was performed by means of the WR2012 Pitman Model configuration obtained from the WR2012 study (WRC, 2014).

14.2 Land-use and water demands

14.2.1 Baseline land-use and domestic demands

Table 14-1 presents the present-day land-use and water demands as per the WR2012 study (WRC, 2014).

Table 14-1: Baseline land-use and water demands for Msinene Scenario MSIN-C

Quaternary Catchment	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic/Industrial Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W32C	18.2	21.6	0	0

14.2.2 Scenario EWRs, domestic demands and land-use

The Scenario Report (DWA, 2014) indicates no future scenarios for the Msinene catchment.

14.3 Provisional scenario impacts on estuary inflows

14.3.1 Provisional impacts on MARs

Table 14-2 presents the MARs at Lake St Lucia for the natural (MSIN-N) and present-day (MSIN–C) scenarios.

Table 14-2: Provisional MARs at Lake St Lucia for different scenarios

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
MSIN-N	26.4	Oct 1959 - Sep 2005
MSIN-C	20.3	

14.3.2 Provisional impacts on flow duration curves

Figure 14-1 presents the monthly flow duration curves of Msinene inflows into Lake St Lucia for the natural and present-day scenarios.

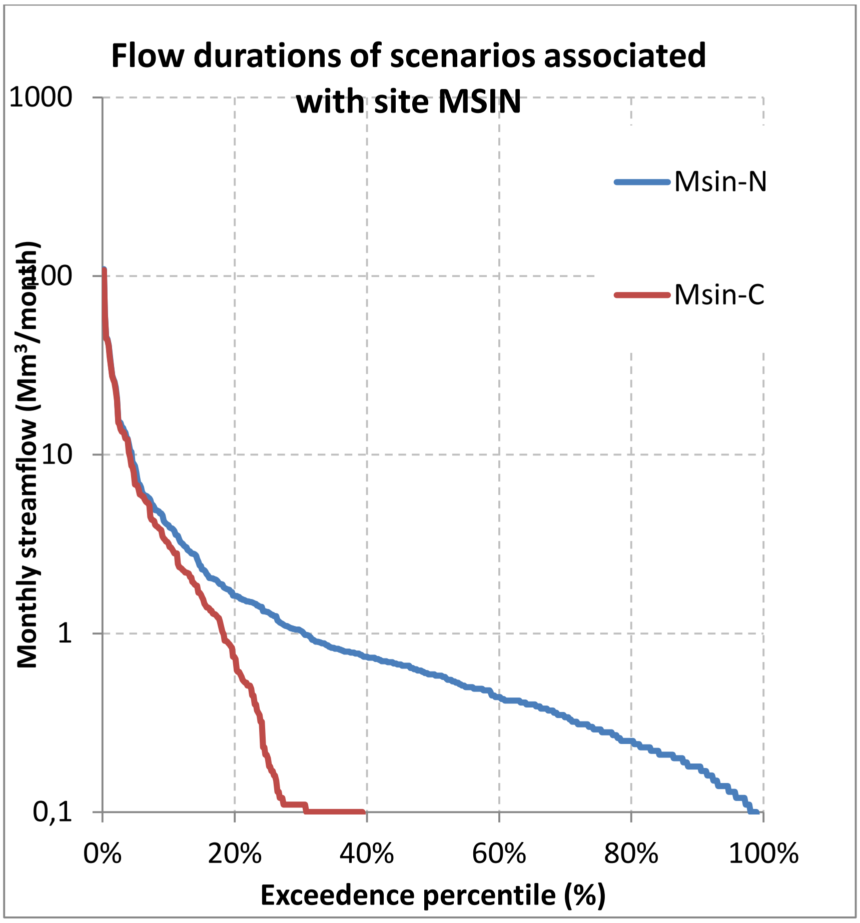


Figure 14-1: Provisional monthly flow duration curves of Msinene inflows into Lake St Lucia for different scenarios

15 LAKE ST LUCIA: PROVISIONAL MKUZE CATCHMENT SCENARIO MODELLING

NB: It should be noted that this Section presents *provisional* scenario simulation outcomes, which were completed and written up in order to satisfy related deliverable dates for this specialist report - September 2014 for the estuary inflow sequences and October 2014 for the report. The models that were used and the monthly time-step of the estuary inflow sequences were contractually-specified. Simulation of the *final* selected scenarios followed more than a year later. These were modelled in the *ACRU* model and for these daily time-step estuary inflow sequences were prepared. The scenario outcomes are presented in Sections 16 and 17.

15.1 *ACRU* model configuration

Section 5.1 provides details of how the ACRU configuration sourced from the iSimangaliso (GEF) study (Aurecon, 2014) was refined and "re-calibrated" for this study.

15.2 Land-use and water demands downstream of EWR Site MK1

15.2.1 Baseline land-use and domestic demands

Table 15-1 presents the present-day land-use and water demands downstream of MK1 that were super-imposed on the natural *ACRU* configuration to form the Baseline Scenario MKE1- 1 (sourced from Aurecon, 2014).

Table 15-1: Baseline land-use and water demands for Scenario MKE1-1

Quaternary	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic/Industrial Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
W31J	0	1.0	0	0
W31K	0	0	0	0
W31L	0	1.2	0	0
W32A	0	0	0	0
W32B	29.7	2.5	0	0

Quaternary	Afforestation and IAPs (km^2)	Irrigation Area (km^2)	Domestic/Industrial Demands (10^6 m^3)	Dam Capacity (10^6 m^3)
TOTAL	29.7	4.7	0	0

15.2.2 Scenario EWRs, domestic demands and land-use

No future development scenarios for the Mkuze downstream of MK1 were contained in the Scenario Report. We pointed out to the aquatic ecology team leader the fact that further water-use is present downstream of MK1 as well as notable losses in the Mkuze Swamp. Consequently, it was then decided to model the full Mkuze catchment with each of the MK1 scenarios in place upstream of MK1 (see sub-section 5.2).

15.3 Provisional scenario impacts on estuary inflows

15.3.1 Provisional impacts on MARs

Table 15-2 presents the MARs at the inflow point to Lake St Lucia for the various future scenarios upstream of EWR Site MK1. It can be seen that the respective scenarios cause relatively minor differences in the MARs, with MKE-2 (reduce irrigation demand by 20%) and MK1-4 (22% WDM savings) improving the MAR marginally.

Table 15-2: Provisional MARs at Lake St Lucia for different scenarios upstream of MK1

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
MKE_N	271.8	Oct 1959-Sep 2010
MKE-1	248.7	
MKE-2	256.5	
MKE-3	248.8	
MKE-4	251.9	

15.3.2 Provisional impacts on flow duration curves

Figure 15-1 presents the monthly flow duration curves of Mkuze inflows into Lake St Lucia for the different scenarios. It can be seen that scenarios MKE-2 (reduce irrigation demand upstream of MK1 by 15% and improve all irrigation efficiencies both above and downstream of MK1) and MK1-4 (22% WDM savings upstream of MK1) have a favourable effect on the monthly low-flow regime below a monthly inflow of about 5 million m^3/m

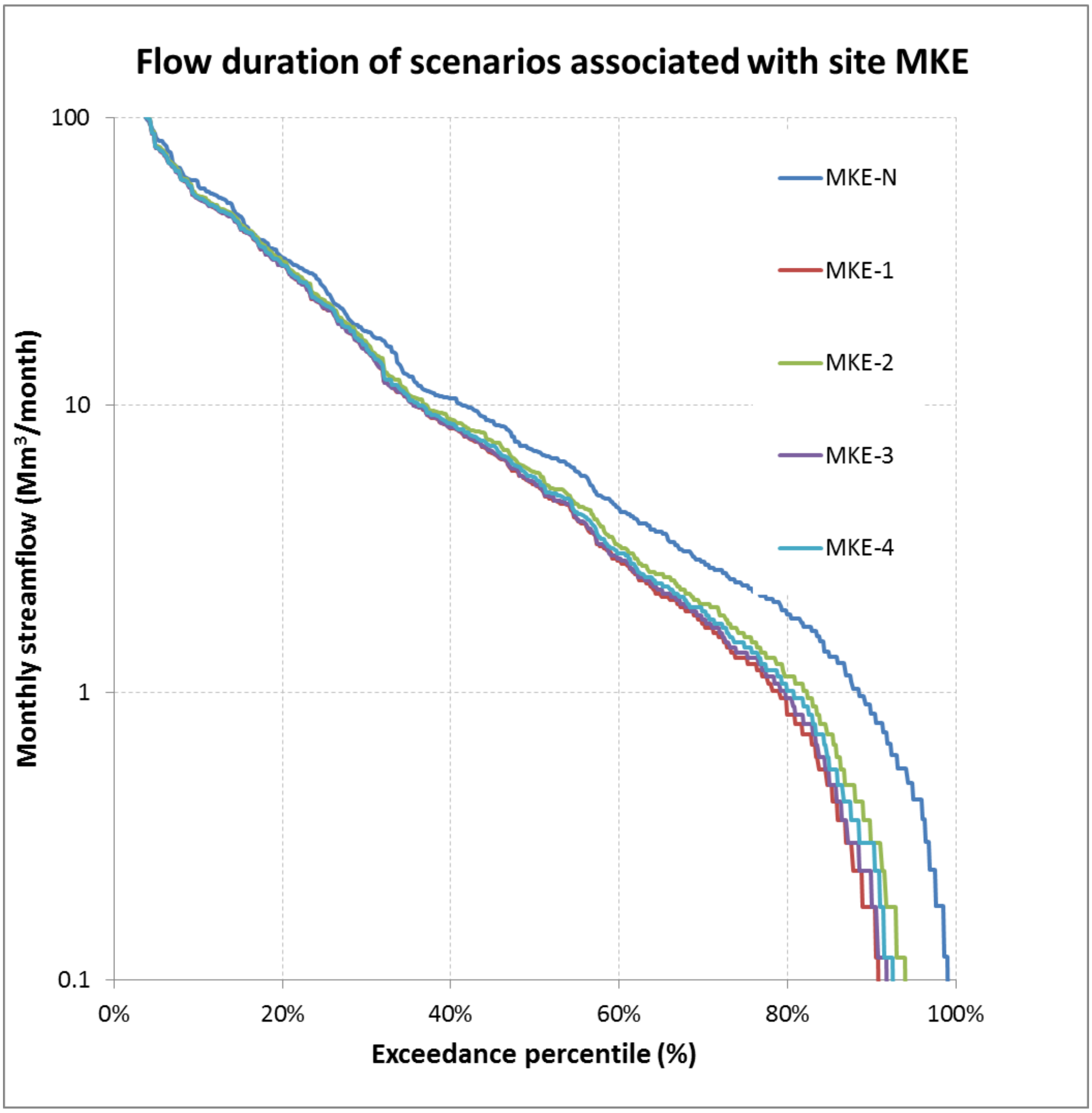


Figure 15-1: Provisional monthly flow duration curves of Mkuze inflows into Lake St Lucia for different scenarios

16 FINAL SCENARIO MODELLING FOR LAKE ST LUCIA INFLOWING RIVERS AND THE MFOLOZI ESTUARY

16.1 Final scenario selection

Given the relatively minor differences in the provisionally simulated outcomes of a number of the future inflow scenarios for the Lake and Mfolozi Estuary (reported in Sections 11 – 15), it was decided at the PSC Meeting of 17 August 2015 that only selected scenarios needed to be simulated by the Estuarine Ecology Team. The selected scenarios for the Mfolozi were LMF1-1, LMF1-4, LMF1-7, LMF1-8 and LMF1-9; however, an additional scenario (LMF-EWR) was later added comprising supplying the river EWRs (including upstream floods) on the Black and White Mfolozi directly to the Estuary. The selected scenario for each of the four inflowing rivers is the present-day case, namely, HH1-1 for the Hluhluwe (Nzimane), NYAL-C for the Nyalazi, MSIN-C for the Msinene and MKE-1 for the Mkuze.

16.2 Final *ACRU* Model calibration for Lake St Lucia inflows and Mfolozi Estuary inflows

Sections 6.1, 7.1 and 8.1 provide details of how, for the purposes of river EWR determination in this study, the *ACRU* configurations for the Black and White Mfolozi, sourced from the iSimangaliso (GEF) study (Aurecon, 2014), were refined and also "re-calibrated" against observed streamflows at DWS gauging stations. This was done by applying a reduction factor of 0.85 to the input rainfall sequences in those two configurations as well as other limited parameter adjustments. In a similar exercise for the Mkuze a rainfall reduction factor of 0.78 was determined, as described in Section 5.1 .

The hydro-dynamic modelling team in this Reserve study determined the maximum present-day inflowing MARs to Lake St Lucia required to maintain the Lake's observed long-term salinity dynamics. For the Mfolozi and the Mkuze these hydro-dynamically required MARs were lower than the MARs generated by the *ACRU* model while using the above rainfall reduction factors that were required to produce reasonable correspondence with observed streamflows at gauging stations.

The matching of the hydro-dynamically required MARs was achieved by reducing rainfall reduction factors further – for the Mfolozi from 0.85 to 0.80 and for the Mkuze from 0.78 to 0.70 upstream of the EWR site and to 0.50 downstream of the EWR site. A similar exercise was conducted for the three smaller inflowing rivers to the Lake.

Table 16-1 presents the relevant MARs for the four rivers at their inflow points to the Lake and for the Mfolozi at its estuary as well as the corresponding rainfall reduction factors.

Table 16-1: Comparison of hydro-dynamically required MARs with final MARs for inflowing rivers and the Mfolozi

River	MAR: Hydro-dynamically Required (million m^3/a)	Present-day MAR: Decreased Rainfall Reduction Factors (million m^3/a)	Rainfall Reduction Factor
Mfolozi	795	784	0.80
Mkuze	127	125	0.70 & 0.50
Nzimane	12	12	0.70
Msinene	31	33	0.76
Nyalazi	77	74	0.70

16.3 Final future scenario impacts on Mfolozi Estuary inflows

16.3.1 Impacts on Mfolozi MARs

The impacts of the selected future scenarios for the Mfolozi on mean annual inflows to the Estuary are presented in **Table 16-2.** As can be expected, scenarios LMF1-8 (large in-channel dam) and LMF1-9 (large diversion to off-channel dam) have the most severe impact on the current-day MAR.

It should be noted that the present-day MARs for the four inflowing rivers to the Lake are presented in **Table 16-1**.

Table 16-2: Final MARs for selected scenarios for Mfolozi

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
LMF1-N	876	Oct 1959-Sep 2010
LMF1-1	784	
LMF1-4	775	

Scenario	Mean Annual Runoff (Million m³/a)	Simulation Period
LMF1-7	765	
LMF1-8	723	
LMF1-9	734	
LMF1-EWR	256	Oct 1960 – Sep 2010

16.3.2 Impacts on Mfolozi flow duration curves

Figure 16-1 presents daily flow duration curves for inflows to the Mfolozi estuary for natural and present-day scenarios, as well as for the selected future scenarios outlined in Section 16.1. Notable negative impacts by Scenarios LMF1-8 and LMF1-9 relative to the present-day case are evident at a daily discharge below 15m³/s. However, below a daily discharge of 0.6 m³/s, these two scenarios, as well as LMF1-4 and LMF1-7, improve the present-day situation because of increased return flow volumes from the higher demands for those cases.

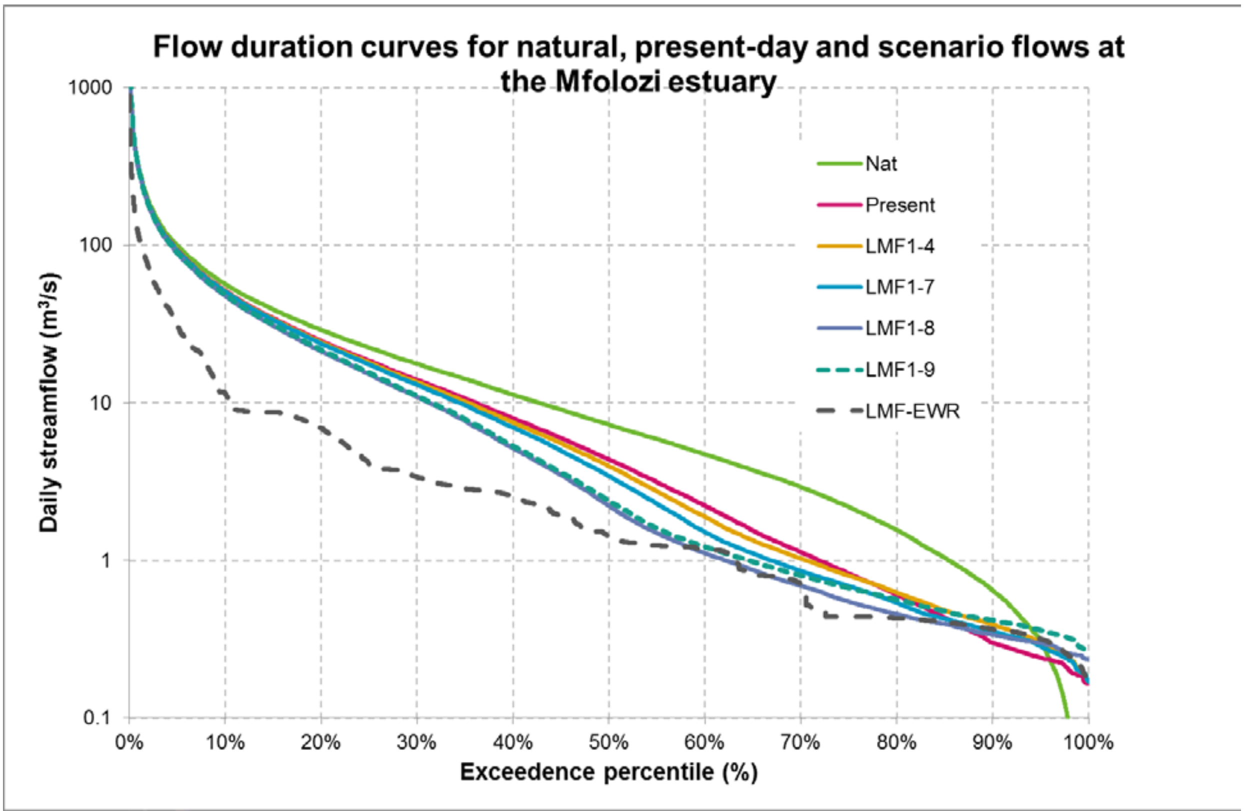


Figure 16-1: Daily flow duration curves for inflows to the Mfolozi Estuary for natural, present-day and other selected scenarios.

17 KOSI BAY: CATCHMENT SCENARIO MODELLING

17.1 WR2012 Pitman model configuration

The scenario modelling for the Kosi Bay Estuary Site KB1 was performed by means of the WR2012 Pitman Model configuration obtained from the WR2012 study (WRC, 2014). The dominant component of this configuration is the Sami Groundwater Module.

For the Baseline Scenario, the long-term inflowing MAR was simulated as 29.1 million m^3/a comprising 12% surface flows and 88% groundwater and interflows. Long-term seepage to the ocean was estimated at about 16% of inflows.

17.2 Land-use and water demands

17.2.1 Baseline land-use and domestic demands

Table 17-1 presents the present-day land-use and water demands that form the Baseline Scenario MKE1-1 (sourced from WRC, 2014).

Table 17-1: Baseline land-use and water demands for Scenario KB1-1

Quaternary Catchment	Afforestation (km^2)	IAPs (km^2)	Irrigation Area (km^2)	Domestic Demand (from groundwater) (10^6 m^3)	Dam Capacity (10^6 m^3)
28% of W70A	43.9	5.5	0	1.91	0

17.2.2 Scenario EWRs, domestic demands and land-use

Table 17-2 presents the main land-use, water demands and operational features of the scenarios for the Kosi Bay catchment.

Table 17-2: Main land-use, water demands and operational features of Kosi Bay scenarios

Item	Baseline (KB1-1)	KB1-2	KB1-3	KB1-4
With EWRs	No	No	No	No
Do	1.91	2.19	2.19	2.19

Item	Baseline (KB1-1)	KB1-2	KB1-3	KB1-4
mestic Demand (10^6 m^3) (from groundwater)				
Domestic Return flows (%)	0	0	0	0
Alie	5.5	5.5	0	0

Item	Baseline (KB1-1)	KB1-2	KB1-3	KB1-4
n vegetation (km^2)				
Afforestation (km^2)	43.9	43.9	43.9	0

17.3 Scenario impacts on estuary inflows

17.3.1 Impacts on MARs

Table 17-3 presents the MARs of inflows into Kosi Bay for the various future scenarios. It can be seen that the removal of afforestation and IAPs (KB1-4) benefits the MAR.

Table 17-3: Mean annual runoff into Kosi Bay for different scenarios

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
KB1_N	33.0	Oct 1950-Sep 2010
KB1-1	29.1	
KB1-2	28.9	
KB1-3	29.1	

Scenario	Mean Annual Runoff (Million m^3/a)	Simulation Period
KB1-4	31.0	

17.3.2 Impacts on flow duration curves

Figure 17-1 presents the monthly flow duration curves of inflows into Kosi Bay for the different scenarios. It can be seen that scenario KB1-4 (removal of afforestation and IAPs) has a favourable effect on the monthly low-flow regime below a monthly inflow of about 6 million m^3/month.

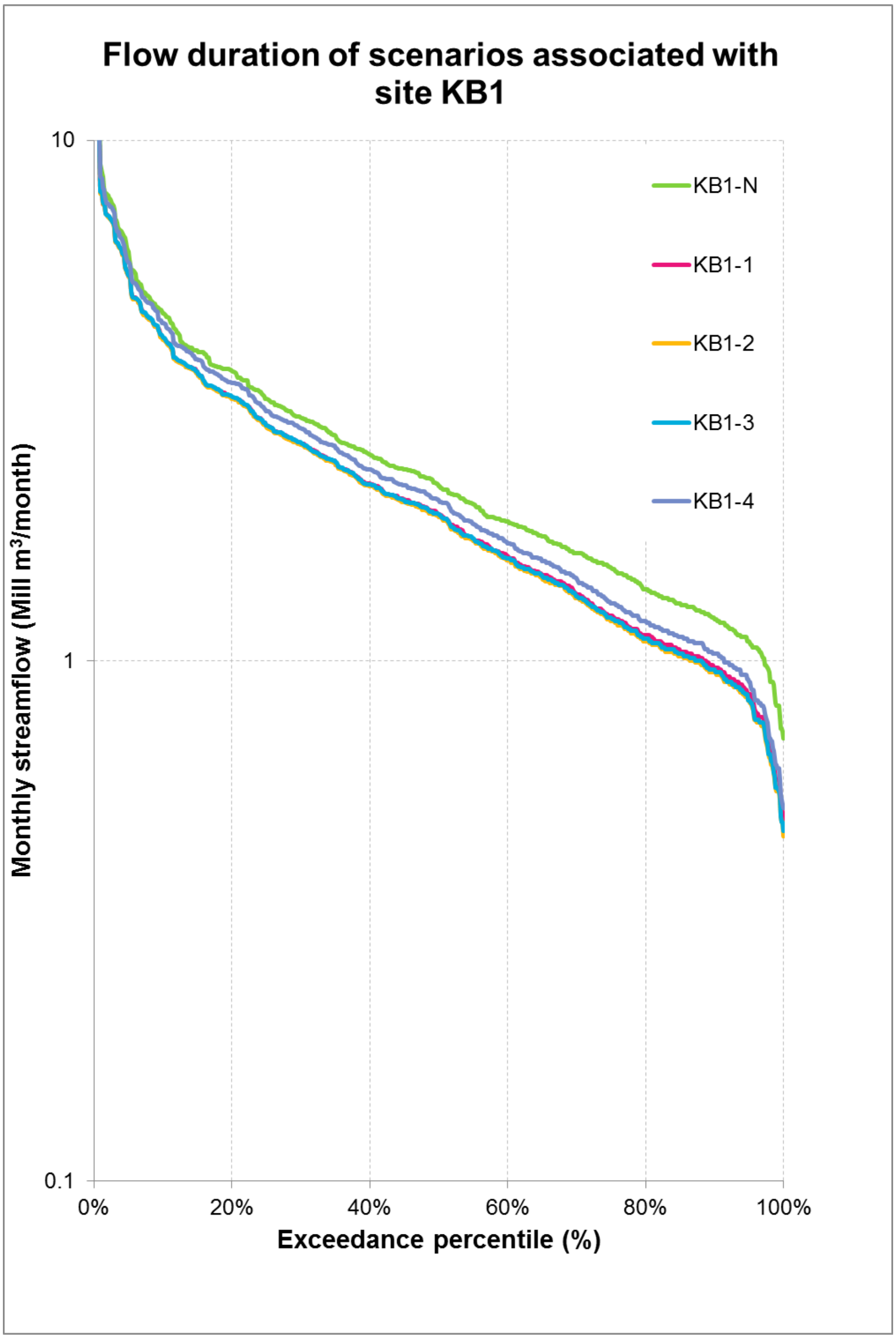


Figure 17-1: Monthly flow duration curves of inflows into Kosi Bay for different scenarios

18 NATURAL MONTHLY STREAMFLOWS AT EXTRAPOLATION NODES

Natural monthly streamflows sequences were determined at 50 river nodes across the Study Area by interrogating the equivalent locations in the existing natural condition configurations of WRYM, Pitman 2012 and *ACRU*, as the case may be.

19 REFERENCES

Aurecon, 2014. *Analysis of alternatives to determine the most feasible solution to the hydrological issues of the Lake St Lucia estuarine system*. *Hydrology Report*. Final Draft Report by Aurecon South Africa to the iSimangaliso Wetland Authority, St Lucia, South Africa.

DWA, 2014. *Reserve determination study of selected surface water and groundwater resources in the Usutu/Mhlathuze Water Management Area. Flow related Development Scenarios*. Final Draft Report by Tlou Consulting to Directorate Resource Directed Measures, Department of Water Affairs, Pretoria.

DWAF, 2009. *Water Resources Information Management System (WRIMS) Version 3.8.2.* Department of Water Affairs and Forestry, Pretoria, South Africa.

Labadie J, 2012. *MODSIM-DSS : A generalized river basin decision support system and network flow model.* Software and Manual developed by Colorado State University, Denver, USA.

Schulze RE, 1995. *Hydrology and Agrohydrology: A Text to Accompany the ACRU 3.00 Agrohydrological Modelling System*. Report, TT69/95, Water Research Commission, Pretoria.

TPTC, 2011. *PRIMA IAAP 10: System Operating Rules for the Incomati and Maputo Watercourses*. Report by Aurecon South Africa to the Tripartite Permanent Technical Committee.

WRC, 2016. *Water Resources of South Africa, 2012 Study (WR2012)*. On-line documents and database developed by Royal Haskoning (previously Stewart Scott Consulting Engineers) for the Water Research Commission, Pretoria.