Feasibility Study for Foxwood Dam (WP10580)

Koonap River Hydrology

Final Issue

DWS Report Number: **P WMA 15/Q92/00/2113/7**

water & sanitation
Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

SIGNATURE PAGE

Project name:	***Feasibility Study for Foxwood Dam***
Report Title:	***Koonap River Hydrology***
Author:	***Arup (Pty) Limited***
Arup project reference no.:	***225739-00***
DWS Report no.:	***P WMA 15/Q92/00/2113/7***
Status of report:	***Final***
First issue:	***February 2014***
Final issue:	***February 2015***

CONSULTANTS: Arup (Pty) Limited

Approved for ***Consultants:***

James Bristow	*James Hampton*
Project Manager	*Project Director*

DEPARTMENT OF WATER AND SANITATION (DWS): Directorate: Options Analysis

Approved for ***DWS:***

S. van Jaarsveld	***L. S. Mabuda***
Project Engineer: Options Analysis (South)	*Chief Director: Integrated Water Resource Planning*

ARUP

STUDY REPORTS

The Koonap River Hydrology report forms one of the suite of reports that make-up the Feasibility Study for Foxwood Dam. The full list of reports is provided below:

Feasibility Study for Foxwood Dam: Inception Report	**P WMA 15/Q92/00/2113/1**
Feasibility Study for Foxwood Dam: Preliminary Study Report	**P WMA 15/Q92/00/2113/2**
Feasibility Study for Foxwood Dam: Environmental Screening	P WMA 15/Q92/00/2113/3
Feasibility Study for Foxwood Dam: Geotechnical Reconnaissance	P WMA 15/Q92/00/2113/4
Feasibility Study for Foxwood Dam: Alternative Water Supply Options	P WMA 15/Q92/00/2113/5
Feasibility Study for Foxwood Dam: Feasibility Study Main Report	**P WMA 15/Q92/00/2113/6**
Feasibility Study for Foxwood Dam: Koonap River Hydrology	P WMA 15/Q92/00/2113/7
Feasibility Study for Foxwood Dam: Water Requirements	P WMA 15/Q92/00/2113/8
Feasibility Study for Foxwood Dam: Agro-Economic Study Report	P WMA 15/Q92/00/2113/9
Feasibility Study for Foxwood Dam: Water Quality	P WMA 15/Q92/00/2113/10
Feasibility Study for Foxwood Dam: Geotechnical Investigation	P WMA 15/Q92/00/2113/11
Feasibility Study for Foxwood Dam: Dam Feasibility Design	P WMA 15/Q92/00/2113/12
Feasibility Study for Foxwood Dam: Project Feasibility Costing	P WMA 15/Q92/00/2113/13
Feasibility Study for Foxwood Dam: Economic Impact Assessment	P WMA 15/Q92/00/2113/14
Feasibility Study for Foxwood Dam: Record of Implementation Decisions	P WMA 15/Q92/00/2113/15
Feasibility Study for Foxwood Dam: Book of Maps	P WMA 15/Q92/00/2113/16
Feasibility Study for Foxwood Dam: Public Participation (Queries & Responses Report)	P WMA 15/Q92/00/2113/17

REPORT REFERENCE

This report is to be referred to in bibliographies as:

Department of Water and Sanitation, 2015. Feasibility Study for Foxwood Dam: Koonap River Hydrology, P WMA 15/Q92/00/2113/7

Note on Departmental name change

In 2014, the Department of Water Affairs (DWA) changed its name to the Department of Water and Sanitation (DWS). This occurred during the course of this study and as a result some reporting which was commenced and/or approved prior to the name change may still refer to DWA. References herein to DWA and DWS should be considered one and the same.

EXECUTIVE SUMMARY

Study purpose and catchment developments

The Department of Water and Sanitation (DWS) has appointed Arup (Pty) Ltd to carry out an investigation into the feasibility of developing a multi-purpose dam on the Koonap River outside of Adelaide in the Eastern Cape. The proposed Foxwood Dam site is located immediately upstream of Adelaide in the Koonap River catchment area with a catchment area of 3 334 km^2, and is situated in the Eastern Cape Province and lies within the Fish to Tsitsikamma Water Management Area (WMA). The project is being considered for implementation as a strategic initiative to mobilize the water resources in the area as a stimulus for socio-economic development in this rural, economically depressed region. This initiative would support the objectives of the National Development Plan (NDP) and is consistent with the National Water Resource Strategy 2 (NWRS2).

The purpose of the Koonap River Hydrology Report within the Feasibility Study for Foxwood Dam (FSFD) is to recommend the storage capacity of the proposed Foxwood Dam. The storage capacity of the reservoir dam will be influenced by various factors including confirmation of developments upstream of Foxwood Dam, future water requirements of the users of the Foxwood Reservoir and ecological reserve requirements.

This report focuses on the water resources of the Foxwood Dam catchment, located within the Koonap River catchment which is a major tributary of the Fish River catchment. The report documents the process of generating incremental natural hydrology for the defined sub-catchments of the Foxwood Dam and Koonap River study area and information relating to the hydrological analysis is presented. It also documents the process of setting up the Water Resource Yield Model to determine the historic and stochastic yields of Foxwood Dam.

The area of the Foxwood Dam catchment is 1 091 km^2 which is 33 % of the total catchment area of the Koonap River catchment. Important tributaries of the Koonap River include the Braambospruit, Mankazana, Waterkloof and Enyara Rivers. A locality map of the study area is presented in Figure 1.1 of this report. The Foxwood Dam and Lower Koonap River catchments have similar landuse in that both catchments are rural in nature with agriculture the dominant activity. The Koonap River catchment falls within the Eastern Cape Province and has no major towns. The small towns of Adelaide and Bedford are located within the lower Koonap River catchment. Water related infrastructure is the Koonap River catchment is dominated by run of river abstractions or diversions for domestic use and for the irrigation of crops ranging from pastures to citrus.

The ecological water requirements for two reserve sites were determined in a separate report, Koonap River: Resources unit delineation and identification of Hotspots Report (Rivers for Africa, 2013). This intermediate level study identified the Recommended Ecological Category (REC) as a C-category at both EWR sites, which is the same as the Present Ecological State (PES). The operating rule recommended by the Reserve specialist is that the low flow EWR assurance rule should be implemented at these sites.

Rainfall and streamflow

The Koonap River catchment falls within the summer rainfall zone but is located adjacent to the year-round zone of coastal catchments which means rainfall can occur at any time of the year. The MAP varies from 662 mm in the northern headwater catchments in the Winterberg Mountains to 446 mm in the southern Enyara catchment.

Information about rainfall was obtained from previous studies and from the DWS in the Eastern Cape. A total of 21 rain gauges in and around the Koonap River catchment were identified and screened using standard validation tests. After screening 4 gauges were excluded from further analysis. The remaining gauges were used in the patching process to generate catchment rainfall records for the period 1920 to 2011 (92 years). The mean annual Symons pan evaporation (MAE) in the Foxwood Dam catchment area is in the order of 1 651 mm.

There are two operational flow gauges within the Koonap River catchment. The Q9H030 gauge is located in the headwaters of the Foxwood Dam catchment. The Q9H002 gauge is located just downstream of the proposed site for Foxwood Dam. After limited patching both gauges were used to calibrate the Upper Koonap River catchments of Q92A, B, C and D. The rain zones, rain gauges and streamflow gauges are shown in Figure 6.1 of this report.

Rainfall-runoff calibration and natural flows
The aim of the calibration was to generate monthly flow records that simulate the observed records at Q9H002 and Q9H030. Reasonable calibrations were obtained at both gauge sites and the calibration statistics are summarized in Table 7.2 of this report.

The naturalized stream flows for all catchments were generated and compared with previous studies. The results of the comparison are provided in Table I and show similar unit runoffs across studies. The naturalized MAR at the proposed Foxwood Dam site is 47.61 million m^3/a.

Table I: Comparison of naturalized runoff

Sub-area	Area	MAP	MAE (S)	nMAR	Standard Deviation	Rf - Ru response	Comparison unit runoff (mm/a)		
	(km ^{2})	(mm/a)	(mm/a)	FSFD $10^6 m^3$	FSFD $10^6 m^3$	FSFD (2011)	FSFD	WR2005	WR90
Q92A1	250	662	1 650	18.86	14.8	11 %	75	63	67
Q92A2	74	662	1 650	5.23	4.2	11 %	71	63	67
Q92B	324	586	1 650	10.98	12.6	6 %	34	36	36
Q92C	601	559	1 650	17.01	20.4	5 %	28	30	31
Q92D	249	594	1 600	9.78	10.5	7 %	39	46	38
Q92E	287	464	1 600	3.38	5.3	3 %	12	12	9
Q92F	665	415	1 650	4.56	7.2	2 %	7	7	6
Q92G	884	466	1 600	9.83	15.2	2 %	11	11	10
Q92	**3334**	**513**		**79.63**	-	-	**24**	**23**	**23**
Foxwood	**1 091**	**577**	**1 650**	**47.61**	-	-	**44**	**42**	**43**

Note: FSFD = Feasibility Study for Foxwood Dam Study = 1920 – 2011
WR90 = 1920 – 1989
WR2005 = 1920 – 2004
Rf – ru = Rainfall – runoff response

Yield model configuration
The Water Resources Yield Model has been configured to assess the historic, long-term and short-term capability of the Foxwood Dam system for a range of live storage capacities ranging from 23.8 million m^3 to 95.2 million m^3. These live capacities are equivalent to nMAR's of 0.5 nMAR to 2nMAR. Analyses were undertaken based on a monthly time-step and at present day (2011/12) development levels. The system diagram or network for the Foxwood Dam and Koonap River system is provided in Figure 9.1 of this report.

Scenario development
Three water requirements scenarios were addressed in this study and are:

- Scenario 1: Best estimate of present day (2012/13) development levels with Foxwood Dam.
- Scenario 2: Best estimate of present day (2012/13) development levels with Foxwood Dam and Total Flow EWR assurance rule implemented.

- Scenario 3: Best estimate of present day (2012/13) development levels with Foxwood Dam and Low Flow EWR assurance rule implemented.

The assumptions and operating rules for scenarios 2 and 3 are detailed in section 9.2 of this report.

Yield Assessment
The results of the firm yield, long term and short term stochastic yield assessments for Foxwood Dam for range of storage capacities are provided for scenarios 2 and 3 in Tables II and III and graphically in Figures I and II.

Table II WRYM model results - Historic and long term yields of proposed Foxwood Dam for range of storage capacities

Reservoir capacity as a ratio of nMAR	Elevation	Wall height	Live storage	Dead Storage	FSC	EWR KOON1	EWR KOON2	HFY	Critical period		Long term yield ($10^6m^3/a$) at Recurrence Interval		
	(m.a.s.l)	(m)	(10^6m^3)	(10^6m^3)	(10^6m^3)	(million m^3/a)			Start	End	1:20	1:50	1:100
Scenario 2 – Foxwood Dam system with EWR rule supplied for total flows (incl. high flows)													
0.5 nMAR	608.5	33.5	23.81	6.11	29.92	7.86	13.00	6.88	7/1944	4/1948	9.7	7.8	6.7
0.75 nMAR	611.6	36.8	35.71	6.11	41.82	7.86	13.00	9.69	7/1944	3/1950	13.7	11.1	9.3
1.0 nMAR	614.6	39.6	47.61	6.11	53.72	7.86	13.00	12.52	7/1944	4/1950	15.9	13.3	11.3
1.5 nMAR	619.5	44.5	71.42	6.11	77.52	7.86	13.00	17.50	7/1954	9/1970	19.8	16.9	14.9
2.00 nMAR	623.1	48.1	95.22	6.11	101.33	7.86	13.00	18.91	7/1954	12/1970	22.8	19.5	17.2
Scenario 3 – Foxwood Dam system with EWR rule supplied for low flows (excl. high flows)													
0.5 nMAR	608.5	33.5	23.81	6.11	29.92	2.18	5.30	10.23	7/1944	4/1948	12.8	11.0	9.5
0.75 nMAR	611.6	36.8	35.71	6.11	41.82	2.18	5.30	13.36	7/1944	3/1950	17.2	13.8	12.4
1.0 nMAR	614.6	39.6	47.61	6.11	53.72	2.18	5.30	16.56	7/1944	3/1950	19.1	16.4	14.6
1.5 nMAR	619.5	44.5	71.42	6.11	77.52	2.18	5.30	20.47	11/1986	4/1997	22.9	20.3	18.0
2.00 nMAR	623.1	48.1	95.22	6.11	101.33	2.18	5.30	21.88	7/1954	12/1970	26.2	22.8	20.6

Likely size of Foxwood Dam based on EWR assurance rules and present day upstream water requirements.

Table III WRYM model results - Short term yields of proposed Foxwood Dam with live storage capacity of 1nMAR

Recurrence Interval	Short term yields for various starting storages ($10^6m^3/a$)					
	100 %	80 %	60 %	40 %	20 %	10 %
Results for scenario 2 for 1nMAR dam with Total Flow EWR						
1:5	28.7	27.7	25.7	23.5	19.2	14.4
1:10	23.0	21.8	20.2	17.5	12.9	9.3
1:20	19.0	17.6	15.9	13.1	9.0	6.2
1:50	15.4	14.0	11.9	9.4	5.7	3.5
1:100	12.8	11.7	10.4	7.1	4.5	2.3
1:200	11.3	10.6	8.7	5.8	3.6	1.8
Results for scenario 3 for 1nMAR dam with Low Flow EWR						
1:5	32.0	30.6	29.0	26.6	21.6	15.6
1:10	26.3	24.8	23.0	20.4	15.7	11.0
1:20	22.1	21.0	19.1	15.8	11.7	8.0
1:50	18.5	16.9	15.1	12.0	8.4	5.6
1:80	16.4	15.4	12.7	10.8	6.7	4.3
1:100	15.3	13.7	11.1	9.9	5.6	3.3

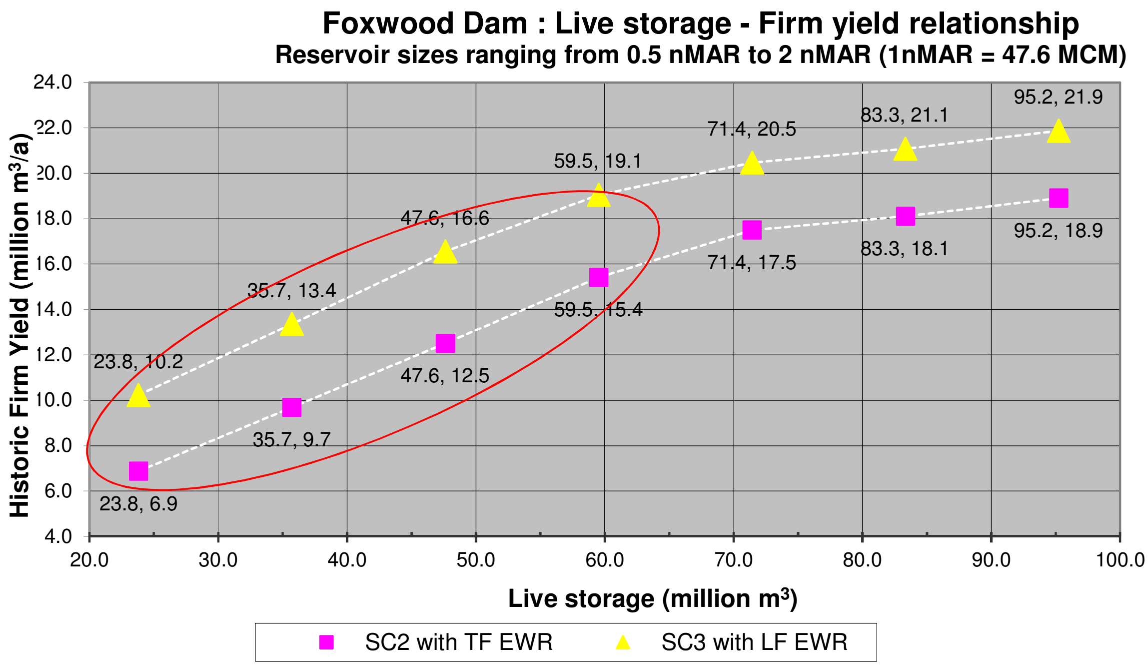


Figure I Comparison of results for Storage-Firm yield relationships

For both scenarios for live storages of 1.5 nMAR and greater the yield gained relative to increased storage capacity is insignificant as shown by flattening of the storage-yield relationship. The final storage capacity of Foxwood Dam should be in the storage range circled in red in Figure I.

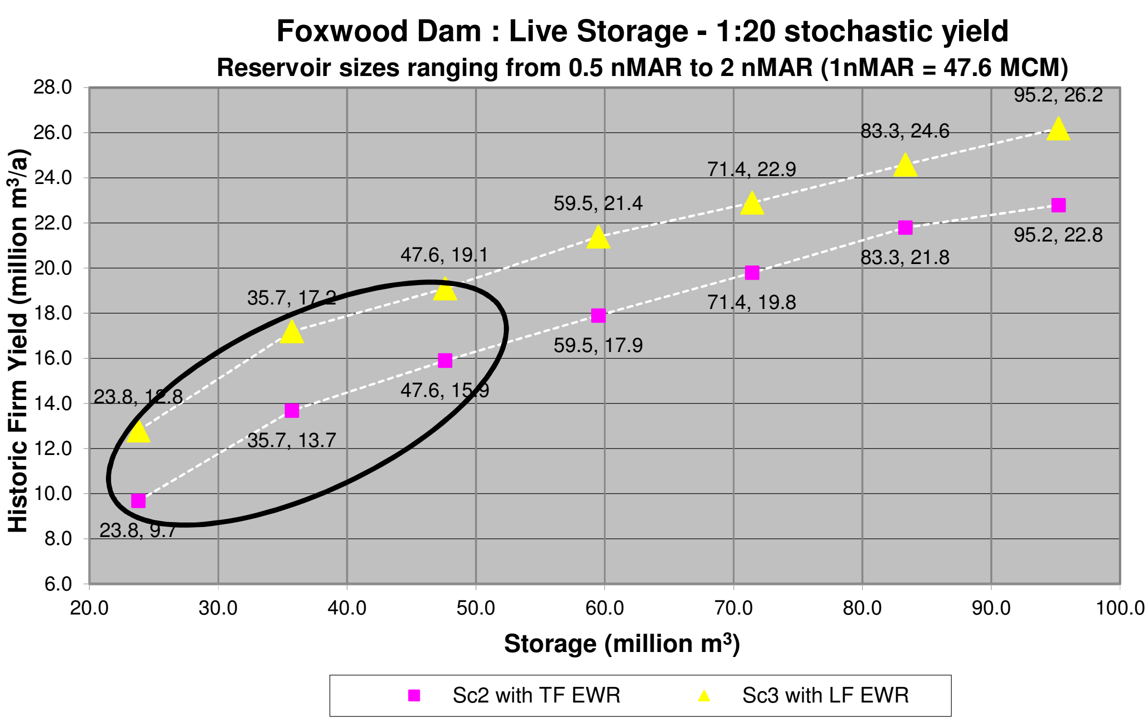


Figure II Comparison of results for storage-1:20 yield relationships

For both scenarios the final storage capacity of Foxwood Dam should be in the storage range circled in black in Figure II. The actual storage capacity of Foxwood Dam will be determined by confirmation of system demands, including the EWR operating rules.

Conclusion and recommendations

From the hydrological analysis of the Foxwood Dam system the following conclusions are drawn:

- The analysis of rainfall produced acceptable data that could be used with confidence to calibrate the Pitman model. However the number of rain gauges that remain in operation are a cause for concern and urgent consideration should be given to the establishment of additional monitoring sites
- Acceptable calibrations were obtained at Q9H002 and Q9H030. The results from the verification and validation of stochastic flows indicated that the flows are plausible and realistic and can be used with confidence for further water resources analysis of the Foxwood Dam system

From the water resources analysis of the Foxwood Dam system the following recommendations are drawn:

- The status of all water users upstream of Foxwood Dam should be confirmed by actual field survey. The results of the field survey should be linked to the lawful use or registration of database, Water Use Registration Database (WARMS).The current water requirements were mostly determined from existing information such as the WARMS database and reconciliation strategies..
- The EWR operating rule recommended for the Foxwood Dam system is for flood EWRs to be met by spills from Foxwood Dam and for low flow EWRs to be met by inflows downstream of Foxwood Dam and upstream of EWR site KOON 1. These rules require confirmation in the form of an Ecological Water Resources Monitoring Programme that will establish additional flow monitoring sites at or near EWR sites to assist in the hydraulic modeling of the Koonap River downstream of Foxwood Dam.
- The likely storage capacity is in the range of 29.3 million m^3 to 53.7 million m^3 for 1:20 stochastic yields of 9.7 million m^3 to 19.1 million m^3.
- The final storage capacity of Foxwood Dam can only be confirmed once the water requirements of all users are established. This information will determine the demand pattern of supply from Foxwood Dam and systems yields will require update and confirmation.

.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

LIST OF ACRONYMS

ACRONYM	DESCRIPTION
AIP	Alien Invasive Plants
AW	Amatola Water
CP	Critical Period
DWS	Department of Water and Sanitation
DAFF	Department of Agriculture, Fisheries and Forestry
EIS	Ecological Importance And Sensitivity
EWR	Ecological Water Requirements
FSC	Full Supply Capacities
GRA	Groundwater Resources Assessment
HFY	Historic Firm Yield
IEI	Integrated Environmental Importance
LTY	Long Term Yield
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
nMAR	Naturalised Mean Annual Runoff
pMAR	Present Day Mean Annual Runoff
MCM	Million Cubic Meters
MRU	Management Resource Units
NEMA	National Environmental Management Act
NGA	Groundwater Database
nMAR	Natural Mean Annual Run-off
Nxuba	Nxuba Local Municipality
PES	Present Ecological State
PSP	Professional Service Provider
RDREM	Reserve Estimation Model
REC	Recommended Ecological State
SA	South Africa
SAWS	South African Weather Service
SCI	Socio-Cultural Importance
SFR	Streamflow Reduction
S.I.	Seasonal Index
StatsSA	Statistics South Africa
STOMSA	Stochastic Model of South Africa
SW - GW	Surface Water - Ground Water
WARMS	Water Use Registration Database

ACRONYM	DESCRIPTION
WfW	Post Retief Working For Water
WMA	Water Management Area
WQT	Water Quality Irrigation Model
WR-IMS	Water Resources Information Management System
WRUI	Water Resource Use Importance
WRYM	Water Resources Yield Model
WSA	Water Service Authority
WSDP	Water Services Development Plan
WSP	Water Service Provider
WTW	Water Treatment Works

LIST OF UNITS

MEASURE	UNIT
Area	m2, ha or km2
Diameter	mm dia., m dia.
Dimension	mm, m
Discharge	m^3/s
Distance	m or km
Elevation	m.a.s.l.
Flow Rate	l/s or m3/s
Gradient (V:H)	%
Percentage	%
Rainfall	mm
Temperature	°C
Velocity, speed	m/s, km/hr
Volume (storage)	m3, million m3
Yield	million m3/a

1 INTRODUCTION

The Koonap River catchment shown in Figure 1.1, has a catchment area of 3 334 km², is situated in the Eastern Cape Province and lies within the Fish to Tsitsikamma Water Management Area (WMA). The headwaters of the Koonap River are in the Winterberg Mountains from which it flows southwards past the town of Adelaide. The Koonap River is a tributary of the Great Fish River. The river is situated in the quaternary catchments Q92A to Q92G. The natural Mean Annual Runoff (MAR) of the Koonap River for the period 1920 to 2011 is 79.6 million m³/a. The runoff ranges from 75 mm in Q92A1 in the Winterberg Mountains to 7 mm in the dry Enyara (Q92F) River catchment. The average runoff from the Koonap catchment is 24 mm.

The average Mean Annual Precipitation (MAP) for the Koonap River is 513 mm with the maximum MAP in Q92A in the Winterberg Mountains of 662 mm and minimum MAP of 415 mm in Q92F. The general trend is decreasing rainfall as you move southward with high lying areas receiving more rainfall.

The Koonap River catchment is rural in nature with farming the main activity. There is some irrigation, which is mostly run of river abstractions and some cattle farming. The urban centres of Adelaide and Bedford are located in the catchment. Adelaide gets much of its water from local resources within the Koonap River catchment while Bedford is supported by local resources and transfers from the Great Fish River.

1.1 Context of the study

DWS have appointed Arup to do an assessment of the surface water resources of the Koonap River catchment to meet the future water requirements of water users. The assessment will be used to determine when interventions such as developing Foxwood Dam may be required to address any shortfalls in water supply.

Hydrological and yield analyses were undertaken to assess the impact of current development levels on the availability and reliability of water supply to users in the Koonap River catchment. The following tasks were undertaken as part of the water resources assessment:

- Data collection
- Land-use assessment
- Water requirements and returns flows
- Hydrological analysis of the Koonap River catchment
- Yield Analysis at Foxwood Dam site.

1.2 Objectives of the Hydrological Analysis

The main objectives of the hydrological analysis are summarised and included:

- Determining current (2012) land use practices and estimated current water use
- Updating and extending the hydrology of the Koonap River catchment to cover the period from 1920/21 to 2011/12.
- Generating time series of natural monthly streamflows for all sub-catchments within the Koonap River for the selected study period.

The rainfall-runoff modeling for the hydrological analysis was undertaken using version 2.7 of the Pitman model. Outputs from the hydrological analysis served as direct input to the water resources system yield analyses.

1.3 Objectives of the Yield Analysis

The main objectives of the yield analysis included:

- Generating time-series of present day flows at selected Reserve sites.
- Determining the historical firm yields (HFY) and long term stochastic yield of Foxwood Dam.
- Determining the short-term stochastic yield of Foxwood Dam.

The model used for the yield analyses was version 7.5.6.7 of the Water Resources Yield Model (WRYM) which is located within version 3.8.2 of the Water Resources Information Management System (WR-IMS).

1.4 Purpose and structure of document

The purpose of this report is to provide a brief description of the hydrological and yield analyses undertaken. The report consists of a number of sections that include:

- An introduction to the study, including background information (section 1).
- References to the primary information sources for the hydrological and yield analyses (section 2).
- A description of the study area (section 3).
- Summary of current water demands /requirements and returns flows related to domestic, industrial and irrigation users, streamflow reductions from commercial forestry and from infestations of alien invasive plants and ecological water requirements (section 4, Appendix A).
- Summary of water storage in study area (section 5, Appendix A).
- Analysis of hydro-meteorological data such as rainfall, evaporation and streamflow (section 6, Appendices B and C).
- Description of rainfall runoff modelling and results including the generation of naturalized streamflow data (section 7, Appendix D).
- Evaluation of results from the stochastic streamflow analysis (section 8, Appendix D).
- Summary of the Koonap River system, configuration of the WRYM and results (section 9, Appendix D).
- Conclusions and Recommendations (section 10).
- References (section 11).
- Summary of Ecological Water Requirements (section 12, Appendix E & F)

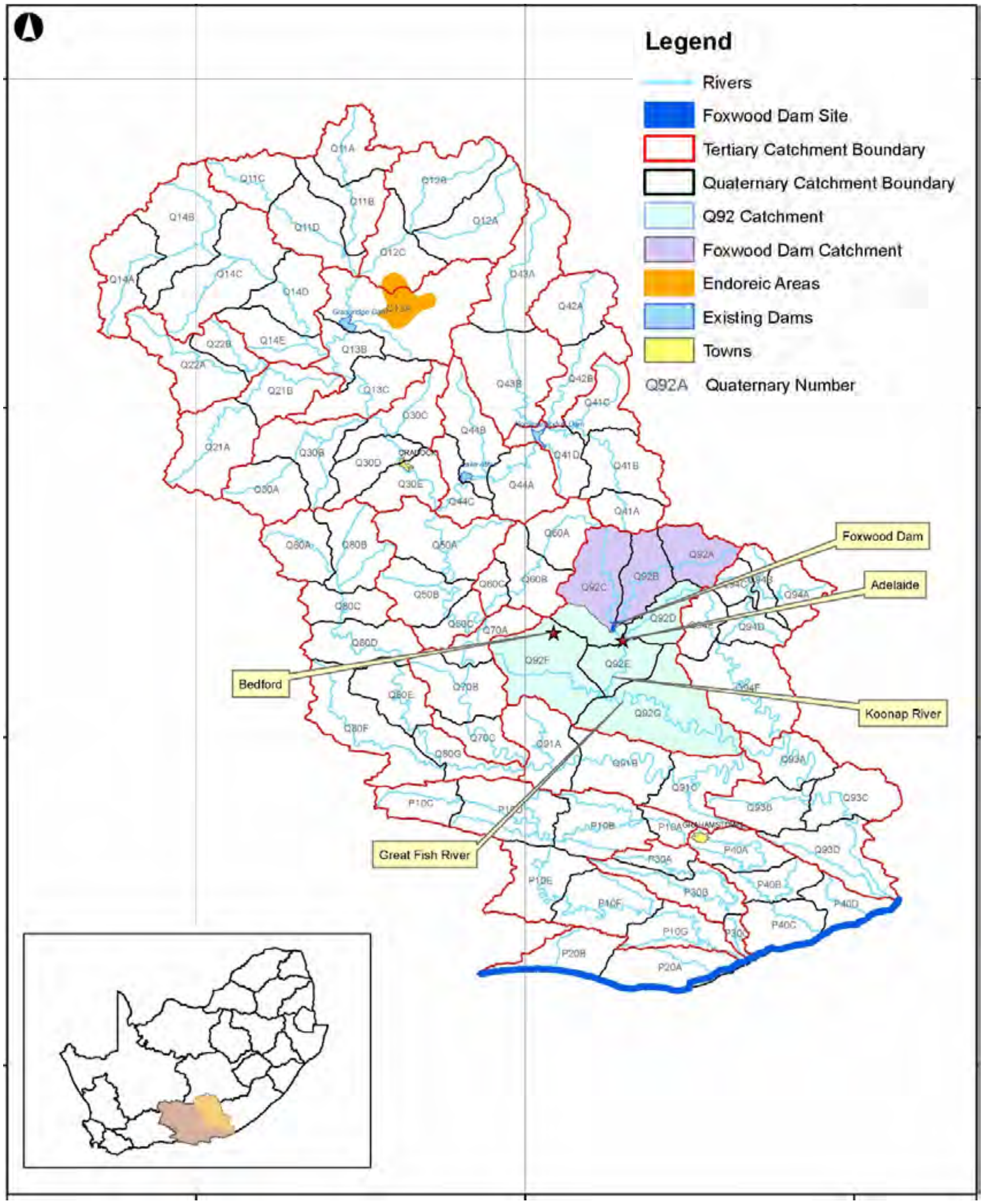


Figure 1.1 Location of the Koonap River catchment

2 INFORMATION SOURCES

The level of confidence that can be placed on the results of a study is dependent on the quality of data and information used in the analyses. The information requirements for a water resources assessment include the need for reliable time-series data for rainfall and streamflow and for information about historical water use and descriptions of physical characteristics of the water resources system such as information of storage dams, etc.

2.1 Previous studies

The following studies have information about the Koonap River system:

- Surface Water Resources of South Africa (WRC, 1994)
- Water Resources of South Africa 2005 (WRC, 2008)
- Adelaide Water Supply: Proposed Foxwood Dam (Ninham Shand, 1992).

The WR2005 hydrology for the Koonap River system (Q92) was used as the basis for this study. The WR2005 system configuration was updated and extended from 2004/5 to 2011/12.

2.2 WARMS database

A copy of the DWS's Water use authorization and registration management system (WARMS) for the Koonap River (Q92) catchment was obtained from the DWS in the Eastern Cape (mfeneT@dwa.gov.za; 9 December 2012). The WARMS database also provides information about the sources of water for domestic and agricultural users and information about crops irrigated and irrigation application systems. The information from this database is provided as an electronic database in Appendix A.

2.3 Other data sources

Following initial review during the Inception phase the WR2005 Pitman model setup of the Koonap River catchment was accepted as reasonable, including the evaporation data and Pitman parameters. However the Sami parameters in the WR2005 setup were not correct and required update from the Groundwater Resources Assessment (GRA)-II study (DWA, 2005). Other data sources were consulted such as the DWS Hydstra database for streamflow data, the RainIMS for rainfall data and patching routines. The DWS in the Eastern Cape provided updated information for rain gauges and streamflow gauges and the Department of Environment in the Eastern Cape provided information on the extent of Invasive Alien Plants in the Q92 catchments.

3 STUDY AREA

The study area has been described in Section 1 of the report. For the hydrological analysis the study area was modeled at quaternary catchment scale, except for the upper Koonap River catchment (Q92A) which was sub-divided into two areas, Q92A1 and Q92A2. Q92A1 is the catchment area of flow gauge Q9H030 and represents a calibration point in the Koonap River system. For the Yield analysis the catchments were subdivided to take into consideration Reserve sites, the Adelaide diversion, the location of irrigation. The WRYM catchment areas are summarised in Table 3.1 and a locality map of the study area, indicating the sub-catchments is provided in Figure 3.1 (full size image provided in Appendix G)

Table 3.1 Summary of Koonap River sub-catchments

Sub-catchment	Catchment area (km^2)	Description
Q92A1	250	Upper Koonap River at Q9H030
Q92A2	74	Lower Upper Koonap River
Q92B1/B3	304	Koonap River / Braambos River
Adelaide off-take(2)	**628**	**Catchment area upstream of Diversion**
Q92B2	20	Koonap River d/s of off-take
Q92C1	443	Koonap River / Mankzana River
Foxwood Dam(2)	**1 091**	**Foxwood Dam catchment area**
Q92C2	90	Cowie River catchment
Q92C3	69	Koonap River d/s Foxwood Dam (Adelaide)
Q9H002	**1 249**	**Catchment area upstream of Q9H002**
Q92D1	105	Kaalhoek River u/s of Endwell Dam
Q92D2	144	Waterkloof River d/s of Endwell Dam
Q92E1	90	Mid-Koonap River u/s EWR KOON1 site
EWR1(2)	**1 588**	**Catchment area upstream of EWR KOON1 site**
Q92E2	197	Mid-Koonap River downstream EWR KOON1
Q92F(1)	665	Enyara River Quaternary catchment area
Q92G1	696	Lower-Koonap at EWR KOON2 Reserve site
EWR2(2)	**3 146**	**Catchment area upstream of EWR KOON2 site**
Q92G2	188	Lower-Koonap River downstream EWR KOON2
Q92 Tertiary	**3 334**	**Koonap River catchment area**

Notes:
1. (1) Catchment areas for quaternary catchments were obtained from WR90 (WRC, 1994) and WR2005 studies (WRC, 2008)
2. (2) Catchment areas for sub-catchments were obtained from 1:20 contour maps.

3.1 Defining the storage capacity of proposed Foxwood Dam

There is a need to define the range of the storage capacities of the proposed Foxwood Dam in terms of the water resources of the Foxwood Dam catchment area. The naturalized mean annual runoff (nMAR) at Foxwood Dam is 47.61 million m^3/a and is defined in section 7. This means a reservoir with a live storage capacity of 47.61 million m^3 will be defined as a 1 nMAR dam. Storage capacities ranging from 0.5 nMAR or 23.8 million m^3 to 2 nMAR or 95.22 million m^3, were defined for the yield modeling in section 9.

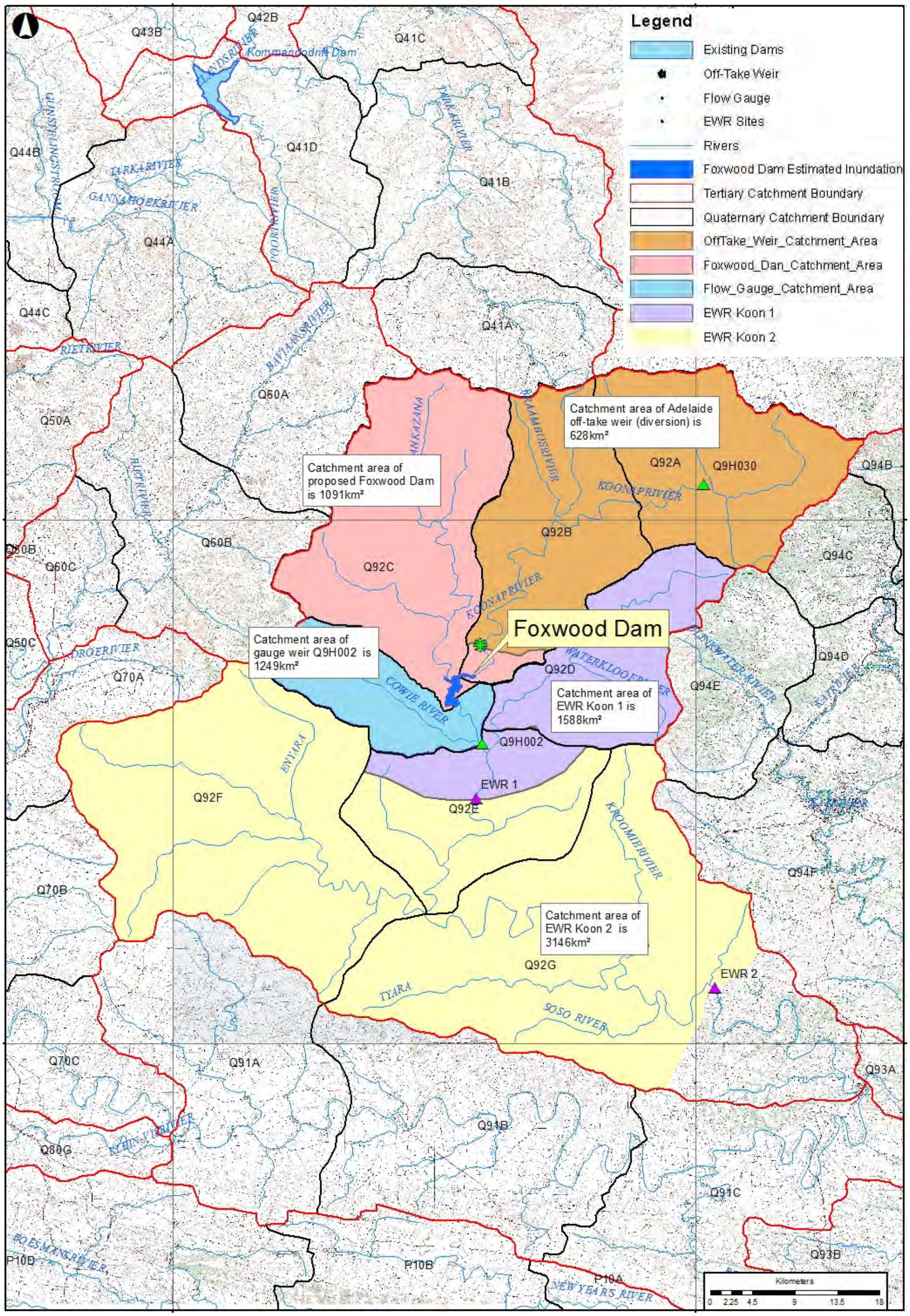


Figure 3.1 Koonap River and Foxwood Dam catchments and related sub-area

4 WATER USE

For the purpose of calibrating the Pitman rainfall-runoff model and for calibrating the yield of the proposed Foxwood Dam, all historical and current (2012/12) human interventions that impact on the stream flow generated within the modeled catchments must be taken into account. Abstractions and return flows by domestic users and irrigators are assessed. Also considered is the impact on stream flow from commercial forestry, alien invasive plants and groundwater abstractions.

4.1 Domestic water abstractions and return flows

The domestic water abstractions from water resources within the Koonap River catchment and associated return flows are summarised in Table 4.1. Information about abstractions for domestic water users and their requirements was obtained from the WARMS database (mfeneT@dwa.gov.za; 9 December 2012) and from the Reconciliation Strategies for the towns of Adelaide (DWA, 2010) and Bedford (DWA, 2010a & b). Both towns are part of the Nxuba Local Municipality. Information about historical abstractions for domestic users was not readily available.

Table 4.1 Summary of domestic water abstractions and return flows

Sub-area	User	Source	Abstraction (million m³/a)	Registered (million m³/a)	Sub-area	Return flows (million m³/a)
Q92B Q92C	Adelaide	Koonap River	0.73	1.05 (WARMS)	Q92C	0.139
Q92F	Bedford	Andrew Turpin Dam / Enyara River	0.30	0.43 (WARMS)	Q92F	0.094

Adelaide's water supply comes mainly from an off-take weir located on the Koonap River upstream of Adelaide and the Foxwood Dam site. The diversion has an estimated capacity of 100 l/s or 0.1 m³/s (Ninham Shand, 1992) that is transferred via canal to the Adelaide off-channel storage dam with estimated capacity of 0.7 million m³. Adelaide can also get water from the Fish River. The Fish River transfer scheme has a designed capacity of 30 l/s (DWA, 2010) and is a pipeline transfer via Bedford. Treated effluent is mostly recycled but there are some releases to the Koonap River downstream of Adelaide.

Bedford's water supply comes from a number of sources. Within the Koonap River catchment water is abstracted from Turpin Dam and Enyara River. These abstractions are in the Enyara River tributary catchment (Q92F) downstream of the Foxwood Dam site however the abstractions are upstream of the lower (EWR2) site.

No industrial water requirement has been identified in the Koonap River catchment in the current and in previous studies (WARMS, 2012; WRC, 1994, 2008). Registered land uses are illustrated in Figure 4.1 below (A3 size image provided in Appendix G)

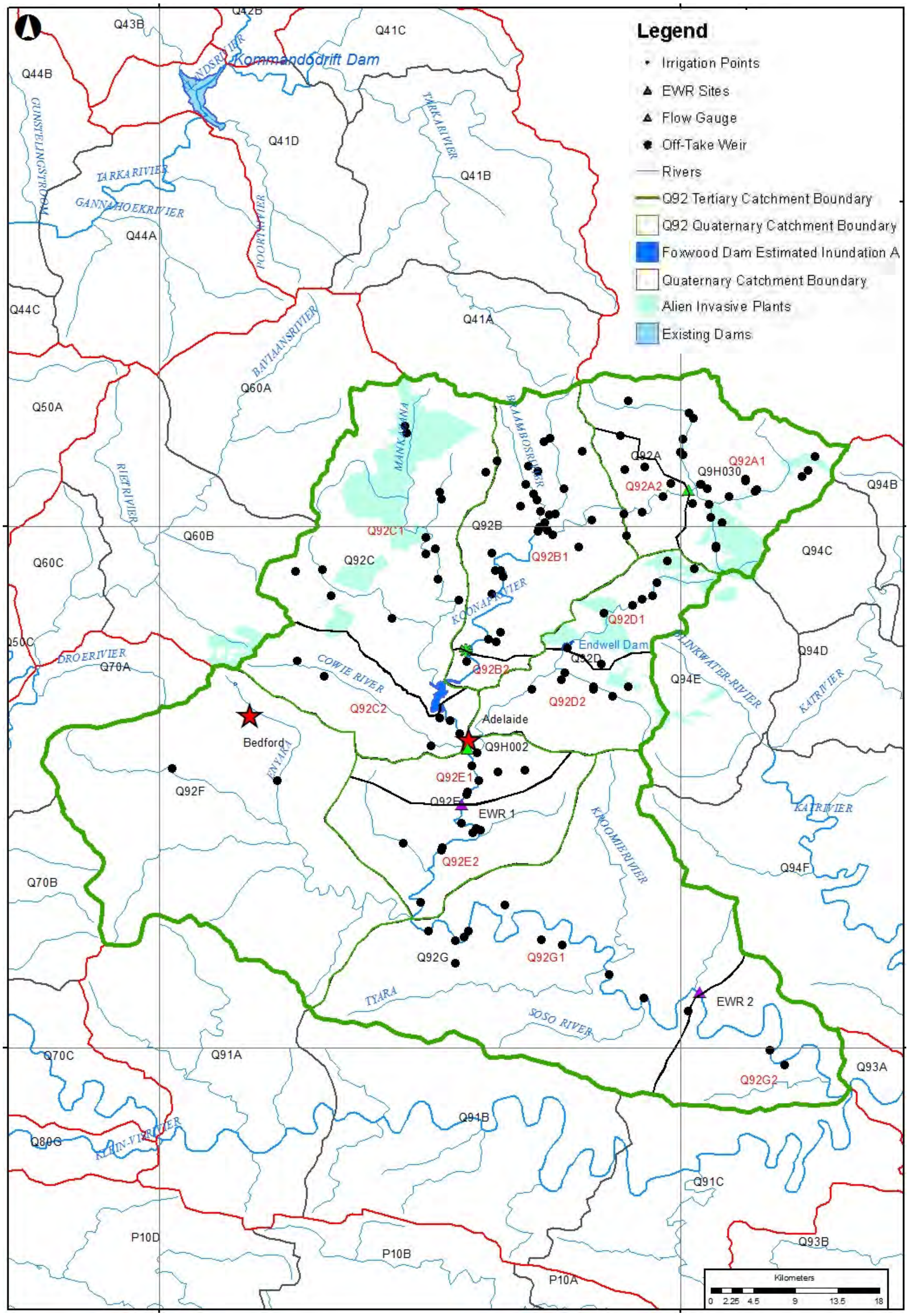


Figure 4.1 Land use in the Koonap River Catchment

4.2 Irrigation water requirements and return flows

According to the WARMS database (mfeneT@dwa.gov.za; 9 December 2012) a total field area of 21.48 km^2 (2148 ha) is registered as irrigation in the Koonap River catchment. The irrigation of crops occurs from a number of water sources. Of the total area registered, 93 % is registered to surface water sources and 7 % to groundwater sources. Most abstractions are from run of river sources (88 %) with remaining abstractions from farm dams (5 %).

The WARMS information has been used to represent the current (2011/12) development level as no other information was readily available. Historical information about irrigation was extracted from the WR90 and WR2005 studies (WRC, 1994; WRC, 2008). The growth in irrigation area from surface water resources shown in Table 4.2 was used in the Water Quality (WQT) irrigation block sub-module to calibrate the hydrology (Pitman) model.

Table 4.2 Historical growth in irrigation area and WARMS allocations

Quat	Source	Irrigated area (km^2)					WARMS
		1920	1950	1989	1995	2011	(million m^3)
Q92A1	Run-of-River	0.00	Linear ↑	1.70	6.22	6.66	4.04
Q92A2	Run-of-River	0.00	Linear ↑	0.40	0.43	0.52	0.15
Q92B	Run-of-River	0.00	0.00	0.00	6.90	2.84	1.24
Q92C	Farm Dams	0.00	0.00	0.28	0.28	0.28	0.20
Q92C	Run-of-River	0.00	Linear ↑	13.42	6.03	2.57	1.90
Q9H002	**Upper Koonap**	**0.00**	**-**	**15.80**	**19.86**	**12.87**	**7.53**
Q92D	Farm Dams	0.00	0.00	0.05	0.05	0.05	0.05
Q92D	Run-of-River	0.00	Linear ↑	1.10	2.24	3.72	2.18
Q92E	Farm Dams	0.00	0.00	0.00	0.00	0.16	0.13
Q92E	Run-of-River	0.00	Linear ↑	13.50	3.60	1.51	1.17
Q92F	Farm Dams	0.00	0.00	0.50	0.50	0.50	0.26
Q92F	Run-of-River	0.00	0.00	0.03	0.06	0.06	0.07
Q92G	Run-of-River	0.00	Linear ↑	3.80	0.67	1.06	0.61
Lower Koonap		**0.00**	**-**	**18.98**	**7.12**	**7.05**	**4.47**
Q92		**0.00**	**-**	**34.78**	**26.98**	**19.92**	**12.00**

Irrigation water requirements, supplies and return flows were simulated in the Pitman and Yield Model using the WQT Irrigation Block sub-module. The distribution of irrigation from surface water resources in the Yield Model is summarised in Table 4.3.

Table 4.4 summarises the crops irrigated and their crop factors. The irrigation of fodder crops such as lucerne, rye grass and pastures (63 %) is dominant with some irrigation of high value crops such as citrus (13 %) and avocados.

Table 4.3 WRYM irrigation information for sub-areas

Crops	Irrigated area (ha)					
1) Irrigation upstream of Foxwood Dam						
Crops and sub-catchments	**Q92A1 RoR**	**Q92A2 RoR**	**Q92B1 RoR**	**Q92B3 RoR**	**Q92C1 RoR**	**Total area**
Avocado	0	0	35	0	0	**35**
Cabbage (late)	6	0	0	0	0	**6**
Citrus	0	0	12	0	0	**12**
Deciduous fruit	12	0	0	0	0	**12**
Lucerne, rye grass	383	34	117	23	127	**684**
Maize (late)	116	0	21	0	4	**141**
Pasture (incl. teff)	24	13	35	13	28	**113**
Oats (winter)	125	5	13	15	2	**160**
Total irrigated area	**666**	**52**	**233**	**51**	**161**	**1163**
Application efficiency	75%	75%	65%	70%	75%	
Return flow factor	0.02	0.02	0.03	0.03	0.02	
2) Irrigation from Koonap River downstream of Foxwood Dam						
Crops and sub-catchments	**Q92C2 RoR**	**Q92E1 RoR**	**Q92E2 RoR**	**Q92G1 RoR**	**Q92G2 RoR**	
Cabbage (late)	0	0	0	0	10	**10**
Citrus	0	82	6	21	6	**115**
Lucerne, rye grass	68	4	8	20	20	**120**
Pasture (inc. teff)	0	0	40	19	0	**59**
Pecan nuts	13	6	0	0	0	**19**
Oats (winter)	0	0	5	0	10	**15**
Total irrigated area	**81**	**92**	**59**	**60**	**46**	**338**
Allocation (million m ³)	**0.44**	**0.95**	**0.22**	**0.44**	**0.17**	**2.22**
Application efficiency	75%	80%	80%	80%	80%	
Return flow factor	0.02	0.02	0.02	0.02	0.02	
3) Irrigation from tributary catchments downstream of Foxwood Dam						
Crops and sub-catchments	**Q92C2 FD**	**Q92D RoR**	**Q92D FD**	**Q92E1 FD**	**Q92F FD/RoR**	
Cabbage (late)	0	18	0	0	0	**18**
Citrus	0	124	0	16	0	**140**
Lucerne, rye grass	43	135	3	0	48	**229**
Maize (late)	0	18	0	0	8	**26**
Pasture (inc. teff)	0	55	2	0	0	**57**
Oats (winter)	0	22	0	0	0	**22**
Total irrigated area	**43**	**372**	**5**	**16**	**56**	**492**
Allocation (million m ³)	**0.31**	**2.18**	**0.05**	**0.13**	**0.32**	**2.99**
Application efficiency	75%	75%	75%	90%	80%	
Return flow factor	0.02	0.02	0.02	0.02	0.02	

Table 4.4 Representative crop factors for crops irrigated in the Koonap River catchment

Crop	Area (%)	Crop factors											
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Lucerne, rye grass	51.8	0.70	0.80	0.80	0.80	0.80	0.70	0.50	0.40	0.30	0.30	0.30	0.50
Citrus	13.4	0.45	0.45	0.50	0.55	0.60	0.65	0.70	0.65	0.60	0.45	0.45	0.45
Pastures	11.5	0.70	0.80	0.80	0.80	0.80	0.80	0.60	0.50	0.50	0.50	0.50	0.60
Oats (winter)	9.8	1.00	0.65								0.30	0.50	0.95
Maize (late)	8.4			0.20	0.79	1.08	0.95	0.25					
Avocado	1.8	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Cabbage (late)	1.7						0.20	0.58	0.70	0.70	0.12		
Pecan nut trees	1.0	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.35	0.35	0.35	0.65	0.65
Deciduous fruit	0.6	0.27	0.31	0.41	0.50	0.59	0.42	0.20	0.20	0.20	0.20	0.20	0.20
	100												

Source: Appendix 3.3.2 in WR90 report for Region V (WRC, 1994)

4.3 Forestry

The climatic conditions in the Koonap catchments are generally not conducive for the development of commercial forestry. The headwater catchments of Q92B, C and D have historically (1989) supported small areas of forestry. The WARMS database has no forestry registered for this area. However according to the WR2005 study (WRC, 2008) about 3.1 km^2 (310 ha) of Pine plantations were present in the Waterkloof (Q92D) catchment in 2004 and assumed to be present in 2011.

The forestry assessment is done to determine the streamflow reduction (SFR) impact on surface runoff. The forestry water requirements was calculated in the Pitman model using the Smoothed-Gush method. A summary of the historical growth in forested area and the present day (2011) streamflow reduction (SFR) impact are provided in Table 4.5

Table 4.5 Historical growth in forestry area and assessment of SFR

Quaternary catchment	Area under forestry (km^2)					SFR
	1920	1945	1989	2004	2011	(million m^3)
Q92A	0.0	0.0	0.0	0.0	0.0	0.00
Q92B	0.0	0.0	1.0	0.0	0.0	0.00
Q92C	0.0	0.0	1.0	0.0	0.0	0.00
Foxwood Dam	0.0	0.0	2.0	0.0	0.0	0.00
Q92D	0.0	0.0	2.0	3.1	3.1	0.09
Total	**0.0**	**0.0**	**4.0**	**3.1**	**3.1**	**0.09**
Q92E,F,G	Climatic conditions are not suitable for forestry					

The long term reduction in streamflow from forestry at current development levels for the period 1920 to 2011 is not significant. If the information about forestry is accurate, streamflow from the catchment areas upstream of Foxwood Dam site is not impacted.

4.4 Alien Invasive Plants

Information about the extent of Alien Invasive Plants (AIPs) such as Acacia baileyana (black wattle), populus spp (Poplar), Pinus spp (Pine), chromolaena (shrub), solanum mauritanum (shrub), etc, was obtained from the Department of Environment in the Eastern Cape (E-mail: mkawa@environment.gov.za; 29 January 2013). The information provided reflects the current day (early 2012) situation and comes from the Post Retief Working for Water (WfW) Project. The extent of AIP is shown in the land use map (Figure 4.1) and is summarised in Table 4.6

Table 4.6 Present day extent of AIP's and assessment of SFR

Catchment	Catch area	Condensed area		Species occurrence (%)			Riparian zone^	Average SFR
	(km²)	2004 (km²)	2011 (km²)	Tall trees	Medium trees	Tall Shrubs	(%)	(million m³)
Q92A1	250	0.50	4.83	60.0	0.0	40.0	5%	0.30
Q92A2	74		0.00	0.0	0.0	0.0	0%	0.00
Q92B	324	0.00	0.00	0.0	0.0	0.0	0%	0.00
Q92C	601	0.00	6.80	100.0	0.0	0.0	5%	0.19
Upper Koonap	**1249**	**0.50**	**11.63**	**83%**	**0%**	**17%**	**3%**	**0.49**
Q92D	249	0.70	7.64	100.0	0.0	0.0	10%	0.28
Q92E*	287	0.00	3.38	100.0	0.0	0.0	1%	0.06
Q92F*	665	0.00	17.02	100.0	0.0	0.0	1%	0.19
Q92G*	884	0.00	4.98	96.0	0.0	4.0	1%	0.08
Q92	**3 334**	**1.20**	**44.65**	**99.0**	**0.0**	**0.1**		**1.10**

Notes:

* No SW – GW connection; Pitman GW model used; Sami GW model in all other areas.
^ No information about infestation in riparian zone, likely under-estimated.

In the Upper Koonap River catchment the long term streamflow reduction from AIPs at current development levels is insignificant. The total SFR for the Koonap River catchment at 2011 infestation levels is estimated to be about 1.10 million m³/annum. Information about the historical growth in AIPs was not readily available. The WR2005 study had some information for 2004 which is summarised in Table 4.6.

4.5 Groundwater abstractions

Like Forestry and AIPs, groundwater abstractions can impact runoff but only in catchments with baseflows indicating surface – ground water connection. Information on groundwater abstractions in the Koonap River catchment was obtained from the WARMS database (E-mail: mfeneT@dwa.gov.za; 9 December 2012). Abstractions are mainly for domestic and agricultural water use. Catchment Q92B is the only catchment that has significant groundwater abstractions of around 0.3 million m³/a. The estimated SFR from groundwater abstractions in this catchment is around 0.12 million m³/annum.

4.6 Ecological Water Requirements

The Ecological Water Requirements (EWR) using the Intermediate Reserve determination method have been defined by Rivers for Africa (October 2013) at two sites, KOON 1 and KOON 2 in the Koonap River downstream of the proposed Foxwood Dam. The location of the EWR sites is shown in Figure 3.1 and Figure 4.1. The EWR report "Ecoclassification, EWR Scenario and Scenario determination for the Koonap River" is provided in APPENDIX E: EWR REPORT: ECOCLASSIFICATION, EWR SCENARIO AND SCENARIO DETERMINATION OF THE KOONAP RIVER..

According to the EWR study the Ecological Importance and Sensitivity (EIS) was assessed at both sites as Moderate and the Present Day Ecological State (PES) at both sites was assessed as C. The Recommended Ecological Category (REC) at both sites was determined as category C. This means that PES and REC are similar and PES of C should be maintained at both sites.

A summary of the results from the EWR study, expressed as a percentage of the natural Mean Annual Runoff (nMAR) is provided in Table 4.7. The Executive Summary and reports generated by the Revised Desktop Ecological Model (RDEM) are provided in section 12.

Table 4.7 Summary of results from assessment of Koonap EWR

EWR SITE	EIS	PES	REC	nMAR	EWR Low flows	EWR Total flows
		Category	Category	($10^6 m^3$)	%nMAR	%nMAR
KOON1	Moderate	C	C	62.9	4.8%	16.0%
KOON2	Moderate	C	C	77.54	8.9%	21.3%

The C category EWR rules are provided for total flows (TF) and for low flows (LF) at KOON 1 and KOON 2 in Table 4.8 and Table 4.9. According to the EWR study the low flow EWR assurance rule table should be used to define the operation of the system. The total flow EWR assurance rule table should only be used if high flow EWR's need to be supported by releases and spills from Foxwood Dam.

The distance from Foxwood Dam to the first EWR site, KOON 1 is around 18 km and the incremental catchments between these points contributes about 20 % of total present day flows at KOON 1. If the low flow EWR is implemented at KOON 1 as recommended in the EWR study it is assumed that these flows could be met from incremental inflows from the catchments downstream of Foxwood Dam. However this will require confirmation by hydraulic modeling of the Koonap River from the dam to the EWR site Koon 1. The hydraulic modeling should be undertaken before sizing the outlet gate or valve to support the Reserve.

The Reserve study recommends that consideration should be given to establishing flow gauges at or near the EWR sites to assist in developing the hydraulic model of the system. The gauges would lead to an improvement in hydraulic confidence and establish whether the Reserve needs to be supported by releases from Foxwood Dam. The study also recommends that there is no need to support high flow EWRs with releases from Foxwood Dam as flood flows should be met by spills from Foxwood Dam. This is important when considering the final storage capacity of Foxwood Dam.

According to the EWR report there is low confidence in the biota information and the EWR assessment. This should be resolved by improving baseline information through the implementation of an Ecological Water Resources Monitoring programme (EWRMP). The EWRMP should be initiated as soon as possible.

As a first estimate the size of the release gate could be in the order of 6 m^3/s as the peak flood flow at KOON 1 for the 1:1 flood is 5.3 m^3/s. While attenuation of any release is likely to occur this should be balanced by inflows from the incremental catchments downstream of Foxwood Dam.

Table 4.8 EWR Rule (assurance) Tables at EWR Koon1 site

Summary of EWR rule curves for : Catchment Q92E1 - Mid Koonap River

Total Runoff : Runoff : W REGION

Regional Type : E. Cape

Ecological Category = C

Data are given in m³ / s mean monthly flow

Month	Percentiles (data in m³/s)									
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Total Flow assurance curves for PES of C										
Oct	0.183	0.108	0.075	0.048	0.029	0.017	0.010	0.005	0.003	0.002
Nov	0.401	0.209	0.086	0.056	0.048	0.030	0.014	0.008	0.004	0.001
Dec	0.845	0.546	0.382	0.286	0.261	0.214	0.167	0.097	0.005	0.001
Jan	0.721	0.395	0.293	0.237	0.214	0.187	0.143	0.082	0.004	0.001
Feb	1.705	1.137	0.827	0.703	0.678	0.622	0.489	0.283	0.009	0.001
Mar	3.018	2.176	1.650	1.380	1.306	1.193	0.941	0.544	0.013	0.000
Apr	1.557	1.005	0.746	0.633	0.588	0.544	0.425	0.245	0.008	0.001
May	0.419	0.158	0.100	0.063	0.049	0.025	0.015	0.008	0.004	0.001
Jun	0.299	0.145	0.099	0.057	0.047	0.030	0.017	0.009	0.004	0.001
Jul	0.245	0.149	0.101	0.055	0.049	0.031	0.018	0.009	0.004	0.001
Aug	0.236	0.144	0.094	0.059	0.048	0.030	0.016	0.011	0.004	0.001
Sep	0.227	0.122	0.087	0.056	0.049	0.030	0.017	0.009	0.004	0.001
Low Flow assurance rule for PES of C										
Oct	0.183	0.108	0.075	0.048	0.029	0.017	0.010	0.005	0.003	0.002
Nov	0.401	0.209	0.086	0.056	0.048	0.030	0.014	0.008	0.004	0.001
Dec	0.422	0.244	0.146	0.078	0.058	0.024	0.015	0.008	0.003	0.001
Jan	0.366	0.141	0.095	0.062	0.043	0.028	0.015	0.007	0.003	0.001
Feb	0.389	0.197	0.095	0.056	0.047	0.030	0.016	0.008	0.003	0.001
Mar	0.478	0.361	0.237	0.131	0.086	0.052	0.028	0.013	0.003	0.000
Apr	0.434	0.203	0.121	0.081	0.048	0.039	0.022	0.010	0.004	0.001
May	0.419	0.158	0.100	0.063	0.049	0.025	0.015	0.008	0.004	0.001
Jun	0.299	0.145	0.099	0.057	0.047	0.030	0.017	0.009	0.004	0.001
Jul	0.245	0.149	0.101	0.055	0.049	0.031	0.018	0.009	0.004	0.001
Aug	0.236	0.144	0.094	0.059	0.048	0.030	0.016	0.011	0.004	0.001
Sep	0.227	0.122	0.087	0.056	0.049	0.030	0.017	0.009	0.004	0.001
Natural flow duration curves										
Oct	3.075	1.265	0.800	0.612	0.493	0.421	0.359	0.288	0.239	0.123
Nov	8.557	3.192	1.053	0.761	0.505	0.414	0.351	0.297	0.223	0.107
Dec	6.971	4.202	2.638	1.066	0.642	0.435	0.326	0.248	0.187	0.086
Jan	5.779	1.970	1.111	0.622	0.459	0.332	0.278	0.237	0.191	0.074
Feb	7.835	3.082	1.663	1.091	0.774	0.465	0.328	0.264	0.205	0.098
Mar	7.116	5.109	3.311	2.311	1.497	0.800	0.592	0.408	0.251	0.172
Apr	6.180	2.322	1.650	1.419	0.810	0.580	0.425	0.356	0.279	0.149
May	5.213	1.263	0.767	0.579	0.493	0.426	0.396	0.336	0.273	0.173
Jun	3.526	0.941	0.745	0.530	0.494	0.439	0.405	0.354	0.290	0.212
Jul	1.872	0.939	0.708	0.568	0.515	0.417	0.383	0.340	0.268	0.216
Aug	2.882	0.985	0.700	0.547	0.467	0.381	0.344	0.315	0.266	0.183
Sep	2.764	1.052	0.710	0.587	0.478	0.405	0.342	0.278	0.242	0.146

Table 4.9 EWR Rule (assurance) Table at EWR Koon2 site

Summary ofEWR rule curves for : Catchment Q92G1 - Lower Koonap River

Total Runoff : Runoff : W REGION

Regional Type : E. Cape

Ecological Category = C

Data are given in m³ / s mean monthly flow

Month	Percentiles (data in m³/s)									
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**99%**
Total Flow assurance rule for PES of C										
Oct	0.517	0.265	0.115	0.073	0.044	0.025	0.014	0.008	0.004	0.003
Nov	0.927	0.516	0.151	0.096	0.078	0.047	0.044	0.044	0.041	0.019
Dec	1.799	1.033	0.667	0.476	0.433	0.335	0.275	0.177	0.040	0.017
Jan	1.551	0.851	0.525	0.453	0.394	0.339	0.267	0.170	0.035	0.016
Feb	2.777	1.757	1.099	0.905	0.866	0.782	0.632	0.383	0.041	0.017
Mar	4.712	3.218	2.384	1.979	1.744	1.570	1.247	0.740	0.060	0.043
Apr	2.523	1.521	1.002	0.822	0.761	0.673	0.532	0.329	0.044	0.026
May	0.904	0.367	0.161	0.095	0.088	0.045	0.044	0.044	0.040	0.028
Jun	0.586	0.327	0.177	0.145	0.086	0.044	0.044	0.043	0.040	0.027
Jul	0.555	0.326	0.155	0.137	0.088	0.047	0.044	0.043	0.040	0.028
Aug	0.548	0.322	0.139	0.129	0.086	0.052	0.044	0.044	0.041	0.029
Sep	0.545	0.292	0.132	0.131	0.088	0.051	0.043	0.043	0.041	0.022
Low Flow assurance rule for PES of C										
Oct	0.517	0.265	0.115	0.073	0.044	0.025	0.014	0.008	0.004	0.003
Nov	0.927	0.516	0.151	0.096	0.078	0.047	0.044	0.044	0.041	0.019
Dec	1.082	0.565	0.313	0.158	0.119	0.040	0.040	0.040	0.037	0.017
Jan	0.884	0.390	0.176	0.139	0.084	0.049	0.035	0.035	0.032	0.016
Feb	0.962	0.574	0.204	0.099	0.070	0.037	0.037	0.037	0.034	0.017
Mar	1.134	0.884	0.619	0.391	0.176	0.103	0.074	0.057	0.047	0.043
Apr	1.038	0.552	0.269	0.163	0.110	0.064	0.045	0.045	0.039	0.026
May	0.904	0.367	0.161	0.095	0.088	0.045	0.044	0.044	0.040	0.028
Jun	0.586	0.327	0.177	0.145	0.086	0.044	0.044	0.043	0.040	0.027
Jul	0.555	0.326	0.155	0.137	0.088	0.047	0.044	0.043	0.040	0.028
Aug	0.548	0.322	0.139	0.129	0.086	0.052	0.044	0.044	0.041	0.029
Sep	0.545	0.292	0.132	0.131	0.088	0.051	0.043	0.043	0.041	0.022
Natural flow duration curves										
Oct	4.260	1.593	0.881	0.639	0.534	0.436	0.376	0.288	0.240	0.123
Nov	9.487	3.703	1.542	0.912	0.559	0.452	0.367	0.320	0.236	0.107
Dec	9.577	4.973	3.018	1.501	0.743	0.503	0.335	0.255	0.205	0.086
Jan	7.620	2.280	1.316	0.774	0.556	0.371	0.302	0.247	0.200	0.074
Feb	9.660	4.078	2.016	1.409	0.922	0.588	0.355	0.290	0.218	0.098
Mar	10.236	6.252	3.951	2.630	1.878	1.060	0.640	0.473	0.258	0.172
Apr	7.524	2.846	1.971	1.638	0.903	0.612	0.450	0.359	0.282	0.149
May	6.422	1.340	0.806	0.592	0.497	0.429	0.404	0.339	0.273	0.173
Jun	3.824	0.973	0.745	0.530	0.494	0.446	0.410	0.354	0.290	0.212
Jul	1.895	0.939	0.708	0.568	0.519	0.417	0.383	0.340	0.268	0.216
Aug	2.956	0.994	0.702	0.553	0.467	0.381	0.344	0.315	0.266	0.183
Sep	3.147	1.252	0.715	0.601	0.490	0.405	0.342	0.278	0.242	0.146

5 RESERVOIRS / FARM DAMS

Currently there are no major reservoirs in the Koonap River catchment. There are several small reservoirs, off-channel storage dams and farm dams that are used for domestic (Adelaide Dam and Andrew Turpin Dam), irrigation and livestock water requirements.

Storage dams impact the hydrological behaviour of available water resources in a catchment by virtue of the storage capability provided by reservoirs, weirs and lakes, which have the benefit of increasing the assurance of supply to water users.

The Pitman and WRYM models require the physical characteristics of a particular reservoir or of a group of smaller farm dams. This includes at least the full supply area (FSA) and full supply capacity (FSC) of a reservoir or representative reservoir. To simulate the effects of evaporation on a water body the area-capacity relationship is also required.

5.1 Major Dams

The proposed Foxwood Dam will represent the first major impoundment of the Koonap River. The basin of the proposed dam was surveyed in late 2013 using aerial imagery. The area capacity data from aerial survey is provided in Appendix A. The area-capacity-elevation information from the survey was summarized and is presented in Table 5.1. The area capacity relationships as used in the WRYM model is provided in Figure 5.1 for live storage capacities up to 95.2 million m^3 (equivalent to a 2 nMAR dam).

5.2 Minor or farm dams

Historical information about minor dams was transferred from the WR2005 study. Additional information about the historical and present day situation was sourced from the WARMS database (E-mail: mfeneT@dwa.gov.za; 9 December 2012) and from a database provided by S Mallory (IWR Water Resources, 2006). The ‘Mallory’ database is an extensive verification and update of information in the DWS Dam Safety database.

The historical growth in storage capacity in the Koonap catchment over the study period of 1920 to 2011 is provided in Table 5.2.

Table 5.1 Area capacity curve and information for Foxwood Dam for various Full Supply Capacities

Elevation (m.a.s.l)	Wall Height	Area (km ²)	Storage (million m³)	Live Storage (million m³)	Description
575.0	0.0	0.0	0.0	-	Reservoir bottom
580.0	5.0	0.024	0.031	-	
586.0	11.0	0.138	0.406	-	
590.0	15.0	0.332	1.306	-	
597.5*	22.5	1.163	6.109	0.0	Dead storage level (refer section 9.1)
600.0	25.0	1.562	9.788	3.679	
605.0	30.0	2.472	19.690	13.581	
607.0	32.0	2.913	25.045	18.936	
608.5	33.5	3.216	29.914	23.805	0.5-MAR Dam
610.0	35.0	3.524	34.702	28.593	
611.0	36.0	3.721	38.341	32.232	
611.5	36.6	3.831	41.816	35.708	0.75-MAR Dam
613.0	38.0	4.152	46.226	40.117	
614.0	39.0	4.391	50.490	44.381	
614.6*	39.6	4.512	53.719	47.610	1-MAR Dam
616.0	41.0	4.922	59.775	53.666	
617.4*	42.4	5.325	65.621	59.513	1.25-MAR Dam
619.0	44.0	5.751	75.763	69.655	
619.5	44.5	5.912	77.524	71.415	1.5-MAR Dam
621.0	46.0	6.379	87.908	81.799	
621.2*	46.2	6.479	89.426	83.318	1.75-MAR Dam
622.0	47.0	6.663	94.436	88.328	
623.1*	48.1	6.950	101.329	95.220	2-MAR Dam

* Extrapolated from aerial survey data set.

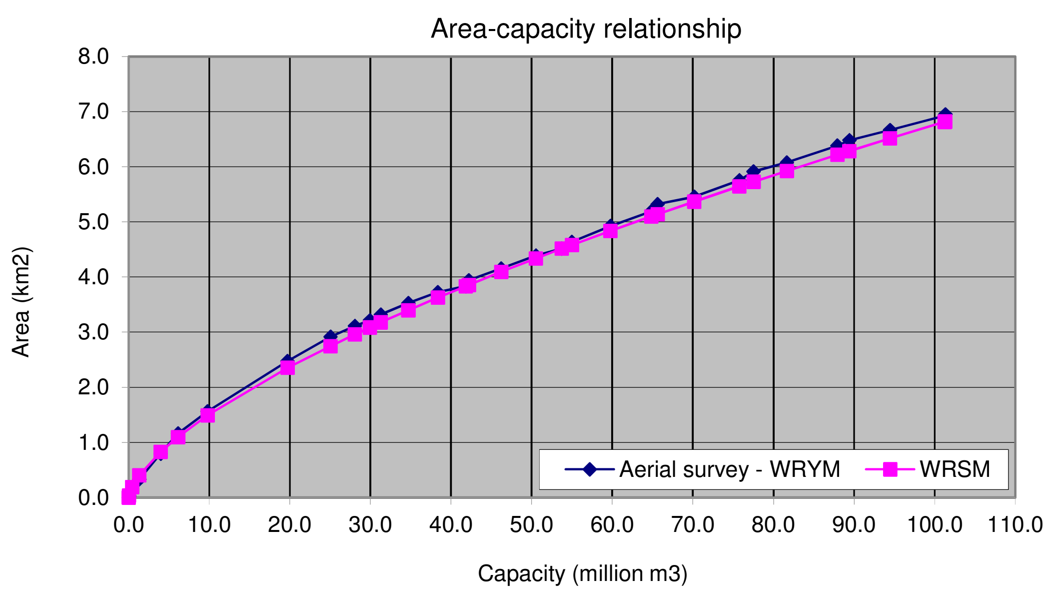


Figure 5.1 Area-capacity curve for proposed Foxwood Dam

Table 5.2 Historical growth in farm dams

Catchment	Minor dam characteristics									
	Description	1920	1933	1950	1952	1970	1989	1995	2004	2011
Q92A1	FSC (million m ^{3})	0.00	0.00	0.00	0.00	0.00	0.24	0.24	0.24	0.47
	FSA (km ^{2})	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.06	0.29
Q92C	FSC (million m ^{3})	0.00	0.74	0.89	1.11	1.20	1.16	1.16	1.38	1.15
	FSA (km ^{2})	0.00	0.12	0.18	0.23	0.29	0.31	0.31	0.35	0.32
Q9H002	**FSC (million m ^{3})**	**0.00**	**0.74**	**0.89**	**1.11**	**1.20**	**1.40**	**1.40**	**1.62**	**1.62**
	FSA (km ^{2})	**0.00**	**0.12**	**0.18**	**0.23**	**0.29**	**0.37**	**0.37**	**0.41**	**0.61**
Q92D	FSC (million m ^{3})	0.00	0.00	0.00	1.82	1.82	1.82	1.82	1.28	1.28
	FSA (km ^{2})	0.00	0.00	0.00	0.27	0.27	0.27	0.27	0.20	0.20
Q92E	FSC (million m ^{3})	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.32	0.32
	FSA (km ^{2})	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.13	0.13
Q92F	FSC (million m ^{3})	0.00	0.00	0.24	0.48	0.48	0.48	0.48	0.48	0.48
	FSA (km ^{2})	0.00	0.00	0.04	0.19	0.19	0.19	0.19	0.19	0.19
Q92G	FSC (million m ^{3})	0.00	0.00	0.08	0.08	0.13	0.26	0.26	0.26	0.30
	FSA (km ^{2})	0.00	0.00	0.03	0.03	0.05	0.07	0.07	0.07	0.09
Q92 all	**FSC (million m ^{3})**	**0.00**	**0.74**	**1.21**	**3.49**	**3.63**	**3.96**	**4.28**	**3.96**	**4.00**
	FSA (km ^{2})	**0.00**	**0.12**	**0.26**	**0.72**	**0.80**	**0.90**	**1.03**	**1.00**	**1.22**

Notes: FSC – full supply capacity
FSC – full supply area

6 HYDRO-METEOROLOGICAL DATA

The analysis of hydro-meteorological data involves the review of rainfall, evaporation and streamflow data. The quality of available hydro-meteorological data affects the level of confidence that can be placed on the results of a water resources study. Figure 6.1 shows the geographical location of water related infrastructure such as rain gauges, flow gauges, diversion structures and rain zones.

6.1 Rainfall data

Monthly sequences of rainfall time-series data are the main input to the Pitman rainfall-runoff model and are also required for the modelling of irrigation water requirements and for simulating the behaviour of water bodies in the WRYM model. The rainfall analysis undertaken as part of the hydrological analysis of the Koonap River catchment involved an assessment of rainfall gauges identified in the WR2005 study.

Assessment of rain gauges to extend hydrological record
A total of 16 rainfall gauges positioned in and around the Koonap River catchment were identified from previous studies for use in the analysis. Monthly rainfall data for operational gauges was obtained up to September 2012 from the DWS (Cobus Ferreira, October 2012) and from the Rain-IMS.

Each rain gauge was screened for reliability using standard validation tests. The mass plot graph plots cumulative annual rainfall against time and is used to assess the stationarity of rain gauge data. In the case of a stationary data set, the trend identified in the data approximates a straight line. Where a gap or change in trend occurred the record was split into more than one stationary component and treated as separate records. The following gauges, 0076884 W, 0077131 W, 0077522 W and 0100025 W, have split records.

The cumulative difference (Qsum) plot represents the cumulative difference of the annual totals from the mean. This plot is sensitive to trends in rainfall data and reflects climate variations, with dry periods associated with negative slopes and wet periods with positive slopes. The validation test plots for the rain gauges are provided in electronic Appendix B.

After the initial screening, gauges 0077309 W, 0077881 W and 0078587 W were excluded from further analysis. Gauge 0100329 W was used in the patching process but was not used to generate catchment rainfall records.

Details about the rain gauges reviewed and analysed are summarised in Table 6.1. The following gauges, 0076884 W, 0077131 W, 077522 W, 0099735 W and 0100329 W were used to patch the rainfall records from 1995 to 2011.

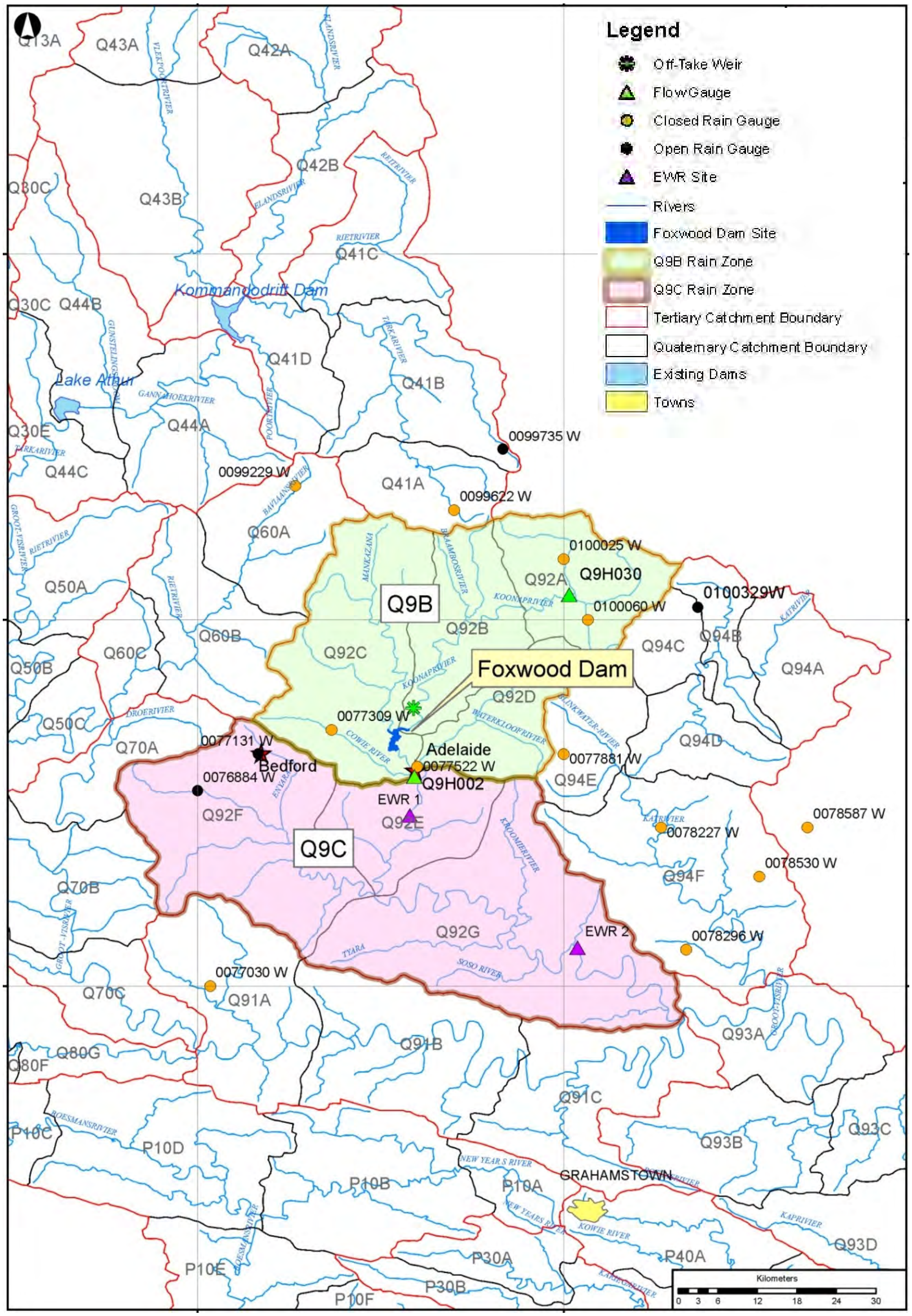


Figure 6.1 Water related infrastructure and Rain Zones (see full image in Appendix G)

Table 6.1 Rainfall gauges in and around the Koonap River catchment

Catch-ment	SAWS Number	SAWS Name	Geographical position			Period		Record
			Latitude (South)	Longitude (East)	MAP (mm)	Start year	End year	length (years)
Gauges used in rainfall data analysis and to generate catchment rainfall records								
Q92F	0076884 W	Albertvale	-32° 44'	26° 00'	444	1920	1952	33
Q92F	0076884 W*	Albertvale	-32° 44'	26° 00'	506	1954	2011	58
Q91A	0077030 W	Eesterling	-33° 00'	26° 01'	346	1920	1964	45
Q92F	0077131 W	Bedford-Mun	-32° 41'	26° 05'	668	1971	1988	18
Q92F	0077131 W*	Bedford-Mun	-32° 41'	26° 05'	595	1993	2011	19
Q92C	0077522 W	Adelaide-Pol	-32° 42'	26° 18'	410	1920	1968	49
Q92C	0077522 W	Adelaide-Pol	-32° 42'	26° 18'	443	1971	2002	32
Q94F	0078227 W	Fort Beaufort	-32° 47'	26° 38'	490	1920	2001	82
Q94F	0078296 W	Merino	-32° 57'	26° 40'	480	1938	1985	48
Q94F	0078530 W	Garfield	-32° 51'	26° 46'	408	1920	1952	33
Q60A	0099229 W	Cheviot Fells	-32° 19'	26° 08'	486	1927	1988	62
Q41A	0099622 W	Ventnor	-32° 21'	26° 21'	665	1920	1986	67
Q41B	0099735 W*	Glenroy	-32° 16'	26° 25'	520	1923	2011	89
Q92A	0100025 W	Fountain Head	-32° 25'	26° 30'	610	1920	1952	33
Q92A	0100025 W	Fountain Head	-32° 25'	26° 30'	652	1955	1996	42
Q92A	0100060 W	Millholme	-32° 30'	26° 32'	568	1920	1997	78
Gauge included in rainfall data analysis but NOT used to generate catchment rainfall records								
Q94C	0100329 W*	Katberg-Bos	-32° 29'	26° 41'	907	1974	2011	38
Gauges excluded from rainfall data analysis								
Q92C	0077309 W	Cullendale	-32° 39'	26° 11'	479	1931	1968	38
Q94E	0077881 W	Fort Fordyce	-32° 41'	26° 30'	982	1920	1950	31
Q94E	0077881 W	Fort Fordyce	-32° 41'	26° 30'	995	1952	1989	38
R10H	0078587 W	Alice-Mun	-32° 47'	26° 50'	497	1945	1998	54

Notes
* Gauge operational in 2011
SAWS South African Weather Service

Generation of catchment rainfall records

One of the main reasons for patching rain gauge data is to generate representative rainfall data for selected groups of catchments. The rain zones Q9B and Q9C, identified in previous studies (WRC, 1994, 2008) were maintained and catchment rainfall data for these zones was generated for the period 1920 to 2011. The rainfall zones and groups of gauges used to generate representative rainfall records are provided in bar charts for each rainfall zone in Figure 6.2. The bar charts show the overlap of records and that each year of the record has at least 2 gauges to generate representative rainfall data.

The rainfall zones and groups of gauges used to generate catchment rainfall data for the Koonap River catchments is summarised in Table 6.2

The resulting catchment rainfall records created for rainfall zones Q9B and Q9C and the catchment rainfall records created for the WRYM are provided in electronic format in Appendix B. The mass and cumulative difference plots are provided in Figure 6.3 for rain zone Q9B and in Figure 6.4 for rain zone Q9C. The plots are acceptable, stationary and show no trends in the rainfall over the period reviewed.

Table 6.2 Rainfall gauges in Rainfall Zones and Catchment MAP's

Catchment	Patched rainfall gauges used in Koonap River catchments	MAP (mm)
Rain zone Q9B	0077131(A), 0077131(B), 0077522(A), 0077522(B), 0078227, 0099229, 0099622, 0099735, 0100025(A), 0100025(B), 0100060	
Q92A1		662
Q92A2		662
Q92B		586
Q92C		559
Q92D		594
Rain zone		**593**
Rain zone Q9C	0076884(A), 0076884(B), 0077030, 0077131(A), 0077131(B), 0077522(A), 0077522(B), 0078227, 0078296, 0078530, 0099735	
Q92E		464
Q92F		415
Q92G		466
Rain zone		**447**
Q92 catchment		**513**

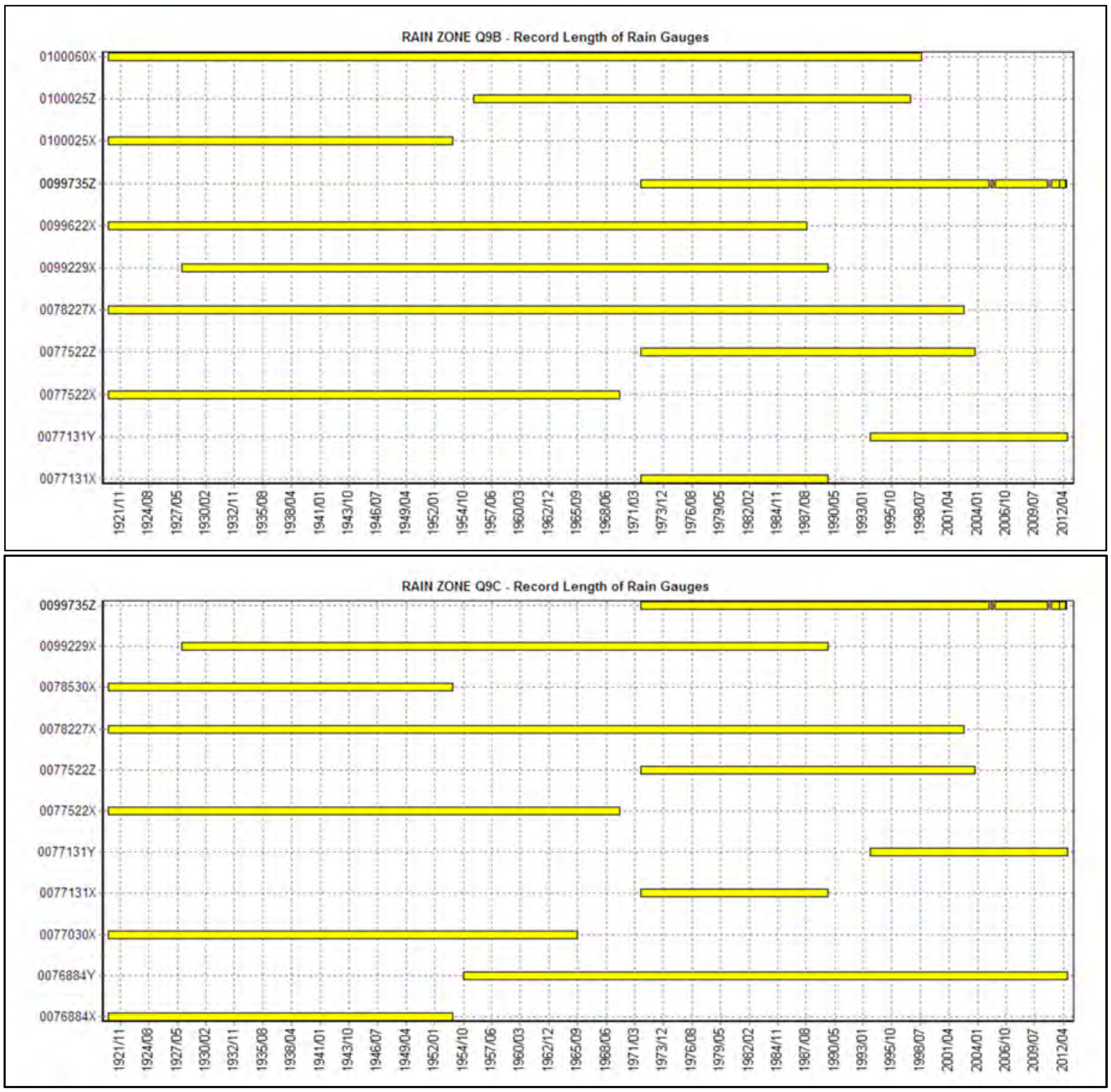
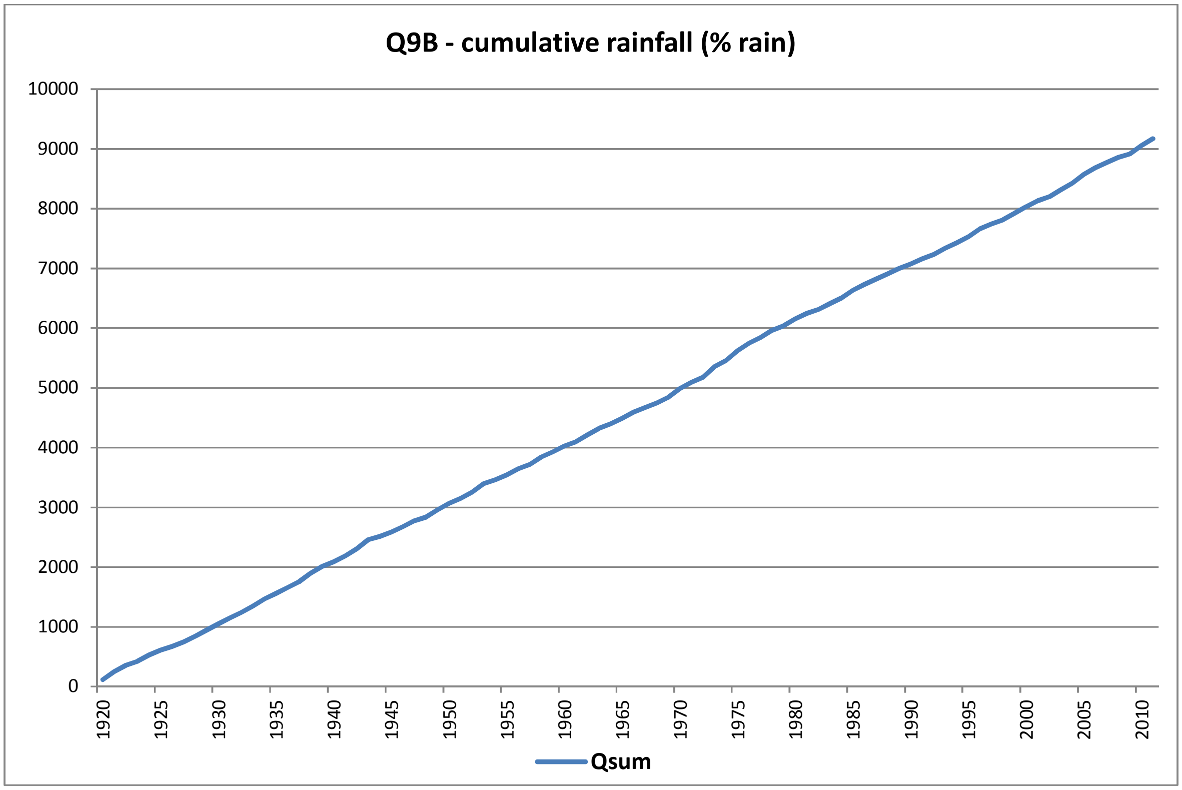


Figure 6.2 Record length for rain gauges in Rain Zones Q9B and Q9C



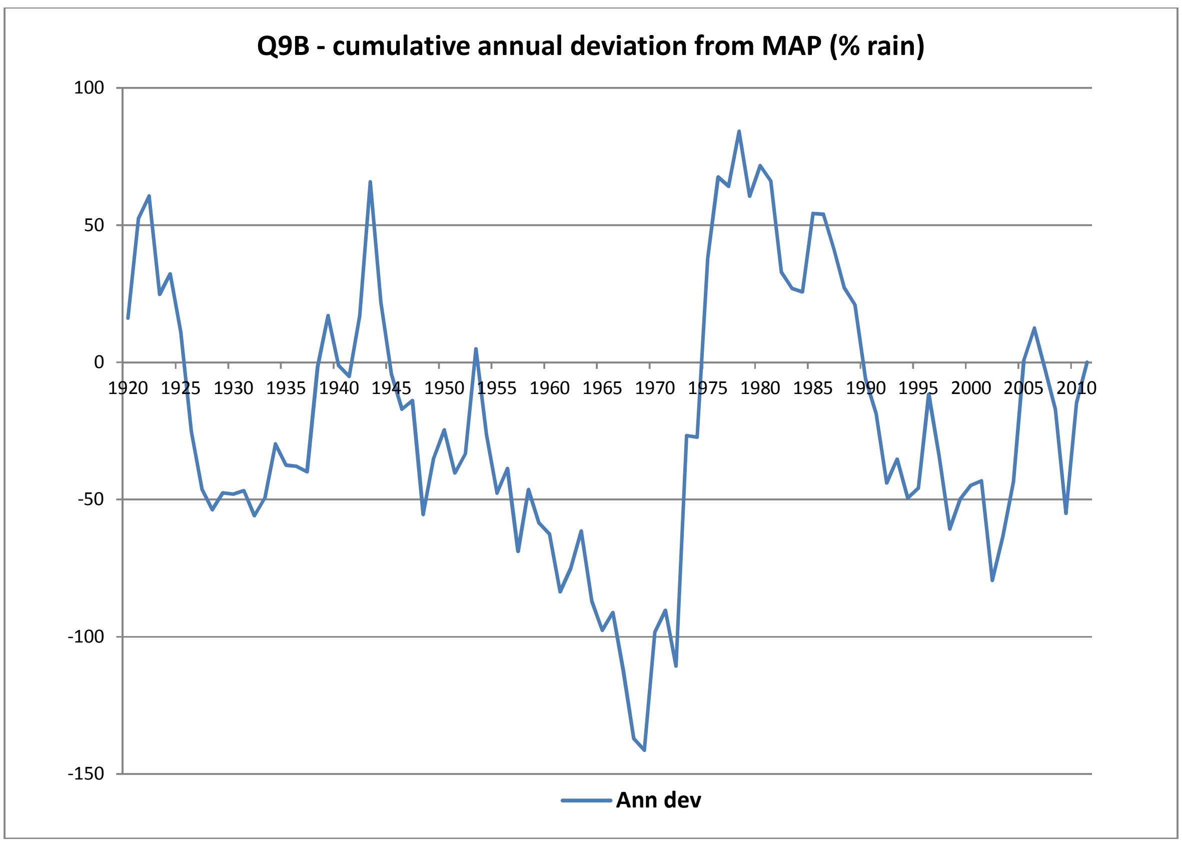
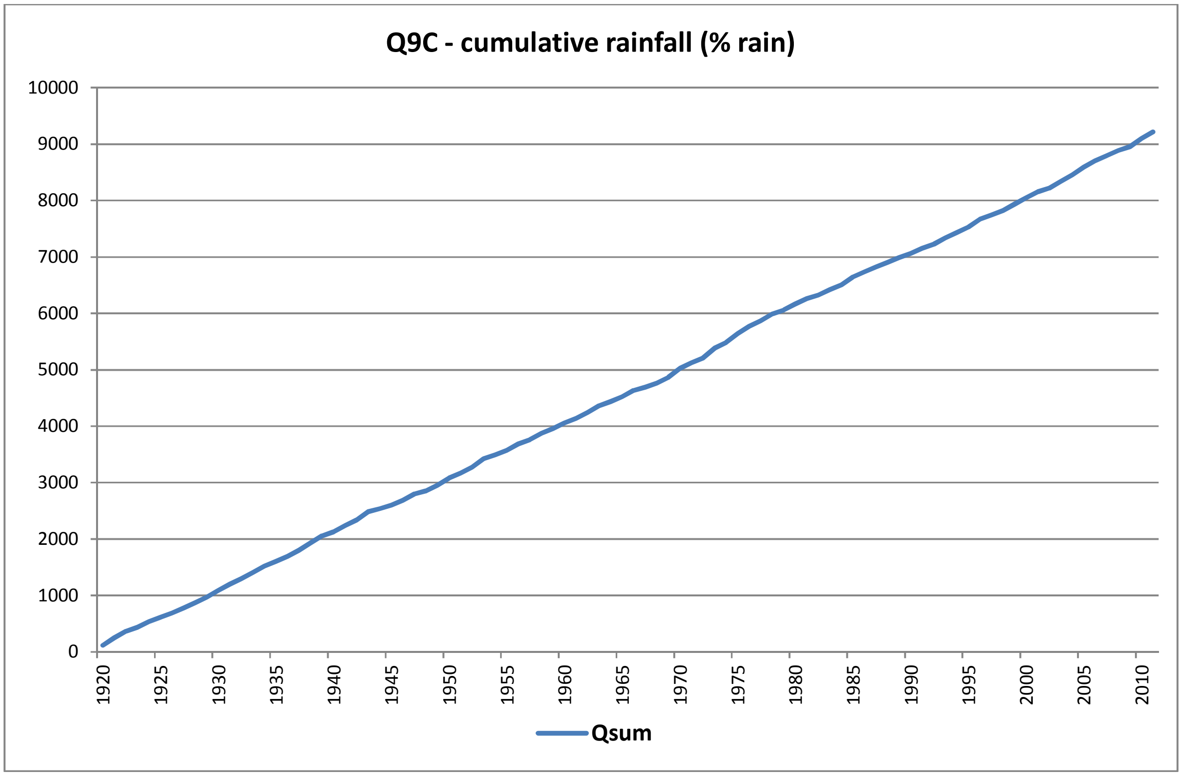


Figure 6.3 Rain zone Q9B standard validation plots



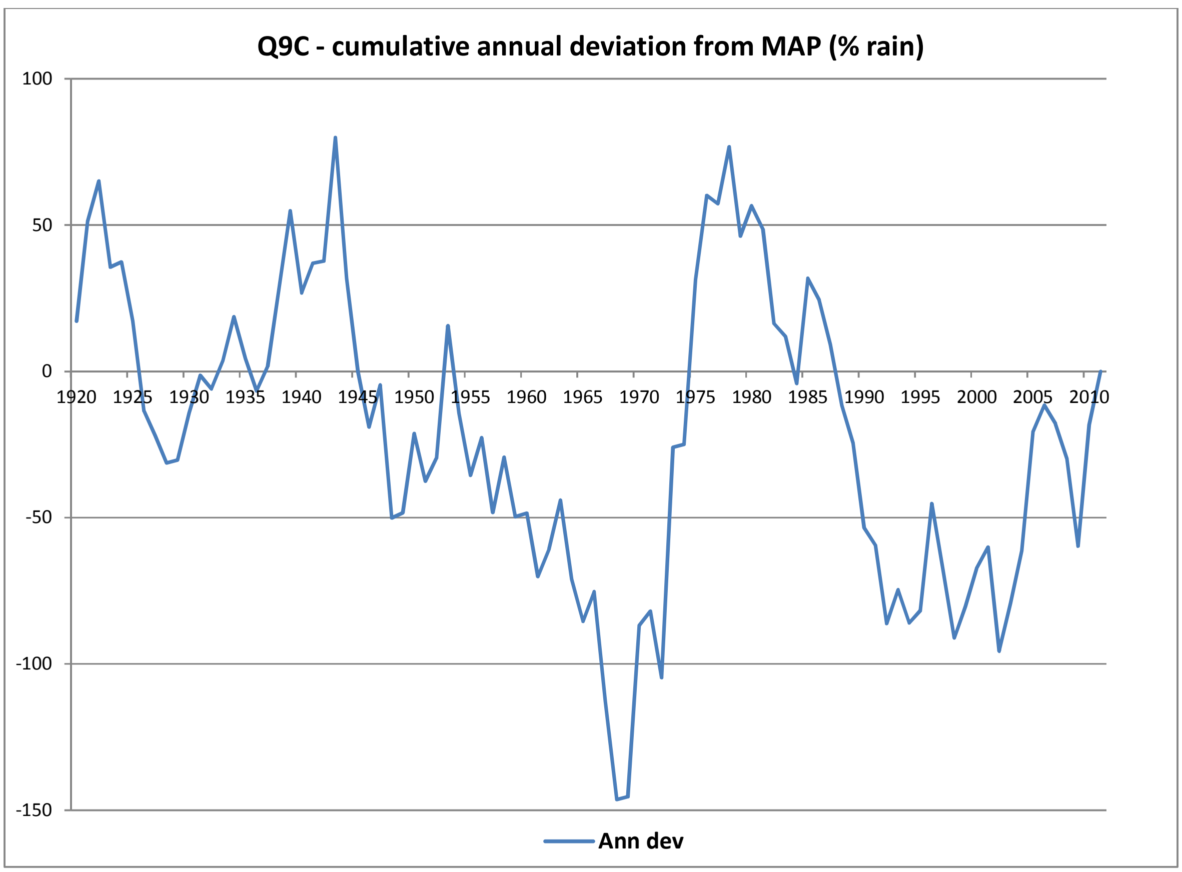


Figure 6.4 Rain zone Q9C standard validation plots

6.2 Evaporation data

For the purposes of the hydrological analysis the Symons-pan (S-pan) and Class A-pan evaporation data used in the WR90 and WR2005 studies was regarded as acceptable. The S-pan evaporation is required to determine catchment evapo-transpiration and evaporation losses from water bodies such as reservoirs and lakes. The A-pan evaporation is required to determine evapo-transpiration from irrigated crops.

The S-pan evaporation values for the Koonap River catchments are summarised in Table 6.3. The conversion factors to determine evaporation from water bodies and catchment evapo-transpiration are also provided.

Table 6.3 S-pan Evaporation and Conversion Factors for the Koonap River Catchments

Quaternary Catchment	Monthly average S-pan evaporation (mm)												MAE (mm)
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
Q92A1	161	184	216	217	173	149	108	80	66	73	98	126	1 650
Q92A2	161	184	216	217	173	149	108	80	66	73	98	126	1 650
Q92B	161	184	216	217	173	149	108	80	66	73	98	126	1 650
Q92C	161	184	216	217	173	149	108	80	66	73	98	126	1 650
Q9H002	**161**	**184**	**216**	**217**	**173**	**149**	**108**	**80**	**66**	**73**	**98**	**126**	**1 650**
Q92D	156	178	209	211	168	145	104	78	64	71	95	122	1 600
Q92E	156	178	209	211	168	145	104	78	64	71	95	122	1 600
Q92F	161	184	216	217	173	149	108	80	66	73	98	126	1 600
Q92G	156	178	209	211	168	145	104	78	64	71	95	122	1 600
Factors	0.81	0.82	0.83	0.84	0.88	0.88	0.88	0.87	0.85	0.83	0.81	0.81	

The A-pan evaporation values for the Koonap River catchments are summarised in Table 6.4 and the conversion factors to determine evapo-transpiration from crops.

Table 6.4 A-pan Evaporation for the Koonap River Catchments

Quaternary Catchment	Monthly average A-pan evaporation (mm)												MAE (mm)
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	
Q92A1	200	225	259	261	213	187	143	113	97	105	132	162	2097
Q92A2	200	225	259	261	213	187	143	113	97	105	132	162	2097
Q92B	200	225	259	261	213	187	143	113	97	105	132	162	2097
Q92C	200	225	259	261	213	187	143	113	97	105	132	162	2097
Q92D	195	219	252	254	207	183	139	110	95	102	129	158	2043
Q92E	195	219	252	254	207	183	139	110	95	102	129	158	2043
Q92F	200	225	259	261	213	187	143	113	97	105	132	162	2097
Q92G	195	219	252	254	207	183	139	110	95	102	129	158	2043
Factors	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	

6.3 Streamflow data

The selection of streamflow gauges for inclusion in the hydrological analysis to calibrate the Pitman rainfall-runoff model was based on length of record, quality of data and geographical location. There are two gauges within the Koonap River catchment, both are operational and both are located in the Upper Koonap River catchment on the Koonap River. Both gauges will assist in the calibration of the hydrology of the Foxwood Dam catchment area and both gauges are assessed to meet the criteria of length (more than 15 years) and quality. The observed monthly and daily streamflow information was downloaded from the DWS Hydstra database.

The period of record used to calibrate the hydrological model is provided in Table 6.5 and the application of each gauge in the hydrological analysis is summarised. The headwater flow gauge Q9H030 was not used as a calibration gauge in previous studies but is assessed as reliable for calibrating the Pitman rainfall-runoff model. An assessment of the gauges that was undertaken by the DWA is provided in electronic Appendix C along with the patched monthly flow records for Q9H002 and Q9H030.

Table 6.5 Streamflow gauges used for the Hydrological Analysis

Flow gauge	Q9H002	Q9H030
Gauge name	Koonap at Adelaide	Koonap at Frisch Gewaagd
Accuracy of gauge	Good for low to medium flows	Good for low to high flows
MAP at gauge	560 mm/a	662 mm/a
Catchment area (km^2)	1 249	250
Start of record	Oct-1933	Oct-1982
End of record	Sep-2012	Sep-2012
Aplication in analysis	Used to calibrate Foxwood Dam catchments Q92A; Q92B and Q92C	Used to calibrate headwater catchment Q92A

According to the DWS in the Eastern Cape (Cobus Ferreira, FerreiraC@dwa.gov.za) the Q9H002 gauge measures low to medium flows accurately. At higher flows the weir structure can be subjected to submergence depending on over-growth in the downstream section. The Q9H030 gauge measures low to high lows accurately up to a structural limit. If the limit is exceeded the river flows onto the banks and bypasses the flow gauge. The geographical location of the flow gauges are provided in the water infrastructure map in Figure 6.1.

7 RAINFALL-RUNOFF MODELLING

Rainfall-runoff modelling is the primary activity of the hydrological assessment and involves a process where the response of a sub-catchment is simulated based on the monthly time-series of representative catchment rainfall data. Rainfall-runoff modeling was undertaken in the hydrological analysis of the Koonap River catchment using the Pitman model.

The rainfall-runoff modeling undertaken involved two processes, namely the configuration and calibration of the Pitman Model.

7.1 Configuration of the system network model

The process of developing a representative system network model includes three main aspects:

- The identification of physical system features,
- Assessing the appropriate spatial resolution and
- Combining and aggregating system features until the appropriate spatial resolution is achieved.

The network developed during the WR2005 study (WRC, 2008) was generally used as a base and refined. The quaternary catchment delineation used in WR2005 setup was generally retained with the only change being the splitting of Q92A into Q92A1 and Q92A2. The split was required as the catchment was divided into a sub-area upstream of the flow gauge Q9H030 and a sub-area downstream of Q9H030 (Q92A2). The Pitman network or system diagram for the Koonap River (Q92) catchment is provided in Figure 7.1.

7.2 Calibration of Rainfall-runoff model

An initial calibration was undertaken using the parameters from the WR2005 setup for the Koonap River (Q92) catchments. The WR2005 setup divided the Koonap River catchment into an upper section that has catchment with baseflows and a lower section that has no baseflow or SW-GW interaction. The upper catchments all fall within the Q9B rain zone and were calibrated using the Sami Groundwater Model. The lower catchments in the Q9C rain zone were calibrated using the Pitman Groundwater Model. From the start, an update of the Sami model parameters was required, as the information in the WR2005 study was outdated as it was from the GRA-I study. Updated Sami parameters for the Q92 catchment were obtained from the GRA-II study from Allan Bailey of Royal Haskoning DHV (e-mail: 16 November 2012). The catchment rainfall files generated for the period 1920 to 2011 were added to the model setup and the initial calibration undertaken. The distribution of irrigation was also reviewed and adjusted to reflect the present day situation.

The Koonap River system Pitman model setup was forwarded to Bill Pitman for review and final calibration. The final calibration parameters values for the Koonap River catchments are summarised in Table 7.1.

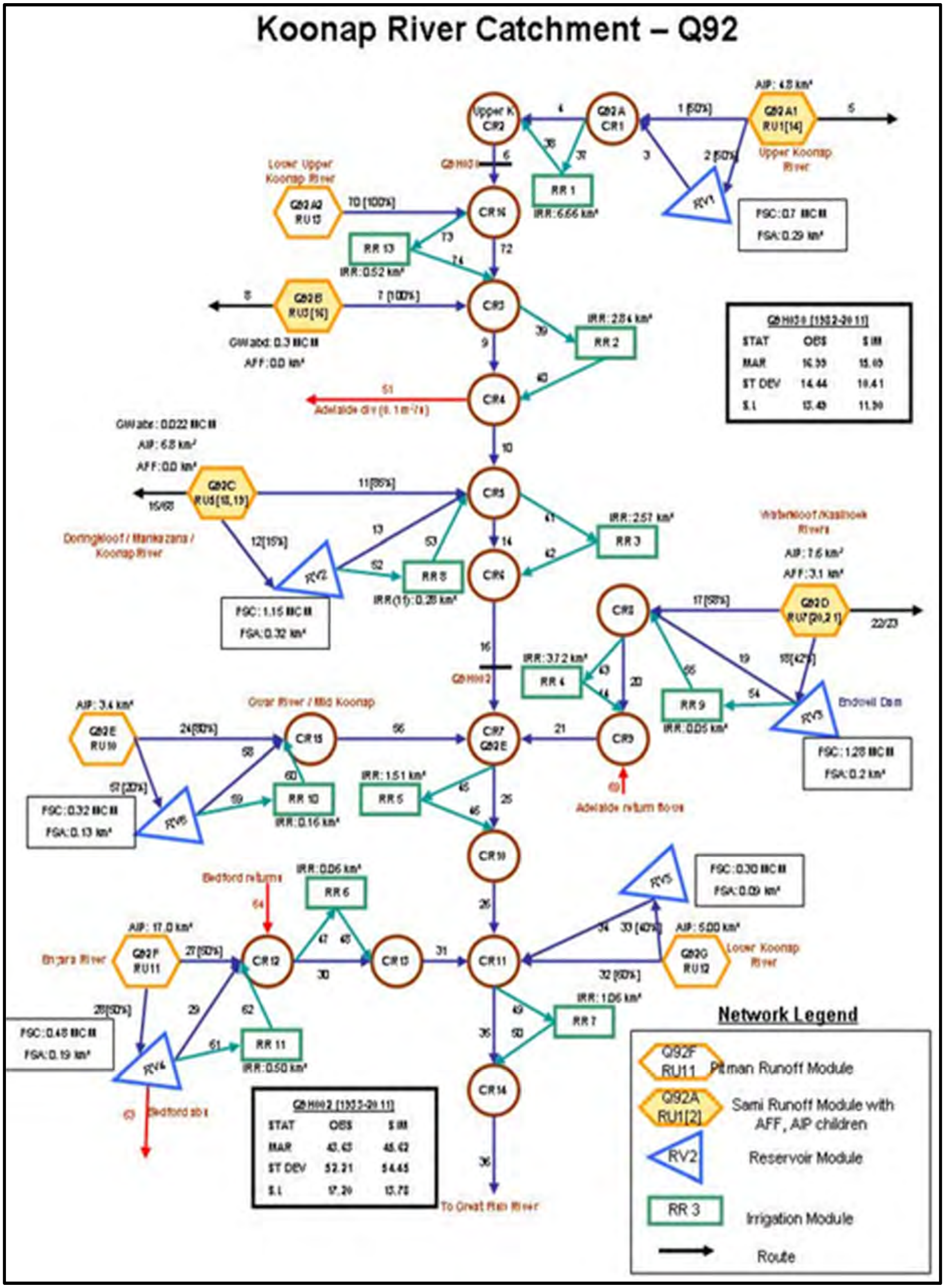


Figure 7.1 Network Diagram for the Q92 System

Table 7.1 Final Rainfall-Runoff Model parameter values

Parameters	Q92A1	Q92A2	Q92B	Q92C	Q92D	Q92E	Q92F	Q92G
Rain zone			Q92B				Q92C	
Pitman Model Parameters								
POW (Power in soil moisture / subsurface flow equation)	3	3	3	3	3	3	3	3
SL (Soil moisture state where no subsurface flows occur)	0	0	0	0	0	0	0	0
ST (Soil moisture storage capacity in mm)	110	110	110	110	110	150	150	150
FT (Subsurface flow at full storage capacity)	10	7	1	1	1	0	0	0
GW (Maxiumum groundwater flow in mm/month	-	-	-	-	-	0	0	0
ZMIN (Minimum catchment absorption rate in mm/month)	55	55	55	55	45	45	45	45
ZMAX (Maximum catchment absorption rate in mm/month)	400	400	400	400	400	480	480	480
PI (Interception storage in mm)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
TL (Lag of flow (excluding groundwater)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
R (Coefficient in evaporation / soil moisture equation)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Sami Model Parameters								
GPOW (Power in the soil moisture recharge equation)	3	3	3	3	3	-	-	-
HGSL (No recharge occurs below storage of)	0	0	0	0	0	-	-	-
HGGW (Maximum soil moisture recharge)	10	7	1	1	1	-	-	-
Aquifer thickness (m)	20.27	20.27	20.47	19.68	20.30	-	-	-
Storativity	0.0042	0.0042	0.0041	0.0041	0.0041	-	-	-
Initial Aquifer storage (mm)	76.82	76.82	75.92	71.80	74.91	-	-	-
Static water level (mm)	49.51	49.51	49.14	46.84	48.59	-	-	-
Maximum discharge rate (mm)	2.0	2.0	2.0	2.0	2.0	-	-	-
Power	-0.05	-0.05	-0.05	-0.05	-0.05	-	-	-
Maximum hydraulic gradient	0.0010	0.0010	0.0010	0.0010	0.0010	-	-	-
GW evaporation area (km ^{2})	3.24	0.00	3.24	6.01	2.49	-	-	-
Months to recharge	5	5	8	9	8	-	-	-
Unsaturated storage capacity (mm)	34.55	34.55	35.42	36.03	35.62	-	-	-
Initial unsaturated storage cap	17.28	17.28	17.71	18.02	17.81	-	-	-
Percolation power	0.20	0.20	0.20	0.20	0.20	-	-	-
Transmissivity (m ^{2}/day)	10.0	10.0	10.0	10.0	10.0	-	-	-
Borehole distance to river (m)	1 000	1 000	1 000	1 000	1 000	-	-	-
Parameter K2	0.10	0.10	0.10	0.10	0.10	-	-	-
Parameter K3	-3.0	-3.0	-3.0	-3.0	-3.0	-	-	-
Interflow lag	0.0	0.0	0.0	0.0	0.0	-	-	-
Abstractions in 2011 (million m ^{3})	0.001	0.000	0.296	0.022	0.000	-	-	-

7.3 Calibration results

To determine whether a satisfactory calibration has been achieved, a comparison was made between the characteristics of the observed and simulated flows at gauged sites within the system. The comparison was based on standard statistical results that included:

- Statistics, such as the mean annual runoff (MAR), standard deviation, seasonal index, etc
- Yearly hydrograph
- Mean monthly flows
- Gross yield curve
- Scatter diagram
- Cumulative frequency plot

A comparison of the final calibration statistics for flow gauges Q9H002 and Q9H030 is provided in Table 7.2. The calibration plots for the flow gauges and the final WRSM setup (WRSM_Q\Q92\) are included in Appendix D. It is important to understand that the calibration results relate to the Upper Koonap River catchments Q92A, Q92B, Q92C and Q92D. No attempt was made to calibrate the lower catchments.

Based on these results the final calibrations of the flow gauges are considered acceptable. The poor standard deviation result related to flows at gauge Q9H030 is due to the gauge being exceeded during high flows for the period 1983 to 2004. The rating table for the gauge has since been reviewed and increased (DWS Hydstra database) to measure a greater proportion of the high flows.

Table 7.2 Calibration Statistics at Flow Gauges in the Koonap River System

Stations	Q9H002 (R16)			Q9H030 (R6)		
Calibration period	(1933-2011)			(1982-2011)		
Statistics	Obs	Sim	Diff	Obs	Sim	Diff
MAR (million m^3)	43.63	45.62	4.6%	16.99	15.09	-11.2%
Mean (log)	1.31	1.39	6.1%	1.03	1.05	1.9%
Std Deviation (million m^3)	52.21	54.45	4.3%	14.44	10.41	-27.9%
Std Dev (log)	0.62	0.54	12.9%	0.47	0.38	-19.1%
Seasonal Index (million m^3)	17.20	13.78	19.9%	13.49	11.9	-11.8%

7.4 Generation of natural streamflows

Naturalised runoff or streamflow was simulated for each sub catchment by omitting all catchment impacts and water uses. To ensure that the simulated natural flows are realistic the natural runoff statistics were compared with previous studies undertaken in this area, namely WR2005 and WR90. The naturalised hydrology of the current study and the comparison with other studies is summarized in
Table 7.3. The results of the comparison show similar unit runoffs between studies for same periods. The naturalised time-series are provided in electronic format in Appendix D.

As yield analyses are based on present day condition a comparison of naturalised MAR (n MAR) and present day (p MAR) is provided at sub catchment level in Table 7.4.

Table 7.3 Comparison of Naturalised Runoff

Sub-area	Area	MAP	MAE (S)	nMAR	Standard Deviation	Rf - Ru response	Comparison unit runoff (mm/a)		
	(km ²)	(mm/a)	(mm/a)	FSFD $10^6 m^3$	FSFD $10^6 m^3$	FSFD (2011)	FSFD	WR2005	WR90
Q92A1	250	662	1650	18.86	14.8	11 %	75	63	67
Q92A2	74	662	1650	5.23	4.2	11 %	71	63	67
Q92B	324	586	1650	10.98	12.6	6 %	34	36	36
Q92C	601	559	1650	17.01	20.4	5 %	28	30	31
Q92D	249	594	1600	9.78	10.5	7 %	39	46	38
Q92E	287	464	1600	3.38	5.3	3 %	12	12	9
Q92F	665	415	1650	4.56	7.2	2 %	7	7	6
Q92G	884	466	1600	9.83	15.2	2 %	11	11	10
Q92	**3334**	**513**		**79.63**	-	-	**24**	**23**	-
Foxwood	**1 091**	**598**	**1 650**	**47.61**	-	-	**42**	**42**	-

Note: FSFD = Feasibility Study for Foxwood Dam Study = 1920 – 2011
WR90 = 1920 – 1989
WR2005 = 1920 – 2004
Rf – Ru = Rainfall – runoff response

Table 7.4 Comparison of naturalised runoff (nMAR) with present day runoff (pMAR)

Sub-area	Area	MAP	nMAR	pMAR	nMAR	pMAR
	(km²)	(mm/a)	(million m³/a)		(mm/a)	
Q92A1	250	662	18.86	15.63	75	63
Q92A2	74	662	5.23	5.23	71	71
Q92B	324	586	10.98	10.73	34	33
Q92C*	601	559	17.01	11.62	28	19
Q92D	249	594	9.78	8.20	39	33
Q92E	287	464	3.38	3.13	12	11
Q92F*	665	415	4.56	3.83	7	6
Q92G	884	466	9.83	8.94	11	10
Q92 - Koonap	**3 334**	**513**	**79.63**	**67.31**	**24**	**20**
Foxwood Dam	**1 091**	**577**	**47.61**	**40.15**	**44**	**37**

Note: *Adelaide and Bedford abstractions

Based on the calibration results and the comparison with previous studies the hydrological analysis of the Koonap River system is considered acceptable and reasonable and can be used in the Yield (WRYM) model to determine the yield of the proposed Foxwood Dam for various storage capacities.

8 STOCHASTIC STREAMFLOW ANALYSIS

Stochastic streamflow sequences are generated by applying statistical distribution models. The selection of the statistical model is based on the need to determine the inherent statistical characteristics of the historical streamflow sequences of individual sub-catchments as well as the cross correlation that occurs between the streamflows generated in different sub-catchments.

The statistical testing of stochastically generated streamflows was undertaken using the Stochastic Model of South Africa (STOMSA). STOMSA incorporates version 7.1 of the ANNUAL and CROSSYR programs and has been used extensively in South Africa. The analysis was based on the naturalized historical sequences for each sub-catchment in the Koonap River catchment as obtained from the hydrological analysis for the period 1920 to 2011. The results of the statistical analysis by STOMSA are summarised in the statistical parameter file, called PARAM.DAT. The PARAM.DAT file provides direct input to the WRYM and is used by the model to generate the stochastic streamflow sequences that are applied in a stochastic yield analysis.

The testing of stochastic streamflows was undertaken to ensure that the naturalized streamflow sequences generated for Koonap River sub-catchments provided results that are realistic and plausible. The tests can be classified as verification tests that involve the re-sampling of various statistics from the generated sequences to ensure that STOMSA can reproduce statistics from the historical sequence with reasonable accuracy. Examples are tests of the monthly and annual means and standard deviations. The *validation tests*, involve testing certain features of the stochastically generated flows that are not directly involved in the generation of flows. Tests in this category include various storage checks such as maximum deficits, duration of maximum deficits, duration of longest depletion and yield-capacity characteristics.

The relevant historical values are shown as a diamond within standard box-and-whisker plots and should generally fall within the box range (25 % to 75 %) of the flow sequences analysed. An example of a standard box-and-whisker plot is provided in Figure 8.1. In the Koonap River catchment verification and validation tests were performed on the stochastic streamflow sequences for all the sub-catchments in the Koonap River system and the results are presented electronically in Appendix D.

Overall the stochastic tests undertaken for this study fall within acceptable ranges. Therefore the hydrology generated for the Koonap River catchments can be used for Yield modeling.

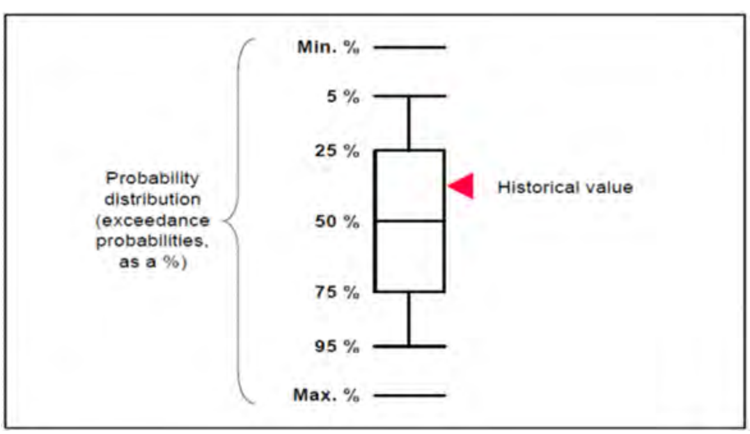


Figure 8.1 Standard Box-and-Whisker Plot

9 YIELD ANAYLSIS

Yield analyses were undertaken using version 7.5.6.7 of the Water Resources Yield Model (WRYM). The WRYM has been developed by the DWS for the purpose of modelling water resource systems. The WRYM uses a sophisticated network solver in order to analyse reservoir water resource systems for a variety of planning and operating policies. It is designed to assess a systems long-term and short-term resource capability (or yield). Analyses are undertaken based on a monthly time-step and for constant development levels, i.e. the system configuration and modelled demands remain unchanged over the simulation period.

The model configuration for the Foxwood Dam and Koonap system is provided in Figure 9.1. The WRYM network configuration is different to the hydrological network diagram as it includes Foxwood Dam, the Reserve at two sites and a more realistic distribution of irrigation within the sub-catchments of the Koonap River. The distribution of irrigation in the WRYM was summarised in Table 4.3 in Section 4.2. Irrigation areas have been split between irrigation abstractions upstream of Foxwood Dam, irrigation abstractions from the Koonap River downstream of Foxwood Dam and abstractions from the tributary rivers downstream of Foxwood Dam. In addition irrigation areas were split within catchments. For example the irrigation area in catchment Q92G was split into irrigation upstream and downstream of the Reserve site EWR KOON 2, etc.

9.1 Loss of storage due to sedimentation

All reservoirs are subject to sedimentation due to landscape erosion processes. This results in decreasing yield because of increasing dead storage from a reservoir over its life span. The relationship between dead storage (i.e. sediment accumulation) and life span is non-linear as the density of the sediment increases over time.

The Koonap River catchment falls within Region 9 of the sediment yield potential map of Southern Africa (WR90, Vol. 5, Map 8.2, 1994). The estimated average rate of sedimentation in the Upper Koonap catchments is 185 tons\km^2\annum based on the Rooseboom methodology (Rooseboom, et al, 1992). This region is characterized by medium erodibility indices.

The loss of storage from sedimentation for the proposed Foxwood Dam was determined for various life spans for a reservoir capacity of around 1 nMAR and is summarised in Table 9.1.

Table 9.1 Dead storage volumes for Foxwood Dam

Life span	Dead storage volume (million m^3)	
(years)	100 % trap efficiency	95 % trap efficiency
20	4.21	4.00
30	5.19	4.93
40	5.89	5.60
50	6.43	6.11

In terms of the yield analysis a life-span of 50 years has been assumed for Foxwood Dam and dead storage of 6.11 million m^3 for all storage capacities.

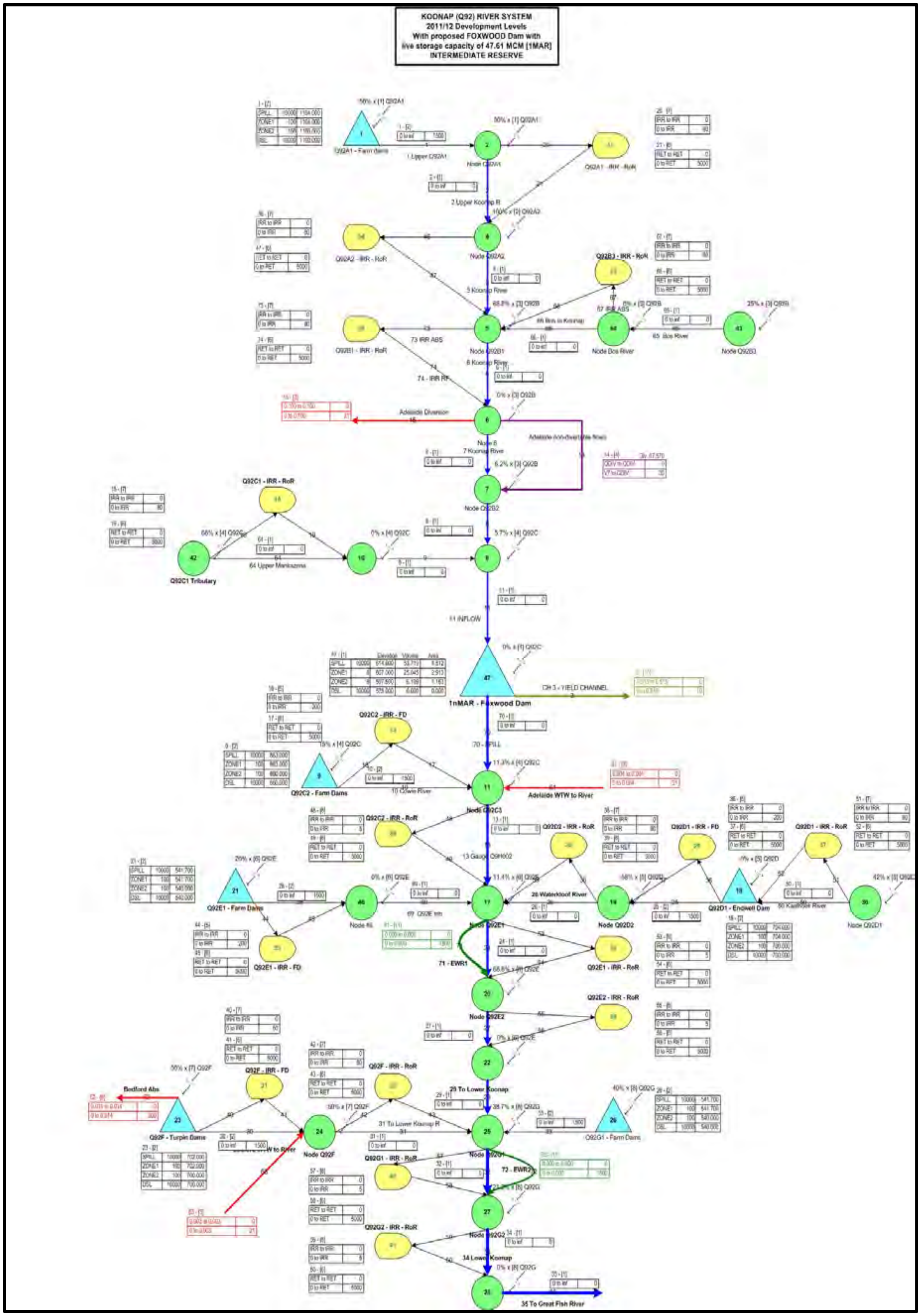


Figure 9.1 Foxwood Dam system diagram

9.2 Yield Scenarios

The Yield Model (WRYM) was setup to determine the yield of the Foxwood Dam system for storage capacities ranging from 29.9 million m^3 to 101.3 million m^3. These storages reflect live storage capacities equivalent to 0.5 nMAR (23.8 million m^3) to 2nMAR (95.3 million m^3).

Three scenarios were setup to determine the yield of the Foxwood Dam system. Scenario 1 reflects the base system with no support of the EWR. Scenarios 2 and 3 support releases for different EWR assurance rules and are described in the following section.

Scenario 2 assumptions and operating rules:

- The Total Flow EWR assurance rules for a Recommend Ecological Category (REC) of C are defined at EWR sites, KOON 1 and KOON 2. Using penalties the system supplies the Reserve before determining the yield of Foxwood Dam.
- Development levels within the Koonap River catchment reflect the situation as at 2011/12.
- The dead storage volume of Foxwood Dam is 6.11 million m^3 for all storage capacities.
- Farm dams are operated so that only spills are available to downstream users because these reservoirs do not have the ability to release storage.
- The starting storages of all dams are set to full supply level (100 %), at the start of historical and long term simulations.
- The annual domestic registered water requirement for Adelaide is 1.05 million m^3 and is supplied by the existing run-of-river diversion in the Upper Koonap River. Using penalties the system supplies this requirement before determining the yield of Foxwood Dam.
- The irrigation requirements upstream of Foxwood Dam reflect the registered areas and requirements as defined in the WARMS database. Using penalties the system supplies these lawful irrigation water requirements before determining the yield of Foxwood Dam.
- The irrigation requirements from tributary catchments downstream of Foxwood Dam reflect the registered areas and requirements defined in the WARMS database. Using penalties the system supplies these lawful tributary irrigation requirements before supplying users in the lower Koonap River.
- Existing irrigation from the lower Koonap River will automatically fall within the Foxwood Dam Water Supply area. In other words these existing users will be supported by the available yield (releases) of Foxwood Dam.

Scenario 3 assumptions and operating rules:

- The Low Flow EWR assurance rules for a REC of C are defined at KOON 1 and KOON 2. Using penalties the system supplies the Reserve before determining the yield of Foxwood Dam.
- All other assumptions are as for Scenario 2.

9.3 Results of Yield Analyses

The historic firm yields (HFY) were determined for the Foxwood Dam system for live storage capacities ranging from 0.5 nMAR (23.8 million m^3) to 2 nMAR (95.2 million m^3), using the historical flow sequences generated by the hydrological model. The HFY of a system is the available yield with no failures in the historical record.

The Firm Yields are provided in Table 9.2 for both scenarios. At live storages of 1.5 nMAR and greater, the yield gained relative to the increased storage capacity is insignificant as shown by the flattening of the curves in Figure 9.2.

Table 9.2 Results of Historical and Long-term Yield Analyses

Reservoir capacity as a ratio of nMAR	Elevation	Wall height	Live storage	Dead Storage	FSC	EWR KOON1	EWR KOON2	HFY	Critical period		Long term yield (10^6 m^3/a) at Recurrence Interval		
	(m.a.s.l)	(m)	(10^6 m^3)	(10^6 m^3)	(10^6 m^3)	(million m^3/a)			Start	End	1:20	1:50	1:100
Scenario 2 – Foxwood Dam system with EWR rule supplied for total flows (incl. high flows)													
0.5 nMAR	608.5	33.5	23.81	6.11	29.92	7.86	13.00	6.88	7/1944	4/1948	9.7	7.8	6.7
0.75 nMAR	611.6	36.8	35.71	6.11	41.82	7.86	13.00	9.69	7/1944	3/1950	13.7	11.1	9.3
1.0 nMAR	614.6	39.6	47.61	6.11	53.72	7.86	13.00	12.52	7/1944	4/1950	15.9	13.3	11.3
1.5 nMAR*	619.5	44.5	71.42	6.11	77.52	7.86	13.00	17.50	7/1954	9/1970	19.8	16.9	14.9
2.00 nMAR*	623.1	48.1	95.22	6.11	101.33	7.86	13.00	18.91	7/1954	12/1970	22.8	19.5	17.2
Scenario 3 – Foxwood Dam system with EWR rule supplied for low flows (excl. high flows)													
0.5 nMAR	608.5	33.5	23.81	6.11	29.92	2.18	5.30	10.23	7/1944	4/1948	12.8	11.0	9.5
0.75 nMAR	611.6	36.8	35.71	6.11	41.82	2.18	5.30	13.36	7/1944	3/1950	17.2	13.8	12.4
1.0 nMAR	614.6	39.6	47.61	6.11	53.72	2.18	5.30	16.56	7/1944	3/1950	19.1	16.4	14.6
1.5 nMAR*	619.5	44.5	71.42	6.11	77.52	2.18	5.30	20.47	11/1986	4/1997	22.9	20.3	18.0
2.00 nMAR*	623.1	48.1	95.22	6.11	101.33	2.18	5.30	21.88	7/1954	12/1970	26.2	22.8	20.6

nMAR is the naturalized Mean Annual runoff at Foxwood Dam which is 47.61 million m^3/annum

* Size of reservoir storage results in long critical period

Likely size of Foxwood Dam based on EWR assurance rules and present day developments in the Foxwood Dam catchment.

The critical period (CP) of Foxwood Dam, for the various dam sizes are also noted in Table 9.2. The length of the CP is a function of the size of reservoir and the degree of variation in the streamflow and allows identification of the start and end of the low flow period over the historical record. The CP's for both scenarios for live storages of 1.5 nMAR and greater are long (greater than 10 years), indicating that the Foxwood Dam at these storage capacities will NOT spill for extended periods thus requiring release gates to support the Koonap River Reserve.

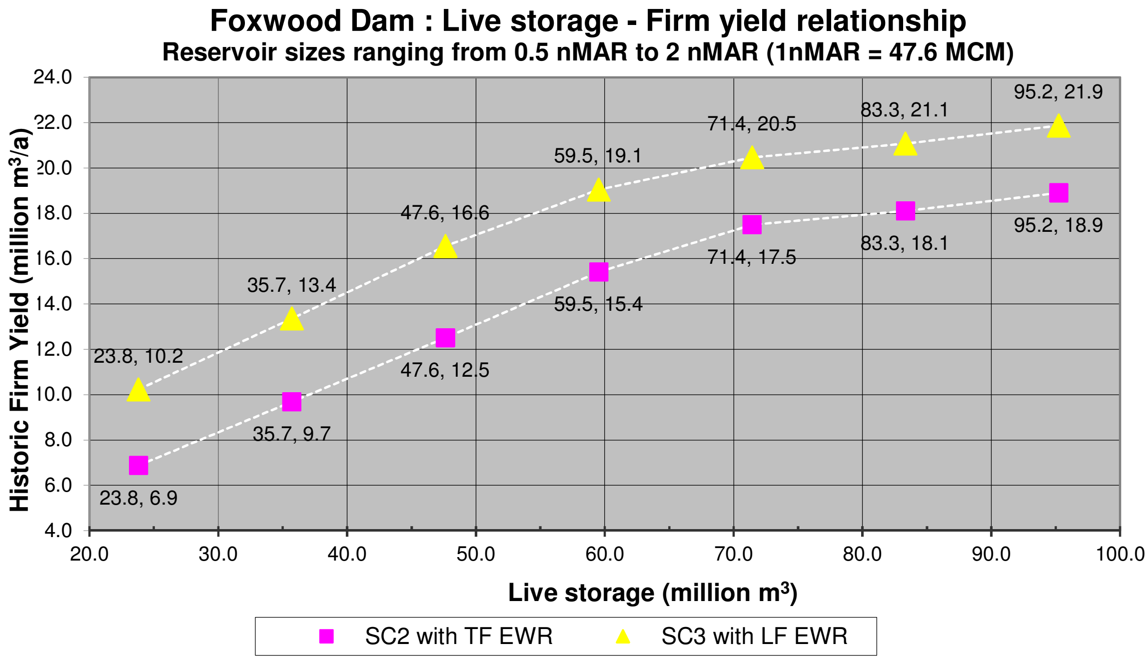


Figure 9.2 Comparison of results for Storage-Firm Yield relationship

In Figure 9.3 and Figure 9.4 the reservoir trajectories for scenario 2 and 3 are shown for live storage capacities of 1 nMAR and 0.5 nMAR respectively. These graphs show the frequency of spills from the reservoir and critical period for the historical record.

The long-term risk based yields for Foxwood Dam for both scenarios were determined for the range of storage capacities and for a range of assurances using 201 stochastically generated hydrology sequences. The results are summarised in Table 9.2 for the standard recurrence intervals of failure of 1:200, 1:100, 1:50 and 1:20. These correspond to annual assurances of supply of 99.5 %, 99 %, 98 % and 95 %. The results are presented graphically in Figure 9.5 for 1:50 and 1:20 stochastic yields.

Determining the most appropriate storage capacity of Foxwood Dam depends on the system requirements which are not confirmed and how the Reserve should be managed. It is assumed that the major users of Foxwood Dam will come from agriculture in the form of irrigation of crops and that high flow EWR's will be supported by spills from Foxwood Dam and low flow EWR's will be supported by inflows from the incremental catchments downstream of the reservoir. This means that most users will accept assurance of supply levels of 95 % (1:20) and lower. In the terms of reference for this project the assurance of supply levels for irrigation was set at 80 % for high value crops and 70 % for cash crops.

The stochastic yield-storage relationships in Figure 9.5 show that appropriate storage capacity of Foxwood Dam is in the range of 29.9 million m^3 (0.5 MAR) to 53.7 million m^3 (1 MAR). At these storages there are regular spills from the dam that should support the high flow EWR requirements defined in the Reserve study. Thus under Scenario 3 system requirements of 12.8 million m^3/a to 19.0 million m^3/a could be supported.

The long term yield curves for Foxwood Dam with live storage capacity of 47.6 million m^3 (1nMAR) for both scenarios are provided in Figure 9.6 and Figure 9.7. The Foxwood Dam system (WRYM model) setups and results are provided in Appendix D.

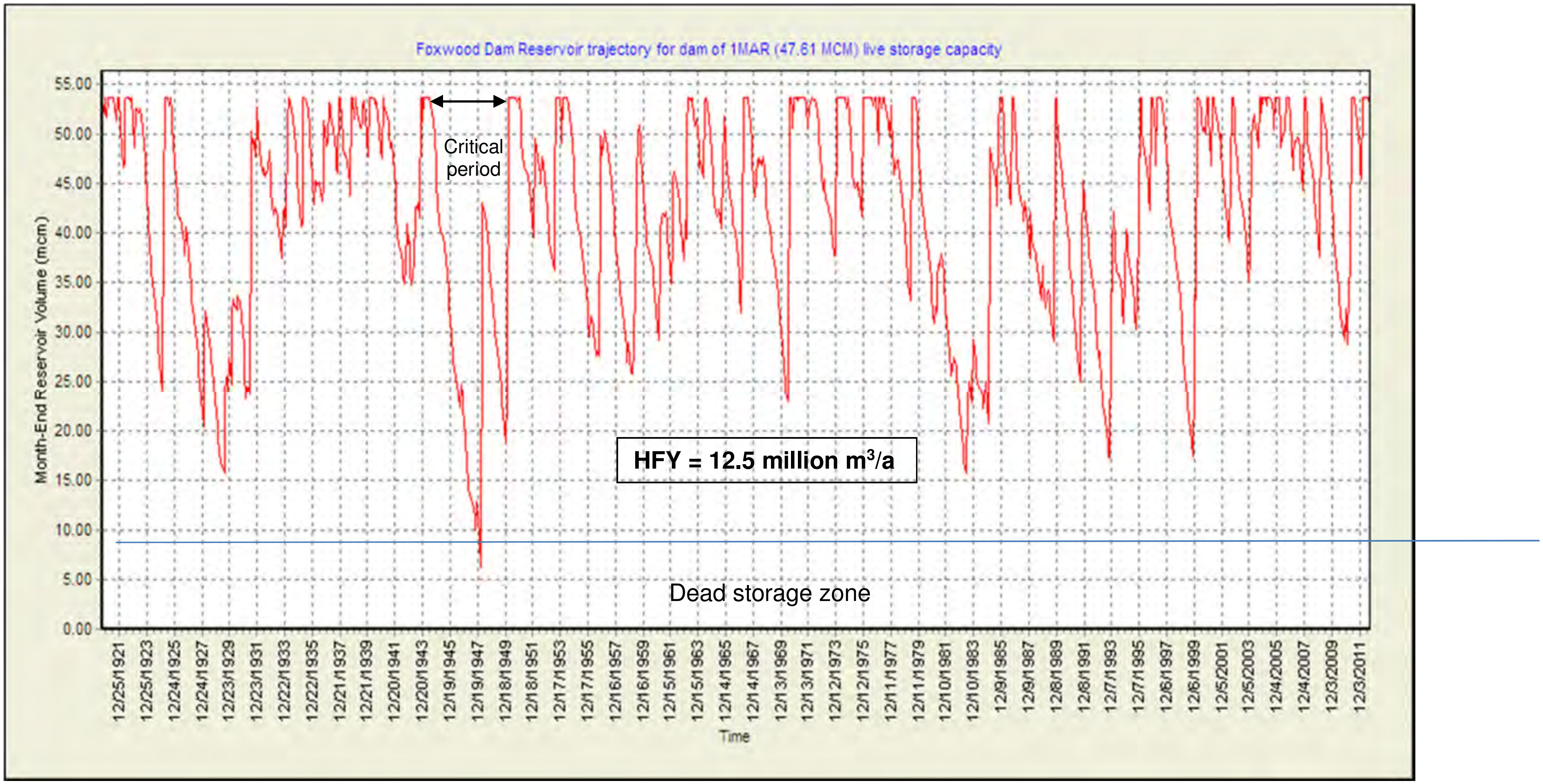


Figure 9.3 Scenario 2 –Foxwood Dam storage trajectory for reservoir with live storage capacity of 47.6 million m^3 and total flow EWR assurance rule

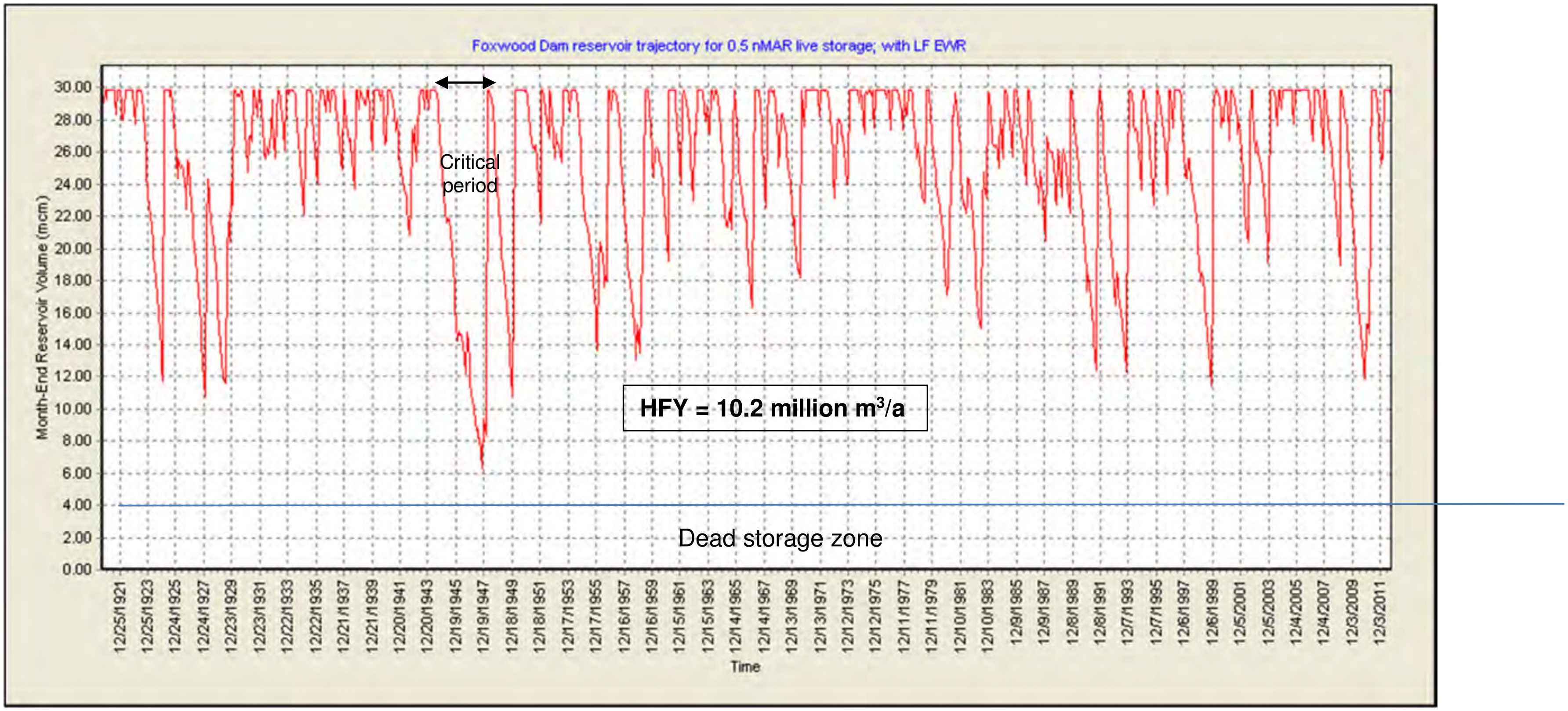
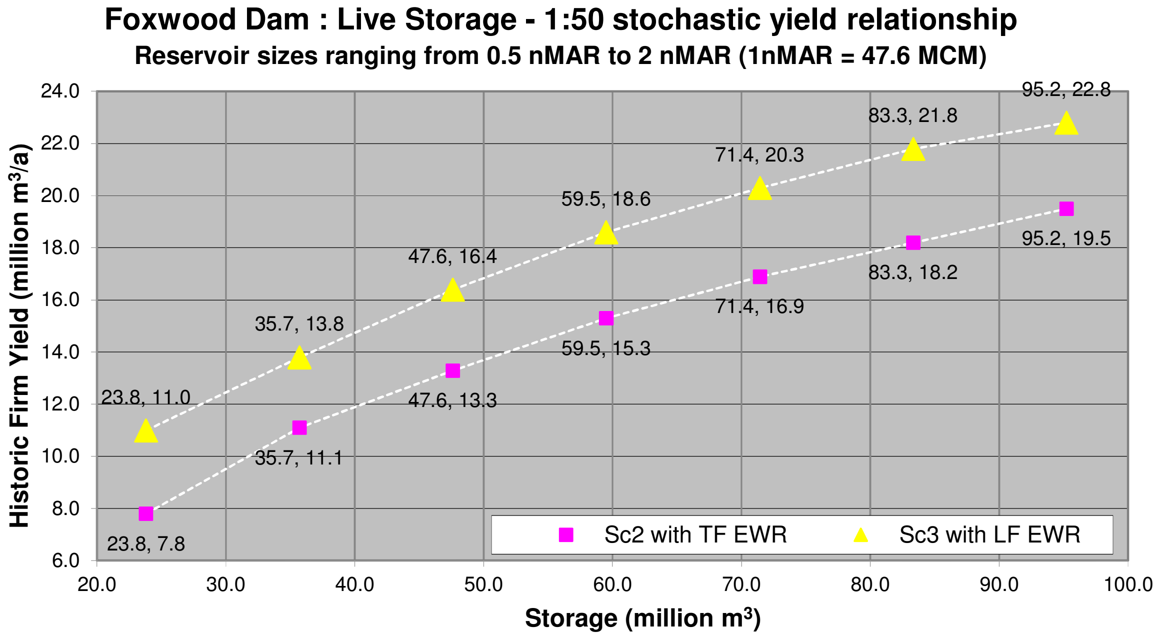


Figure 9.4 Scenario 3 – Foxwood Dam storage trajectory for reservoir with live storage of 23.8 million m^3 and Low flow EWR assurance rule



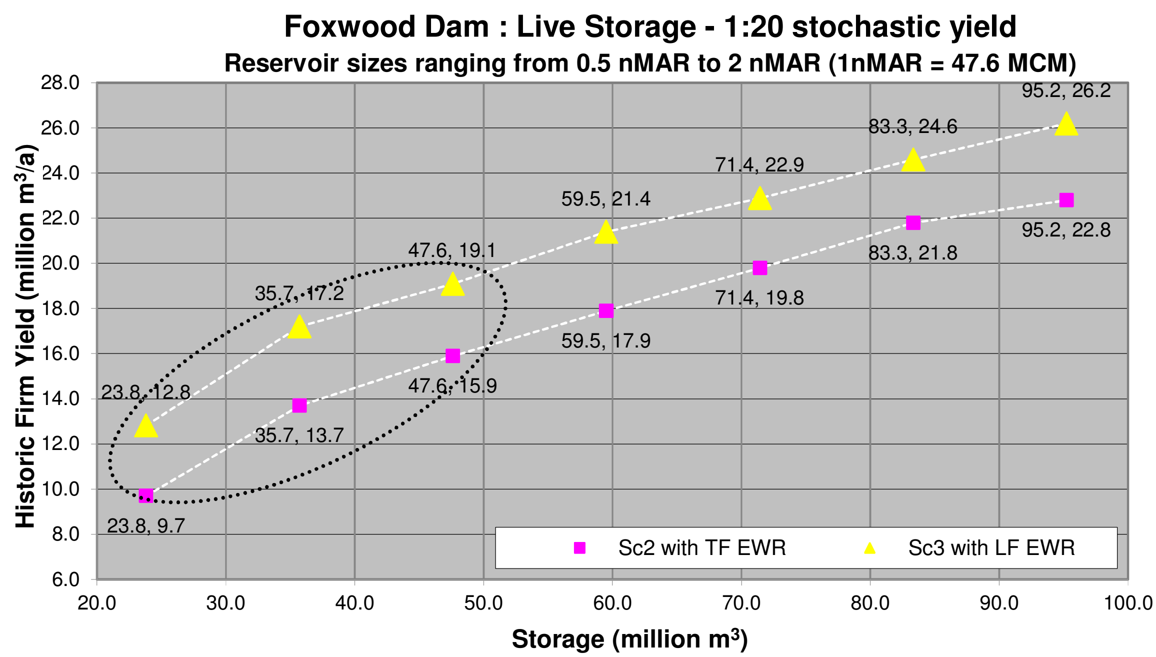


Figure 9.5 Comparison of results for live storage-stochastic yield relationships

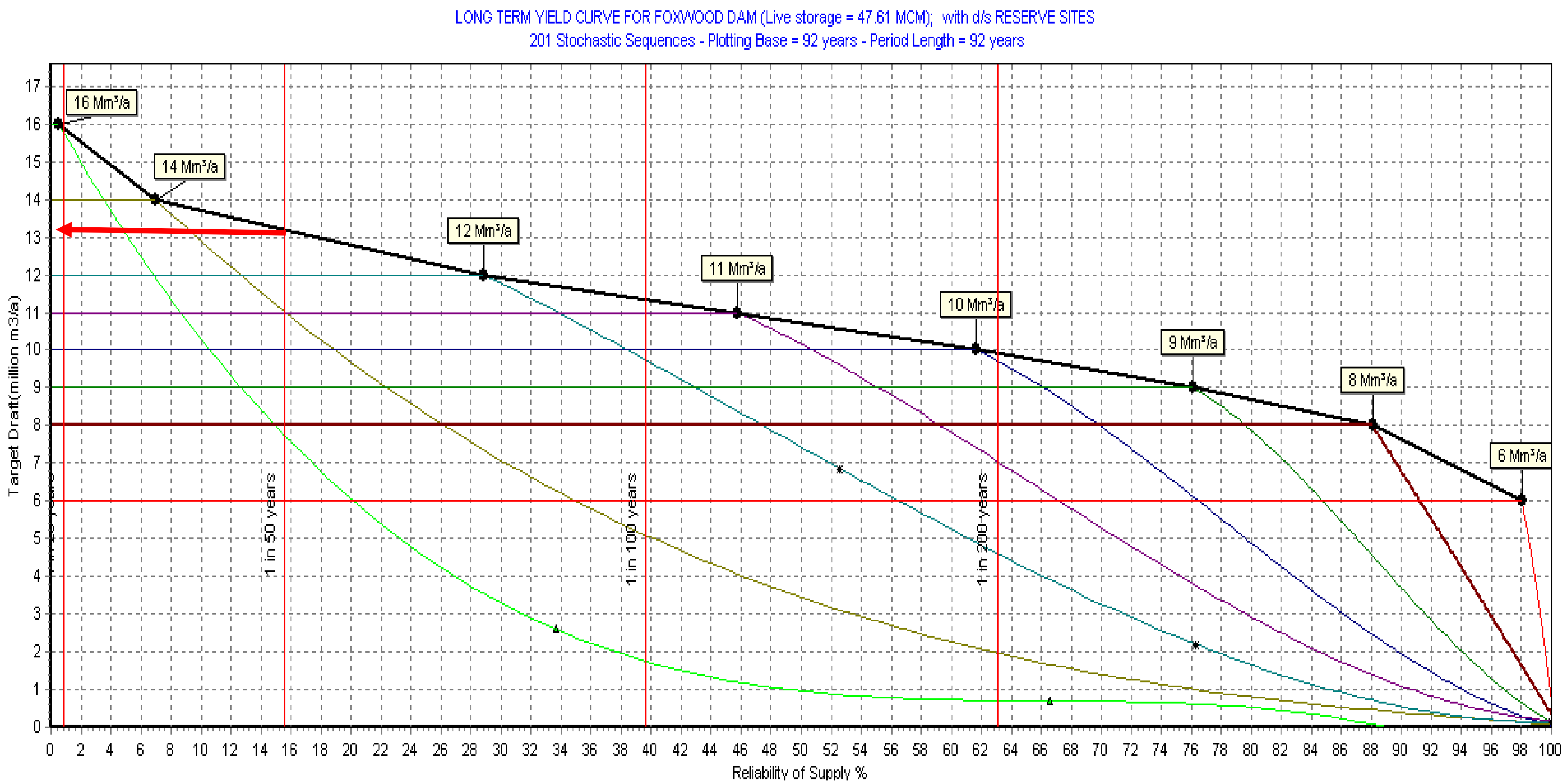


Figure 9.6 Scenario SC2 - LTY Curve for 1 nMAR Foxwood Dam with Total flow EWR rule

Notes:

The reliability of supply axis (x-axis) describes the results of 201 sequences. For 1:50 assurance of supply, about 16 % of the 201 stochastic sequences will experience no failures while the remaining 84 % of 201 sequences have a 2 % risk of at least 1 failure over the period of 92 years.

At 1:50 assurance of supply the LTY or target draft (TD) of Foxwood Dam is 13.3 million m^3/annum

At 1:20 assurance of supply the LTY or TD of Foxwood Dam is 15.9 million m^3/annum

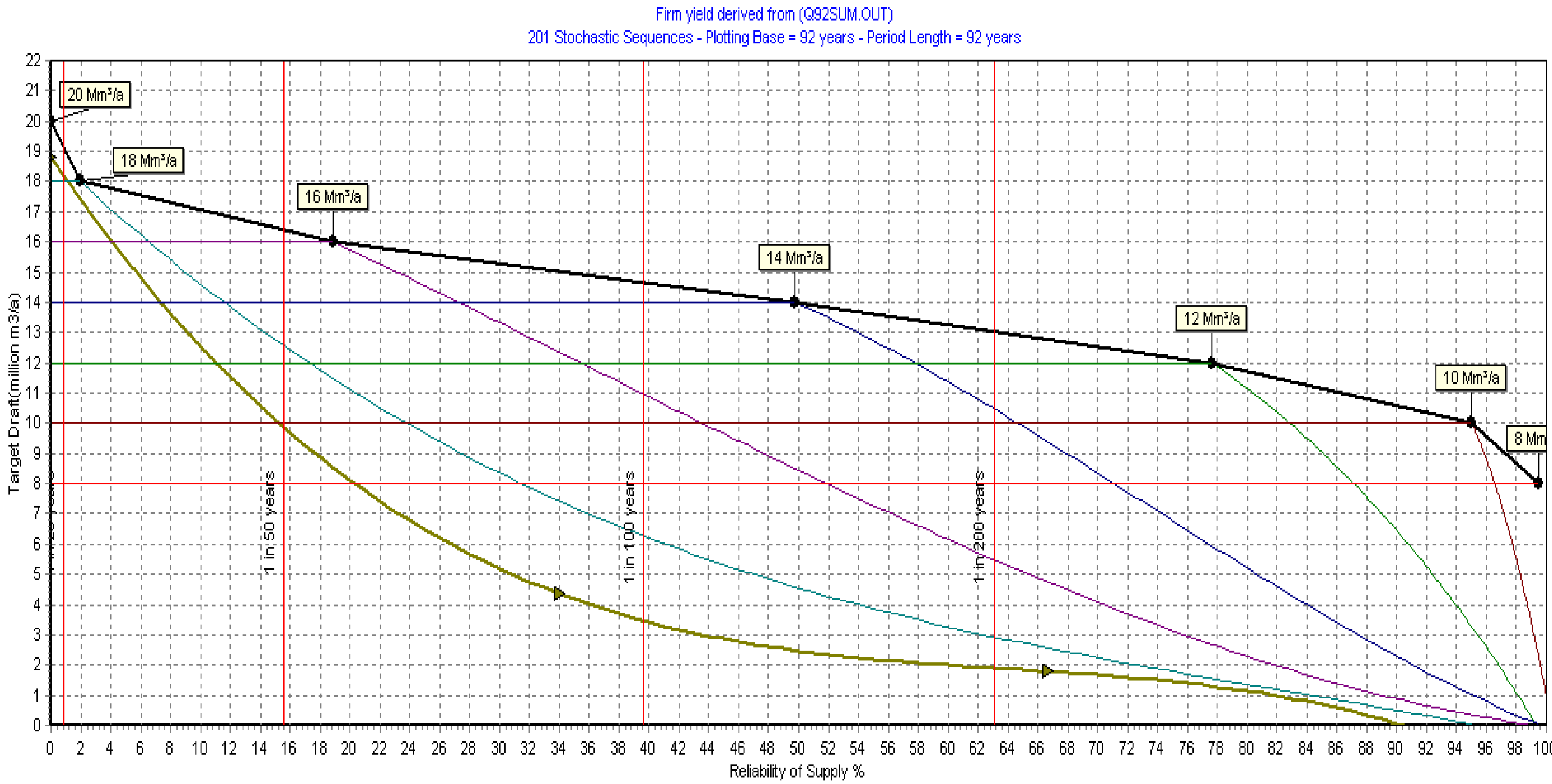


Figure 9.7 Scenario SC3 - LTY Curve for 1 nMAR Foxwood Dam with low flow EWR rule

Notes:

The reliability of supply axis (x-axis) describes results of 201 sequences. For 1:50 assurance of supply, about 16 % of the 201 stochastic sequences will experience no failures while the remaining 84 % of 201 sequences have a 2 % risk of at least 1 failure over the period of 92 years.

At 1:50 assurance of supply the LTY or target draft (TD) of Foxwood Dam is 16.4 million m³/annum

At 1:20 assurance of supply the LTY or TD of Foxwood Dam is 19.1 million m³/annum

9.4 Results of short-term yield analyses for 1nMAR storage dam

The short term reliability characteristics for the proposed Foxwood Dam at the end of the wet season (May decision month) were determined for scenarios 2 and 3. Yield characteristics were determined for the one of the likely storage capacities of the proposed Foxwood Dam, i.e. 1n MAR storage reservoir. The short term yield analysis is based on 501 (5-year) generated stochastic sequences, at starting storage levels of 10 %, 20 %, 40 %, 60 %, 80 % and 100 % for recurrence intervals ranging from 1:5 to 1:200. The results are summarized in Table 9.3 and in Figure 9.8 and Figure 9.9.

The STY characteristics are generally required at the operating level and at the detailed design stage.

Table 9.3 Results of short-term yield analyses for 1nMAR storage dam

Recurrence Interval	Short term yields for various starting storages					
	100 %	80 %	60 %	40 %	20 %	10 %
Results for scenario 2 for 1 nMAR dam with Total Flow EWR						
1:5	28.7	27.7	25.7	23.5	19.2	14.4
1:10	23.0	21.8	20.2	17.5	12.9	9.3
1:20	19.0	17.6	15.9	13.1	9.0	6.2
1:50	15.4	14.0	11.9	9.4	5.7	3.5
1:100	12.8	11.7	10.4	7.1	4.5	2.3
1:200	11.3	10.6	8.7	5.8	3.6	1.8
Results for scenario 3 for 1 nMAR dam with Low Flow EWR						
1:5	32.0	30.6	29.0	26.6	21.6	15.6
1:10	26.3	24.8	23.0	20.4	15.7	11.0
1:20	22.1	21.0	19.1	15.8	11.7	8.0
1:50	18.5	16.9	15.1	12.0	8.4	5.6
1:80	16.4	15.4	12.7	10.8	6.7	4.3
1:100	15.3	13.7	11.1	9.9	5.6	3.3

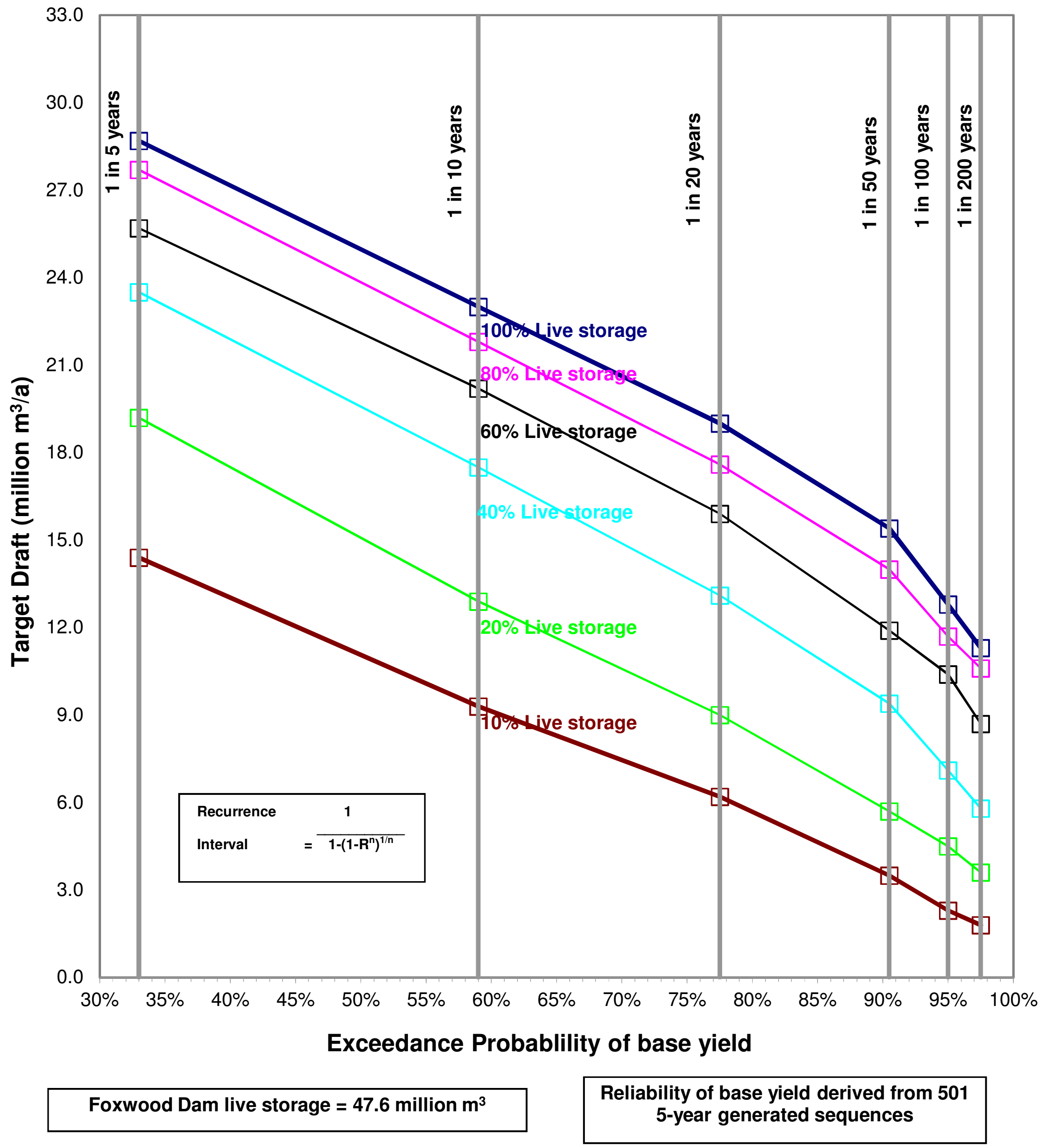


Figure 9.8 Scenario SC2 - STY curves for 1 nMAR Foxwood Dam with total flow EWR assurance rule for various starting storages

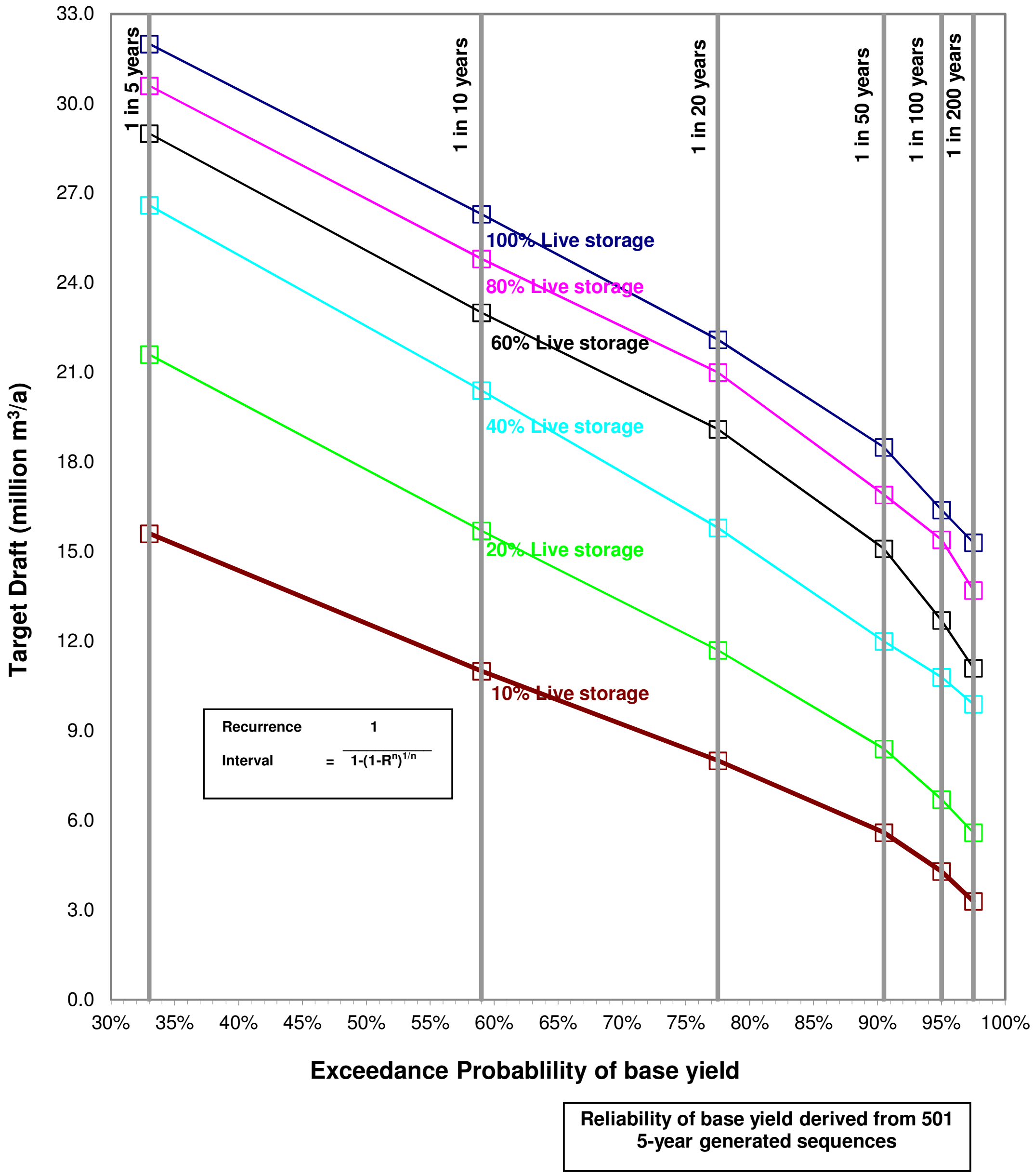


Figure 9.9 Scenario SC3 - STY curves for 1 nMAR Foxwood Dam with low flow EWR assurance rule for various starting storages.

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

- The catchment rainfall generated for the Foxwood Dam and Koonap River system for the period 1920 to 2011 is considered acceptable and is appropriate to be used in the rainfall runoff model and in the yield model.

- The hydrology developed during this study produced acceptable calibrations and could be used to setup the yield model (WRYM) to determine the yield of the Foxwood Dam system for a range of reservoir sizes ranging from 29.9 million m^3 to 101.3 million m^3.

- The EWR operating rule recommended for the Foxwood Dam system is that high flow EWRs should be met by spills from Foxwood Dam and that the low flow EWRs can be completely met by inflows from the incremental catchments downstream of Foxwood Dam. This operating rule impacts the storage size of Foxwood Dam as it is important that regular spills can occur.

- The final storage capacity of Foxwood Dam will depend on the requirements that need to be supplied by the dam and the operating rule recommended for the Reserve. The requirements still require clarification while an operating rule has been recommended by the Reserve specialist.

- The results of the yield analyses and the Reserve study indicate that Scenario 3 should be used to determine the final storage capacity of Foxwood Dam.

- The likely storage capacity of Foxwood Dam should be in the range of 29.9 million m^3 to 53.7 million m^3 with 1:20 yields of 9.7 million m^3/a to 19.1 million m^3/a.

- All yield results were determined using a ‘constant use’ demand pattern of supply.

10.2 Recommendations

The following recommendations will apply if Foxwood Dam is developed:

- All land use information including water abstractions upstream of Foxwood Dam requires verification and confirmation.

- The status of all users in the Foxwood Dam system must be clarified. Including the assurance of supply to users.

- Hydro meteorological and Ecological Water Resources Monitoring Programmes should be initiated as soon as possible and should include:
  1) Weather station to be installed at Foxwood Dam and rain gauges at selected locations in the Upper Koonap River catchment. Currently there are no operational rain gauges in the catchment area of Foxwood Dam.

  2) Flow gauges are required at or near EWR sites to assist in hydraulic modeling of the system.

- Hydraulic modeling of the Foxwood system should be considered to confirm the operating rule for the Reserve. This should be supported by a cost benefit analysis to establish the cost of outlet works for the reserve.

- The extent of water requirements that will be supported by Foxwood Dam requires confirmation.

- The pattern of supply or abstraction from Foxwood Dam still requires defining. The system yields will have to be reassessed once the pattern of supply is defined.

- The final storage capacity of Foxwood Dam will depend on the requirements that need to be supplied by the dam and whether high flow EWR's can be met by spills from Foxwood Dam and low flow EWR's met by inflows from the incremental catchments downstream of Foxwood Dam.

- An Operational model should be setup up of the Foxwood Dam system.

11 REFERENCES

ADM, 1992 — Water supply: Proposed Foxwood Dam; Report prepared by Ninham Shand

DWA, 2010a — Reconciliation Strategy for Adelaide, a report compiled by Umvoto Africa (Pty) Ltd for the Department of Water and Sanitation, July 2010

DWA, 2010b — Reconciliation Strategy for Bedford, a report compiled by Umvoto Africa (Pty) Ltd for the Department of Water and Sanitation, July 2010

DWS. 2013. — Koonap River: EcoClassification and EWR Scenario Assessment Prepared by Rivers for Africa for ARUP

WRC, 1992 — The Development of New Sediment Yield Map of Southern Africa; Rooseboom A, Verster E, Zietsman HL and Loriet, HH; WRC Report No. 297/2/92

WRC, 1994 — Surface Water Resources of South Africa 1990; Vol. 5; Midley, DC, Pitman, WV and Middleton, BJ; WRC Report No. 298/5.1/94

WRC, 2008 — Water Resources of South Africa 2005; Pitman, WV; Bailey A; Hughes, DA and Sami, K; WRC Report No. K5/1491

12 ECOLOGICAL WATER REQUIREMENTS INFORMATION

The below is an extract from the Executive Summary of the Ecological Water Requirements report in Section 12.

BACKGROUND
The Koonap River Irrigation Board (KRIB) was formed in the 1960's for the purposes of promoting and managing irrigation development in the area. The most cost-effective scheme identified during studies to identify and optimise the irrigation development potential was a dam at the Foxwood site close to Adelaide. This dam will supply water to existing commercial irrigators, to smaller municipal lands on the outskirts of the town for food plots, as well as domestic water to the town. Water for Africa through ARUP has been appointed to undertake the determination of Ecological Water Requirements (EWR, or the Ecological Reserve) for the system under investigation, i.e. the Koonap River, following the 8-step methodology currently in place for Reserve determinations.

STUDY AREA
The study area comprises the Foxwood Dam site on the Koonap River, the selected conveyance routes between the dam site and the extended supply area as well as the proposed area to be developed for irrigation. In terms of the river Reserve study, the catchment is from Foxwood Dam to the Fish River confluence.

The locality of the EWR sites in the Koonap River within the Management Resource Units (MRUs) as identified during this study is provided below.

Locality and characteristics of EWR sites

EWR site	Latitude	Longitude	Level II EcoRegion	Geo-zone	Altitude (m)	MRU	Quat[1]	Gauge
KOON1	-32.76671	26.28989	18.02	Lower Foothills	538	MRU Koo A: Foxwood Dam site to the eNyara River.	Q92E	Q9H002
KOON 2	-32.94719	26.51870	18.02	Lower Foothills	340	MRU Koo B: Downstream of MRU 1 to the Great Fish confluence.	Q92G	None

1 Quaternary catchment

OBJECTIVES
The objectives of the study were to:

- Determine the EWR for different ecological states at each EWR site.
- Determine the Present Ecological State (PES) and describe alternative ecological states if relevant.
- Set the Ecological Water Requirement (EWR).
- Address scenarios in terms of the existing and new dams in the Koonap River.
- Determine the Ecological and Goods and Services consequences of the operational scenarios.

APPROACH
As indicated in the Terms of Reference, Ecological Water Requirements (EWRs) were determined applying the Intermediate Ecological Reserve Methodology (IERM) (DWAF, 1999). The methodology consisted of two different steps:

- EcoClassification: Process was followed according to the methods of Kleynhans and Louw (2007).; and

- EWR quantification of different ecological states: The Habitat Flow Stressor Response method (HFSR) (O'Keeffe *et al.*, 2002; IWR S2S, 2004; Hughes and Louw, 2010), a modification of the Building Block Methodology (BBM; King and Louw, 1998) was used to determine the low (base) flow EWRs. The approach to set high flows is a combination of the Downstream Response to Imposed Flow Transformation (DRIFT; Brown and King, 2001) approach and the BBM (King and Louw, 1998).
- Consequences of operational scenarios on Goods and Services: A scenario-based approach was followed. Assessment of the impacts of the various scenarios on the ecological goods and services 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.
- Ecological consequences of operational scenarios: All information used during EcoClassification (Chapter 3 and 7) and the Ecological Water Requirement (EWR) scenario determination (Chapter 5 and 9) is used as baseline for this assessment. A table is provided which compares the impact of each scenario per site against the PES and REC. The resulting EC for each component is provided as well as the EcoStatus. The table is then summarised according to whether the scenarios meet the REC or not, and if not, to what degree.

The following coding is used throughout the document and an example is provided below.

✓ 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.
Dark Green with black ✓:	Meets the REC EcoStatus, but not all the components.
Purple with X:	The scenario results in an EC below the PES; but still above a D EC.
Red with X:	The results are below an E EC.

RESULTS

EcoClassification

The EcoClassification results are summarised below.

EcoClassification results summary

EWR KOON 1

EIS: MODERATE
Highest scoring metrics were intolerance of instream biota to no flow and physico-chemical changes, diversity of instream habitat types, unique riparian species and important riparian migration corridors.

PES: C

- Deteriorated water quality (increased salinity and nutrients) due to WWTW and irrigation return flows.
- Flow alteration due to farm dams and irrigation leading to reduced baseflows.
- Clearing for agriculture, targeted removal of woody species and the presence of alien vegetation.

REC: C
EIS was MODERATE and the REC was therefore to maintain the PES.

Driver Components	PES and REC
IHI HYDROLOGY	C
WATER QUALITY	B/C
GEOMORPHOLOGY	B
Response Components	**PES and REC**
FISH	C
INVERTEBRATES	C
INSTREAM	C
RIPARIAN VEGETATION	C
ECOSTATUS	C
INSTREAM IHI	C
RIPARIAN IHI	C
EIS	MODERATE

EWR KOON 2

EIS: MODERATE
Highest scoring metrics were rare and endangered species (*Sandelia bainsii*) intolerance of instream biota to no flow and physico-chemical changes, diversity of instream habitat types, four unique riparian species and important riparian migration corridors.

PES: C

- Reduced base flows and flow alteration due to abstractions and agricultural return flows.
- Reduced water quality due to agriculture.
- Migration barriers result in decrease species frequency of occurrence.
- Presence of alien vegetation and removal of indigenous species.

REC: C
EIS was MODERATE and the REC was therefore to maintain the PES.

Driver Components	PES and REC
IHI HYDROLOGY	C
WATER QUALITY	C
GEOMORPHOLOGY	B
Response Components	**PES and REC**
FISH	C
INVERTEBRATES	B/C
INSTREAM	C
RIPARIAN VEGETATION	C
ECOSTATUS	C
INSTREAM IHI	C
RIPARIAN IHI	B/C
EIS	MODERATE

There is low confidence in the biota information and EWR assessment. The low confidence can be addressed by improving the baseline through the implementation of an Ecological Water Resources Monitoring (EWRM) programme and should be initiated as soon as possible. An improvement in hydraulic confidence could be achieved by obtaining a calibration in the region of the recommended low flows (EWR KOON 1 and EWR KOON 2) and during a flood (EWR KOON 2).

EWR quantification

The final flow requirements are expressed as a percentage of the natural Mean Annual Runoff (MAR).

Summary of results as a percentage of the natural MAR

EWR site	PES	REC	NMAR (MCM)	PMAR (MCM)	Long term mean: Low flows (MCM)	Low flows (%NMAR)	High flows (MCM)	High flows (%NMAR)	Total flows (MCM)	TOTAL (%NMAR)
KOON 1	C	C	62.93	52.04	2.997	4.8	7.08	11.25	10.076	16
KOON 2	C	C	77.54	65.30	6.917	8.9	9.624	12.41	16.541	21.33

Ecological consequences of operational scenarios

A comparison of the ecological consequences of the scenarios at EWR KOON 1 and EWR KOON 2 are provided below.

Comparison of ecological consequences at EWR KOON 1 and EWR KOON 2

KOONAP RIVER				
EWR SITE	Sc 1	Sc 2	Sc 3	Sc 4
EWR 1	✓	✓	✓	✓
EWR 2	X	X	✓	✓

This analysis shows that none of the scenarios fully meet the ecological objectives at both sites. Scenario 3 and 4 maintain the REC at EWR 1 and EWR 2, although not for all components and has a higher risk of failure. Scenario 1 and 2 are not recommended as these scenarios result in an EC dropping below the PES at EWR KOON 2.

Optimised Scenario

Although Sc 4 does not meet the ecological objectives, it does represent the best of the four options. This scenario includes a desktop estimate of the low flow EWR. To determine an optimised scenario, Sc 4 should be used as the basis and must include the EWR (low flows) as determined during this task.

Consequences of operational scenarios on Goods and Services

Given the nature of ecological Goods and Services utilisation in the area under consideration, none of the scenarios have an impact with either a magnitude or significance that would be considered as a fatal flaw at either EWR KOON1 or EWR KOON 2. With regard to ranking scenarios at EWR KOON 1 the following applies:

- Although Sc 1 has positive impacts, it also has the most negative impacts and the nature of these impacts is such that this scenario cannot be considered as a viable option in future.
- Sc 2 and Sc 3 have very similar impacts and are marginally more preferable to Sc 1.
- Sc 4 is the most preferable and has more positive impacts than negative with an overall positive impact on ecological Goods and Services.

With regard to ranking scenarios at EWR KOON 2 the following applies:

- Although Sc 2 has positive impacts, it also has the most negative impacts and the nature of these impacts is such that this scenario cannot be considered as a viable option in future.
- Sc 1 is marginally better than Sc 2.
- Sc 3 is marginally more preferable to Sc 2 as it has a marginally positive impact on ecological Goods and Services.

Sc 4 is the most preferable and has more positive impacts than negative with an overall positive impact on ecological Goods and Services.

The reports generated by the Revised Desktop Ecological Model are provided for each site and include (Appendix C, Rivers for Africa, 2013):

- Hydrology summary;
- Parameters that were adjusted from the default;
- Final output results (EWR rules) for the Recommended Ecological Category (REC).

EWR KOON 1
Hydrology data summary

12.1.1.1 Natural Flows:

Area (km²)	MAR	Ann.SD	Q75	Ann. CV
	(m³ * 10⁶)			
1 588.0	62.93	64.14	0.88	1.02
% Zero flows	0.0			
Baseflow Parameters:			A	0.97
			B	0.44
BFI				0.32
Hydro Index				13

MONTH	MEAN		CV
	(m³ * 10⁶)		
Oct	4.06	10.9	2.69
Nov	6.59	13.8	2.09
Dec	6.64	10.99	1.66
Jan	4.39	7.94	1.81
Feb	5.87	10.11	1.72
Mar	10.61	24.12	2.27
Apr	6.26	11.55	1.84
May	5.12	12.27	2.4
Jun	3.13	5.76	1.84
Jul	2.82	5.69	2.02
Aug	4.08	11.19	2.74
Sep	3.35	7.19	2.15

Critical months:	Wet Season	Mar	Dry Season	Oct
Max. baseflows (m^3/s)	1.13		0.6	

Present Day Flows:

Area (km²)	MAR	Ann.SD	Q75	Ann. CV
	(m³ * 10⁶)			
0	52.04	62.89	0.06	1.21
% Zero flows	3.3			
Baseflow Parameters:			A	0.97
			B	0.44
BFI				0.21
Hydro Index				23.9

MONTH	MEAN	SD	CV
	(m³ * 10⁶)		
Oct	3	10.87	3.62
Nov	5.45	13.66	2.5
Dec	5.34	10.75	2.01
Jan	3.1	7.59	2.45
Feb	4.64	9.83	2.12
Mar	9.46	24.11	2.55
Apr	5.53	11.44	2.07
May	4.56	12.17	2.67
Jun	2.68	5.72	2.13
Jul	2.34	5.64	2.41
Aug	3.42	11.1	3.25
Sep	2.52	7.12	2.83

Hydraulics data summary

Geomorph. Zone	3
Flood Zone	2
Max. Channel width (m)	21.74
Max. Channel Depth (m)	1.5
Observed Channel XS and rating curve used: (Gradients and Roughness n values calibrated)	
Max. Gradient	0.03
Min. Gradient	0.017
Gradient Shape Factor	9
Max. Mannings n	0.3
Min. Mannings n	0.16
n Shape Factor	20
Max. Channel Discharge (m3/s) between 49.576 and 15.268	

Flow - stressor response data summary

Table of initial SHIFT factors for the Stress Frequency Curves					
Category		**High SHIFT**		**Low SHIFT**	
A		0.1		0.1	
A/B		0.15		0.15	
B		12.1.2	0.2	12.1.3	0.2
12.1.4	B/C	12.1.5	0.3	12.1.6	0.275
12.1.7	C	12.1.8	0.4	12.1.9	0.35
12.1.10	C/D	12.1.11	0.5	12.1.12	0.4
12.1.13	D	12.1.14	0.6	12.1.15	0.5
12.1.16	Perenniality Rules: Non-Perennial Allowed				
12.1.17	Alignment of maximum stress to Present Day stress C Category Aligned				
12.1.18	**Table of flows (m^3/s) v stress index**				
12.1.19	**Stress**	**12.1.20**	**Wet Season Flow**	**12.1.21**	**Dry Season Flow**
12.1.22	1	12.1.23	1.052	12.1.24	0.546
12.1.25	2	12.1.26	0.918	12.1.27	0.476
12.1.28	3	12.1.29	0.639	12.1.30	0.288
12.1.31	4	12.1.32	0.481	12.1.33	0.232
12.1.34	5	12.1.35	0.352	12.1.36	0.129
12.1.37	6	12.1.38	0.242	12.1.39	0.104
12.1.40	7	12.1.41	0.14	12.1.42	0.078
12.1.43	8	12.1.44	0.093	12.1.45	0.052
12.1.46	9	12.1.47	0.047	12.1.48	0.026
12.1.49	10	12.1.50	0	12.1.51	0

High flow estimation summary details

No High flows when natural high flows are < 24% of total flows							
Maximum high flows are 250% greater than normal high flows							
Table of normal high flow requirements (Mill. m^3)							
Category	**A**	**A/B**	**B**	**B/C**	**C**	**C/D**	**D**
Annual	9.985	9.245	8.537	7.858	7.209	6.587	5.992
Oct	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0
Dec	0.753	0.698	0.644	0.593	0.544	0.497	0.452
Jan	0.633	0.586	0.541	0.498	0.457	0.418	0.38
Feb	2.136	1.978	1.826	1.681	1.542	1.409	1.282
Mar	4.526	4.191	3.869	3.562	3.268	2.986	2.716
Apr	1.937	1.793	1.656	1.524	1.398	1.278	1.162
May	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0

Final Reserve summary details

Long term mean flow requirements (Mill. m^3 and %MAR)				
Category	**Low Flows**		**Total Flows**	
	Mill. m^3	**%MAR**	**Mill. m^3**	**%MAR**
A	8.46	13.4	18.265	29
A/B	7.282	11.6	16.361	26
B	6.099	9.7	14.482	23
B/C	4.358	6.9	12.075	19.2
C	**2.997**	**4.8**	**10.076**	**16**
C/D	2.198	3.5	8.667	13.8
D	1.411	2.2	7.296	11.6

Flow duration and Reserve assurance tables

Columns are FDC percentage points:										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Natural Total flow duration curve (mill. m^3)										
Oct	8.236	3.388	2.142	1.640	1.320	1.128	0.962	0.772	0.640	0.329
Nov	22.180	8.274	2.730	1.972	1.310	1.072	0.910	0.77	0.578	0.278
Dec	18.672	11.254	7.066	2.856	1.720	1.164	0.872	0.664	0.500	0.230
Jan	15.478	5.276	2.976	1.666	1.230	0.888	0.744	0.634	0.512	0.199
Feb	19.124	7.522	4.058	2.662	1.890	1.134	0.800	0.644	0.500	0.238
Mar	19.06	13.684	8.868	6.190	4.010	2.144	1.586	1.094	0.672	0.462
Apr	16.018	6.018	4.278	3.678	2.100	1.504	1.102	0.924	0.722	0.387
May	13.962	3.384	2.054	1.552	1.320	1.140	1.060	0.900	0.732	0.463
Jun	9.140	2.440	1.930	1.374	1.280	1.138	1.050	0.918	0.752	0.550
Jul	5.014	2.516	1.896	1.522	1.380	1.118	1.026	0.91	0.718	0.579
Aug	7.718	2.638	1.874	1.464	1.250	1.020	0.922	0.844	0.712	0.491
Sep	7.164	2.728	1.840	1.522	1.240	1.050	0.886	0.720	0.626	0.379
Natural Baseflow flow duration curve (mill. m^3)										
Oct	2.426	1.590	1.364	1.171	1.120	0.949	0.834	0.718	0.603	0.329
Nov	4.047	2.219	1.401	1.250	1.044	0.924	0.838	0.735	0.572	0.278
Dec	4.648	2.373	1.840	1.412	1.250	0.973	0.820	0.627	0.500	0.230
Jan	3.820	1.774	1.374	1.102	0.922	0.818	0.682	0.574	0.449	0.199
Feb	3.666	1.904	1.433	1.205	1.020	0.933	0.731	0.602	0.492	0.237
Mar	4.042	2.967	2.254	1.869	1.324	1.050	0.904	0.795	0.565	0.368
Apr	4.027	2.194	1.692	1.435	1.180	1.030	0.888	0.741	0.522	0.349
May	4.070	1.790	1.544	1.247	1.062	0.948	0.856	0.742	0.534	0.353
Jun	2.867	1.796	1.354	1.186	1.010	0.937	0.867	0.738	0.543	0.399
Jul	2.878	1.890	1.590	1.199	1.050	0.931	0.878	0.749	0.570	0.484
Aug	2.684	1.867	1.491	1.213	1.020	0.900	0.854	0.763	0.569	0.476
Sep	2.182	1.675	1.436	1.199	1.053	0.899	0.830	0.710	0.568	0.379

12.1.52	Category Low Flow Assurance curves (mill. m^3)								
12.1.53	**Columns are FDC percentage points:**									
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
C Category										
Oct	0.489	0.289	0.2	0.129	0.079	0.046	0.026	0.014	0.008	0.005
Nov	1.04	0.541	0.223	0.145	0.125	0.078	0.035	0.020	0.01	0.002
Dec	1.129	0.653	0.392	0.209	0.156	0.063	0.041	0.022	0.009	0.002
Jan	0.98	0.377	0.254	0.167	0.116	0.075	0.04	0.020	0.008	0.002
Feb	0.949	0.482	0.231	0.137	0.114	0.074	0.039	0.019	0.008	0.002
Mar	1.279	0.967	0.634	0.352	0.231	0.138	0.075	0.034	0.009	0.000
Apr	1.124	0.526	0.314	0.209	0.125	0.102	0.056	0.027	0.01	0.002
May	1.121	0.424	0.269	0.168	0.130	0.066	0.041	0.022	0.011	0.003
Jun	0.774	0.377	0.256	0.148	0.123	0.079	0.044	0.024	0.01	0.002
Jul	0.655	0.399	0.271	0.147	0.130	0.082	0.049	0.025	0.011	0.003
Aug	0.631	0.386	0.251	0.159	0.129	0.08	0.042	0.029	0.011	0.003
Sep	0.589	0.315	0.225	0.146	0.126	0.078	0.044	0.023	0.011	0.003
Category Total Flow Assurance curves (mill. m^3)										
Oct	0.489	0.289	0.2	0.129	0.079	0.046	0.026	0.014	0.008	0.005
Nov	1.04	0.541	0.223	0.145	0.125	0.078	0.035	0.020	0.01	0.002
Dec	2.262	1.462	1.022	0.766	0.700	0.573	0.448	0.259	0.014	0.002
Jan	1.932	1.057	0.784	0.635	0.573	0.502	0.382	0.219	0.012	0.002
Feb	4.161	2.775	2.018	1.716	1.656	1.517	1.193	0.691	0.021	0.002
Mar	8.084	5.828	4.42	3.697	3.498	3.196	2.520	1.458	0.036	0.000
Apr	4.036	2.606	1.934	1.641	1.523	1.410	1.102	0.636	0.021	0.002
May	1.121	0.424	0.269	0.168	0.130	0.066	0.041	0.022	0.011	0.003
Jun	0.774	0.377	0.256	0.148	0.123	0.079	0.044	0.024	0.01	0.002
Jul	0.655	0.399	0.271	0.147	0.130	0.082	0.049	0.025	0.011	0.003
Aug	0.631	0.386	0.251	0.159	0.129	0.08	0.042	0.029	0.011	0.003
Sep	0.589	0.315	0.225	0.146	0.126	0.078	0.044	0.023	0.011	0.003

EWR KOON 2

Hydrology data summary

Natural Flows:						Present Day Flows:				
Area (km²)	MAR	Ann.SD	Q75	Ann. CV		Area (km²)	MAR	Ann.SD	Q75	Ann. CV
	($m^3 * 10^6$)						($m^3 * 10^6$)			
3146.0	77.54	85.07	0.9	1.1		0	65.3	83.47	0.03	1.28
% Zero flows	0.0					% Zero flows	3.3			
Baseflow Parameters:			A	0.97		Baseflow Parameters:			A	0.97
			B	0.44					B	0.44
BFI				0.29		BFI				0.21
Hydro Index				14.8		Hydro Index				25.5

MONTH	MEAN	SD	CV		MONTH	MEAN	SD	CV
	($m^3 * 10^6$)					($m^3 * 10^6$)		
Oct	5.34	16.37	3.07		Oct	4.16	16.27	3.91
Nov	8.31	17.79	2.14		Nov	7.01	17.52	2.5
Dec	8.46	14.67	1.73		Dec	6.96	14.33	2.06
Jan	5.44	9.75	1.79		Jan	3.99	9.31	2.33
Feb	7.39	12.87	1.74		Feb	5.97	12.46	12.1.54
Mar	14.68	37.41	2.55		Mar	13.31	37.25	2.8
Apr	7.93	15.55	1.96		Apr	7.1	15.36	2.16
May	5.56	13.67	2.46		May	4.95	13.54	2.73
Jun	3.26	6.15	1.89		Jun	2.79	6.09	2.18
Jul	2.95	6.23	2.11		Jul	2.44	6.13	2.51
Aug	4.51	13.35	2.96		Aug	3.8	13.18	3.46
Sep	3.71	8.04	2.17		Sep	2.81	7.91	2.81

Critical months:	Wet Season	Mar	Dry Season	Oct
Max. baseflows (m^3/s)	1.41		0.651	

Hydraulics data summary

Geomorph. Zone	4
Flood Zone	2
Max. Channel width (m)	28.07
Max. Channel Depth (m)	1.5
Observed Channel XS and rating curve used: (Gradients and Roughness n values calibrated)	
Max. Gradient	0.016
Min. Gradient	0.016
Gradient Shape Factor	10
Max. Mannings n	0.15
Min. Mannings n	0.07
n Shape Factor	35
Max. Channel Discharge (m^3/s) between 59.329 and 55.362	

Flow - stressor response data summary

Table of initial SHIFT factors for the Stress Frequency Curves		
Category	**High SHIFT**	**Low SHIFT**
A	0.1	0.05
A/B	0.15	0.075
B	0.2	0.1
B/C	0.3	0.125
C	0.4	0.15
C/D	0.5	0.2
D	0.6	0.3
Perenniality Rules: Wet season perennial forced		
Alignment of maximum stress to Present Day stress C Category Aligned		
Table of flows (m^3/s) v stress index		
Stress	**Wet Season Flow**	**Dry Season Flow**
1	1.421	0.706
2	1.279	0.655
3	1.167	0.592
4	0.965	0.501
5	0.713	0.393
6	0.585	0.198
7	0.415	0.126
8	0.198	0.095
9	0.106	0.063
10	0.053	0.032

High flow estimation summary details

No High flows when natural high flows are < 24% of total flows							
Maximum high flows are 290% greater than normal high flows							
Table of normal high flow requirements (Mill. m^3)							
Category	**A**	**A/B**	**B**	**B/C**	**C**	**C/D**	**D**
Annual	13.414	12.361	11.359	10.406	9.501	8.64	7.822
Oct	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0
Dec	1.189	1.096	1.007	0.923	0.842	0.766	0.694
Jan	1.172	1.08	0.993	0.909	0.83	0.755	0.684
Feb	2.741	2.525	2.321	2.126	1.941	1.765	1.598
Mar	5.929	5.464	5.021	4.6	4.2	3.819	3.458
Apr	2.382	2.195	2.017	1.848	1.687	1.534	1.389
May	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0
Aug	0	0	0	12.1.55	12.1.56	12.1.57	12.1.58
12.1.59 Sep	12.1.60	12.1.61	12.1.62	12.1.63	12.1.64	12.1.65	12.1.66

Final Reserve summary details

Long term mean flow requirements (Mill. m^3 and %MAR)				
Category	Low Flows		Total Flows	
	Mill. m^3	%MAR	Mill. m^3	%MAR
A	10.698	13.8	24.286	31.3
A/B	9.778	12.6	22.299	28.8
B	8.91	11.5	20.417	26.3
B/C	7.76	10	18.301	23.6
C	6.917	8.9	16.541	21.3
C/D	5.928	7.6	14.679	18.9
D	4.495	5.8	12.419	16

Flow duration and Reserve assurance tables

Columns are FDC percentage points:										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Natural Total flow duration curve (mill. m^3)										
Oct	11.41	4.268	2.36	1.712	1.43	1.168	1.008	0.772	0.642	0.329
Nov	24.59	9.598	3.996	2.364	1.45	1.172	0.95	0.83	0.612	0.278
Dec	25.652	13.32	8.084	4.02	1.99	1.348	0.898	0.682	0.548	0.23
Jan	20.41	6.106	3.524	2.072	1.49	0.994	0.808	0.662	0.536	0.199
Feb	23.578	9.954	4.92	3.438	2.25	1.434	0.866	0.708	0.532	0.238
Mar	27.416	16.746	10.582	7.044	5.03	2.838	1.714	1.266	0.69	0.462
Apr	19.502	7.376	5.108	4.246	2.34	1.586	1.166	0.93	0.732	0.387
May	17.2	3.588	2.158	1.586	1.33	1.15	1.082	0.908	0.732	0.463
Jun	9.912	2.522	1.93	1.374	1.28	1.156	1.062	0.918	0.752	0.55
Jul	5.076	2.516	1.896	1.522	1.39	1.118	1.026	0.91	0.718	0.579
Aug	7.918	2.662	1.88	1.482	1.25	1.02	0.922	0.844	0.712	0.491
Sep	8.156	3.244	1.852	1.558	1.27	1.05	0.886	0.72	0.626	0.379
Natural Baseflow flow duration curve (mill. m^3)										
Oct	2.767	1.727	1.462	1.294	1.137	0.967	0.844	0.723	0.611	0.329
Nov	4.376	2.707	1.553	1.361	1.102	0.951	0.882	0.764	0.586	0.278
Dec	6.079	2.757	2.059	1.555	1.359	0.99	0.867	0.647	0.548	0.23
Jan	4.202	2.117	1.551	1.228	1.021	0.88	0.75	0.596	0.458	0.199
Feb	4.869	2.89	1.816	1.371	1.167	0.998	0.772	0.651	0.502	0.237
Mar	5.15	3.77	2.823	2.243	1.469	1.231	1.01	0.834	0.57	0.369
Apr	5.023	2.611	2.012	1.598	1.29	1.099	0.922	0.822	0.535	0.349
May	4.468	1.912	1.654	1.306	1.11	0.978	0.894	0.743	0.561	0.353
Jun	3.002	1.831	1.465	1.224	1.069	0.977	0.876	0.785	0.551	0.4
Jul	2.878	1.916	1.6	1.217	1.1	0.964	0.894	0.751	0.571	0.484
Aug	2.692	1.898	1.547	1.222	1.029	0.923	0.857	0.764	0.58	0.476
Sep	2.681	1.736	1.491	1.216	1.1	0.907	0.832	0.713	0.568	0.379

Columns are FDC percentage points:										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Category Low Flow Assurance curves (mill. m^3)										
C Category (REC)										
Oct	1.385	0.71	0.307	0.195	0.117	0.067	0.038	0.021	0.012	0.007
Nov	2.403	1.337	0.392	0.248	0.203	0.122	0.113	0.113	0.106	0.049
Dec	2.898	1.513	0.838	0.423	0.319	0.108	0.107	0.106	0.099	0.045
Jan	2.26	1.044	0.472	0.373	0.224	0.132	0.093	0.093	0.086	0.044
Feb	2.348	1.400	0.498	0.242	0.172	0.091	0.090	0.090	0.084	0.042
Mar	3.038	2.369	1.658	1.048	0.471	0.275	0.199	0.153	0.127	0.114
Apr	2.690	1.431	0.698	0.422	0.285	0.165	0.117	0.117	0.100	0.067
May	2.420	0.982	0.431	0.255	0.235	0.120	0.118	0.117	0.108	0.074
Jun	1.519	0.848	0.460	0.377	0.223	0.113	0.113	0.112	0.103	0.071
Jul	1.486	0.872	0.415	0.366	0.235	0.126	0.117	0.115	0.108	0.074
Aug	1.469	0.862	0.371	0.346	0.23	0.139	0.118	0.118	0.111	0.079
Sep	1.413	0.757	0.343	0.34	0.227	0.133	0.112	0.111	0.105	0.058
Category Total Flow Assurance curves (mill. m^3)										
C Category (REC)										
Oct	1.385	0.71	0.307	0.195	0.117	0.067	0.038	0.021	0.012	0.007
Nov	2.403	1.337	0.392	0.248	0.203	0.122	0.113	0.113	0.106	0.049
Dec	4.819	2.767	1.786	1.276	1.161	0.897	0.737	0.473	0.106	0.045
Jan	4.154	2.28	1.407	1.214	1.054	0.909	0.714	0.455	0.093	0.044
Feb	6.777	4.289	2.683	2.208	2.113	1.908	1.543	0.936	0.1	0.042
Mar	12.62	8.619	6.386	5.301	4.67	4.205	3.341	1.983	0.161	0.114
Apr	6.54	3.942	2.597	2.131	1.973	1.745	1.38	0.852	0.114	0.067
May	2.42	0.982	0.431	0.255	0.235	0.12	0.118	0.117	0.108	0.074
Jun	1.519	0.848	0.46	0.377	0.223	0.113	0.113	0.112	0.103	0.071
Jul	1.486	0.872	0.415	0.366	0.235	0.126	0.117	0.115	0.108	0.074
Aug	1.469	0.862	0.371	0.346	0.23	0.139	0.118	0.118	0.111	0.079
Sep	1.413	0.757	0.343	0.34	0.227	0.133	0.112	0.111	0.105	0.058

ELECTRONIC APPENDICES

APPENDIX A: DATABASES

WARMS database for Q92
Aerial survey

APPENDIX B: RAINFALL DATA

Includes rain gauge records, validation plots of rain gauges and rainzones, rainfall zone grouping; catchment rainfall records

APPENDIX C: STREAMFLOW DATA

Observed flow records at Q9H002 and Q9H030
DWS assessment of flow gauges

APPENDIX D: WATER RESOURCES MODELS AND RELATED INFORMATION

WRSM setup for ‘Q92’
Calibration plots for Q9H002 and Q9H030 Flow Gauges
Naturalised incremental runoff for all sub-catchments
WRYM setup for ‘Q92r’

APPENDIX E: EWR REPORT: ECOCLASSIFICATION, EWR SCENARIO AND SCENARIO DETERMINATION OF THE KOONAP RIVER.

Feasibility Study for Foxwood Dam (WP10580)

Koonap River Ecoclassification, EWR Scenario and Scenario Determination

Final

water affairs
Department
Water Affairs
REPUBLIC OF SOUTH AFRICA

Department of Water Affairs and Forestry

KOONAP RIVER: ECOCLASSIFICATION, EWR SCENARIO AND SCENARIO DETERMINATION

OCTOBER 2013

PREPARED BY: Rivers for Africa
PO Box 1684
Derdepark
Pretoria
0035

REFERENCE

This report is to be referred in bibliographies as:

Department of Water Affairs, South Africa. 2013. Koonap River: EcoClassification and EWR Scenario Assessment Prepared by Rivers for Africa for ARUP.

AUTHORS

The information in this report was authored by the multi-disciplinary group of specialists involved. Contributions were provided as follows:

- Delana Louw: EWR coordinator, EcoClassification and EWR scenario process, application of the Index of Habitat Integrity
- Ms Anne Beater: Hydrology
- Dr Andrew Birkhead: EcoHydraulics
- Dr Anton Bok: Fish
- Greg Huggins: Ecological Goods and Services
- Prof Denis Hughes: EcoHydrology
- Shael Koekemoer: Diatoms
- Dr Pieter Kotze: Fish
- James Mackenzie: Riparian vegetation
- Mark Rountree: Fluvial geomorphology
- Dr Patsy Scherman: Water quality
- Dr Mandy Uys: Macro-invertebrates

ACKNOWLEDGEMENTS

Input provided by:
Sanet van Jaarsveld: DWA, Option Analysis

EXECUTIVE SUMMARY

BACKGROUND

The Koonap River Irrigation Board (KRIB) was formed in the 1960's for the purposes of promoting and managing irrigation development in the area. The most cost-effective scheme identified during studies to identify and optimise the irrigation development potential was a dam at the Foxwood site close to Adelaide. This dam will supply water to existing commercial irrigators, to smaller municipal lands on the outskirts of the town for food plots, as well as domestic water to the town. Water for Africa through ARUP has been appointed to undertake the determination of Ecological Water Requirements (EWR, or the Ecological Reserve) for the system under investigation, i.e. the Koonap River, following the 8-step methodology currently in place for Reserve determinations.

STUDY AREA

The study area comprises the Foxwood Dam site on the Koonap River, the selected conveyance routes between the dam site and the extended supply area as well as the proposed area to be developed for irrigation. In terms of the river Reserve study, the catchment is from Foxwood Dam to the Fish River confluence.

The locality of the EWR sites in the Koonap River within the Management Resource Units (MRUs) as identified during this study is provided below.

Locality and characteristics of EWR sites

EWR site	Latitude	Longitude	Level II EcoRegion	Geo-zone	Altitude (m)	MRU	Quat[1]	Gauge
KOON1	-32.76671	26.28989	18.02	Lower Foothills	538	MRU Koo A: Foxwood Dam site to the eNyara River.	Q92E	Q9H002
KOON 2	-32.94719	26.51870	18.02	Lower Foothills	340	MRU Koo B: Downstream of MRU 1 to the Great Fish confluence.	Q92G	None

1 Quaternary catchment

OBJECTIVES

The objectives of the study were to:

- Determine the EWR for different ecological states at each EWR site.
- Determine the Present Ecological State (PES) and describe alternative ecological states if relevant.
- Set the Ecological Water Requirement (EWR).
- Address scenarios in terms of the existing and new dams in the Koonap River.
- Determine the Ecological and Goods and Services consequences of the operational scenarios.

APPROACH

As indicated in the Terms of Reference, Ecological Water Requirements (EWRs) were determined applying the Intermediate Ecological Reserve Methodology (IERM) (DWAF, 1999). The methodology consisted of two different steps:

- EcoClassification: Process was followed according to the methods of Kleynhans and Louw (2007).; and

- EWR quantification of different ecological states: The Habitat Flow Stressor Response method (HFSR) (O'Keeffe *et al*., 2002; IWR S2S, 2004; Hughes and Louw, 2010), a modification of the Building Block Methodology (BBM; King and Louw, 1998) was used to determine the low (base) flow EWRs. The approach to set high flows is a combination of the Downstream Response to Imposed Flow Transformation (DRIFT; Brown and King, 2001) approach and the BBM (King and Louw, 1998).
- Consequences of operational scenarios on Goods and Services: A scenario-based approach was followed. Assessment of the impacts of the various scenarios on the ecological goods and services 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.
- Ecological consequences of operational scenarios: All information used during EcoClassification (Chapter 3 and 7) and the Ecological Water Requirement (EWR) scenario determination (Chapter 5 and 9) is used as baseline for this assessment. A table is provided which compares the impact of each scenario per site against the PES and REC. The resulting EC for each component is provided as well as the EcoStatus. The table is then summarised according to whether the scenarios meet the REC or not, and if not, to what degree.

The following coding is used throughout the document and an example is provided below.

✓ 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.
Dark Green with black ✓:	Meets the REC EcoStatus, but not all the components.
Purple with X:	The scenario results in an EC below the PES; but still above a D EC.
Red with X:	The results are below an E EC.

RESULTS

EcoClassification

The EcoClassification results are summarised below.

EcoClassification results summary

EWR KOON 1		
EIS: MODERATE Highest scoring metrics were intolerance of instream biota to no flow and physico-chemical changes, diversity of instream habitat types, unique riparian species and important riparian migration corridors. **PES: C** ▪ Deteriorated water quality (increased salinity and nutrients) due to WWTW and irrigation return flows. ▪ Flow alteration due to farm dams and irrigation leading to reduced baseflows. ▪ Clearing for agriculture, targeted removal of woody species and the presence of alien vegetation. **REC: C** EIS was MODERATE and the REC was therefore to maintain the PES.	**Driver Components**	**PES and REC**
	IHI HYDROLOGY	C
	WATER QUALITY	B/C
	GEOMORPHOLOGY	B
	Response Components	**PES and REC**
	FISH	C
	INVERTEBRATES	C
	INSTREAM	C
	RIPARIAN VEGETATION	C
	ECOSTATUS	C
	INSTREAM IHI	C
	RIPARIAN IHI	C
	EIS	MODERATE

EWR KOON 2		
EIS: MODERATE Highest scoring metrics were rare and endangered species (*Sandelia bainsii*) intolerance of instream biota to no flow and physico-chemical changes, diversity of instream habitat types, four unique riparian species and important riparian migration corridors. **PES: C** ▪ Reduced base flows and flow alteration due to abstractions and agricultural return flows. ▪ Reduced water quality due to agriculture. ▪ Migration barriers result in decrease species frequency of occurrence. ▪ Presence of alien vegetation and removal of indigenous species. **REC: C** EIS was MODERATE and the REC was therefore to maintain the PES.	**Driver Components**	**PES and REC**
	IHI HYDROLOGY	C
	WATER QUALITY	C
	GEOMORPHOLOGY	B
	Response Components	**PES and REC**
	FISH	C
	INVERTEBRATES	B/C
	INSTREAM	C
	RIPARIAN VEGETATION	C
	ECOSTATUS	C
	INSTREAM IHI	C
	RIPARIAN IHI	B/C
	EIS	MODERATE

There is low confidence in the biota information and EWR assessment. The low confidence can be addressed by improving the baseline through the implementation of an Ecological Water Resources Monitoring (EWRM) programme and should be initiated as soon as possible. An improvement in hydraulic confidence could be achieved by obtaining a calibration in the region of the recommended low flows (EWR KOON 1 and EWR KOON 2) and during a flood (EWR KOON 2).

EWR quantification

The final flow requirements are expressed as a percentage of the natural Mean Annual Runoff (MAR).

Summary of results as a percentage of the natural MAR

EWR site	PES	REC	NMAR (MCM)	PMAR (MCM)	Long term mean					
					Low flows (MCM)	Low flows (%NMAR)	High flows (MCM)	High flows (%NMAR)	Total flows (MCM)	TOTAL (%NMAR)
KOON 1	C	C	62.93	52.04	2.997	4.8	7.08	11.25	10.076	16
KOON 2	C	C	77.54	65.30	6.917	8.9	9.624	12.41	16.541	21.33

Ecological consequences of operational scenarios

A comparison of the ecological consequences of the scenarios at EWR KOON 1 and EWR KOON 2 are provided below.

Comparison of ecological consequences at EWR KOON 1 and EWR KOON 2

KOONAP RIVER				
EWR SITE	Sc 1	Sc 2	Sc 3	Sc 4
EWR 1	✓	✓	✓	✓
EWR 2	X	X	✓	✓

Poor **Good**

This analysis shows that none of the scenarios fully meet the ecological objectives at both sites. Scenario 3 and 4 maintain the REC at EWR 1 and EWR 2, although not for all components and has a higher risk of failure. Scenario 1 and 2 are not recommended as these scenarios result in an EC dropping below the PES at EWR KOON 2.

Optimised Scenario

Although Sc 4 does not meet the ecological objectives, it does represent the best of the four options. This scenario includes a desktop estimate of the low flow EWR. To determine an optimised scenario, Sc 4 should be used as the basis and must include the EWR (low flows) as determined during this task.

Consequences of operational scenarios on Goods and Services

Given the nature of ecological Goods and Services utilisation in the area under consideration, none of the scenarios have an impact with either a magnitude or significance that would be considered as a fatal flaw at either EWR KOON1 or EWR KOON 2. With regard to ranking scenarios at EWR KOON 1 the following applies:

- Although Sc 1 has positive impacts, it also has the most negative impacts and the nature of these impacts is such that this scenario cannot be considered as a viable option in future.

- Sc 2 and Sc 3 have very similar impacts and is marginally more preferable to Sc 1.
- Sc 4 is the most preferable and has more positive impacts than negative with an overall positive impact on ecological Goods and Services.

With regard to ranking scenarios at EWR KOON 2 the following applies:

- Although Sc 2 has positive impacts, it also has the most negative impacts and the nature of these impacts is such that this scenario cannot be considered as a viable option in future.
- Sc 1 is marginally better than Sc 2.
- Sc 3 is marginally more preferable to Sc 2 as it has a marginally positive impact on ecological Goods and Services.

Sc 4 is the most preferable and has more positive impacts than negative with an overall positive impact on ecological Goods and Services.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

AEC	Alternative Ecological Category
ASPT	Average Score Per Taxon
AVE	Average
BBM	Building Block Methodology
DRIFT	Downstream Response to Imposed Flow Transformation
DRM	Desktop Reserve Model
DWA	Department of Water Affairs
DWA: RQS	Department Water Affairs: Resource Quality Objectives
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirement
EWRM	Ecological Water Resources Monitoring
FHA	Flow Habitat Assessment
FRAI	Fish Response Assessment Index
FROC	Frequency of Occurrence
GAI	Geomorphological Driver Assessment Index
HFSR	Habitat Flow Stressor Response
IERM	Intermediate Ecological Reserve Methodology
IHI	Instream Habitat Integrity
Inverts	Macro-invertebrates
IWRM	Integrated Water Resources Monitoring
KRIB	Koonap River Irrigation Board
MAR	Mean Annual Runoff
MCM	Million Cubic Meters
MIRAI	Macro Invertebrate Response Assessment Index
MRU	Management Resource Units
PAI	Physico-chemical Driver Assessment Index
PD	Present Day
PES	Present Ecological State
POSA	Plants of South Africa
RDERM	Revised Desktop Ecological Reserve Model
REC	Recommended Ecological Category
SASS5	South African Scoring System version 5
SPATSIM	Spatial and Time Series Modelling
SPI	Specific Pollution Index
VEGRAI	Riparian Vegetation Response Assessment Index
WTW	Water Treatment Works
Fish Hydraulic biotopes:	
FD	Fast-Deep
FS	Fast-Shallow
FI	Fast Intermediate
FVS	Fast Very Shallow
Macro-invertebrate hydraulic biotopes:	
FCS	Fast over coarse substrate
VFCS	Very fast over coarse substrate habitat
MV	Marginal Vegetation

1 INTRODUCTION

1.1 BACKGROUND

The Koonap River Irrigation Board (KRIB) was formed in the 1960's for the purposes of promoting and managing irrigation development in the area. The most cost-effective scheme identified during studies to identify and optimise the irrigation development potential was a dam at the Foxwood site close to Adelaide. This dam will supply water to existing commercial irrigators, to smaller municipal lands on the outskirts of the town for food plots, as well as domestic water to the town.

The National Water Act (NWA, Act No. 36 of 1998, Section 3) requires that the Reserve be determined for rivers, i.e. the quantity, quality and reliability of water needed to sustain both human use and aquatic ecosystems, so as to meet the requirements for economic development without seriously impacting on the long-term integrity of ecosystems. Water for Africa through ARUP has been appointed to undertake the determination of Ecological Water Requirements (EWR, or the Ecological Reserve) for the system under investigation, i.e. the Koonap River, following the 8-step methodology currently in place for Reserve determinations.

1.2 STUDY AREA

The study area comprises the Foxwood Dam site on the Koonap River, the selected conveyance routes between the dam site and the extended supply area as well as the proposed area to be developed for irrigation. In terms of the river Reserve study, the catchment is from Foxwood Dam to the Fish River confluence.

The locality of the EWR sites in the Koonap River within the Management Resource Units (MRUs) (DWA, 2013a) as identified during this study is provided in Table 1.1 and in Figure 1.1. Photographs illustrating the site conditions are provided in Figure 1.2.

Table 1.1 Locality and characteristics of EWR sites

EWR site	Latitude	Longitude	Level II EcoRegion	Geo-zone	Altitude (m)	MRU	Quat[1]	Gauge
KOON1	-32.76671	26.28989	18.02	Lower Foothills	538	MRU Koo A: Foxwood Dam site to the eNyara River.	Q92E	Q9H002
KOON 2	-32.94719	26.51870	18.02	Lower Foothills	340	MRU Koo B: Downstream of MRU 1 to the Great Fish confluence.	Q92G	None

1 Quaternary catchment

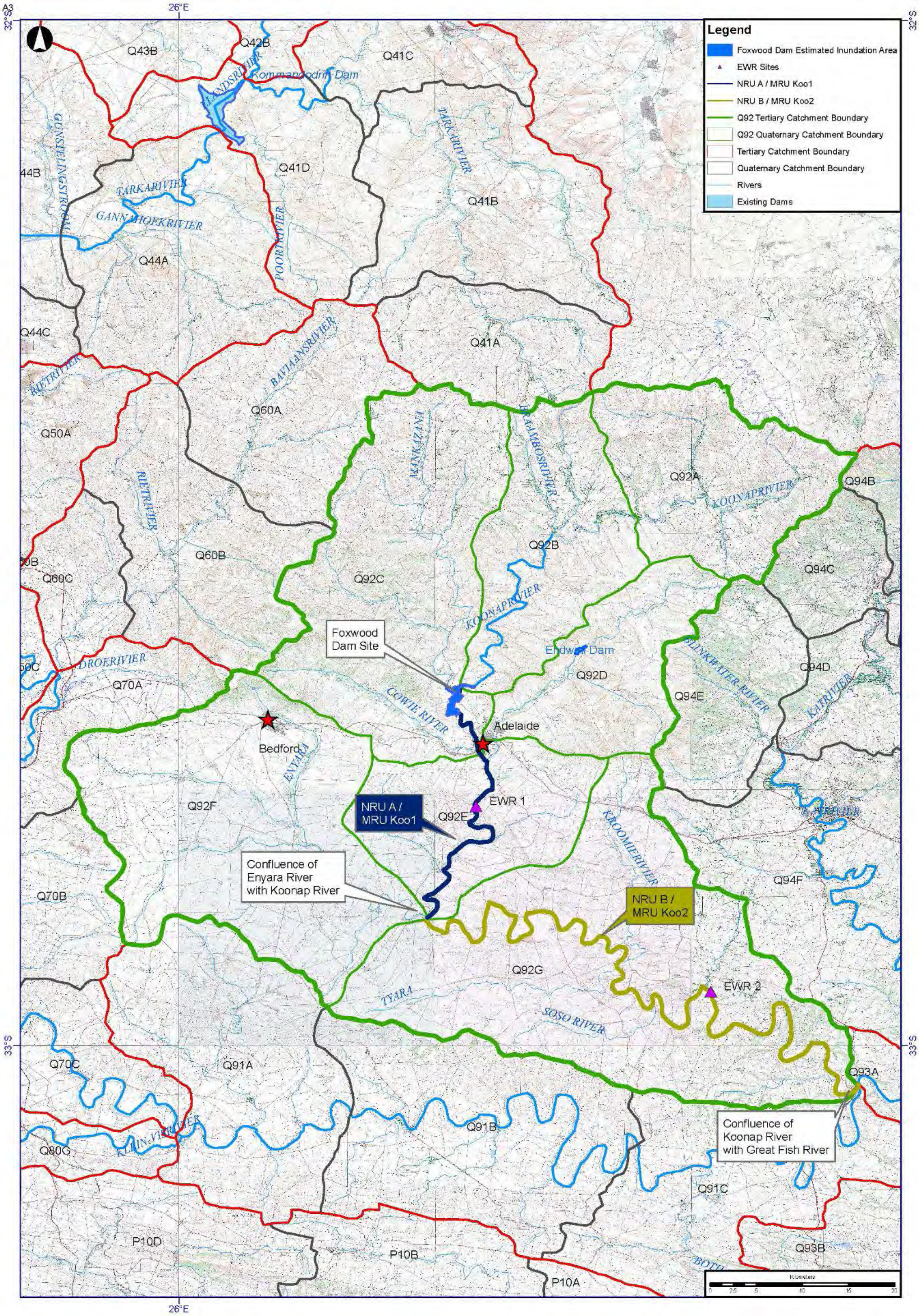


Figure 1.1 Study area indicating EWR sites

EWR 1: Downstream

EWR 2: Downstream

Figure 1.2 EWR KOON 1 and EWR KOON 2

1.3 OBJECTIVES OF THE RESERVE TASK

The objectives of the study were to:

- Determine the EWR for different ecological states at each EWR site.
- Determine the Present Ecological State (PES) and describe alternative ecological states if relevant.
- Set the Ecological Water Requirement (EWR).
- Address scenarios in terms of the existing and new dams in the Koonap River.
- Determine the Ecological and Goods and Services consequences of the operational scenarios.

1.4 DATA AND INFORMATION AVAILABILITY

Information collated during physical surveys was used to provide the results in this report. The data and information availability is summarised in Table 1.2.

Table 1.2 Data and information availability for each EWR site

Data and Information Availability
Hydrology ▪ Two reliable gauges were in close proximity to the EWR site 1. ▪ Q9H002 had a 79 year flow record while Q9H030 had a 30 year flow record. ▪ Both gauges measured low flows and zero flows accurately. Confidence: 4
Physico-chemical variables ▪ A good water quality data record was available from Q9H002Q01 for the assessment of the present state. Confidence: 3.5
Geomorphology ▪ Historical aerial photographs for the study reach were available from 1938 to 1985 and satellite imagery for 2008, 2009 and 2011.

Data and Information Availability
▪ One site visit was undertaken in July 2013 to assess in-channel and bank condition of the study site. ▪ Some published studies on sediment yields from nearby catchments were also reviewed to assess potential changes in sediment delivery to the EWR site. Confidence: 3
Index of Habitat Integrity (IHI) ▪ Ground-based observations. ▪ Local knowledge. ▪ Hydrological assessments. ▪ Water quality assessments. ▪ Land cover assessments. ▪ Google Earth (reasonable resolution). The confidence in the data was high due to the detailed ground-based observations and the quality of Google Earth imagery available for large sections of the study area. Confidence: 3.5
Riparian vegetation ▪ Data collected during site visit (17 September 2012). ▪ Historical anecdotal information on the vegetation of the area from 1790 to 1822 (Skead, 2009). ▪ Vegetation Biomes, Bioregions and Vegetation Types (Mucina & Rutherford, 2006). ▪ SANBI distribution data of plant species (SANBI POSA, 2009). ▪ Google Earth © satellite imagery (27 March 2011). Confidence: 4
Fish ▪ Single site visit (July 2013). ▪ Limited historic data for river system, none for specific sub-quaternary reach. ▪ 2013 desktop Present Ecological Status, Ecological Importance and Ecological Sensitivity (DWA, 2013b). ▪ Atlas of Southern African Freshwater fishes (Scott *et al*., 2006). ▪ Reference Fish Frequency of Occurrence (FROC) Report (Kleynhans *et al.,* 2007). Confidence: 2
Macro-invertebrates ▪ There were no known macro-invertebrate data available for this quaternary (Q92E-07784). One sampling trip was conducted for this study in July 2013 (at a flow of 0.2 m^3/s), during which macro-invertebrates were collected using the SASS5 method. ▪ 2013 desktop Present Ecological Status, Ecological Importance and Ecological Sensitivity (DWA, 2013b) Confidence: 2.5
Diatoms ▪ One sample collected from stone substrate at EWR site. Good data was available on species present although no previous diatom data was available for the EWR site. Confidence 2.5

1.5 OPERATIONAL SCENARIOS

The operational scenarios were determined during a meeting held 26 July 2013 and the river scenarios are outlined below. All Foxwood Dam yields were modelled based on 95% assurance (1:20). A summary of the operational scenarios used in the river assessment are provided in Table 1.3.

Scenario 1 (Sc 1):

- 1 Mean Annual Runoff (MAR) dam.
- Adelaide domestic abstraction modelled at correct location upstream of Foxwood.
- Only existing registered irrigation modeled.
- No EWR allowance.

Scenario 2 (Sc 2):

- 1 MAR dam.

- Adelaide domestic abstraction modelled at correct location upstream of Foxwood.
- Maximum potential irrigation assumed and modelled (200 ha municipal irrigation and assumed all excess yield used in commercial irrigation at locations determined by scaling up existing registered users and any guidance following meetings with farmers regarding preferred locations for irrigation development).
- No EWR allowance.

Scenario 3 (Sc 3):

- 0.5 MAR dam.
- Adelaide domestic abstraction modelled at correct location upstream of Foxwood.
- Maximum potential irrigation assumed and modelled (200 ha municipal irrigation and assumed all excess yield used in commercial irrigation at locations determined by scaling up existing registered users and any guidance following meetings with farmers regarding preferred locations for irrigation development).
- No EWR allowance.

Scenario 4 (Sc 4):

- 1 MAR dam.
- Adelaide domestic abstraction modelled at correct location upstream of Foxwood.
- Realistic potential irrigation assumed and modelled (200ha municipal irrigation and assumed probable commercial irrigation development following meetings with farmers regarding preferred locations for irrigation development).
- Desktop EWR (low flows only).

Table 1.3 Summary of Operational Scenarios

Scenario	Dam size	Adelaide domestic abstraction	Irrigation	EWR
Scenario 1	1 MAR	Yes, current location Upstream of Foxwood Dam	Existing	No
Scenario 2	1 MAR		Max potential	No
Scenario 3	0.5 MAR		Max potential	No
Scenario 4	1 MAR		Realistic potential	Desktop low flow EWR

1.6 OUTLINE OF REPORT

The report consists of:

Chapter 1: Introduction
This chapter provides an overview of the study area, objectives of the study and data availability.

Chapter 2: Approaches and Methods
This chapter outlines the methods followed during the Ecological Reserve process. Summarised methods are provided for the EcoClassification and EWR scenario determination and determination of the ecological and Goods and Services consequences of operational scenarios.

Chapter 3 and 7: EcoClassification
The EcoClassification results are provided for each EWR site.

Chapter 4-5 and 8-9: Determination of stress indices and EWR scenarios

The stress indices for all physical and biological components at each EWR site are provided. These chapters provide results of different EWR scenarios with respect to low and high flows for the respective EWR sites. Aspects covered in these chapters are component and integrated/stress curves, generating stress requirements, determining high flows and final results.

Chapter 6 and 10: Ecological Consequences
The results of the Ecological Consequences of the Operational Scenarios are provided for EWR 1 and EWR 2.

Chapter 11: Consequences of Operational Scenarios on Goods and Services
The results are provided and discussed for EWR 1 and EWR 2.

Chapter 12: Conclusions and Recommendations
The EcoClassification and EWR scenario results are summarised and recommendations are made and summary of the Ecological Consequences are summarised and integrated providing overall consequences. Recommendations are also provided.

Chapter 13: References

Chapter 14: Appendix A: Hydraulics

Chapter 15: Appendix B: Diatoms

Chapter 16: Appendix C: RDERM – Revised Desktop Model Outputs

2 APPROACH

As indicated in the Terms of Reference, Ecological Water Requirements (EWRs) were determined applying the Intermediate Ecological Reserve Methodology (IERM) (DWAF, 1999). The methodology consisted of two different steps:

- EcoClassification; and
- EWR quantification of different ecological states.

A follow-on step was the evaluation of operational scenarios to determine the changes in ecological state.

These steps are discussed in the following sections.

2.1 ECOCLASSIFICATION

The EcoClassification process was followed according to the methods of Kleynhans and Louw (2007). Information provided in the following sections is a summary of the EcoClassification approach. For more detailed information on the approach and suite of EcoStatus methods and models, refer to:

- Physico-chemical Driver Assessment Index (PAI): Kleynhans *et al*. (2005).
- Geomorphological Driver Assessment Index (GAI): Rountree and du Preez (in prep).
- Fish Response Assessment Index (FRAI): Kleynhans (2007).
- Macroinvertebrate Response Assessment Index (MIRAI): Thirion (2007).
- Riparian Vegetation Response Assessment Index (VEGRAI): Kleynhans *et al*. (2007a).
- Index of Habitat Integrity (IHI): Kleynhans *et al*. (2009).

EcoClassification refers to the determination and categorisation of the Present Ecological State (PES) (health or integrity) of various biophysical attributes of rivers compared to the natural (or close to natural) reference condition. The purpose of EcoClassification is to gain insight into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. This provides the information needed to derive desirable and attainable future ecological objectives for the river. The EcoClassification process also supports a scenario-based approach where a range of ecological endpoints has to be considered.

The state of the river is expressed in terms of biophysical components:

- Drivers (physico-chemical, geomorphology, hydrology), which provide a particular habitat template; and
- Biological responses (fish, riparian vegetation and macro-invertebrates).

Different processes are followed to assign a category (A→F; A = Natural, and F = critically modified) to each component. Ecological evaluation in terms of expected reference conditions, followed by integration of these components, represents the Ecological Status or EcoStatus of a river. The EcoStatus can therefore be defined as the totality of the features and characteristics of the river and its riparian areas that bear upon its ability to support an appropriate natural flora and fauna (modified from: Iversen *et al*., 2000). This ability relates directly to the capacity of the system to provide a variety of goods and services.

2.1.1 Present Ecological State

The steps followed in the EcoClassification process are as follows:

- Determine reference conditions for each component.
- Determine the Present Ecological State (PES) for each component, as well as for the EcoStatus which represents an integrated PES for all components.
- Determine the trend for each component, as well as for the EcoStatus.
- Determine the reasons for the PES and whether these are flow or non-flow related.
- Determine the Ecological Importance and Sensitivity (EIS) for the biota and habitat.
- Considering the PES and the EIS, suggest a realistic Recommended Ecological Category (REC) for each component, as well as for the EcoStatus.
- Determine alternative Ecological Categories (ECs) for each component, as well as for the EcoStatus.

Note: The Alternative Ecological Categories (AECs) are designed by using a combination of the most likely impacts or changes that could result in a decrease or improvement of the present state. This could include both flow and non-flow related changes depending on the issues governing conditions at the site.

The Level 4 EcoStatus assessment was applied according to standard methods. The minimum tools required for this assessment are shown in Figure 2.1 (from Kleynhans and Louw, 2007).

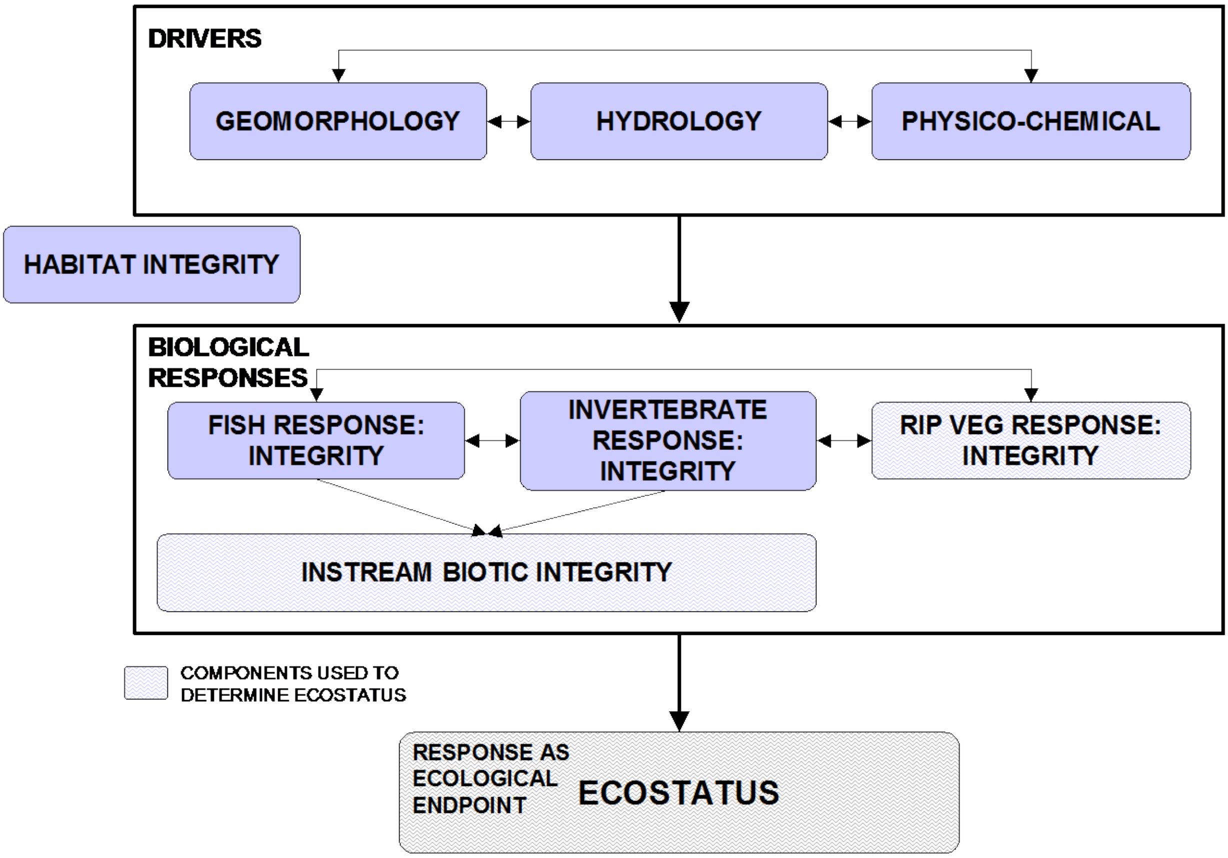


Figure 2.1 EcoStatus Level 4 determination

The role of the EcoClassification process is, amongst others, to define the various ECs for which Ecological Flow Requirements (EWRs) will be set. It is therefore an essential step in the EWR process. The EWR process is essentially a scenario-based approach and the EWRs determined for a range of ECs are referred to as EWR scenarios. The range of ECs would include the PES, REC (if different from the PES) and the AECs. When designing a scenario that could decrease the PES, flow changes are first to be evaluated. If this, and the response of other drivers, are deemed to be insufficient on its own to change the category, then the current non-flow related impacts are 'increased', or new non-flow related impacts are included. It is attempted to create a realistic scenario, however, it must be acknowledged that there are many scenarios that could result in a changed EC.

2.1.2 Ecological Importance and Sensitivity (EIS)

The EIS was calculated using a refined (from Kleynhans and Louw, 2007) EIS model which was developed during 2010 by Dr Kleynhans. This approach estimates and classifies the EIS of the streams in a catchment by considering a number of components surmised to be indicative of these characteristics.

The following ecological aspects are considered as the basis for the estimation of EIS:

- The presence of rare and endangered species, unique species (i.e., endemic or isolated populations) and communities, intolerant species and species diversity were taken into account for both the instream and riparian components of the river.
- Habitat diversity was also considered. This included specific habitat types such as reaches with a high diversity of habitat types, i.e., pools, riffles, runs, rapids, waterfalls, riparian forests, etc.

With reference to the bullets above, biodiversity in its general form (i.e. Noss, 1990) is taken into account as far as the available information allowed:

- The importance of a particular river or stretch of river in providing connectivity between different sections of the river, i.e., whether it provided a migration route or corridor for species, was considered.
- The presence of conservation or relatively natural areas along the river section also served as an indication of ecological importance and sensitivity.
- The sensitivity (or fragility) of the system and its resilience (i.e., the ability to recover following disturbance) of the system to environmental changes was also considered. Consideration of both the biotic and abiotic components was included here.

The EIS results of the study are summarised in this report and the models are provided electronically. EIS categories are summarised in Table 2.1.

Table 2.1 EIS categories (Modified from DWAF, 1999)

EIS Categories	General Description
Very high	Quaternaries/delineations that are considered to be unique on a national or even international level based on unique biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) are usually very sensitive to flow modifications and have no or only a small capacity for use.
High	Quaternaries/delineations that are considered to be unique on a national scale due to biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) may be sensitive to flow modifications but in some cases, may have a substantial capacity for use.
Moderate	Quaternaries/delineations that are considered to be unique on a provincial or local scale due to biodiversity (habitat diversity, species diversity, unique species, rare and endangered species). These rivers (in terms of biota and habitat) are usually not very sensitive to flow

EIS Categories	General Description
	modifications and often have a substantial capacity for use.
Low/Marginal	Quaternaries/delineations that are not unique at any scale. These rivers (in terms of biota and habitat) are generally not very sensitive to flow modifications and usually have a substantial capacity for use.

2.2 EWR DETERMINATION

The Habitat Flow Stressor Response method (HFSR) (O'Keeffe *et al*., 2002; IWR S2S, 2004; Hughes and Louw, 2010), a modification of the Building Block Methodology (BBM; King and Louw, 1998) was used to determine the low (base) flow EWRs. This method is one of the methods used to determine EWRs at the intermediate level.

The basic approach is to compile stress indices for fish and macro-invertebrates. The stress index describes the consequences of flow reduction on flow dependent biota (or guilds) and is determined by assessing the response of critical habitat, and hence the indicator guild, to a flow reduction. The stress index therefore describes the habitat conditions and biota response for fish and macro-invertebrates at a range of low flows. The fish and macro-invertebrate stress-flow relationship may not be the same as the responses to the same flow will/can result in different stress for fish and macro-invertebrates, as well as for different seasons (wet and dry).

A stress flow index is generated for every component (fish and macro-invertebrates) and season (wet and dry), and describes the progressive response of flow dependent biota to flow reduction. The stress flow index is generated in terms of habitat and hence biotic response.

The stress index is described as an instantaneous response of habitat to flow in terms of a 0 to 10 index relevant for the specific site where:

- 0 - Optimum habitat with least amount of stress possible for the indicator groups (fixed at the natural maximum base flow which was based on the 20% annual value using separated natural baseflows).
- 10 - Zero discharge (Note: Surface water may still be present). Maximum stress on indicator group.
- 2 to 9: Gradual decrease in habitat suitability and increase in stress as a result of decreased discharge.

The ecohydraulics for the site are mainly used to evaluate the range of flows (from zero flow to maximum baseflow separated flow). This process is done through the use of the MS Excel based Fish Flow Habitat Assessment (FFHA) (developed by Dr. N. Kleynhans, DWA: RQS) as well as using a modified but similar approach built into the Revised Desktop Ecological Reserve Model (RDERM) (Hughes *et al*., 2011). The optimal critical habitats for each indicator species/taxon or guild are identified by the relevant specialist. An automated habitat suitability and stress value is then calculated for each flow (discharge) evaluated, based on the extent of change of these critical habitats from the natural flow.

The integrated stress curve represents the highest stress for either fish or macro-invertebrates at a specific flow for the wet and dry season.

The stress index is then used to convert separate natural and present day flow time series to a stress time series. The stress time series is converted to a stress duration graph for the highest and lowest flow months. This then provides the specialist with the information of how much the stress has changed from natural under present conditions due to changes in flow. It would follow that if flow has decreased from natural, stress would increase and vice versa. If specialists do not agree with the levels of stress under natural conditions based on their knowledge of the species, the stress indices are refined.

Tools used to determine the stress indices are specialist knowledge and information about the indicator species habitat requirements, the hydraulics in the specific format required, and the natural hydrology.

At this stage only the instantaneous response of habitat and biota to flow reduction has been assessed. This means that the actual stress requirements AT SPECIFIC DURATIONS AND DURING SPECIFIC SEASONS to maintain the biota in a certain ecological state has not yet been assessed. The information used to determine the Ecological Category for the instream biota is considered when determining the stress required to maintain or achieve this ecological state. The stress requirement is set at various percentiles to shape the EWR stress duration curve in relation to the present day and the natural stress conditions. Drought stress is set at 0 - 20% exceedance.

Specialists determine the allowable stress (based on the habitat and biota response) for different durations and for different ecological categories. The complexity here, as with all flow requirement methods, is to interpret an instantaneous response in terms of duration and seasonal requirements. The required stress is plotted on a graph which also shows the natural and present day flow converted to integrated stress. This therefore supplies the ‘hydrological check’ to ensure that the requirements are realistic in terms of the natural hydrology and present day hydrology. The low flow stress requirement for an EC consists of the component requirement with the lowest stress requirement (highest flow requirements).

2.2.1 High flows

The approach to set high flows is a combination of the Downstream Response to Imposed Flow Transformation (DRIFT; Brown and King, 2001) approach and the BBM (King and Louw, 1998). The high flows are determined as follows:

- Flood ranges for each flood class and the geomorphology and riparian vegetation functions are identified and tabled by the relevant specialists.
- These are provided to the instream specialists who indicate:
  - which instream function these floods cater for;
  - whether additional instream functions apart are required; and
  - whether they require any additional flood classes to the ones identified.
- The number of floods for each flood class is identified as well as where (early, mid, late) in the season they should occur.
- These numbers of floods are then adjusted for the different Ecological Categories.
- The floods are evaluated by the hydrologist to determine whether they are realistic. A nearby gauge with daily data is used for this assessment. Without this information it is difficult to judge whether floods are realistic.
- The hydrologist then determines the daily average and documents the months in which the floods are spaced.
- The floods are then entered into the DRM to provide the final .rul and .tab files.

2.2.2 Final flow requirements

The low and high flows are combined to produce the final flow requirements for each EC as:

- An EWR table, which shows the results of high flows and low flows for each month separately. Floods with a frequency higher than 1:1 are often not included as they cannot be managed.
- An EWR rule table which provides the recommended EWR flows as a duration table, showing flows which should be provided when linked to a natural trigger (natural modelled hydrology in this case). EWR rules are supplied for total flows as well as for low flows only.

The low flow EWR rule table is useful for operating the system, whereas the EWR table must be used for operation of high flows.

2.3 ECOLOGICAL CONSEQUENCES OF OPERATIONAL SCENARIOS

2.3.1 Process

When determining the ecological consequences of operational scenarios, the objective is 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.

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 (EC) which will be signed off as the Ecological Reserve.

Operational scenarios are any flow scenario other than the present which could be implemented in future and the purpose of this task is to predict the driver and biota responses to each operational scenario and derive the EC for the EWR site and Management Resource Unit (MRU).

All information used during EcoClassification (Chapter 3 and 7) and the Ecological Water Requirement (EWR) scenario determination (Chapter 5 and 9) is used as baseline for this assessment.

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

- The operational scenarios 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 physic-chemical and geomorphology specialist.
- These specialists had to provide a conclusion and resulting EC of the operational scenario assessed at the EWR sites to the biological responses team.

Note: As only monthly modelling was available, the assessment of floods will always be of low confidence

- These specialists completed the PAI and 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 VEGRAI model to predict the EC for the operational scenario.

The following was then undertaken for the instream biota assessment:

- Each time series was converted into a stress duration table and provided on a graph for two months (the same months evaluated during the EWR scenario determination) that included the EWR scenarios, natural, and present day hydrology.
- The operational scenarios were then compared to the EWRs set for various ECs. For example, if the operational scenario lays between the B EC and C EC for fish for a flow in the dry season, the operational scenario could either be a B, a B/C or a C.
- The information on the driver responses were also used to interpret the response to the operational scenarios.
- If it was not obvious what the resulting EC was, the stress and habitat implications for the operational scenario were investigated and the responses modelled in the FRAI and MIRAI to determine the EC.
- The VEGRAI, MIRAI and FRAI results (EC percentages and confidence evaluation) was used to determine the EcoStatus.

2.3.2 Comparisons of the impact of the different Scenarios

A table is provided which compares the impact of each scenario per site against the PES and REC. The resulting EC for each component is provided as well as the EcoStatus. The table is then summarised according to whether the scenarios meet the REC or not, and if not, to what degree.

The following coding is used throughout the document and an example is provided in Table 2.2.

✓ REC EcoStatus or REC instream IS met.

X REC EcoStatus or REC instream is NOT met.

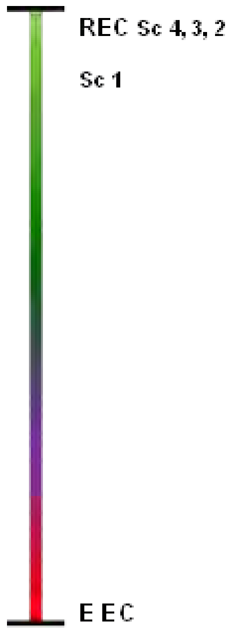
Light green with black ✓:	Meets REC EcoStatus including all components.
Dark Green with black ✓:	Meets the REC EcoStatus, but not all the components.
Purple with X:	The scenario results in an EC below the PES; but still above a D EC.
Red with X:	The results are below an E EC.

Table 2.2 An example of the operational scenario consequences summary for EWR KOON 1

EWR KOON 1				
Scenario	Sc 1	Sc 2	Sc 3	Sc 4
EWR 1	✓	✓	✓	✓

The above example illustrates that Sc 2 - 4 meets the REC requirement for all components and Sc 1 meets the REC but not all the components. In this case there was a deterioration in the instream components.

The results of Table 2.2 are then illustrated on a scale from good (REC) to 'bad' (an E EC). In this case the REC is an improvement of the PES and the PES is therefore placed in the middle of the scale (Figure 2.2). The scale indicates the degree of improvement the scenarios are from the PES. This is for illustration purposes and comparing all the scenarios at each site in a system context. As the scale can be subjective, a typical explanation as provided below should accompany the figure.



Scenario 2 - 4 meets the REC while Scenario 1 does not meet the REC requirement.

Figure 2.2 Illustration of the degree to which a REC is met

2.4 CONSEQUENCES OF OPERATIONAL SCENARIOS ON GOODS AND SERVICES

The method that was employed is essentially scenario based. Assessment of the impacts of the various scenarios on the ecological goods and services 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 undertaken in steps.

Firstly, the analysis of potential economic changes was initially based on a valuation of the status quo, that is, the value of the Goods and Services currently provided by the water in the Koonap River. A list of the relevant ecological Goods and Services that were found in the various reaches examined, and deemed to be significant, were generated by secondary research. These were cross checked with the biophysical experts that formed part of the project team at a specialist workshop held in September 2013.

The biophysical specialists then identified the potential change that each of the key Goods and Services may undergo in the each of the scenario clusters. The potential change will be noted as a factor and used in later calculations. For example, no change = 1, a 50% increase = 1.5, and a 20% decrease = 0.8.

The categories of ecological goods and services that were deemed to be important in at least parts of the catchment are as follows:

- Fishing – subsistence and recreational.
- Floral species associated with riparian zones.
- Geomorphological services.
- Water quality services.
- Ritual and cultural services.
- Recreational Services and associated aesthetic value.

Categories of goods and services were further analysed and assessed by species or subset of service where relevant.

Dis-services including pathogens and pets were looked at but deemed not to be significant.

3 ECOCLASSIFICATION: EWR KOON 1 (KOONAP RIVER)

3.1 EIS RESULTS

The EIS evaluation resulted in a **MODERATE** importance. The highest scoring metrics were:

- Intolerant to no flow and physico-chemical changes (instream biota): Intolerant macro-invertebrate taxa were present.
- Diversity of habitat types and features (instream habitat): Rapids, riffles, pool, and overhanging vegetation.
- Unique species (riparian): *Combretum caffrum, Acacia karoo* and *Cyperus textilis*.
- Migration corridor (riparian): Distinct vegetation structure exists from the upland area. Riparian woody banks are thick with distinct species and longitudinal continuity is good which is important for birds, and other riparian fauna.

3.2 REFERENCE CONDITIONS

The reference conditions at EWR 1 are summarised below in Table 3.1.

Table 3.1 EWR KOON 1: Reference conditions

Hydrology (Confidence: 4)
The natural Mean Annual Runoff (MAR) is 62.9 million cubic meters (MCM).
Physico-chemical variables (Confidence: 2.5)
Refer to Table 3.3.
Geomorphology (Confidence: 3)
The river was predominantly a single channel, with seasonal and flood (secondary) channels in places. The macro-channel floor would have been well-wooded (as indicated from historical accounts of the region), with the main and secondary channels probably dominated by cobbles.
Riparian vegetation (Confidence 4)
EWR 1 occurs in Bedford Dry Grassland (Mucina & Rutherford, 2006). This vegetation unit was characterised by gently undulating plains of open grassland interspersed with *Acacia karoo* woodland, especially along drainage channels. In 1790 J. van Reenen (in Skead, 2009) described the Caapna (Koonap River - which means “fine fields”) in the vicinity of Adelaide as a beautiful countryside interspersed with perennial streams and broken grassland which supported a “great deal” of game, including buffalo. In 1797 J. Barrow described the Caapna as [meandering] level plains where the Ghonaqua tended their flocks and herds. Such level plains implied extensive grassland in keeping with the Bedford Dry Grassland vegetation type surrounding EWR 1. In 1809, R. Collins (in Skead, 2009) described the area between the Koonap and Great Fish Rivers (from Adelaide to Fort Beaufort) as “extensive plains rich in pasture [grassland], but unadorned by arboreus plants”. It was also noted that some of the river banks supported groves of yellowwood trees. In 1821, T. Pringle described the Koonap Valley (near Adelaide) as “open upland pastures and fertile meadows sprinkled with willows and acacias, and occasionally with groves of stately yellowwood. Wild animals such as elephant, buffalo and rhino abounded. In 1822, T. Pringle described the Koonap Valley at Adelaide as green sloping hills full of wild animals and the prevalence of jungle in ravines. He noted dense thorny forests (*Acacia karoo*) that were impenetrable had it not been for paths created by elephants. Marginal Zone: A mix of woody overhanging vegetation (especially *Salix mucronata* and *A. karoo*) was expected in pool areas where the marginal zone was all but absent and non-woody sedges in non-pool areas such as riffles, braided or anastomosing sections or unconsolidated alluvia. The rheophyte, *Gomphostigma virgatum* was expected in cobble and riffle habitats permanently (or near so) inundated by fast flowing water. Lower Zone: Similar to the marginal zone, but with a greater *S. mucronata* component, especially where alluvium was deposited. Upper Zone: It was expected that this zone was dominated by medium to tall woody vegetation, dense in cover and density with some open areas and paths maintained by megaherbivores. *A. karoo* and

Combretum caffrum would dominate but pockets of yellowwoods would frequently occur. Macro Channel Bank (MCB): As with the upper zone, but with higher woody cover and density, more terrestrial woody species and less *C. caffrum*. Floodplain/s: Where these occurred, they would predominantly represent Bedford Dry Grassland, with scattered acacias and the addition of hydrophilic grasses.
Fish (Confidence: 2)
Based on the available fish distribution data and expected habitat composition, five indigenous fish species had a high to definite probability of occurrence under reference conditions. These included three freshwater eel species (*Anguilla bicolor bicolor, A. marmorata* and *A. mossambica*) and two cyprinids (*Barbus anoplus* and *Labeo umbratus*). According to the DWA (2013a) results, *Glossogobius callidus* also occurs in this SQ reach under present conditions. There is however no previous known records of this species occurring so far inland in this system, and it was excluded from the expected fish species list. The instream habitat composition under reference conditions was estimated to be very similar to those available under present conditions and the habitats available at the EWR site met the requirements of all expected fish species. Since no information for the Koonap River was provided in Kleynhans *et al.* (2007), the estimated Fish Frequency of Occurrence (FROC) under reference conditions was based on available knowledge of general occurrence patterns of these species.
Macro-invertebrates (Confidence: 1)
There were no available data for this quaternary (Q92E-07784). Reference conditions were based on the actual sample and on the macro-invertebrate data set derived for the sub-quaternary reach during the DWA (2013a) project. SASS5 Score: 162 Number of Taxa: 29 Average Score Per Taxon (ASPT): 5.6

3.3 PRESENT ECOLOGICAL STATE

The Present Ecological State (PES) reflects the changes in terms of the ecological category (EC) from reference conditions. The summarised PES information is provided in Table 3.2 and Table 3.3 provides summarised water quality data.

Table 3.2 EWR KOON 1: Present Ecological State

Hydrology: PES: C, Confidence: 3
PMAR: 52.04 MCM (82.7% of the MAR). Present day flows are impacted by run-of-river abstractions and diversions for domestic and irrigation requirements as well as streamflow reduction caused by infestation of alien invasive plants in the upper Koonap catchments. The observed flows are reasonably consistent with present day flows. There has been a decrease in base flow volumes from natural especially during Oct, Jan, Feb and Sep, although the seasonal distribution has remained the same. There has been no change in flood frequency and seasonality.
Physico-chemical variables: PES: B/C, Confidence 3.5
Data for the PES assessment was of moderate confidence as no DO, temp., turbidity or metals data were available. This site is directly downstream of Adelaide town in the Amathole District Municipality, with the proposed Foxwood Dam site located upstream of Adelaide. The water quality state is represented by gauging weir Q9H002Q01 (2007-2013), which is upstream of Adelaide and the Waste Water Treatment Works (WWTW). Note that the Adelaide WWTW is in a High Risk category with low effluent compliance (DWA, 2012), which impacts on the quality at the site in terms of increased nutrients levels and salts. The EWR site is found in sub-quaternary reach Q92E-7784. The PES/EI/ES project for WMA 15 (Scherman Colloty & Associates, 2013) estimated the water quality impact rating to be a 2, i.e. a moderate impact rating due to extensive irrigation, numerous crossings and the impact of Adelaide upstream. Flows at the site are lower than the natural state. Although this is an arid system, flows have been further reduced due to abstraction for irrigation activities and the river stops flowing at times. The geology is assumed to be similar to the rest of the catchment, i.e. marine shales, so some elevation in salinities is assumed under the natural state. The river is shaded at EWR KOON 1 so temperature increases are not expected.
Geomorphology: PES B, Confidence: 3.5
The river remains predominantly in a single channel planform. There has been some encroachment of woody vegetation alongside and into the secondary seasonal/ flood channels, so the macro-channel floor is

slightly denser with regard to woody vegetation than may have been encountered under reference conditions, with some encroachment into the secondary flood channels. Many of the floodplain pockets/terraces have been cleared for agriculture, but these represent a small proportion of the riparian area. Instream conditions are regarded as largely natural despite a probable small increase in fines.
IHI Instream: PES: C, Confidence 2.5 **IHI Riparian: PES: C, Confidence 4.2**
Instream habitat was mostly affected by reduced baseflows due to abstraction for domestic use and agriculture. Riparian habitat was impacted by degraded bank structure due to alien invasive species as well as reduced substrate quality due to increased nutrients within the system.
Riparian vegetation: PES: C, Confidence: 3.4
Marginal and Lower zone: Dominated by sedges (see species lists in the VEGRAI spreadsheets) and the woody rheophyte *G. virgatum*. Sedges have likely increased in density due to reduced base flows. Upper zone: Dominated by woody species, mainly *C. caffrum.* This zone had a higher woody density and cover than under reference due to the absence of megaherbivores. MCB: Dense woody thicket with riparian and terrestrial species. *A. karoo* was dominant, while yellowwoods were absent. Floodplain: Largely cleared for agricultural purposes.
Fish: PES: C, Confidence: 3
It was estimated that all the expected fish species were still present in this river reach albeit in a moderately reduced FROC. The FROC of the eels species were estimated to be reduced due to the presence of downstream migration barriers (dams) that did not prevent migration but reduced the success rate of migration. Reduced abundance of food sources (especially macro-invertebrates) was also thought to be responsible for decreased FROC of the eel species as well as *Barbus anoplus*. The decrease in flow, resulting in loss of habitat abundance and availability was thought to be the primary contributor for decreased FROC of *L. umbratus*.
Macro-invertebrates: PES: C, Confidence: 3
The largest change in the macro-invertebrate community relative to natural appeared to be in the abundances of taxa, which in general were lower than expected. While some sensitive flow-dependent taxa were collected in low numbers (e.g. Heptageniidae, scoring 13), the majority of the community comprised more resilient taxa (scoring <10), with many opportunists, all with a range of tolerances for different flow types, water quality and habitat conditions. These taxa also occurred at lower abundances than expected. The major changes in conditions for macro-invertebrates at the site were: ▪ The water quality, which was more nutrient-rich than it would be under natural conditions as a result of return flows from agriculture and non-compliant treated wastewater effluent. ▪ The increased habitat surface offered by reeds such as *Cyperus textilis* and *C. sexangularis*, which were denser than would be expected under natural conditions; and ▪ the 'packing' of cobbles as a result of slightly increased siltation, which resulted in a reduction in the availability of important underside surfaces for taxa including the more sensitive mayflies (e.g. Heptageniidae, Tricorythidae) and certain caddisfly taxa. SASS5 Score: 120 Number of Taxa: 21 Average Score Per Taxon (ASPT): 5.7

Table 3.3 shows the physico-chemical reference conditions and present state assessment for EWR KOON 1. Note that two approaches to selecting reference condition (RC) data were assessed. The first was to use early data from the Q9H002Q01 gauging weir data record, i.e.1971-1981 data (n=96 to 142 for electrical conductivity), versus defaulting to the benchmark tables for an A category river in the water quality manual (DWAF, 2008). Comparative results are shown in the EWR KOON 1 results table (Table 3.3). The final decision for the use of RC data was to use the benchmark tables, as the 1971-1981 data record did not reflect an unimpacted system. This data were therefore used to run the PAI models for the final evaluation of water quality for both EWR sites.

Table 3.3 EWR KOON 1: Present Ecological State: Water Quality

Water Quality Constituents	RC Value	PES Value	Category/Comment
Salt ions (mg/L)			
Ca, CL, K, Mg, Na, SO_4	No data for aggregated salts		
Nutrients (mg/L)			
SRP	0.3	0.026	A (0): RC from Q9H002 C (2): RC from DWAF (2008)
TIN	0.7	0.12	A (0)
Physical Variables			
pH (5^{th} + 95^{th} %ile)	6.7 and 8.3	7.8 and 8.5	A (0)
Temperature	No data		
Dissolved oxygen			
Turbidity (NTU)	No data	No known or few concerns about turbidity. Changes in turbidity appear to be largely natural and related to natural catchment processes such as rainfall runoff.	A/B (0.5)
Electrical Conductivity (mS/m)	123.1 (median: 72.4)	76.5 (median: 42.6)	A (0): RC from Q9H002 C (2): RC from DWAF (2008)
Response variables			
Invertebrate PES	A	C (70.4%)	
Fish PES	A	C (75.6%)	
Diatoms	No data	SPI=12.5	C (n=1)
Toxics			
Fluoride (mg/L)	0.84	0.51	A (0)
OVERALL SITE CLASSIFICATION (PAI model)			**B/C (78.4%)**

The reasons for changes from reference condition had to be identified and understood. These are referred to as causes and sources (http://cfpub.epa.gov/caddis/). The PES for the components at EWR 1 as well as the causes and sources for the PES are summarised in Table 3.4.

Table 3.4 EWR KOON 1: PES Causes and Sources

Causes	Sources
Physico-chemical variables (PES B/C)	
Increasing nutrients and salts	Adelaide town upstream, particularly the High Risk WWTW with poor effluent compliance. Extensive irrigation results in increased nutrients. Although salts expected to be naturally high, levels are exacerbated due to landuse. (Non-flow and flow-related)
Geomorphology (PES B)	
Probable small increase in fine sediment load.	Catchment landuse (agriculture) and return flows from irrigated agriculture. (Non-flow related)
Loss of upper riparian floodplain pockets.	Many of the floodplain pockets/terraces have been cleared for agriculture. These however represent a small proportion of the river area. (Non-flow related)

Causes	Sources
Riparian vegetation (PES C)	
Removal of indigenous riparian vegetation	Clearing of floodplains (where they exist) for agriculture and collection of fire wood and targeted species that have wood useful for furniture making. (Non-flow related)
Altered species composition	Presence of alien species but also the targeted removal of woody species such as yellowwoods and stinkwoods (presumably for furniture). (Non-flow related)
Increased density and abundance of sedges in the marginal and lower zones	Reduced base flows as well as increased nutrients in the water promote sedge growth where habitat is available. (Non-flow and flow-related)
Fish (PES C)	
Migration barriers result in decrease FROC of three catadromous eel species that requires free movement between fresh and salt water.	Presence of various dams. (Non-flow related)
Decrease abundance of fish due to decreased availability of habitat.	Reduced base flows due to abstraction and damming. (Flow-related)
Decrease in water quality and habitat result in decreased availability of food source (especially macro-invertebrates.	Deteriorated water quality (WWTW, irrigation return flows) and flow alteration (farm dams, irrigation). (Non-flow and flow-related)
Macro-invertebrates (PES C)	
Deterioration in water quality.	Adelaide WWTW upstream (non-compliant); nutrient-rich return flows from agriculture. (Non-flow related)
Decreased baseflows.	Impoundments, abstractions. (Flow-related)
Slight alteration in habitat availability: increased packing of cobbles and loss of some undersurface habitat for certain taxa; increased density of *Cyperus* spp. which represents a slight increase in habitat for other taxa.	Slight increase in catchment siltation – this could be due to the gradual change in vegetation from grassland to thicket-dominated and the associated increase in exposed catchment surface (exacerbated by grazing pressure). (Non-flow related)

The major issues that have caused the change from reference condition were non-flow and flow related (catchment activities) which included:

- Deteriorated water quality (increased salinity and nutrients) due to WWTW and irrigation return flows.
- Flow alteration due to farm dams and irrigation leading to reduced baseflows.
- Clearing for agriculture, targeted removal of woody species and the presence of alien vegetation.

To determine the EcoStatus, the macro-invertebrates and fish component scores firstly had to be combined to determine an instream EC. The instream and riparian ECs were then integrated to determine the EcoStatus. Confidence was used to determine the weight which the EC should carry when integrated into an EcoStatus (riparian, instream and overall). The EC percentages are provided (Table 3.5) as well as the portion of those percentages used in calculating the EcoStatus.

Table 3.5 EWR KOON 1: EcoStatus

INSTREAM BIOTA	Importance Score	Weight
FISH		
1. What is the natural diversity of **fish** species with different flow requirements?	1	70
2. What is the natural diversity of **fish** species with a preference for different cover types?	2	100
3. What is the natural diversity of **fish** species with a preference for different flow depth classes?	2	100
4. What is the natural diversity of **fish** species with various tolerances to modified water quality?	1	70
MACRO-INVERTEBRATES		
1. What is the natural diversity of **macro-invertebrate** biotopes?	4	100
2. What is the natural diversity of **macro-invertebrate** taxa with different velocity requirements?	3	90
3. What is the natural diversity of **macro-invertebrate** taxa with different tolerances to modified water quality?	3	90
Fish	**C**	
Macro-invertebrates	**C**	
Confidence rating for instream biological information	**3**	
INSTREAM ECOLOGICAL CATEOGORY	**C**	
Riparian vegetation	**C**	
Confidence rating for riparian vegetation zone information	**3.4**	
ECOSTATUS	**C**	

3.4 RECOMMENDED ECOLOGICAL CATEGORY

The REC was determined based on ecological criteria only and considered the EIS, the restoration potential and attainability there-of. As the EIS was MODERATE no improvement was required. The REC was therefore set to maintain the PES. The final EcoClassification results are summarised in Table 3.6.

Table 3.6 EWR KOON 1: Summary of EcoClassification results

Driver Components	PES and REC
IHI HYDROLOGY	C
WATER QUALITY	B/C
GEOMORPHOLOGY	B
Response Components	**PES and REC**
FISH	C
INVERTEBRATES	C
INSTREAM	C
RIPARIAN VEGETATION	C
ECOSTATUS	C
INSTREAM IHI	C
RIPARIAN IHI	C
EIS	MODERATE

4 EWR KOON 1 (KOONAP RIVER) – DETERMINATION OF STRESS INDICES

4.1 INDICATOR SPECIES OR GROUP

4.1.1 Fish indicator group: Semi-rheophilic species

The only fish species present in this reach with a preference for fast-flowing habitats (flow-sensitive) habitats are the juvenile and sub-adult life stages of the eels (A. *mossambica, A. bicolor* and *A. marmorata*). The anguillid species, particularly juvenile and sub-adult *A. mossambica,* prefer Fast-Shallow (FS) and Fast-Deep (FD) habitat among unembedded cobbles and boulders in riffles. Sufficient depths >15 cm in critical riffle habitats are required for migration and dispersal of eels upstream from the lower reaches, particularly during the summer wet season.

4.1.2 Macro-invertebrate indicator group: Heptageniidae

Heptageniid mayflies have a high preference for fast flows (0.3 - 0.6 m/s) with cobble substrates, and moderate water quality.

4.2 STRESS FLOW INDEX

A stress flow index was generated for every component (fish and macro-invertebrates) and season (wet and dry), and describes the progressive response of flow dependent biota to flow reduction. The stress flow index was generated in terms of habitat and hence biotic response. The integrated stress curve represents the highest stress for either fish or macro-invertebrates at a specific flow for the wet and dry season (Table 4.1). The integrated stress index is provided in Figure 4.1.

Table 4.1 EWR KOON 1: Component and integrated stress index

Stress	DRY SEASON discharge (m^3/s)			WET SEASON discharge (m^3/s)		
	Macro-invertebrates	Fish	Integrated	Macro-invertebrates	Fish	Integrated
0	0.6	0.6	0.6	1.13	1.13	1.13
1	0.52	0.32	0.52	0.99	0.96	0.99
2	0.44	0.14	0.44	0.78	0.84	0.84
3	0.38	0.09	0.38	0.69	0.73	0.73
4	0.3	0.07	0.3	0.52	0.61	0.61
5	0.2	0.06	0.2	0.41	0.5	0.5
6	0.15	0.04	0.15	0.29	0.4	0.4
7	0.12	0.03	0.12	0.18	0.3	0.3
8	0.06	0.02	0.06	0.09	0.21	0.21
9	0.03	0.01	0.03	0.04	0.12	0.12
10	0	0	0	0	0	0

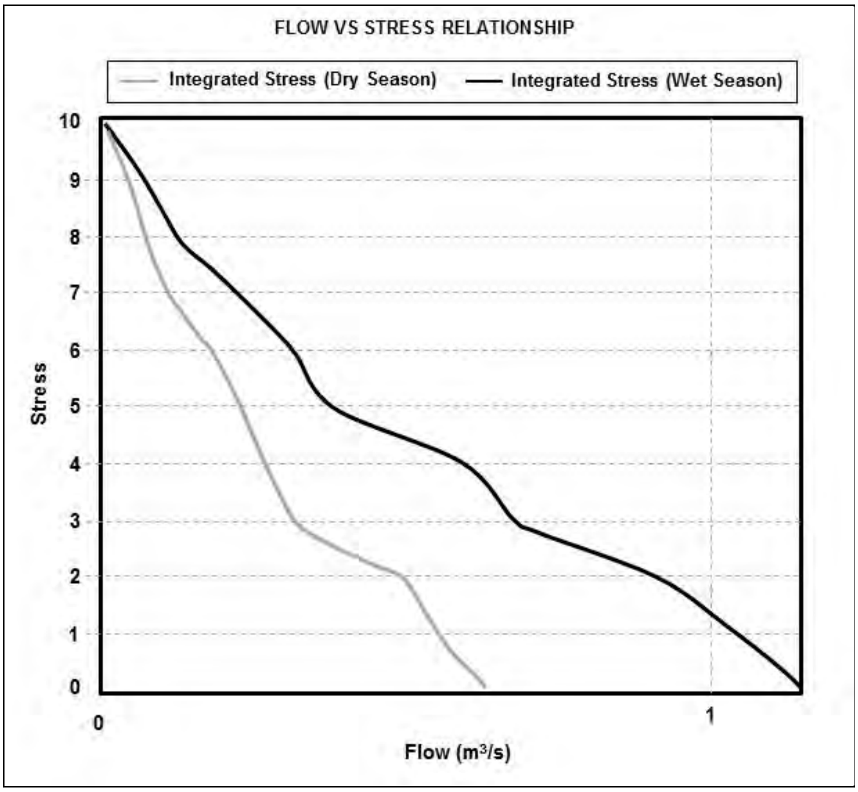


Figure 4.1 EWR KOON 1: Stress index

Table 4.2 and 4.3 provides the summarised biotic response for the integrated stresses during dry and wet season.

Table 4.2 EWR KOON 1: Integrated stress and summarised habitat/biotic responses for the dry season

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or biotic responses
0	0.6	Maximum base flow	Selected on the basis of the maximum base flow based on a separated base flow time series. October was selected as the lowest base flow month and the maximum base flow was set at the 20^{th} percentile.
1	0.52	Inverts	Plentiful very fast and fast flow, instream and marginal vegetation stems inundated, providing surplus habitat for juvenile Ephemeroptera and for Simuliidae. Depth in critical flow habitat will cover smaller cobbles and provide plentiful upper- and side-surface habitat. Indicator taxa will likely be present in B abundances. Adequate inundation of marginal vegetation to ensure that the habitat also occurs in slow-flow areas, providing refuge for hemipterans and juvenile Ephemeroptera (early summer). Taxa scoring < 9 likely to be present in B abundances at least.
2	0.44	Inverts	
3	0.38	Inverts	Stress has increased relative to the zero condition as a result of a reduction in wetted perimeter which represents a loss in both cobble and marginal vegetation habitat area. Depth and flow conditions still support indicator and other more flow-sensitive taxa in a B abundances (abundance between 10 to 99), and a diverse community overall (possibly with higher abundances and including more sensitive taxa than those collected during the July 2013 sampling, e.g. Crambidae).

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or biotic responses
4	0.3	Inverts	
5	0.2	Inverts	Site sampled at this flow (0.2 m^3/s). The associated stress pinned at 5 for Dry Season. Average depth of *ca*.17 cm means that most of cobbles in critical flow areas still covered by fast flow. Very fast over coarse substrate habitat (VFCS) is lost at this flow, which will gradually affect abundances of taxa with a preference for flows >0.6m^3/s (e.g. Hydropsychidae). Indicator taxa present in low abundances. Community comprises largely resilient taxa scoring <10. Abundances of all taxa are reduced.
6	0.15	Inverts	
7	0.12	Inverts	VFCS is lost, little Fast over coarse substrate (FCS), at this average depth, instream sedge bases and rootwads will be inundated but the most useful vegetation habitat will be the overhanging vegetation in pools. With the reduction in fast flow area, indicator taxa will be present but in low abundances and may not be collected in samples.
8	0.06	Inverts	The majority of habitat at this flow is slow or very slow flow. Flow connectivity is likely lost in the critical habitat areas which are now shallow. Reduced velocity and depth result in a condition dominated by pools and small out-of-flow refugia. Marginal vegetation almost lost as a macro-invertebrate habitat. Indicator taxa unlikely to be collected and probably occur in very small numbers if at all. Community largely comprises taxa scoring <9. The pools (large deep and minor shallow) serve as habitat to the more resilient taxa only. Aerial hemipterans likely to relocate to pools with wetted marginal or overhanging vegetation.
9	0.03	Inverts	
10	0.001	No flow, surface water only	

Table 4.3 EWR KOON 1: Integrated stress and summarised habitat/biotic responses for the wet season

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or biotic responses
0	1.13	Maximum base flow	Selected on the basis of the maximum base flow based on a separated base flow time series. March was selected as the highest base flow month and the maximum base flow was set at the 20th percentile.
1	0.99	Inverts	Maximum habitat diversity, large areas of very fast flow (> 0.6 m/s) and fast flow (0.3 - 0.6 m/s) over coarse sediments, width (>14 m) and depth (max 0.56 m) support the inundation required to cover critical flow habitat, and inundate and activate instream and marginal vegetation (sedge stems) as habitat. Habitat conditions support the indicator taxa at a B to C abundance, and a community with a similar composition but higher abundances than those sampled. Additional sensitive taxa may be present (e.g. Calopterygidae, Crambidae, and Philopotamidae).
2	0.84	Fish	A 20% reduction in the availability of fast habitats (Fast Very Shallow habitat (FVS), FS, Fast Intermediate habitat (FI) and FD) compared to natural conditions, expected to result in some stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).
3	0.73	Fish Inverts	**Fish:** A 28% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in some stress exerted on the fish assemblage (especially juvenile

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or biotic responses
			and sub-adult eels with a preference for this habitat type). **Inverts:** Habitat diversity is slightly reduced by the reduction in width and associated loss of inundated marginal vegetation (MV). Indicator taxa present at an abundance of B, community with a similar composition but largely higher abundances than those sampled at 0.2m^3/s. Additional hemipterans may be collected due to the availability of sedge stems and overhanging MV as habitat and cover.
4	0.61	Fish	A 38% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in moderate stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).
5	0.5	Fish	A 60% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in moderate stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).
6	0.4	Fish	A 50% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in moderate stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).
7	0.3	Fish	Limited availability of fast habitats (70% reduced from natural maximum baseflow).
8	0.21	Fish	Limited availability of fast habitats (80% reduced from natural maximum baseflow). This will limit the FROC of all fish species since pool quality (depth and water quality) will also be affected negatively under these low flows.
9	0.12	Fish	Very limited availability of fast habitats (90% reduced from natural maximum baseflow). This will limit the FROC of all fish species since pool quality (depth and water quality) will also be affected negatively under these low flows.
10	0	Zero discharge, pools remain	Complete loss of fast habitats with zero flows, only pools available.

5 EWR KOON 1 (KOONAP RIVER) - DETERMINATION OF EWR SCENARIOS

5.1 ECOCLASSIFICATION SUMMARY OF EWR KOON 1

<table>
<tr><th colspan="2">EWR KOON 1</th></tr>
<tr><td>

EIS: MODERATE
Highest scoring metrics were intolerance of instream biota to no flow and physico-chemical changes, diversity of instream habitat types, unique riparian species and important riparian migration corridors.

PES: C
▪ Deteriorated water quality (increased salinity and nutrients) due to WWTW and irrigation return flows.
▪ Flow alteration due to farm dams and irrigation leading to reduced baseflows.
▪ Clearing for agriculture, targeted removal of woody species and the presence of alien vegetation.

REC: C
EIS was MODERATE and the REC was therefore to maintain the PES.

</td><td>

<table>
<tr><th>Driver Components</th><th>PES and REC</th></tr>
<tr><td>IHI HYDROLOGY</td><td>C</td></tr>
<tr><td>WATER QUALITY</td><td>B/C</td></tr>
<tr><td>GEOMORPHOLOGY</td><td>B</td></tr>
<tr><th>Response Components</th><th>PES and REC</th></tr>
<tr><td>FISH</td><td>C</td></tr>
<tr><td>INVERTEBRATES</td><td>C</td></tr>
<tr><td>INSTREAM</td><td>C</td></tr>
<tr><td>RIPARIAN VEGETATION</td><td>C</td></tr>
<tr><td>ECOSTATUS</td><td>C</td></tr>
<tr><td>INSTREAM IHI</td><td>C</td></tr>
<tr><td>RIPARIAN IHI</td><td>C</td></tr>
<tr><td>EIS</td><td>MODERATE</td></tr>
</table>

</td></tr>
</table>

5.2 HYDROLOGICAL CONSIDERATIONS

The wettest and driest months were identified as March and October respectively. Note that October was selected as the driest month based on separated base flows. The lowest flow month based on total flows was July.

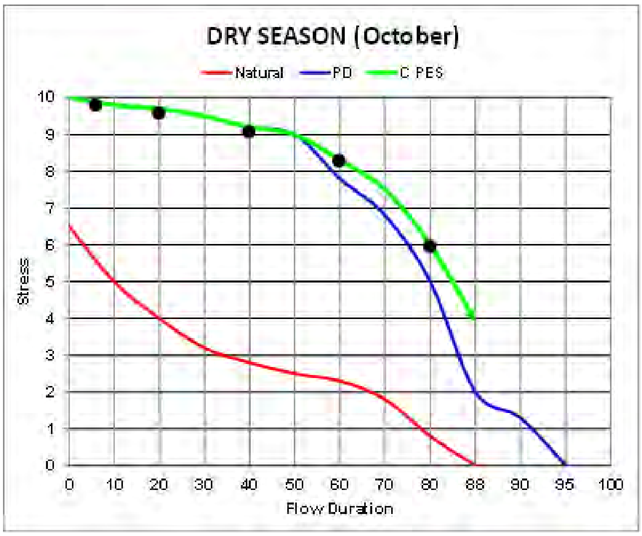
5.3 STRESS REQUIREMENTS

Stress requirements were set for low flows only. Floods were recommended separately (Section 5.4). The integrated stress index was used to identify required stress levels at specific durations for the wet and dry month/season.

The stress requirements and motivations for the PES (REC) are provided in Table 5.1 and graphically illustrated in Figure 5.1.

Table 5.1 EWR KOON 1: Stress requirements and summary of motivations

% Stress duration	Integrated stress	Discharge (m^3/s)	Motivation
PES and REC: C EcoStatus			**Fish: C** **Macro-invertebrates: C**
DRY SEASON			
5% drought	9.7	0.009	The minimum allowable flows to maintain the PES cannot be decreased from the PD, since the stress in the dry season is already extremely high (especially on fast habitats) and a further reduction in flows will result in a possible decrease in EC.
20%	9.5	0.016	
40%	9	0.03	
60%	8.3	0.05	**Invertebrates:** At this discharge there is no very fast flow, but adequate fast and slow flow to maintain the majority of the macro-invertebrate community in its current state. As water quality deteriorates, heptageniids are likely to disappear.
80%	6	0.15	**Invertebrates:** The maximum flow reduction advised. This and higher discharges for 20% of the time ensures adequate suitable habitat and flow to facilitate reproductive processes that will occur in the early summer month of October, and supplies sufficient refuge (inundated sedge stems, etc.) for hatchlings and juveniles, particularly baetids.
WET SEASON			
5% drought	10	0.002	**Fish:** The minimum allowable flows to maintain the PES cannot be decreased from the PD, since the stress at these flow durations are already extremely high (especially on fast habitats) and a further reduction in flows will result in a possible decrease in EC.
20%	9.9	0.017	
40%	9	0.12	
60%	7	0.3	**Invertebrates:** This flow provides the VFCS required for the indicator taxa.
80%	5	0.5	Fish: This reduction in flow is possible because the discharge associated with an integrated stress of 5 represents an macro-invertebrate stress of 4. All hydraulic habitat classes are represented and adequate depth to sustain the indicator taxa and community and allow suitable water quality (etc.) for late summer breeding.



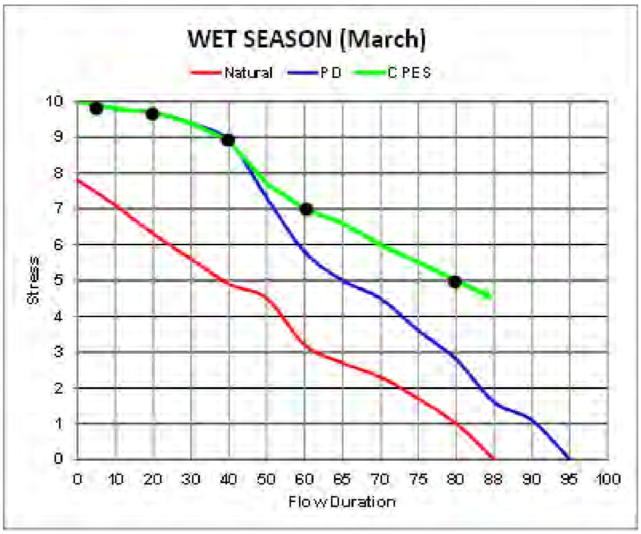


Figure 5.1 EWR KOON 1: Stress duration curve for a PES and REC

5.4 FINAL LOW FLOW REQUIREMENTS

To achieve the final low flow requirements, a process in the RDERM is followed to adjust the C initial desktop estimate to specialist requirements. The C estimate is aligned to present day and the shape of the curve is adjusted to the requirements. Once the final C EWR is available then the other categories are derived from the C EWR. The parameters that were changed are available in a report generated by the RDERM (Appendix C) and the final results are graphically illustrated in Figure 6.1 (Section 6).

5.5 HIGH FLOW REQUIREMENTS

The high flow classes were identified as follows:

- The geomorphologist and riparian vegetation specialist identified the range of flood classes required and listed the functions of each flood.
- The instream specialists then indicated which of the instream flooding functions were addressed by the floods identified for geomorphology and riparian vegetation (indicated by a ✓ in Table 5.2).
- Any of the floods required by the instream biota and not addressed by the floods already identified, were then described (in terms of ranges and functions) for the instream biota.

Detailed motivations are provided in Table 5.2 and final high flow results are provided in Table 5.3.

Table 5.2 EWR KOON 1: Identification of instream functions addressed by the identified floods for geomorphology and riparian vegetation

Flood Class Flood Range (m^3/s) (Peak)	Geomorphology and riparian vegetation motivation	Fish flood functions						Macro-invertebrate flood functions						
		Migration cues & spawning	Migration habitat (depth etc.)	Clean spawning substrate	Create nursery areas	Resetting water quality	Inundate vegetation for spawning	Breeding and hatching cues	Clear fines	Scour substrate	Reach or inundate specific areas	Sorting coarse substrates	Transport; migration cues for shrimps	Clear + inundate MV and fringing veg e.g. for shelter (juveniles)
CLASS I (2 m^3/s)	**Geomorphology:** Frequent small flushes (or high wet season baseflows) entrain and remove fines from the bed of the active channel, maintaining good in-channel habitat for biota. **Vegetation:** Flooding of sedge population (*Cyperus textilis*) to its upper limit. This prevents establishment of terrestrial or alien species in the marginal zone; provides recruitment opportunities in the marginal and lower zones, but at the same time can scour vegetation to maintain habitat patchiness and species diversity; stimulates growth and reproduction and distributes propagules downstream. Prevents encroachment of marginal zone vegetation towards the channel.	√	√	√	√	√	√	√	√	√	√		√	√
CLASS II (5.3 m^3/s)	**Geomorphology:** Small floods entrain and remove fines and sands from the bed of the active channel, maintaining good in-channel habitat for macro-invertebrates and fish. **Vegetation:** Required to flood 50% or more of the *S. mucronata* and *G. virgatum* population. Provides recruiting opportunities for these marginal and lower zone woody species, especially at the higher limits of the population and sustains existing saplings going into their first dry season.	√	√	√	√	√	√	√	√	√	√	√	√	√
CLASS III (9 m^3/s)	**Geomorphology:** The flood class is the most important to maintain in the system as it represents the effective discharge for sands, gravels and cobbles, transporting about 40% of the bed sediments over the long term. Cobbles mobilised in these flows inhibit embeddedness of the active channel and improve habitat conditions for biota **Vegetation:** Inundation of the lower portion of the upper zone, scour the marginal and lower zones and maintain vegetation patchiness and heterogeneity. Specifically, required to elicit recruiting opportunities for *C. caffrum* - samaras (fruits) from the previous season lie in the leaf litter and wetting by floods (or rainfall) will promote germination on site or in other areas where hydrochory takes place.	√	√	√	√	√	√		√	√	√	√	√	√

Flood Class Flood Range (m^3/s) (Peak)	Geomorphology and riparian vegetation motivation	Fish flood functions						Macro-invertebrate flood functions						
		Migration cues & spawning	Migration habitat (depth etc.)	Clean spawning substrate	Create nursery areas	Resetting water quality	Inundate vegetation for spawning	Breeding and hatching cues	Clear fines	Scour substrate	Reach or inundate specific areas	Sorting coarse substrates	Transport; migration cues for shrimps	Clear + inundate MV and fringing veg e.g. for shelter (juveniles)
CLASS IV (24 m^3/s)	**Vegetation:** Required to inundate the upper zone macro channel and some portion of the MCB. Similar functions to above. Scour marginal, lower and upper zones, maintain vegetation patchiness and heterogeneity. Activates *Olea europaea* subsp. *africana*.	√	√	√	√	√	√	√	√	√	√	√	√	√
CLASS V (40 m^3/s – daily ave)	**Geomorphology:** Very large, infrequent floods mobilise cobbles and clear out the secondary flood channels (removing some of the encroaching vegetation here).	√	√	√	√	√	√		√	√	√	√	√	√

The number of high flow events required for each EC is provided in Table 5.3. The availability of high flows was verified using the observed data at gauge Q9H002.

Table 5.3 EWR KOON 1: The recommended number of high flow events required

Flood Class (Peak in m^3/s)	Macro-invertebrates	Fish	Vegetation	Geomorphology	FINAL*	Months	Daily average	Duration
PES and REC: C EcoStatus								
CLASS I (2 m^3/s)			4	2	4	Dec, Jan, Feb, Mar	2	3
CLASS II (5.3 m^3/s)			1	1	1	Feb	4	3
CLASS III (9 m^3/s)			1:3	1:2	1:2**	Apr	12	4
CLASS IV (24 m^3/s)			1:5+		1:5			
CLASS V (40 m^3/s – daily ave)				1:5	1:5	Mar	40	5

* Final refers to the agreed on number of events considering the individual requirements for each component.
** Refers to frequency of occurrence, i.e. the flood will occur once in two years.

5.6 FINAL FLOW REQUIREMENTS

The low and high flows were combined to produce the final flow requirements for each EC as:

- An EWR table, which shows the results for each month for high flows and low flows separately (Table 5.4). Floods with a high frequency were not included in the modelled results as they cannot be managed.
- An EWR rule table which provides the recommended EWR flows as a duration table, linked to a natural trigger (natural modelled hydrology in this case). EWR rules were supplied for total flows as well as for low flows only (Table 5.5).

The low flow EWR rule table is useful for operating the system, whereas the EWR table must be used for operation of high flows.

Table 5.4 EWR KOON 1: EWR table for PES and REC: C

Month	Low Flows		High Flows (m^3/s)	
	60% (m^3/s)	Drought (90%) (m^3/s)	Instantaneous peak	Duration (days)
OCTOBER	0.017	0.003		
NOVEMBER	0.030	0.004		
DECEMBER	0.214	0.005	2	3
JANUARY	0.187	0.004	2	3
FEBRUARY	0.622	0.009	2 5.3	3 3
MARCH	1.193	0.013	2 40	3 5
APRIL	0.544	0.008	9	4
MAY	0.025	0.004		
JUNE	0.030	0.004		
JULY	0.031	0.004		
AUGUST	0.030	0.004		
SEPTEMBER	0.030	0.004		

Table 5.5 EWR KOON 1: Assurance rules (m^3/s) for PES and REC: C

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.183	0.108	0.075	0.048	0.029	0.017	0.010	0.005	0.003	0.002
Nov	0.401	0.209	0.086	0.056	0.048	0.030	0.014	0.008	0.004	0.001
Dec	0.845	0.546	0.382	0.286	0.261	0.214	0.167	0.097	0.005	0.001
Jan	0.721	0.395	0.293	0.237	0.214	0.187	0.143	0.082	0.004	0.001
Feb	1.705	1.137	0.827	0.703	0.678	0.622	0.489	0.283	0.009	0.001
Mar	3.018	2.176	1.650	1.380	1.306	1.193	0.941	0.544	0.013	0.000
Apr	1.557	1.005	0.746	0.633	0.588	0.544	0.425	0.245	0.008	0.001
May	0.419	0.158	0.100	0.063	0.049	0.025	0.015	0.008	0.004	0.001
Jun	0.299	0.145	0.099	0.057	0.047	0.030	0.017	0.009	0.004	0.001
Jul	0.245	0.149	0.101	0.055	0.049	0.031	0.018	0.009	0.004	0.001
Aug	0.236	0.144	0.094	0.059	0.048	0.030	0.016	0.011	0.004	0.001
Sep	0.227	0.122	0.087	0.056	0.049	0.030	0.017	0.009	0.004	0.001

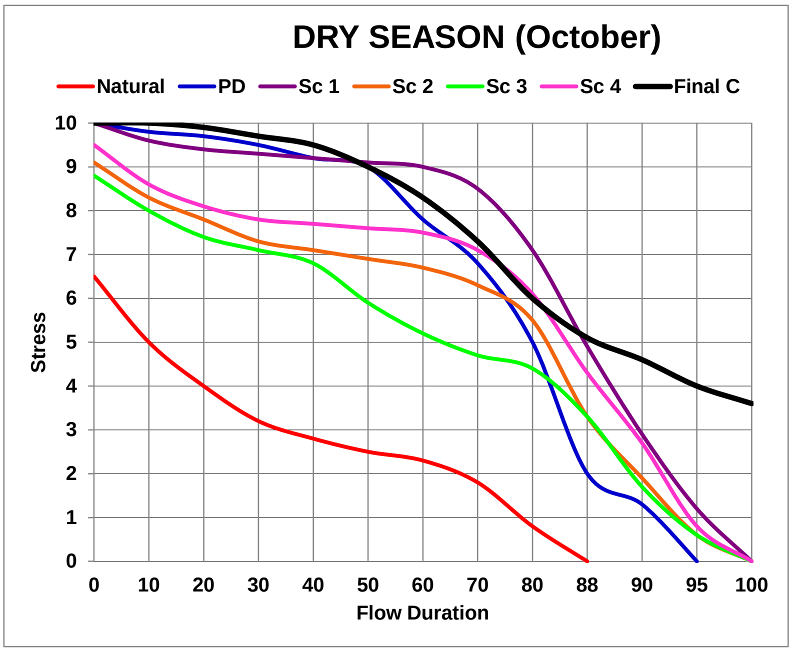
Table 5.6 Summary of results as a percentage of the natural MAR (NMAR)

					Long term mean					
EWR site	PES	REC	NMAR (MCM)	PMAR (MCM)	Low flows (MCM)	Low flows (%NMAR)	High flows (MCM)	High flows (%NMAR)	Total flows (MCM)	Total (%NMAR)
KOON 1	C	C	62.93	52.04	2.997	4.8	7.08	11.25	10.076	16

6 ECOLOGICAL CONSEQUENCES AT EWR KOON 1

The four scenarios (referred to as Sc 1 - Sc 4) were evaluated to determine the ecological consequences in terms of change in ecological state from the present. The consequences for each component are provided and the overall consequences is then summarised.

The stress duration graphs which include the final requirements as well as the scenarios are provided below for EWR 1 (Figure 6.1). For up to 60% of the time in the dry season, Sc 1 (purple curve) provides similar stresses to Present Day, but increased stresses (lower flows) during the remainder of the time. For the majority of the time in the dry season, Sc 2 (orange curve), 3 (green curve) and particularly Sc 4 (pink curve) represent substantially lower stresses than Present Day. During the wet season the stress is significantly higher relative to natural (red curve) and PD (blue curve) and Sc 2 – 4 represent lower stress than PD up 50 % of the time.



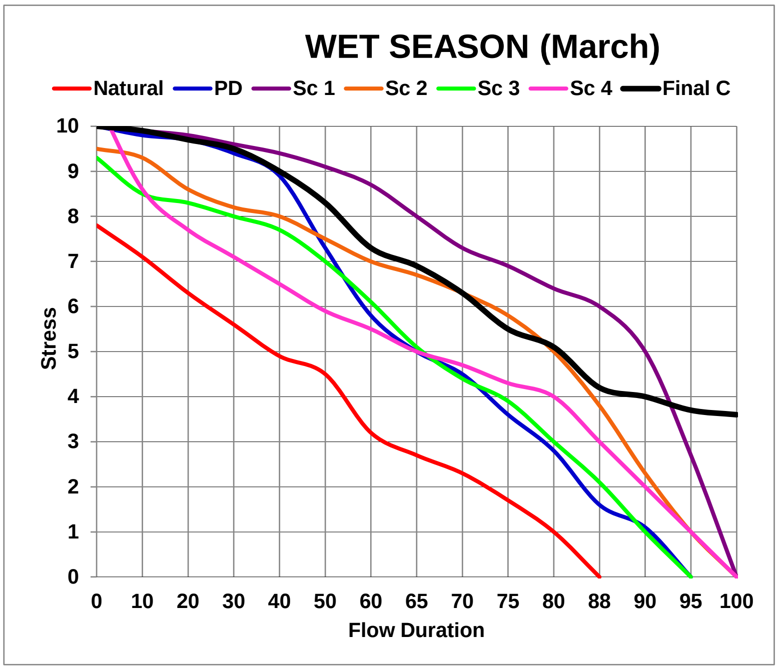


Figure 6.1 EWR KOON 1: Stress duration for the operational scenarios

6.1 DRIVER COMPONENTS

PES (REC)	Sc 1	Sc 2	Sc 3	Sc 4
Physico-chemical				
B/C	C (71.8%)	C (75.8%)	C (74.8%)	C (75.8%)
	Dry Season: The worst conditions are seen under Sc 1, with the lowest baseflows in the dry season. Baseflows are higher under Sc 2, 3 and 4 although expanded irrigation is seen with associated return flows. Conditions under Sc 2, 3 and 4 are expected to be similar as at present during the dry season as more (good quality) water is available, but higher irrigation return flows (poor quality water) are expected. The impact under Sc 3 is slightly lower due to the smaller dam size.		**Wet Season:** The largest impact on large floods is under Sc 1. The total water quality impact under Sc1 is an expected increase in nutrients, toxics and impacts on temperature and oxygen due to lower flows. The impact on fewer large floods will result in a reduction of flushing flows in the system under all scenarios. An elevation in nutrient and possible increase in toxic levels are expected due to higher irrigation return flows in the area under Sc 2, 3 and 4. Temperature and oxygen levels are expected to stay stable under Sc 3 due to the smaller dam size (and therefore lower dam wall), while an impact is expected with a 1 MAR dam size.	
Geomorphology				
B	C (68.4%)	C (72.3%)	B/C (80.7%)	C (72.3%)
The site is currently in a good geomorphological condition, but the impact of reduced floods due to the proposed dam will be most pronounced under Sc 1 and to a slightly lesser extent under Sc 2 and 4. These scenarios are associated with a 1 MAR dam which would attenuate many larger floods. These scenarios are expected to result in a deterioration to a C EC. The 0.5 MAR dam proposed under Sc 3 would have a lesser impact and is expected to result in a slight decline of the PES to a B/C EC.				

6.2 BIOTIC RESPONSES

PES (REC)	Sc 1	Sc 2	Sc 3	Sc 4
Riparian vegetation				
C	C (67.6%)	C (73.7%)	C (72.1%)	C (74.4%)
	Sc 1: High flows are reduced, but maintain seasonality. This is likely to result in woody encroachment due to reduced flooding stress. Low flows are generally reduced with more zero flow in winter. Sedges are activated for 50% of the time from Feb to Sep (PD) but only in Mar for Sc 1. Sedges are inundated for 10% of the time throughout the year (PD) and only from Oct to Jun for Sc 1. Both activation and inundation of sedges is less than PD in Mar and Oct. Sedges are therefore likely to encroach and increase in abundance in the marginal and lower zones. Both *G. virgatum* and *S. mucronata* are inundated less than PD but are not water stressed to the point of mortality. Both *G. virgatum* and *S. mucronata* are therefore likely to increase in abundance in the marginal and lower zones. **Sc 2:** High flows are reduced, but maintain seasonality. This is likely to result in woody encroachment due to reduced flooding stress. Low flows are generally reduced but with less zero flows. Sedges are activated for 50% of the time from Feb to Sep (PD) but all year round for Sc 2. Sedges are inundated for 10% of the time throughout the year (PD) and only from Sep to Jul for Sc 2. Inundation of sedges is less than PD in Mar and Oct, but activation is more. Sedges are therefore likely to remain unchanged or reduce in abundance in the marginal and lower zones. Both *G. virgatum* and *S. mucronata* are inundated less than PD but are not water stressed to the point of mortality. Both *G. virgatum* and *S. mucronata* are therefore likely to increase in abundance in the marginal and lower zones. **Sc 3:** High flows are reduced but not as much as Sc 1, 2, and 4, and maintain seasonality. This is likely to result in woody encroachment due to reduced flooding stress, but less so than other scenarios. Low flows are generally reduced and seasonality altered, but with less zero flows. Sedges are activated for 50% of the time from Feb to Sep (PD) and from Aug to May for Sc 3. Sedges are inundated for 10% of the time throughout the year for both PD and Sc 3. Inundation of			

<table>
<tr><th>PES (REC)</th><th>Sc 1</th><th>Sc 2</th><th>Sc 3</th><th>Sc 4</th></tr>
<tr><td></td><td colspan="4">sedges is less than PD in Mar and Oct, but activation is more. Sedges are therefore likely to remain unchanged or reduce in abundance in the marginal and lower zones. Both G. virgatum and S. mucronata are inundated less than PD but are not water stressed to the point of mortality. Both G. virgatum and S. mucronata are therefore likely to increase in abundance in the marginal and lower zones.
Sc 4: High flows are reduced, but maintain seasonality. This is likely to result in woody encroachment due to reduced flooding stress. Low flows are generally reduced and seasonality altered, but with less zero flows. Sedges are activated for 50% of the time from Feb to Sep (PD) but all year round for Sc 4. Sedges are inundated for 10% of the time throughout the year (PD) and only from Sep to Jul for Sc 4. Inundation and activation of sedges is more than PD in Mar and Oct. Sedges are therefore likely to remain unchanged or reduce in abundance in the marginal and lower zones. Both G. virgatum and S. mucronata are inundated less than PD but are not water stressed to the point of mortality. Both G. virgatum and S. mucronata are therefore likely to increase in abundance in the marginal and lower zones.</td></tr>
<tr><th colspan="5">Fish</th></tr>
<tr><td>C</td><td>C (59.4%)</td><td>B/C (79.6%)</td><td>B (82.3%)</td><td>B (83.6%)</td></tr>
<tr><td></td><td colspan="2">Dry Season:
Sc 1: A slight deterioration can be expected (approximately one EC) in the fish assemblage due to lower flows than PD, resulting in worse habitat availability (increased habitat stress).
Sc 2 and Sc 4: An improvement can be expected in the fish assemblage due to higher flows than PD, resulting in improved habitat availability (decreased habitat stress).
Sc 3: A notable improvement in PES can be expected in the dry season due to a significant improvement in flow that will result in the supply of abundant and suitable habitat for all fish species.</td><td colspan="2">Wet Season:
Sc 1: Conditions are expected to deteriorate notably due to significantly lower than PD flows. The lower flows will result in decreased connectivity for migration (of especially eels) and reduction in riffle/rapid habitats for feeding of the juvenile eels. Lower flows will furthermore reduce pool depth, impacting on Labeo umbratus.
Sc 2: Conditions will be very similar to slightly better than under PD, and the fish assemblage is expected to remain in the same EC during the wet season.
Sc 3 and Sc 4: A slight improvement in PES under Sc 3 and a notable improvement in the PES under Sc 4 can be expected in the wet season due to an improvement in flow that will result in the supply of abundant and suitable habitat for all fish species. Improved flows will improve connectivity for eel migration, as well as increased FROC of riffle/rapid habitats for juvenile eel feeding habitats. Increased abundance of pools and improved substrate quality will increase the FROC of L. umbratus and B. anoplus.</td></tr>
<tr><td colspan="5">Sc 1: The overall trend expected is that the fish EC will decrease from the PES to a C/D EC. The decrease is attributed all habitat availability and suitability for fish decreasing under dry and wet season.
Sc 2: The overall trend expected is a slight improvement in the fish assemblage from the PES to a category B/C) due to the improved habitat suitability (abundance) during the dry season.
Sc 3 and Sc 4: The overall trend is a notable improvement in the fish assemblage to a category B due to the improved habitat suitability (abundance) during the wet and dry season.</td></tr>
<tr><th colspan="5">Macro-invertebrates</th></tr>
<tr><td>C</td><td>C/D (60%)</td><td>C (70.4%)</td><td>C (70.4%)</td><td>C (70.4%)</td></tr>
<tr><td colspan="5">Sc 1: This scenario has the worst effect on the flood regime. The loss of flow and floods is likely to result in habitat loss, reduced habitat quality, water quality deterioration and a loss or lowering in abundances of indicator taxa and altered community balance. All higher-scoring macro-invertebrates are likely to be affected, particularly during the summer months. The PES is likely to be reduced to a C/D.
Sc 2 - 4: For the majority of the time in the dry and wet seasons, Sc 2 and 3 and particularly Sc 4 represent substantially higher flows and lower stresses than Present Day. During the dry season (early summer) this increased width and depth represents important habitat for breeding and for developing juveniles and also provides additional habitat for indicator taxa, and would appear to provide an improved PES. However, the loss of floods for up to 3 years at a time will have a negative outcome on the instream cobble habitat, which is likely to deteriorate over time (cleaning and flushing function of floods lost). In addition, the regulated flows and loss of floods will gradually result in an increased density of sedges, which will not necessarily</td></tr>
</table>

PES (REC)	Sc 1	Sc 2	Sc 3	Sc 4
benefit the macro-invertebrate community. For Sc 2 and 3, the PES of a C is likely to be maintained, but the percentage may decrease from 70% to 65% or lower. For Sc 4, where flow may be more variable due to the provision of EWR baseflows and release of realistic flows for irrigation, the PES will be maintained or may be slightly increased in percentage (within the C category).				

6.3 SUMMARY OF ECOLOGICAL CONSEQUENCES

The ecological consequences of the operational flow scenarios at EWR KOON 1 are provided in Table 6.1.

Table 6.1 Ecological consequences of operational flow scenarios at EWR KOON 1

	PES and REC	Sc 1	Sc 2	Sc 3	Sc 4
WATER QUALITY	B/C	C	C	C	C
GEOMORPH	B	C	C	B/C	C
Response Components	PES and REC	Sc 1	Sc 2	Sc 3	Sc 4
FISH	C	C/D	B/C	B	B
INVERTS	C	C/D	C	C	C
INSTREAM	C	C/D	C	C	C
RIP VEG	C	C	C	C	C
ECOSTATUS	C	C-	C	C	C

The reduced floods and deteriorated water quality resulted in a deterioration in the geomorphology and water quality components under Sc 1. There was also a deterioration in fish and macro-invertebrates and therefore the resulting instream condition. Scenario 1 resulted in the PES being maintained although the requirements of the REC were not met. Scenario 2 – 4 resulted in the REC requirements being met. Under Sc 2 and 4 the fish improve due to improved habitat suitability while geomorphology and water quality deteriorate due to reduced flooding and increased deteriorated water quality entering the system due to irrigation return flows. Conditions are similar under Sc 3. However, due to the smaller dam the impact on geomorphology is not as great as under Sc 2 and Sc 4 and therefore the EC only drops half a category. Water quality still deteriorates while the overall improvement in habitat quality results in the fish improving a category. Although the geomorphology and fish component improves under this scenario the overall EcoStatus is maintained and the REC requirements are met.

The degree to which each scenario at EWR KOON 1 meets the REC is summarised in Figure 6.2 below.

EWR KOON 1				
Scenario	**Sc 1**	**Sc 2**	**Sc 3**	**Sc 4**
EWR 1	✓	✓	✓	✓

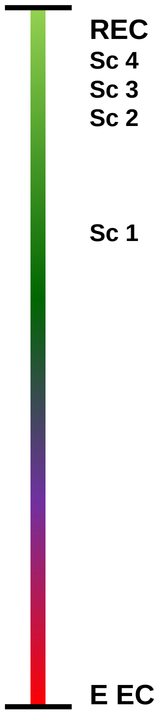


Figure 6.2 Summary of the impacts of operational flow scenarios at EWR KOON 1

7 ECOCLASSIFICATION: EWR KOON 2 (KOONAP RIVER)

7.1 EIS RESULTS

The EIS evaluation resulted in a **MODERATE** importance. The highest scoring metrics were:

- Rare and Endangered (instream) species: *Sandelia bainsii* (endangered fish species) is present.
- Intolerant to no flow and physico-chemical changes (instream biota): Macro-invertebrate taxa and *S. bainsii*.
- Diversity of habitat types and features (instream habitat): Rapids, riffles, pool, and overhanging vegetation.
- Unique species (riparian): *Combretum caffrum*, *Acacia karoo*, *Cyperus textilis* and *Schoenoplectus paludicola*.
- Migration corridor (riparian): Distinct vegetation structure exists from the upland area. Riparian woody banks are thick with distinct species and longitudinal continuity is good which is important for birds, and other riparian fauna.

7.2 REFERENCE CONDITIONS

The reference conditions at EWR 2 are summarised below in Table 7.1.

Table 7.1 EWR KOON 2: Reference conditions

Hydrology (Confidence: 4)
The natural MAR is 77.5 MCM.
Physico-chemical variables (Confidence: 2.5)
Refer to Table 6.3.
Geomorphology (Confidence: 3)
The river was predominantly a single channel, with seasonal and flood (secondary) channels in places. The macro-channel floor would have been well-wooded (as indicated from historical accounts of the region), with the main and secondary channels probably dominated by cobbles.
Riparian vegetation (Confidence 4)
EWR 2 occurred in Great Fish Thicket (Mucina & Rutherford, 2006) which is a highly heterogeneous vegetation unit, but generally dominated by short, medium and tall thicket types, with well-developed woody dominance. In 1838 and 1839 both Bunbury and Backhouse in Skead (2009) respectively described the Koonap near Fort Brown as thick or vast bush (the Koonap not flowing in 1839). In 1848 W.T. Black (Skead, 2009) described riparian vegetation near Fort Brown and included both the Fish and Koonap Rivers: "The river bush is of a different nature to that covering the rest of the country and marks the course of the stream distinctly to the spectator from some height overlooking the valley; it is greener and loftier, and completely overhangs the water in most places…". Of the riparian vegetation Black noted that Willow trees (*Salix*) constituted the largest of the riparian bush and that elephant, hippo, leopard, hyena, kudu and bushbuck frequented the riparian zone. Marginal zone: A mix of woody overhanging vegetation (especially *Salix mucronata* and *A. karoo*) in pool areas were expected where the marginal zone was all but absent and non-woody sedges in non-pool areas such as riffles, braided or anastomosing sections or unconsolidated alluvia. The rheophyte, *G. virgatum* was expected in cobble and riffle habitats permanently (or near so) inundated by fast flowing water. Lower zone: As with the Marginal Zone, but with a greater *S. mucronata* component, especially where alluvium was deposited. Upper zone: It was expected that this zone was dominated by medium to tall woody vegetation, dense in cover and density with some open areas and paths maintained by megaherbivores. *A. karoo* and *C. caffrum* would dominate but pockets of yellowwoods would frequently occur. MCB: As with the upper zone, but with higher woody cover and density, more terrestrial woody species and less *C. caffrum.*

Floodplain: Where these occurred, they would predominantly consist of *A. karoo* thicket.
Fish (Confidence: 2)
Based on the available fish distribution data and expected habitat composition of the river reach, seven indigenous fish species had a high to definite probability of occurrence. These include three freshwater eel species (*Anguilla bicolor bicolor*, *A. marmorata* and *A. mossambica*), two cyprinids (*B. anoplus* and *L. umbratus*), the river goby, *Glossogobius callidus*, and the endangered Cape rocky *Sandelia bainsii*. The instream habitat composition under reference conditions was estimated to be very similar to those available under present conditions and the habitats available at the EWR site met the requirements of all expected fish species. Since no information for the Koonap River was provided in Kleynhans *et al*. (2007) the estimated FROC under reference conditions was based on available knowledge of general occurrence patterns of these species.
Macro-invertebrates (Confidence: 2.5)
There were no available data for this sub-quaternary reach (Q92G-08047). Reference conditions were based on the actual sample and on the macro-invertebrate data set derived for the sub-quaternary reach during the DWA (2013a) project.) SASS5 Score: 209 Number of Taxa: 35 Average Score Per Taxon (ASPT): 6

7.3 PRESENT ECOLOGICAL STATE

The Present Ecological State (PES) reflects the changes in terms of the Ecological Category (EC) from reference conditions. The summarised PES information is provided in Table 6.2 and Table 6.3 provides summarised water quality data.

Table 7.2 EWR KOON 2: Present Ecological State

Hydrology: PES C, Confidence: 3	
PMAR: 65.3 MCM (84% of the MAR). Present day flows are impacted by run-of-river abstractions and diversions for domestic and irrigation requirements as well as streamflow reduction caused by infestation of alien invasive plants in the upper Koonap catchments.	
Physico-chemical variables: PES B/C, Confidence 3	
Data for the PES assessment was of moderate confidence as no DO, temp., turbidity or metals data were available. Data from Q9H002 and Q9H029 were compared for PES. The high number of weirs between EWR KOON 1 and EWR KOON 2 negatively impacted on instream flows, which exacerbated high nutrient levels from irrigation return flows. Higher nutrient levels than at EWR KOON 1 were assumed due to filamentous algae observed during the July 2013 site visit. These algae probably developed due to lower flows and warmer temperatures as the site was not shaded. Although nutrients are bound up in filamentous algae and periphyton at times, it is assumed that these high levels were due to irrigation return flows in the area. Levels would be exacerbated by low flows, as in July 2013.	
Geomorphology: PES B, Confidence: 3.5	
The river remained predominantly in a single channel planform. As with EWR 1, there has been some encroachment of woody vegetation alongside and in to the secondary seasonal/ flood channels, so the macro-channel floor was slightly denser with regard to woody vegetation than may have been encountered under reference conditions, with some encroachment into the secondary flood channels. Instream conditions were regarded as largely natural despite a probable small increase in fines.	
IHI Instream: PES C, Confidence 2.5	**IHI Riparian: PES B/C, Confidence 4**
Instream habitat was mostly affected by reduced baseflows due to abstraction for domestic use and agriculture. Increased algal growth due to increased nutrients impacted available instream habitat. Riparian habitat was impacted by alien invasive species as well as reduced substrate quality due to increased nutrients within the system.	
Riparian vegetation: PES C, Confidence: 3.3	
Marginal: The zone was dominated by sedges (see species list) and the woody rheophyte *G. virgatum*. It is likely that there has been an increase in sedge cover and density due to flow reductions and elevated nutrients.	

Lower: Same as the marginal zone, as well as *Schoenoplectus* and *Marsilea* occurring in the secondary channels which are dependent on perennial or near perennial pools. Upper: Dominated by woody species, mainly *C. caffrum* but also terrestrial species. There has been an increase in woody cover and density, largely due to the absence of megaherbivores. MCB: Dense woody thicket with riparian and terrestrial species. *A. karoo* was dominant; yellowwoods were absent (likely removed for furniture making). Floodplain: Large areas cleared for roads and road maintenance. Now characterised by grasses and low shrub.
Fish: PES C, Confidence: 3
It was estimated that all the expected fish species were still present in this river reach albeit in a slightly to moderately reduced FROC. The FROC of the eel species were estimated to be reduced due to the presence of downstream migration barriers (dams) that may not prevent migration but reduces the success rate of migration. Presence of extensive filamentous algae on rocks as a result of nutrient enrichment reduced the substrate quality for especially juvenile eels. Reduced abundance of food sources (especially macro-invertebrates) were also thought to be responsible for decreased FROC of the eel species as well as *B. anoplus, G. callidus* and *S. bainsii*. The decrease in flow, resulting in loss of habitat abundance and availability was thought to be the primary contributor for slight decreased FROC of *L. umbratus*.
Macro-invertebrates: PES B/C, Confidence: 2.5
The macro-invertebrate community was slightly more diverse than that at EWR 1. A number of taxa scoring 10 or greater were collected, including a number that were not collected at EWR 1 (Crambidae/Pyralidae, Philopotamidae, Calopterygidae). Taxa scoring >12 were Heptageniidae and Baetidae (> 2spp), which were the same as those occurring at EWR 1. The SASS results were slightly higher than EWR 1). The overall PES was improved relative to that of EWR 1 as a result of the relatively large number of more sensitive taxa, and the increased abundances of most taxa at this site. SASS5 Score: 149 Number of Taxa: 23 Average Score Per Taxon (ASPT): 6.5

Table 7.3 shows the water quality present state assessment for EWR KOON 2.

Table 7.3 EWR KOON 2: Present Ecological State: Water Quality

Water quality constituents	RC value	PES value	Category/comment
Salt ions (mg/L)			
Ca, CL, K, Mg, Na, SO_4	No data for aggregated salts		
Nutrients (mg/L)			
SRP	0.026	0.023	C (2)
TIN	0.12	0.32	A (0): Data from Q9H002 B (1): Data from Q9H029
Physical Variables			
pH (5^{th} + 95^{th} %ile)	7.8 and 8.5	7.8 and 8.5	B (10)
Temperature	No data		
Dissolved oxygen			
Turbidity (NTU)	No data	Changes in turbidity appear to be largely natural and related to natural catchment processes such as rainfall runoff, although a bit higher than EWR KOON 1.	B (1)
Electrical Conductivity (mS/m)	76.5 (median: 42.6)	71.2 (median: 33.3)	C (2)
Response variables			
Macro-invertebrate score (MIRAI)	A	B/C (77.6%)	

Water quality constituents	RC value	PES value	Category/comment
Fish score (FRAI)	A	C (63.2%)	
Diatoms	A	SPI=13.8	C (n=1)
Toxics			
Fluoride (mg/L)	0.51	0.49	A (0)
OVERALL SITE CLASSIFICATION (PAI model)			**C (77%)**

The reasons for changes from reference condition had to be identified and understood. These are referred to as causes and sources (http://cfpub.epa.gov/caddis/). The PES for the components at EWR 2 as well as the causes and sources for the PES are summarised in Table 7.4.

Table 7.4 EWR KOON 2: PES Causes and Sources

Causes	Sources
Physico-chemical variables (PES C)	
Increasing nutrients and salts	Extensive irrigation results in increased nutrients, as shown by high algal growth at EWR KOON 2. Algae also develop due to a shallower system and higher temperatures as the site is not shaded. Although salts are expected to be naturally high, levels are exacerbated due to landuse. All conditions are exacerbated by the extensive number of weirs and flow abstractions in the area. (Non-flow related)
Geomorphology (PES B)	
Probable small increase in fine sediment load.	Catchment landuse (agriculture) and return flows from irrigated agriculture.
Encroachment of woody vegetation into the secondary flood channels, which reduces flood capacity of the river.	The loss of browsing pressures from large mammals (elephants, buffalo, kudu), and possibly a reduced incidence of fire, as well as the introduction of invasive alien plants, has allowed a slight increase in woody vegetation. (Non-flow related)
Loss of upper riparian floodplain pockets.	Many of the floodplain pockets/terraces have been cleared for agriculture. These however represent a small proportion of the river area. (Non-flow related)
Riparian vegetation (PES C)	
Removal of indigenous riparian vegetation	Clearing of floodplains (where they exist) for agriculture or road construction, and collection of fire wood and targeted species that have wood useful for furniture making. The presence of goats results in grazing and trampling pressure but has not been considered more intense than would have been by large antelope herds.(Non-flow related)
Altered species composition	Presence of alien species but also the targeted removal of woody species such as yellowwoods and stinkwoods (presumably for furniture). (Non-flow related)
Increased density and abundance of sedges in the marginal and lower zones	Reduced base flows as well as increased nutrients in the water promote sedge growth where habitat is available. (Non-flow and flow related)
Fish (PES C)	
Migration barriers result in decrease FROC of three catadromous eel species that requires free movement between fresh and salt water.	Presence of various dams. (Non-flow related)
Decreased FROC of all species due to competing and predatory introduced	Presence of introduced indigenous *Clarias gariepinus*, *Labeobarbus aeneus, Labeo capensis* and *Tilapia sparrmanii*.

Causes	Sources
(indigenous) species.	(Non-flow related)
Decrease abundance of fish due to decreased availability of habitat.	Reduced base flows due to abstraction and damming. (Flow related)
Decrease in water quality and habitat result in decreased availability of food source (especially macro-invertebrates.	Deteriorated water quality (WWTW, irrigation return flows) and flow alteration (farm dams, irrigation). (Non-flow and flow related)
Macro-invertebrates (PES C)	
Deterioration in water quality.	Agricultural return flows (Non-flow related)
Decreased baseflows.	Abstractions. (Flow related)
Slight alteration in available habitat.	Increase in density of sedges *(Cyperus* spp.*)*

The major issues that have caused the change from reference condition were flow and non-flow related (catchment activities) which included:

- Reduced base flows and flow alteration due to abstractions and agricultural return flows.
- Reduced water quality due to agriculture.
- Migration barriers result in decrease species frequency of occurrence.
- Presence of alien vegetation and removal of indigenous species.

To determine the EcoStatus, the macro-invertebrates and fish component scores firstly had to be combined to determine an instream EC. The instream and riparian ECs were then integrated to determine the EcoStatus. Confidence was used to determine the weight which the EC should carry when integrated into an EcoStatus (riparian, instream and overall). The EC percentages are provided (Table 7.5) as well as the portion of those percentages used in calculating the EcoStatus.

Table 7.5 EWR KOON 2: EcoStatus

INSTREAM BIOTA	Importance Score	Weight
FISH		
1. What is the natural diversity of **fish** species with different flow requirements?	1	60
2. What is the natural diversity of **fish** species with a preference for different cover types?	3	100
3. What is the natural diversity of **fish** species with a preference for different flow depth classes?	3	100
4. What is the natural diversity of **fish** species with various tolerances to modified water quality?	2	70
MACRO-INVERTEBRATES		
1. What is the natural diversity of **macro-invertebrate** biotopes?	4	100
2. What is the natural diversity of **macro-invertebrate** taxa with different velocity requirements?	3	90
3. What is the natural diversity of **macro-invertebrate** taxa with different tolerances to modified water quality?	3	90
Fish	**C**	
Macro-invertebrates	**B/C**	
Confidence rating for instream biological information	**2.8**	
INSTREAM ECOLOGICAL CATEOGORY	**C**	
Riparian vegetation	**C**	
Confidence rating for riparian vegetation zone information	**3.3**	
ECOSTATUS	**C**	

7.4 RECOMMENDED ECOLOGICAL CATEGORY

The REC was determined based on ecological criteria only and considered the EIS, the restoration potential and attainability there-of. As the EIS was MODERATE no improvement was required. The REC was therefore set to maintain the PES. The final EcoClassification results are summarised in Table 7.6.

Table 7.6 EWR KOON 2: Summary of EcoClassification results

Driver Components	PES and REC
IHI HYDROLOGY	C
WATER QUALITY	C
GEOMORPHOLOGY	B
Response Components	**PES and REC**
FISH	C
INVERTEBRATES	B/C
INSTREAM	C
RIPARIAN VEGETATION	C
ECOSTATUS	C
INSTREAM IHI	C
RIPARIAN IHI	B/C
EIS	MODERATE

8 EWR KOON 2 (KOONAP RIVER) – DETERMINATION OF STRESS INDICES

8.1 INDICATOR SPECIES OR GROUP

8.1.1 Fish indicator group: Small Semi-rheophilic species

Refer to Section 4.1.1.

8.1.2 Macro-invertebrate indicator group: Heptageniidae

Heptageniid mayflies have a high preference for fast flows (0.3 - 0.6 m/s) with cobble substrates, and moderate water quality. Lower-scoring (but still useful) indicator taxa were Philopotamiidae, which have a preference for very fast flow over cobbles (VFCS) and moderate water quality; Pyraliidae, which have a preference for slow flow (0.1 - 0.3 m/s) through vegetation, and Calopterygiidae which have a preference for slow flow (0.1 - 0.3 m/s) through cobbles. Both the latter taxa prefer moderate water quality.

8.2 STRESS FLOW INDEX

A stress flow index was generated for every component (fish and macro-invertebrates) and season (wet and dry), and describes the progressive response of flow dependent biota to flow reduction. The stress flow index was generated in terms of habitat and hence biotic response. The integrated stress curve represents the highest stress for either fish or macro-invertebrates at a specific flow for the wet and dry season (Table 8.1). The integrated stress index is provided in Figure 8.1.

Table 8.1 EWR KOON 2: Component and integrated stress index

Stress	DRY SEASON discharge (m^3/s)			WET SEASON discharge (m^3/s)		
	Macro-invertebrates	Fish	Integrated	Macro-invertebrates	Fish	Integrated
0	0.65	0.65	0.65	1.41	1.41	1.41
1	0.5	0.55	0.55	1.1	1.21	1.21
2		0.46	0.46	0.98	1.11	1.11
3	0.39	0.39	0.39	0.81	0.94	0.94
4	0.28	0.29	0.29	0.61	0.82	0.82
5	0.17	0.18	0.18	0.44	0.63	0.63
6	0.1	0.14	0.14	0.29	0.35	0.35
7	0.08	0.12	0.12	0.17	0.17	0.17
8	0.03	0.08	0.08	0.1	0.11	0.11
9	0.008	0.03	0.03	0.03	0.08	0.08
10	0	0	0	0	0	0

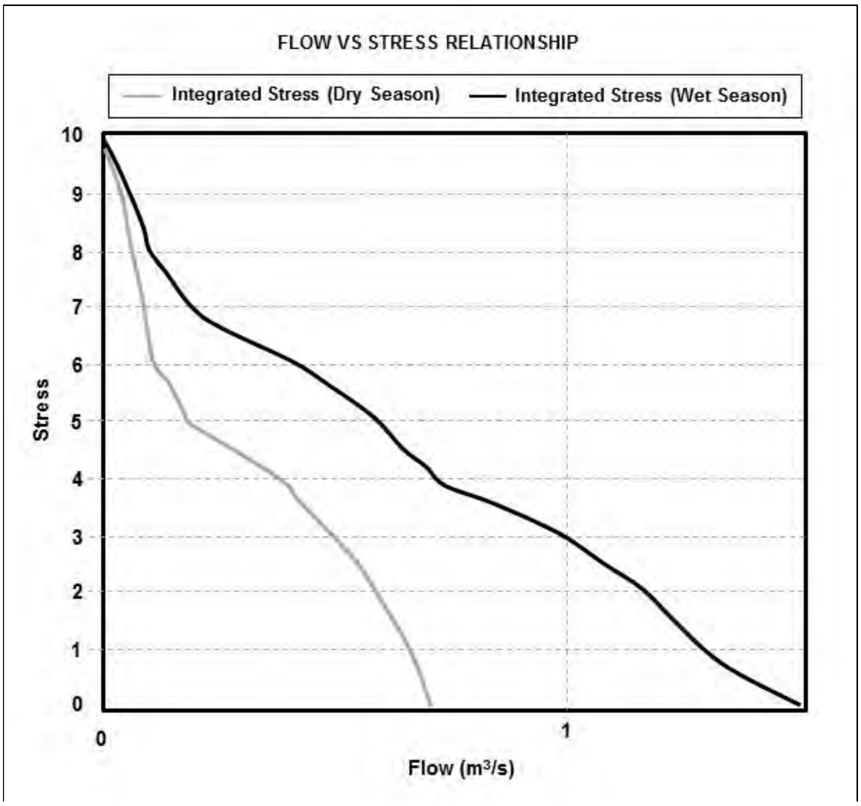


Figure 8.1 EWR KOON 2: Stress index

Table 8.2 and 8.3 provides the summarised biotic response for the integrated stresses during dry and wet season.

Table 8.2 EWR KOON 2: Integrated stress and summarised habitat/biotic responses for the dry season

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or biotic responses
0	0.65	Maximum base flow	Selected on the basis of the maximum base flow based on a separated base flow time series. October was selected as the lowest base flow month and the maximum base flow was set at the 20th percentile.
1	0.55	Fish	A 19% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in some stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).
2	0.46	Fish	A 39% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in some stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).
3	0.39	Fish Inverts	**Fish:** A 52% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in some stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type). **Inverts:** Very fast flow habitat still present. Vegetation inundated and stems available as habitat for juveniles. All indicator taxa still present.
4	0.29	Fish Inverts	**Fish:** A 69% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in some stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type). **Inverts:** Loss of FCS habitat and rapid reduction in fast flow

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or biotic responses
			habitat. Instream and marginal vegetation stems are inundated and provide good habitat and refuge for juveniles. All indicator taxa still present.
5	0.18	Fish Inverts	**Fish:** A 90% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type), although it will still be adequate to maintain the fish population in the dry season. **Inverts:** Fast flow present at riffle upstream of cross section. Habitat dominated by slow flows over coarse substrates. Instream and marginal vegetation stems inundated and provide excellent habitat and refuge for juveniles. All indicator taxa still present. Preferred hydraulic habitat for Philopotamidae (velocity > 0.6m/s) absent.
6	0.14	Fish	A 95% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type), although it will still be adequate to maintain the fish population in the dry season.
7	0.12	Fish	A 97% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in severe stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).
8	0.08	Fish	Complete loss of fast habitats (100% reduced from natural maximum baseflow). This will limit the FROC of all fish species since pool quality (depth and water quality) will also be affected negatively under these low flows.
9	0.03	Fish	Complete loss of fast habitats (100% reduced from natural maximum baseflow). This will limit the FROC of all fish species since pool quality (depth and water quality) will also be severely affected under these low flows.
10	0.001	No flow, surface water only	

Table 8.3 EWR KOON 2: Integrated stress and summarised habitat/biotic responses for the wet season

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or biotic responses
0	1.41	Maximum base flow	Selected on the basis of the maximum base flow based on a separated base flow time series. March was selected as the highest base flow month and the maximum base flow was set at the 20^{th} percentile.
1	1.21	Fish	A 16% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in some stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).
2	1.11	Fish	A 29% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in some stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).
3	0.94	Fish	A 45% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in some stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).

Integrated stress	Flow (m^3/s)	Driver (fish/inverts/both)	Habitat and/or biotic responses
4	0.82	Fish	A 49% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in moderate stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).
5	0.63	Fish	A 61% reduction in the availability of fast habitats (FVS, FS, FI and FD) compared to natural conditions, expected to result in moderate stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).
6	0.35	Fish	A 83% reduction in the availability of fast habitats (FVS, FS ,FI and FD) compared to natural conditions, expected to result in moderate stress exerted on the fish assemblage (especially juvenile and sub-adult eels with a preference for this habitat type).
7	0.17	Fish Inverts	**Fish:** Limited availability of fast habitats (97% reduced from natural maximum baseflow). **Inverts:** Site sampled at this flow. All hydraulic habitat classes present, small area of fast flow in riffle upstream of cross section, and shallow moderate to fast flow through the critical habitat. Marginal and instream vegetation inundated only just sufficiently to create some habitat (but not a large contributor to overall habitat).
8	0.11	Fish	Almost complete loss of fast habitats (99% reduced from natural maximum baseflow). This will severely limit the FROC of all fish species since pool quality (depth and water quality) will also be affected negatively under these low flows.
9	0.08	Fish	Complete loss of fast habitats (100% reduced from natural maximum baseflow). This will limit the FROC of all fish species since pool quality (depth and water quality) will also be severely affected under these low flows.
10	0	Zero discharge, pools remain	Complete loss of fast habitats with zero flows, only pools available.

9 EWR KOON 2 (KOONAP RIVER) - DETERMINATION OF EWR SCENARIOS

9.1 ECOCLASSIFICATION SUMMARY OF EWR KOON 2

EWR KOON 2		
EIS: MODERATE Highest scoring metrics were rare and endangered species (*Sandelia bainsii*) intolerance of instream biota to no flow and physico-chemical changes, diversity of instream habitat types, four unique riparian species and important riparian migration corridors. **PES: C** ▪ Reduced base flows and flow alteration due to abstractions and agricultural return flows. ▪ Reduced water quality due to agriculture. ▪ Migration barriers result in decrease species frequency of occurrence. ▪ Presence of alien vegetation and removal of indigenous species. **REC: C** EIS was MODERATE and the REC was therefore to maintain the PES.	**Driver Components**	**PES and REC**
	IHI HYDROLOGY	C
	WATER QUALITY	C
	GEOMORPHOLOGY	B
	Response Components	**PES and REC**
	FISH	C
	INVERTEBRATES	B/C
	INSTREAM	C
	RIPARIAN VEGETATION	C
	ECOSTATUS	C
	INSTREAM IHI	C
	RIPARIAN IHI	B/C
	EIS	MODERATE

9.1 HYDROLOGICAL CONSIDERATIONS

The wettest and driest months were identified as March and October respectively. Note that October was selected as the driest month based on separated base flows. The lowest flow month based on total flows was July.

9.2 STRESS REQUIREMENTS

Stress requirements were set for low flows only. Floods were recommended separately (Section 9.4). The integrated stress index was used to identify required stress levels at specific durations for the wet and dry month/season.

The stress requirements and motivations for the PES (REC) are provided in Table 9.1 and graphically illustrated in Figure 9.1.

Table 9.1 EWR KOON 2: Stress requirements and summary of motivations

% Stress duration	Integrated stress	Discharge (m^3/s)	Motivation
PES and REC: C EcoStatus		**Fish: C**	**Macro-invertebrates: B/C**
DRY SEASON			
5% drought	9.9	0.004	**Fish:** The minimum allowable flows to maintain the PES cannot be decreased from the PD, since the stress in the dry season is already extremely high (especially on fast habitats) and a further reduction in flows will result in a possible decrease in EC.
20%	9.8	0.007	
40%	9.7	0.01	
60%	7	0.12	
WET SEASON			
5% drought	9.9	0.003	**Fish:** A slight decrease from the PD separated baseflow can be allowed under drought conditions, since no rheophilic species are present and the fish assemblage is expected to be able to survive and be maintained in the PES at this very high stress level.
20%	9.8	0.001	**Fish:** The flow under PD is already critically low at this flow duration (based on separated base flows) and a very slight further decrease can be allowed. This is due to the fact that no rheophilic species are present and the fish assemblage should be able to survive and be maintained in the PES at this very high stress level.
40%	8.5	0.1	**Fish:** The flow under PD is already critically low at this flow duration (based on separated base flows) and a very slight further decrease can be allowed. This is because no rheophilic species are present and the fish assemblage should be able to survive and be maintained in the PES at this very high stress level.

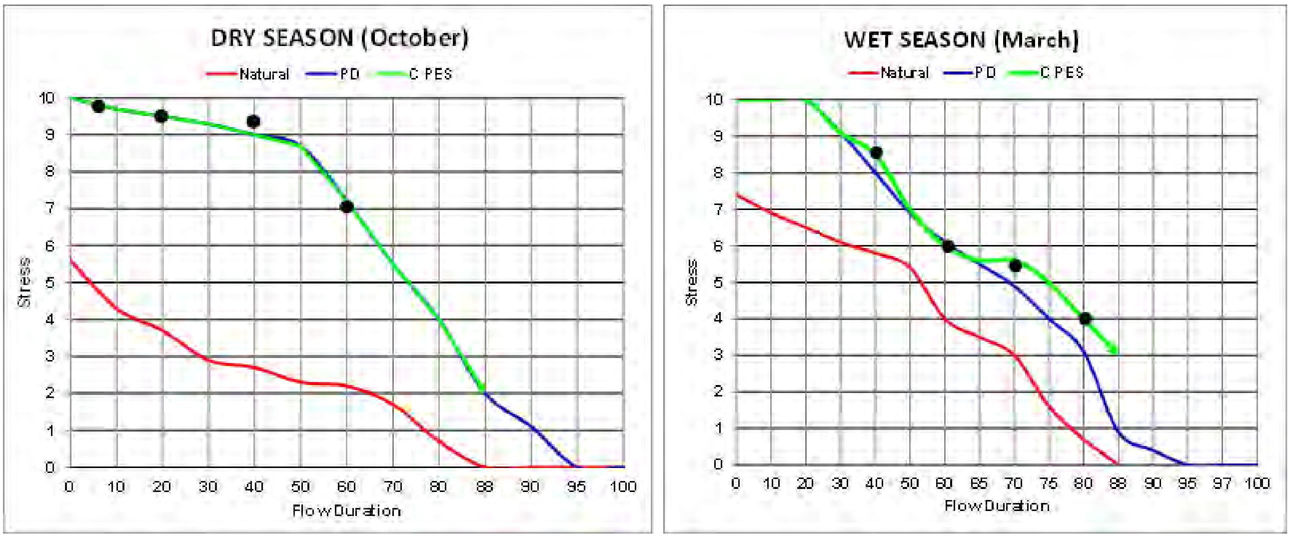


Figure 9.1 EWR KOON 2: Stress duration curve for a PES and REC

9.3 FINAL LOW FLOW REQUIREMENTS

To achieve the final low flow requirements, a process in the RDERM is followed to adjust the C initial desktop estimate to specialist requirements. The C estimate is aligned to present day and the shape of the curve is adjusted to the requirements. Once the final C EWR is available then the other categories are derived from the C EWR. The parameters that were changed are available in a report generated by the RDERM (Appendix C) and the final results are graphically illustrated in Figure 10.1 (Section 10).

9.4 HIGH FLOW REQUIREMENTS

The high flow classes were identified as follows:

- The geomorphologist and riparian vegetation specialist identified the range of flood classes required and listed the functions of each flood.
- The instream specialists then indicated which of the instream flooding functions were addressed by the floods identified for geomorphology and riparian vegetation (indicated by a ✓ in Table 9.2).
- Any of the floods required by the instream biota and not addressed by the floods already identified, were then described (in terms of ranges and functions) for the instream biota.

Detailed motivations are provided in Table 9.2 and final high flow results are provided in Table 9.3.

Table 9.2 EWR KOON 2: Identification of instream functions addressed by the identified floods for geomorphology and riparian vegetation

Flood Class Flood Range (m^3/s) (Daily ave.)	Geomorphology and riparian vegetation motivation	Fish flood functions						Invertebrate flood functions			
		Migration cues & spawning	Migration habitat (depth etc.)	Clean spawning substrate	Create nursery areas	Resetting water quality	Inundate vegetation for spawning	Breeding and hatching cues	Clear fines	Scour substrate	Reach or inundate specific areas
CLASS 1 (3-4 m^3/s)	**Geomorphology:** These frequent small flushes will entrain and remove fines from the bed of the active channel, and activate the secondary channel to recharge the small pools. **Vegetation**: Flood 50% of the *C. textilis* population or to its upper limit at least four times in the wet season. This flood prevents the establishment of terrestrial or alien species in the marginal zone; provides recruitment opportunities in the marginal and lower zones, but at the same time can scour vegetation to maintain habitat patchiness and species diversity; stimulates growth and reproduction and distributes propagules downstream and prevents encroachment of marginal zone vegetation towards the channel.	√	√	√	√	√	√	√	√	√	√
CLASS II (8-10 m^3/s)	**Geomorphology:** These small floods will activate the small mid-channel bar as well as the levee adjacent to the secondary channel, and scour the bed and secondary channels. **Vegetation:** Required to activate mid-channel bar and secondary channel where *Marsilea* grows, also fill pools in this area.	√	√	√	√	√	√	√	√	√	√
CLASS III (15-20 m^3/s)	**Vegetation:** Flood the *C. sexangularis* population to its upper limit each year or alternate year (for species that favour seasonal inundation/activation).	√	√	√	√	√	√		√	√	√
CLASS IV (50-70 m^3/s)	**Vegetation:** Required to elicit recruiting opportunities for *C. caffrum* - samaras from the previous season lie in the leaf litter and wetting by floods (or rainfall) will promote germination on site or in other areas where hydrochory takes place.	√	√	√	√	√	√		√	√	√

The number of high flow events required for each EC is provided in Table 9.3. The availability of high flows was verified using the observed data at gauge Q9H002.

Table 9.3 EWR KOON 2: The recommended number of high flow events required

Flood Class (Peak in m^3/s)	Macro-invertebrates	Fish	Vegetation	Geomorphology	FINAL*	Months	Daily average	Duration
PES and REC: C ECOSTATUS								
CLASS 1 (3-4 m^3/s)			4	3	4	Dec, Jan, Feb, Mar	4	3
CLASS II (8-10 m^3/s)			1:1	1:1	1:1	Feb	9	4
CLASS III (15-20 m^3/s)			1:2		1:2**	Apr	15	4
CLASS IV (50-70 m^3/s)			1:3		1:3	Mar	60	5

* Final refers to the agreed on number of events considering the individual requirements for each component.
** Refers to frequency of occurrence, i.e. the flood will occur once in two years.

9.5 FINAL FLOW REQUIREMENTS

The low and high flows were combined to produce the final flow requirements for each EC as:

- An EWR table, which shows the results for each month for high flows and low flows separately (Table 9.4). Floods with a high frequency were not included in the modelled results as they cannot be managed.
- An EWR rule table which provides the recommended EWR flows as a duration table, linked to a natural trigger (natural modelled hydrology in this case). EWR rules were supplied for total flows as well as for low flows only (Table 9.5).

The low flow EWR rule table is useful for operating the system, whereas the EWR table must be used for operation of high flows.

Table 9.4 EWR KOON 2: EWR table for PES and REC: C

Month	Low Flows		High Flows (m^3/s)	
	60% (m^3/s)	Drought (90%) (m^3/s)	Daily average	Duration (days)
OCTOBER	0.025	0.004		
NOVEMBER	0.047	0.041		
DECEMBER	0.040	0.037	4	3
JANUARY	0.049	0.032	4	3
FEBRUARY	0.037	0.034	4 9	3 4
MARCH	0.103	0.047	4 60	3 5
APRIL	0.064	0.039	15	4
MAY	0.045	0.040		
JUNE	0.044	0.040		
JULY	0.047	0.040		
AUGUST	0.052	0.041		
SEPTEMBER	0.051	0.041		

Table 9.5 EWR KOON 2: Assurance rules (m^3/s) for PES and REC: C

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	0.517	0.265	0.115	0.073	0.044	0.025	0.014	0.008	0.004	0.003
Nov	0.927	0.516	0.151	0.096	0.078	0.047	0.044	0.044	0.041	0.019
Dec	1.082	0.565	0.313	0.158	0.119	0.040	0.040	0.040	0.037	0.017
Jan	0.844	0.390	0.176	0.139	0.084	0.049	0.035	0.035	0.032	0.016
Feb	0.962	0.574	0.204	0.099	0.070	0.037	0.037	0.037	0.034	0.017
Mar	1.134	0.884	0.619	0.391	0.176	0.103	0.074	0.057	0.047	0.043
Apr	1.038	0.552	0.269	0.163	0.110	0.064	0.045	0.045	0.039	0.026
May	0.904	0.367	0.161	0.095	0.088	0.045	0.044	0.044	0.040	0.028
Jun	0.586	0.327	0.177	0.145	0.086	0.044	0.044	0.043	0.040	0.027
Jul	0.555	0.326	0.155	0.137	0.088	0.047	0.044	0.043	0.040	0.028
Aug	0.548	0.322	0.139	0.129	0.086	0.052	0.044	0.044	0.041	0.029
Sep	0.545	0.292	0.132	0.131	0.088	0.051	0.043	0.043	0.041	0.022

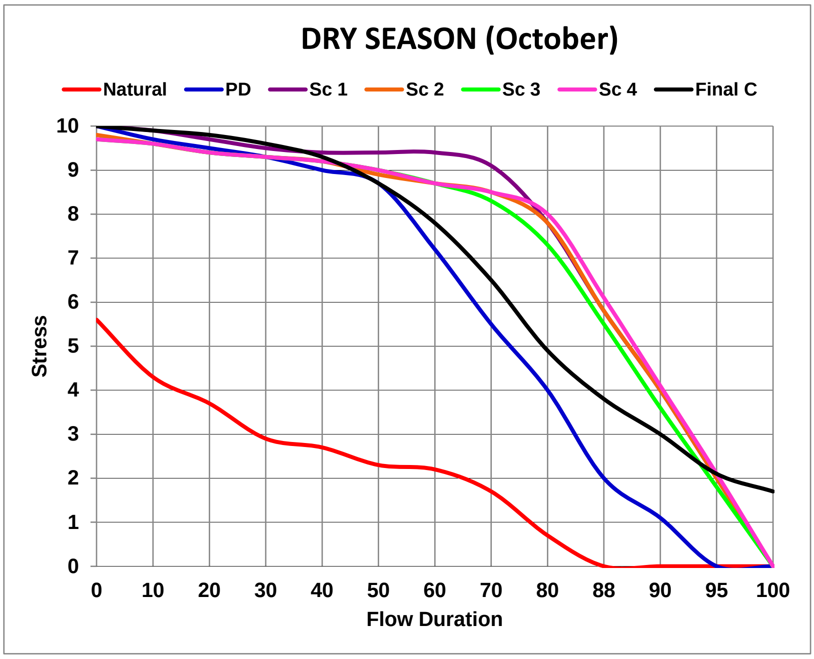
Table 9.6 Summary of results as a percentage of the natural MAR (NMAR)

					Long term mean					
EWR site	PES	REC	NMAR (MCM)	PMAR (MCM)	Low flows (MCM)	Low flows (%NMAR)	High flows (MCM)	High flows (%NMAR)	Total flows (MCM)	Total (%NMAR)
KOON 2	C	C	77.54	65.30	6.917	8.9	9.624	12.41	16.541	21.33

10 ECOLOGICAL CONSEQUENCES AT EWR KOON 2

The four scenarios (referred to as Sc 1 - Sc 4) were evaluated to determine the ecological consequences in terms of change in ecological state from the present. The consequences for each component are provided and the overall consequences is then summarised.

The stress duration graphs which include the final requirements as well as the scenarios are provided below for EWR 2 (Figure 10.1). For up to 40% of the time in the dry season, all scenarios provide similar or less stresses than Present Day, but increased stresses (lower flows) during the remainder of the time. During the wet season the stress is significantly higher relative to natural (red curve) and PD (blue curve).



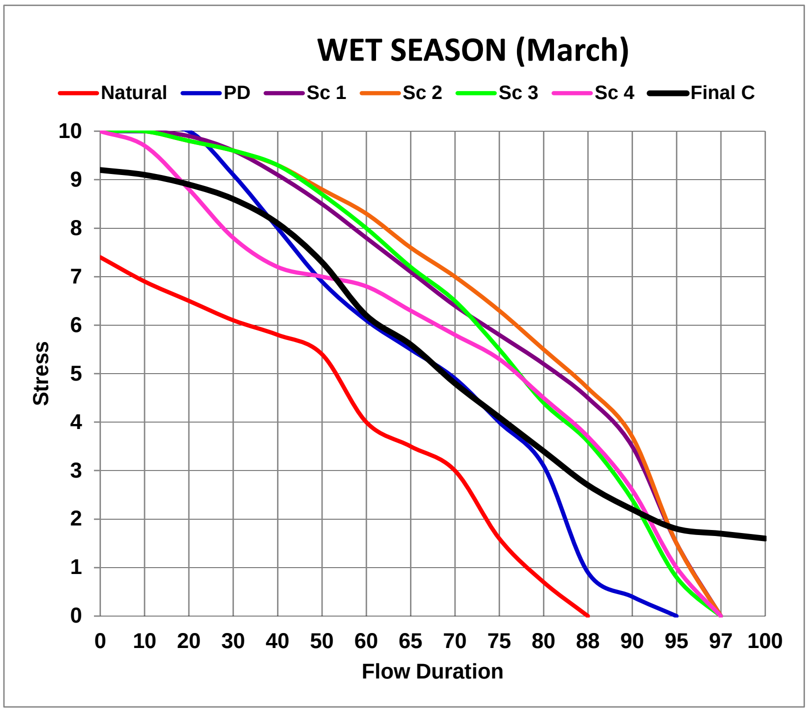


Figure 10.1 EWR KOON 2: Stress duration for the operational scenarios

10.1 DRIVER COMPONENTS

PES (REC)	Sc 1	Sc 2	Sc 3	Sc 4
Physico-chemical				
C	C (68.4%)	C (68.4%)	C (68.4%)	C (68.4%)
	Dry Season: It is expected that instream water quality conditions will deteriorate under all scenarios, with an expected increase in nutrients levels, salts and toxics (due to increased irrigation return flows), and impacts on temperature and oxygen due to lower flows. Note that conditions are very poor under all scenarios in May to August, particularly for Sc1.		**Wet Season:** All scenarios in the wet season show less water than PD for approximately 70% of the time. Note that Sc 2 and 3 are also maximum additional development scenarios for irrigation. Sc 3 shows better (higher) flows as compared to other scenarios for some of the time due to the smaller dam size.	
Geomorphology				
B	B/C (79.6%)	B/C (79.6%)	B (68.4%)	B/C (79.6%)
As with EWR 1, this site is currently in a good geomorphological condition (B EC). The proposed (Foxwood) dam is far upstream and affects a smaller proportion of the EWR 2 catchment in terms of altered runoff and sediment patterns. Sc 3 has a minimal impact on high flows (relative to present day) and is not expected to result in a decline in the PES. Sc 1, 2 and 4 are expected to result in a slight decline in ecological condition, resulting in a B/C condition, due to reduced floods.				

10.2 BIOTIC RESPONSES

PES (REC)	Sc 1	Sc 2	Sc 3	Sc 4
Riparian vegetation				
C	C (66.1%)	C/D (61.8%)	C (72.2%)	C (67.1%)
	Sc 1: High flows are reduced, but maintain seasonality. This is likely to result in woody encroachment due to reduced flooding stress, especially *C. caffrum* and *A. karoo*. Low flows are generally reduced with more zero flow in winter and less in summer. Sedges are activated for 50% of the time from Feb to Sep (PD) but only in Mar and Apr for Sc 1. Sedges are inundated for 5% of the time in summer (PD) and never at 5% for Sc 1. Inundation of sedges is less than PD in Mar and Oct, but activation is more. Sedges are therefore likely to encroach and increase in abundance in the marginal and lower zones. Both *G. virgatum* and *S. mucronata* are inundated less than PD but are not water stressed to the point of mortality. Both *G. virgatum* and *S. mucronata* are therefore likely to increase in abundance in the marginal and lower zones. **Sc 2:** High flows are reduced, but maintain seasonality. This is likely to result in woody encroachment due to reduced flooding stress, especially *C. caffrum* and *A. karoo*. Low flows are generally reduced but with less zero flows. Sedges are activated for 50% of the time from Feb to Sep (PD) but only in Mar and Nov for Sc 2. Sedges are inundated for 5% of the time in summer (PD) and never at 5% for Sc 2. Inundation of sedges is less than PD in Mar and Oct, but activation is more. Sedges are therefore likely to encroach and increase in abundance in the marginal and lower zones. Both *G. virgatum* and *S. mucronata* are inundated less than PD but are not water stressed to the point of mortality. Both *G. virgatum* and *S. mucronata* are therefore likely to increase in abundance in the marginal and lower zones. **Sc 3:** High flows are close to PD. This is likely to result in little change to the woody component of the vegetation. Low flows are generally reduced but with less zero flows. Sedges are activated for 50% of the time from Feb to Sep (PD) but never for Sc 3. Sedges are inundated for 5% of the time in summer (PD % Sc 3). Inundation of sedges is less than PD in Mar and Oct, but activation is more. Sedges are therefore likely to encroach and increase in abundance in the marginal and lower zones. Both *G. virgatum* and *S. mucronata* are inundated less than PD but are not water stressed to the point of mortality. Both *G. virgatum* and *S. mucronata* are therefore likely to increase in abundance in the marginal and lower zones. **Sc 4:** High flows are reduced, but maintain seasonality. This is likely to result in woody encroachment due to reduced flooding stress, especially *C. caffrum* and *A. karoo*. Low flows are generally reduced but with less zero flows. Sedges are activated for 50% of the time from Feb to			

<table>
<tr><th>PES (REC)</th><th>Sc 1</th><th>Sc 2</th><th>Sc 3</th><th>Sc 4</th></tr>
<tr><td></td><td colspan="4">Sep (PD) but only in Mar for Sc 4. Sedges are inundated for 5% of the time in summer (PD) and never at 5% for Sc 4. Inundation of sedges is less than PD in Mar and Oct, but activation is more. Sedges are therefore likely to encroach and increase in abundance in the marginal and lower zones. Both G. virgatum and S. mucronata are inundated less than PD but are not water stressed to the point of mortality. Both G. virgatum and S. mucronata are therefore likely to increase in abundance in the marginal and lower zones.</td></tr>
<tr><td colspan="5">Fish</td></tr>
<tr><td>C</td><td>D (42.8%)</td><td>C/D (58.9%)</td><td>D (54.1%)</td><td>C (69.6%)</td></tr>
<tr><td></td><td colspan="2">Dry Season:
Sc 1 - 3: Flows will be lower than PD and it can be assumed that habitat conditions will deteriorate in the dry season.
Sc 4: Although the flows improved in some dry season months (e.g. Oct) compared to PD, it is notably lower during some other dry season months (Jun, Jul, Aug, and Sep). The habitat for fish is therefore expected to deteriorate overall in the dry season, but may remain within the same EC (C).</td><td colspan="2">Wet Season:
Sc 1: There will be a notable deterioration in the availability of especially fast habitats compared to PD. The EC can be expected to deteriorate by at least one category.
Sc 2 and Sc 3: There will be a slight deterioration in the availability of especially fast habitats compared to PD. The EC can be expected to deteriorate by at least one category.
Sc 4: A general improvement is expected in the wet season, compared to PD conditions. A slight improvement can therefore be expected in the fish assemblage due to improved habitat availability and condition.</td></tr>
<tr><td colspan="5">Sc 1: The overall trend expected under this scenario is a decrease in the EC to a D. This is expected because flows and thus habitat suitability will be notably lower than under PD.
Sc 2 and Sc 3: The overall trend expected under this scenario is a decrease in the EC to a C/D due to flows and thus habitat suitability that will be somewhat lower than under PD. Sc 3 will have a slightly greater impact than Sc 2.
Sc 4: Although there may be a slight deterioration in the dry season, the wet season improvement is expected to increase the overall conditions in the fish assemblage and result in an overall improvement. Although slightly higher than PD, it is expected to still remain in a category C.</td></tr>
<tr><td colspan="5">Macro-invertebrates</td></tr>
<tr><td>C</td><td>C/D (60%)</td><td>C/D (60%)</td><td>C/D (60%)</td><td>C/D (60%)</td></tr>
<tr><td></td><td colspan="2">Sc 1 - 4: For a large proportion of the time in the dry season (October), at lower flows, these scenarios are similar to PD and there will be little effect on the macro-invertebrate community. For the remainder of the dry season (during higher flows) the flows are raised relative to natural; there will be more water at a regulated discharge, but less floods (particularly Sc 1, 2 and 4).</td><td colspan="2">Sc 1 - 3: During the wet season (March), baseflows for Sc 1, 2, and 3 are reduced for the majority of the time relative to PD and this effect, together with the change in flood regime, is likely to govern the overall response of the macro-invertebrates.
Sc 4: The higher stress periods in the wet season are associated with raised flows relative to PD, which will be of benefit to the macro-invertebrates during summer.

Floods are drastically reduced in Sc 1, 2, and 4 but less so in Sc 3. The change in flood regime will result in an increase in fines and loss of the normal habitat scouring and cleansing function, and an overall deterioration in cobble habitat quality over time. It will also result in densification of sedge stands in the channel. However these will not necessarily represent a useful habitat for macro-invertebrates, due to the shallow flows.</td></tr>
<tr><td colspan="5">Sc 1 and Sc 2: The macro-invertebrate PES will reduce to a C/D and over time to a D EC.
Sc 3 and Sc 3: The changes in the macro-invertebrate community may be slightly less under these scenarios, and more gradual, but overall deterioration to a C/D is also predicted.</td></tr>
</table>

10.3 SUMMARY OF ECOLOGICAL CONSEQUENCES

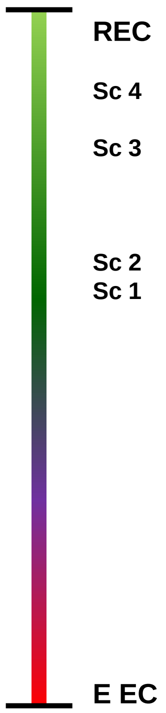
The ecological consequences of the operational flow scenarios at EWR KOON 2 are provided in Table 10.1.

Table 10.1 Ecological consequences of operational flow scenarios at EWR KOON 2

	PES and REC	Sc 1	Sc 2	Sc 3	Sc 4
WATER QUALITY	C	C-	C-	C-	C-
GEOMORPH	B	B/C	B/C	B	B/C
Response Components	PES and REC	Sc 1	Sc 2	Sc 3	Sc 4
FISH	C	D	C/D	D	C
INVERTS	B/C	C/D	C/D	C/D	C/D
INSTREAM	C	D	C/D	D	C
RIP VEG	C	C	C/D	C	C
ECOSTATUS	C	C/D	C/D	C-	C-

Scenarios 1, 2, and 4 results in a general deterioration in water quality due to the accumulative impacts of increased irrigation return flows while under Sc 3 the overall deterioration in water quality is slightly less due to the smaller dam. Geomorphology is impacted to a lesser extent by all scenarios than at EWR 1 because a smaller proportion of the EWR 2 catchment in terms of altered runoff and sediment patterns are affected. Scenario 1 - 4 impact the instream components to varying degrees due to decreased flows in the dry season and increased floods in the wet season leading to habitat alteration as well as habitat loss. Scenario 1 and 2 results in an EcoStatus lower than the PES. Scenario 3 and 4 result in the PES EcoStatus being maintained but the REC is not met for all components under both scenarios.

The degree to which each scenario at EWR KOON 2 meets the REC is summarised in Figure 10.2 below.



EWR KOON 2				
Scenario	Sc 1	Sc 2	Sc 3	Sc 4
EWR 2	X	X	✓	✓

Figure 10.2 Summary of the impacts of operational flow scenarios at EWR KOON 2

11 CONSEQUENCES OF OPERATIONAL SCENARIOS ON GOODS AND SERVICES

11.1 OVERVIEW

The Koonap extends through four local municipalities – the Blue Crane Route, Makana, Nkonkobe and Nxuba. The former two are located in the Cacadu District Municipality and the latter two in the Amathole District Municipality. All are located in the Eastern Cape Province.

The Koonap River considered in this study is located in three quaternary catchments – Q92C, Q92E and O92E, totalling an area of 1730km^2. Based on Census 2001, a total population within the three catchments is 30,770, or a projected population of 36,640 for 2012. Average household density within the catchment is estimated to be 17 individuals per square kilometre. The spatial distribution of this population shows a sharp transition from low density rural populations to more concentrated peri-urban and urban populations, largely associated with the town of Adelaide. Rural populations are essentially those associated with commercial farming enterprises.

Two major aspects are important with regard to these aspects. The first is that provision of ecological Goods and Services needs to be linked to a user base. In the context of the Koonap River system under consideration the low population density means that the magnitude of utilisation is likely to be low. The second is that the kinds of communities that intersect with the system under consideration means that the significance of ecological goods utilisation, particularly those linked with provisioning services and critical to livelihood dependence is also likely to be low.

As set out in Section 2.4 the range of potential ecological Goods and Services, given the limitations with respect to user significance and magnitude, were tested with the teams biophysical experts against the four operational scenarios proposed and at the two EFR sites that have been examined.

11.2 EWR KOON 1: IMPACTS OF SCENARIOS

This section examines the impacts of operational scenarios per major category of ecological Goods and Services considered at EWR KOON 1. With respect to the potential impact on fish species it should be noted that for subsistence fishing abundance as well as utilisation is low. Recreational fishing is virtually non-existent. As such scenario impacts are low both in terms of magnitude and significance.

Table 11.1 provides the impacts on subsistence fishing at EWR KOON 1. All scenarios bar Sc 1 would have a marginal positive impact.

Impacts and the related scores are colour coded as outlined below and are relevant to all tables in this Chapter.

- Score (0.011 to 0.5); Colour - Red: Negative impacts of a high significance
- Score (0.51 to 0.99); Colour – Orange: Marginal negative impact
- Colour – White: No impact.
- Score (1.01 to 1.5); Colour – Blue: Marginal positive impact.
- Score (above 1); Colour – Green: Major positive impact

Table 11.1 EWR KOON 1: Impacts of scenarios on subsistence fishing

Common name	Scientific name	Abundance	Utilisation	Sc 1	Sc 2	Sc 3	Sc 4
Eels and Moggel	Eels: *Anguilla mossambica, A. bicolor, A. marmorata* Moggel: *Labeo umbratus.*	Very Low	Low	0.8	1	1.1	1.1

Also important with respect to provisioning services are the botanical species that are resident in the riparian zone or influenced by this zone and have some utilitarian value. These are set out in Table 11.2. While some species are abundant the actual utilisation is low and as such scenario impacts are low in terms of significance. For most species scenario impacts are positive, albeit marginally so.

Table 11.2 EWR KOON 1: Impacts of scenarios on botanical species with utilitarian value

Common name	Scientific name	Abundance	Utilisation	Sc 1	Sc 2	Sc 3	Sc 4
Sedges potential to use for weaving							
Sedges	*Cyperus textilis*	High	Low	1.1	0.9	1	0.9
Sedges	*C. sexangularis*	Moderate	Low	1.1	1	1	1
Reeds potential to use for building materials							
Reeds	*Phragmites australis*	Low	Low	1.1	1.1	1.1	1.1
Grazing: Grasses assessed as a group							
Grasses	*Cynodon dactylon* *Eragrostis plana* *Eragrostis planiculmis* *Panicum deustum* *Panicum maximum* *Paspalum dilatatum* *Paspalum distichum* *Pennisetum sphacelatum* *Setaria sphacelata* var. *sericea* *Sporobolus fimbriatus*	Low	Low	1.1	1.1	1.1	1.1
Trees: Woody vegetation							
Assorted general firewood		Very High	Low	1.2	1.2	1.1	1.2
Trees: Specific wood							
Wild Olive used for furniture	*Olea europaea* subsp. *africana*	Low	Low	1	1	1	1
Acacias used for furniture and firewood	*Acacia karoo, A. caffra*	Moderate	Low	1.2	1.2	1.1	1.2
Blue Gums used for structural and firewood	*Eucalyptus camaldulensis*	Low	Low	1	1	1	1
Wattle used for structural and firewood	*A. mearnsii*	Moderate	Low	1.2	1.1	1.2	1.2
Stinkwood used for furniture	*Celtis africana*	Moderate	Low	1	1	1	1

Other ecological Goods and Services considered are captured in Table 11.3. Again significance of change given the intersection with utilisation is low. All scenarios have a negative impact on water quality and the ability of the system to dilute waste. Other impacts are either marginally positive marginally negative or are not expected to change. Loss of flood conveyance (through indigenous and exotic vegetation encroachment and land use transformation in riparian areas and floodplains, usually enabled by lowered flows) is worth noting as it potentially causes hundreds of millions of Rands of damages during large floods. The reduced flood conveyance causes increased flood damage from progressively smaller discharges. For rivers, this is more economically important than flood attenuation.

Table 11.3 EWR KOON 1: Scenario impacts on other Goods and Services with utilitarian value

Comments	Utilisation	Sc 1	Sc 2	Sc 3	Sc 4
Waste assimilation					
Related to irrigation return flows.	Low	0.7	0.9	0.8	0.9
Waste dilution					
Treatment works small but some dilution.	Medium	0.8	0.9	0.9	0.9
Cultivated floodplains					
High utilisation of the small floodplain pockets for agriculture. With fewer, smaller floods, slightly more area could be viably converted to agricultural lands. Increase of cultivation is positive (increased utilisation), but negative for ecology.	High	1.1	1	1	1
Recreational river use					
Little use and no expected to change significantly under any scenarios mooted.	Very low	1	1	1	1
Ritual use					
Little use and no expected to change significantly under any scenarios mooted.	Low	1	1	1	1
Flood attenuation					
Ability of the river to slow down and attenuate erosive peak flows, reducing velocities. The steep, narrow river is not particularly good at flood attenuation. Expected vegetation encroachment associated with reduced floods may slightly increase the ability.	Low	1.05	1	1	1
Flood conveyance					
Lands and associated infrastructure are protected from inundation and erosion. Reduced flows and loss of small floods promote encroachment of woody vegetation, which results in lowered flood conveyance (and higher flood levels) during infrequent large floods.	Moderate	0.7	0.9	1	0.9
Stream flow regulation					
The steep, narrow river is not particularly good at regulating stream flow. There are no large attenuating wetlands which can slowly drain to regulate downstream flows. Flows will become less regular under some scenarios however, simply as a result of the release patterns.	Very low	0.8	1.1	0.95	1.1
Groundwater recharge					
Some reduction in recharge could be expected where base flows are reduced/stopped.	Very low	0.7	1.1	0.9	1.1

11.3 EWR KOON 2: IMPACTS OF SCENARIOS

This section examines the scenario impacts per major category of ecological Goods and Services considered at EWR KOON 2. With respect to the potential impact on fish species it should be noted that for subsistence fishing abundance as well as utilisation is low. The same applies to recreational fishing. As such scenario impacts are low both in terms of magnitude and significance. A summary of impacts are provided in Table 11.4. All scenarios bar Sc 4 would have a negative impact. In the case of Sc 1 the impact would be very negative as most species available for both recreational and subsistence fishing would be expected to decline dramatically.

Table 11.4 EWR KOON 2: Scenario impacts on subsistence and recreational fishing

Resources	Common name	Scientific name	Abundance	Utilisation	Sc 1	Sc 2	Sc 3	Sc4
Subsistence fishing	Eels and moggel and introduced species: Yellowfish, labeos, Catfish.	*A. mossambica, A. bicolor, A. marmorata, L. umbratus, L. capensis, Labeobarbus aeneus, Clarias gariepinus.*	Very Low	Low	0.5	0.8	0.7	1.1
Recreational fishing	Introduced species: Yellowfish, labeos, Catfish.	*L. capensis, L. aeneus C.gariepinus.*	Very Low	Low	0.5	0.8	0.7	1.1

As with EWR KOON 1 also important with respect to provisioning services are the botanical species that are resident in the riparian zone or influenced by this zone and have some utilitarian value and are set out in Table 11.5. Again while some species are abundant the actual utilisation is low. As such, scenario impacts are low in terms of significance. For most species scenario impacts are positive, albeit marginally so. Other than the impact on sedges the picture for EWR KOON 2 is very similar to that fro EWR KOON 1.

Table 11.5 EWR KOON 2: Scenario impacts on botanical species with utilitarian value

Common name	Scientific name	Abundance	Utilisation	Sc 1	Sc 2	Sc 3	Sc 4
Sedges potential to use for weaving							
Sedges	*C. textilis*	High	Low	1.1	1.1	1.1	1.1
	C. sexangularis	Moderate	Low	1.1	1.1	1.1	1.1
Reeds potential to use for building materials							
Reeds	*Phragmites australis*	Low	Low	1.1	1.1	1.1	1.1
Grazing grasses assessed as a group							
Grasses	*C. dactylon*, *E. plana*, *E. planiculmis*, *P. deustum*, *P. maximum*, *P. dilatatum*, *P. distichum*, *P. sphacelatum*, *S. sphacelata* var. *sericea*, *S. fimbriatus*	Low	Low	1.1	1.1	1.1	1.1
Trees: Woody vegetation							

Common name	Scientific name	Abundance	Utilisation	Sc 1	Sc 2	Sc 3	Sc 4
Assorted general firewood		Very High	Low	1.2	1.2	1.1	1.2
Trees: Specific wood							
Wild Olive used for furniture	*O. europaea* subsp. *africana*	Low	Low	1	1	1	1
Acacias used for furniture and firewood	*A. karoo, A. caffra*	Moderate	Low	1.2	1.2	1.1	1.2
Blue Gums used for structural and firewood	*E. camaldulensis*	Low	Low	1	1	1	1
Wattle sued for structural and firewood	*A. mearnsii*	Moderate	Low	1.2	1.1	1.2	1.2
Stinkwood used for furniture	*C. africana*	Moderate	Low	1	1	1	1

Other ecological Goods and Services considered are captured in Table 11.6. Again significance of change given the intersection with utilisation is low. All scenarios have a negative impact on water quality and the ability of the system to dilute waste. Other impacts are either marginally positive marginally negative or are not expected to change. An exception is stream flow regulation and groundwater recharge. Both are subject to decline under Sc 1, 2 and 3. Impacts associated with Sc1 are particularly high.

Table 11.6 EWR KOON 2: Scenario impacts on other Goods and Services with utilitarian value

Comments	Utilisation	Sc 1	Sc 2	Sc 3	Sc 4
Waste assimilation					
Related to irrigation return flows but irrigation more and with larger return flow than EWR KOON 1.	Low	1	0.7	0.7	0.7
Waste dilution					
Treatment works small but some dilution.	Medium	1	0.9	0.9	0.9
Cultivated floodplains					
High utilisation of the small floodplain pockets for agriculture. With fewer, smaller floods, slightly more area could be viably converted to agricultural lands. Increase of cultivation is positive (increased utilisation), but negative for ecology.	High	1.05	1	1	1
Recreational river use					
Little use and no expected to change significantly under any scenarios mooted.	Very low	1	1	1	1
Ritual use					
Little use and no expected to change significantly under any scenarios mooted.	Low	1	1	1	1
Flood attenuation					
Ability of the river to slow down and attenuate erosive peak flows, reducing velocities. The steep, narrow river is not particularly good at flood attenuation. Expected vegetation encroachment associated with reduced floods may slightly increase the ability.	Low	1.05	1	1	1
Flood conveyance					
Lands and associated infrastructure are protected from inundation and erosion. Reduced flows and loss of	Moderate	0.9	0.95	1	0.95

Comments	Utilisation	Sc 1	Sc 2	Sc 3	Sc 4
small floods promote encroachment of woody vegetation, which results in lowered flood conveyance (and higher flood levels) during infrequent large floods.					
Stream flow regulation					
The steep, narrow river is not particularly good at regulating stream flow. There are no large attenuating wetlands which can slowly drain to regulate downstream flows. Flows will become less regular under some scenarios however, simply as a result of the release patterns.	Very low	0.5	0.8	0.8	1
Groundwater recharge					
Some reduction in recharge could be expected where base flows are reduced/stopped.	Very low	0.5	0.8	0.8	1

12 CONCLUSIONS AND RECOMMENDATIONS

12.1 ECOCLASSIFICATION

The EcoClassification results are summarised below in Table 12.1.

Table 12.1 EcoClassification Results summary

EWR KOON 1

EIS: MODERATE
Highest scoring metrics were intolerance of instream biota to no flow and physico-chemical changes, diversity of instream habitat types, unique riparian species and important riparian migration corridors.

PES: C
- Deteriorated water quality (increased salinity and nutrients) due to WWTW and irrigation return flows.
- Flow alteration due to farm dams and irrigation leading to reduced baseflows.
- Clearing for agriculture, targeted removal of woody species and the presence of alien vegetation.

REC: C
EIS was MODERATE and the REC was therefore to maintain the PES.

Driver Components	PES and REC
IHI HYDROLOGY	C
WATER QUALITY	B/C
GEOMORPHOLOGY	B
Response Components	**PES and REC**
FISH	C
INVERTEBRATES	C
INSTREAM	C
RIPARIAN VEGETATION	C
ECOSTATUS	C
INSTREAM IHI	C
RIPARIAN IHI	C
EIS	MODERATE

EWR KOON 2

EIS: MODERATE
Highest scoring metrics were rare and endangered species (*Sandelia bainsii*) intolerance of instream biota to no flow and physico-chemical changes, diversity of instream habitat types, four unique riparian species and important riparian migration corridors.

PES: C
- Reduced base flows and flow alteration due to abstractions and agricultural return flows.
- Reduced water quality due to agriculture.
- Migration barriers result in decrease species frequency of occurrence.
- Presence of alien vegetation and removal of indigenous species.

REC: C
EIS was MODERATE and the REC was therefore to maintain the PES.

Driver Components	PES and REC
IHI HYDROLOGY	C
WATER QUALITY	C
GEOMORPHOLOGY	B
Response Components	**PES and REC**
FISH	C
INVERTEBRATES	B/C
INSTREAM	C
RIPARIAN VEGETATION	C
ECOSTATUS	C
INSTREAM IHI	C
RIPARIAN IHI	B/C
EIS	MODERATE

12.1.1 Confidence in results

The confidence in the EcoClassification process is provided below (Table 12.2) and was based on data and information availability and EcoClassification where:

- Data and information availability: Evaluation based on the adequacy of any available data for interpretation of the Ecological Category.
- EcoClassification: Evaluation based on the confidence in the accuracy of the Present Ecological State.

The confidence score is based on a scale of 0 – 5 and colour coded where:

0 – 1.9: Low | 2 – 3.4: Moderate | 3.5 – 5: High

These confidence ratings are applicable to all scoring provided in this chapter.

Table 12.2 Confidence in EcoClassification

EWR site	Data and information availability									EcoClassification								
	Hydrology	Water Quality	Geomorphology	IHI	Fish	Macro-invertebrates	Vegetation	Average	Median	Hydrology	Water Quality	Geomorphology	IHI	Fish	Macro-invertebrates	Vegetation	Average	Median
KOON 1	4.0	3.5	3.0	3.5	2.0	2.5	4.0	**3.2**	**3.5**	4	3.5	3.5	3.3	3.0	3.0	3.4	**3.4**	**3.4**
KOON 2	4.0	3.5	3.0	3.5	2.0	2.5	4.0	**3.2**	**3.5**	4	3.0	3.5	3.3	3.0	2.5	3.3	**3.2**	**3.3**

12.1.2 Conclusions

The confidence in data availability for drivers and riparian vegetation was High at both EWR sites. The confidence in biotic data availability was generally moderate as site information was limited to one field visit. The confidence in the EcoClassification was Moderate due to limited field data for the instream components although driver information was of high confidence.

12.2 ECOLOGICAL WATER REQUIREMENTS

12.2.1 Summary of final results

The final flow requirements are expressed as a percentage of the natural and PD MAR in Table 12.3.

Table 12.3 Summary of results as a percentage of the natural and PD MAR

EWR site	PES	REC	NMAR (MCM)	PMAR (MCM)	Long term mean					
					Low flows (MCM)	Low flows (%NMAR)	High flows (MCM)	High flows (%NMAR)	Total flows (MCM)	TOTAL (%NMAR)
KOON 1	C	C	62.93	52.04	2.997	4.8	7.08	11.25	10.076	16
KOON 2	C	C	77.54	65.30	6.917	8.9	9.624	12.41	16.541	21.33

12.2.2 Confidence in low flows

The question the confidence assessment should answer is the following:

> 'How confident are you that the low flow (with the associated high flows) recommended will achieve the EC?'

To determine the confidence, one should consider:

- The quality of available data; and
- whether your requirement represents the critical requirement. For example, if the macro-invertebrate stress requirement of a 4 at 30% was the final recommendation, and fish was 7 at 30%, then there should be a very high confidence that the recommended flow will achieve the EC for fish. In this case, Fish will receive more flow than required, so even if the fish data availability and understanding of habitat requirements are of low confidence, the confidence that the much higher flow, recommended based on macro-invertebrate flow requirements, will cater for fish requirements and therefore should result in a high confidence that the EC will be maintained/achieved.

The low flow confidence evaluation was representative of the component (fish or macro-invertebrates) confidence which drove the flow requirement. If both components drove the flow requirement, then an average of the confidence rating is provided.

Table 12.4 provides the confidence in the low flow requirements of the biotic components (fish, macro-invertebrates). The columns shaded in green indicate which of these components dictated the final requirements. The final confidence is representative of these requirements.

Table 12.4 Low flow confidence ratings for biotic responses

EWR site	Fish	Inverts	Rip veg	COMMENT	Overall confidence
KOON 1	2	2	3	**Fish:** Very low fish species diversity and no rheophilic species present. Only juvenile and sub-adult eels have preference for fast (flow sensitive) habitats. Fish was therefore of limited use in setting flow requirements. **Inverts:** The habitat requirements of the majority of the macro-invertebrate community should be met by the low flows provided during wet and dry season, however as no sampling has been done at these low flows the confidence is low. **Rip veg:** Indicators used to assess low flow requirements were *C. textilis, G. virgatum* and *S. mucronata*. Generally there is no inundation of any of the marginal zone vegetation, but flows are at sufficient levels to ensure survival through the low flow season. The assessment for March shows that inundation of marginal zone vegetation only starts at the 60th percentile. This together with the high flow requirements however will result in more inundation than this and is sufficient for vegetation to grow and reproduce.	**2**
KOON 2	2	2	3	**Fish:** Very low fish species diversity and no rheophilic species present. Only juvenile and sub-adult eels have preference for fast (flow sensitive) habitats. Confidence in the flow requirements is therefore low. **Inverts:** As this site is downstream of a tributary, it is assumed that the problem inherent at EWR 1 will be catered for by natural hydrology during the early summer months (dry season: October).	**2**

EWR site	Fish	Inverts	Rip veg	COMMENT	Overall confidence
				Rip veg: Indicators used to assess low flow requirements were *C. textilis*, *C. sexangularis* and *G. virgatum*. No change from present day in October. The assessment for March shows that inundation of marginal zone vegetation is negligible during low flows. This together with the high flow requirements however will result in more inundation than this and is sufficient for vegetation to grow and reproduce.	

12.2.3 Confidence in high flows

The question the confidence assessment should answer is the following:
'How confident are you that the high flow (with the associated low flows) recommended will achieve the EC?'

To determine the confidence, one should consider:

- The quality of available data; and
- whether the vegetation requirement was increased to cater for a larger requirement recommended for geomorphology. Then the riparian vegetation confidence could be high as more water is provided.

The high flow confidence (Table 12.5) represents an average of the riparian vegetation and geomorphology confidence as these two components determine the flood requirements.

Table 12.5 Confidence in recommended high flows

EWR site	Fish	Inverts	Rip veg	Geomorphology	COMMENT	Overall confidence
KOON 1	3	2.5	3	4	**Fish:** Floods set will be adequate to serve all flood requirements for fish, especially in terms of providing cues and depth for migration, flushing of habitats and provision of breeding and nursery habitats. **Inverts:** All habitat requirements that will provide the habitat quality to keep the indicator taxa and the overall community in an overall C category (scouring of fines, relocation of cobbles through rolling, thinning of sedges etc.) are met by the high flows requested. **Riparian vegetation:** A profile at the site was surveyed and the vegetation surveyed onto the profile. This together with hydraulics for the profile means that high confidence flows can be determined for different components of the riparian vegetation. In addition there was an abundance of riparian indicator species at the site and covered all sub-zones within the riparian zone (marginal, lower and upper zones).	**3.5**

EWR site	Fish	Inverts	Rip veg	Geomorphology	COMMENT	Overall confidence
					Geomorphology: Confidence in the flood requirements is high. Potential Bed Material Sediment Transport modelling was undertaken to identify the effective discharge (the flood class responsible for most transport of sediment at the site), and these results correlated well with the floods estimated from the vegetation at the site.	
KOON 2	3	2.5	3	2	**Fish:** As above.	**2.5**
					Inverts: As above.	
					Riparian vegetation: A profile at the site was surveyed and the vegetation surveyed onto the profile. This together with hydraulics for the profile means that high confidence flows can be determined for different components of the riparian vegetation. In addition there was an abundance of riparian indicator species at the site and covered all sub-zones within the riparian zone (marginal, lower and upper zones).	
					Geomorphology: Confidence in the flood requirements is moderate because there is no nearby flow gauge, and therefore it was not possible to undertake Potential Bed Material Sediment Transport modelling. Flood requirements were estimated from the morphological cues (sedimentary features, which were unfortunately unpaired) at the EWR site.	

12.2.4 Confidence in hydrology

If natural hydrology was used to guide requirements, then that confidence will carry a higher weight than normal. Hydrology confidence is provided from the perspective of its usefulness to the EWR assessment. This will be different than the confidence in the hydrology for water resources management and planning. The scale of requirements is very different, and therefore high confidence hydrology for water resource management purposes often does not provide sufficient confidence for EWR assessment. The confidence in hydrology is provided in Table 12.6.

Table 12.6 Confidence in hydrology

EWR site	Natural hydrology	Present hydrology	Observed hydrology	Local knowledge/information	Comment	Confidence: Median	Confidence: Average
KOON 1	4	4	3	2	The availability of an observed gauge at the site with a long data record, results in relatively moderate to high confidence.	3.5	3.3
KOON 2	4	4	1	2	The lack of a gauge results in a lower confidence than EWR KOON 1.	3	2.8

12.2.5 Overall confidence in EWR results

The overall confidence in the results are linked to the confidence in the hydrology and hydraulics as the hydrology provides the check and balance of the results and the hydraulics convert the requirements in terms of hydraulic parameters to flow. Therefore, the following rationale was applied when determining the overall confidence:

- If the hydraulics confidence was lower than the biological responses column, the hydraulics confidence determined the overall confidence. Hydrology confidence was also considered, especially if used to guide the requirements.
- If the biological confidence was lower than the hydraulics confidence, the biological confidence determined the overall confidence. Hydrology confidence was also considered. If hydrology was used to guide requirements, than that confidence would be overriding in determining the overall confidence.

The overall confidence in the EWR results is provided in Table 12.7.

Table 12.7 Overall Confidence in EWR results

EWR site	Hydrology	Biological responses Low flows	Hydraulic: Low Flows	OVERALL: LOW FLOWS	COMMENT	Biophysical responses: High flows	Hydraulics: High Flows	OVERALL: HIGH FLOWS	COMMENT
EWR KOON 1	3.5	2	1	**1**	The drought flows were of low confidence as the EWRs were lower than the measured flow. This is because the lowest and highest observed discharges are 0.20 and 20 m^3/s, respectively.	3.5	4	**3.5**	Above measured flow range.
EWR KOON 2	3	2	2	**2**	The lowest and highest observed discharges are 0.18 and 3.7 m^3/s, respectively, and the presence of filamentous algae influences flow resistance estimation, particularly at low flows.	2.5	3	**2.5**	Above measured flow range.

12.3 RECOMMENDATIONS

There is low confidence in the biota information and EWR assessment. The low confidence can be addressed by improving the baseline through the implementation of an Ecological Water Resources Monitoring (EWRM) programme and should be initiated as soon as possible. An improvement in hydraulic confidence could be achieved by obtaining a calibration in the region of the recommended low flows (EWR KOON 1 and EWR KOON 2) and during a flood (EWR KOON 2).

12.4 ECOLOGICAL CONSEQUENCES OF OPERATIONAL SCENARIOS

12.4.1 Comparison of the ecological consequences of the Scenarios at the EWR sites

A comparison of the consequences of the scenarios at EWR KOON 1 and EWR KOON 2 are provided in Table 12.8.

Table 12.8 Comparison of ecological consequences at EWR KOON 1 and EWR KOON 2

KOONAP RIVER				
EWR SITE	Sc 1	Sc 2	Sc 3	Sc 4
EWR 1	✓	✓	✓	✓
EWR 2	X	X	✓	✓

This analysis shows that none of the scenarios fully meet the ecological objectives at both sites. Scenario 3 and 4 maintain the REC at EWR 1 and EWR 2, although not for all components and has a higher risk of failure. Scenario 1 and 2 are not recommended as these scenarios result in an EC dropping below the PES at EWR KOON 2.

12.4.2 Optimised Scenario

Although Sc 4 does not meet the ecological objectives, it does represent the best of the four options. This scenario includes a desktop estimate of the low flow EWR. To determine an optimised scenario, Sc 4 should be used as the basis and must include the EWR (low flows) as determined during this task.

12.5 CONSEQUENCES OF OPERATIONAL SCENARIOS ON GOODS AND SERVICES

Given the nature of ecological Goods and Services utilisation in the area under consideration, none of the scenarios have an impact with either a magnitude or significance that would be considered as a fatal flaw at either EWR KOON1 or EWR KOON 2. With regard to ranking scenarios at EWR KOON 1 the following applies:

- Although Sc 1 has positive impacts, it also has the most negative impacts and the nature of these impacts is such that this scenario cannot be considered as a viable option in future.
- Sc 2 and Sc 3 have very similar impacts and is marginally more preferable to Sc 1.
- Sc 4 is the most preferable and has more positive impacts than negative with an overall positive impact on ecological Goods and Services.

With regard to ranking scenarios at EWR KOON 2 the following applies:

- Although Sc 2 has positive impacts, it also has the most negative impacts and the nature of these impacts is such that this scenario cannot be considered as a viable option in future.
- Sc 1 is marginally better than Sc 2.
- Sc 3 is marginally more preferable to Sc 2 as it has a marginally positive impact on ecological Goods and Services.

- Sc 4 is the most preferable and has more positive impacts than negative with an overall positive impact on ecological Goods and Services.

13 REFERENCES

Brown, C and King, J. (2001). Environmental flow assessment for rivers. A summary of the DRIFT process. Southern Waters information Report No 01/00.

Department of Water Affairs and Forestry (DWAF). (1999). Resource Directed Measures for Protection of Water Resources. Volume 3: River Ecosystems Version 1.0, Pretoria.

Department of Water Affairs and Forestry (DWAF). (2008). Methods for determining the water quality component of the Ecological Reserve. Report prepared for Department of Water Affairs and Forestry, Pretoria, South Africa by P-A Scherman of Scherman Consulting.

Department of Water Affairs (DWA), South Africa. (2012). Green Drop Report, Chapter 5: Eastern Cape Province.

Department of Water Affairs, South Africa (DWA). (2013a). Koonap River: Resource Unit Delineation and Identification of Hotspots: Prepared by Rivers for Africa for ARUP.

Department of Water Affairs, South Africa (DWA). (2013b). Assessment of the Present Ecological State (PES), Ecological Importance (EI) and Ecological Sensitivity (ES) for sub quaternary reaches in secondary drainage regions of South Africa. Department of Water Affairs, South Africa. In preparation.

Hughes, DA and Forsyth, DA. (2006). A generic database and spatial interface for the application of hydrological and water resource models. Computers and Geosciences 32, 1389-1402.

Hughes DA and Louw, D. (2010). Integrating hydrology, hydraulics and ecological response into a flexible approach to the determination of environmental water requirements for rivers. Environmental Modelling and Software 25: 910-918.

Hughes DA, Louw D, Desai AY, Birkhead AL. (2011). Development of a revised desktop model for the determination of the Ecological Reserve for Rivers. WRC report No 1856/1/11.

Iversen, TM, Madsen, BL and Bøgestrand, J. (2000). River conservation in the European Community, including Scandinavia.In: “Global Perspectives on River Conservation: Science Policy and Practice", Edited by P.J. Boon, B.R. Davies and G.E. Petts, John Wiley & Sons Ltd.

IWR Source-to-Sea (eds). (2004). A Comprehensive Ecoclassification and Habitat Flow Stressor Response Manual. Prepared for IWQS: DWAF, Project no: 2002-148.

King, JM and Louw, D. (1998). Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology. Aquatic Ecosystem Health and Management 1: 109-124.

Kleynhans, CJ, Louw, MD, Thirion, C Rossouw, NJ, and Rowntree, K. (2005). River EcoClassification: Manual for EcoStatus determination (Version 1). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. KV 168/05.

Kleynhans, CJ. (2007). Module D: Fish Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2) Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 330/08.

Kleynhans, CJ and Louw, MD. (2007). Module A: EcoClassification and EcoStatus determination in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT329-08.

Kleynhans, CJ and Louw, D. (2007a). Reference frequency of occurrence of fish species in South Africa. Report produced for the Department of Water Affairs and Forestry (Resource Quality Services) and the Water Research Commission. Report produced for the Department of Water Affairs and Forestry (Resource Quality Services) and the Water Research Commission.

Kleynhans, CJ, Mackenzie, J and Louw, MD. (2007b). Module F: Riparian Vegetation Response Index. In River EcoClassification: Manual for EcoStatus Determination (version 2) Water Research Commission Report No. TT 333/08. Joint Water Research Commission and Department of Water Affairs and Forestry report, Pretoria, South Africa.

Kleynhans, CJ, Louw, MD, and Graham, M. (2009). Module G: EcoClassification and EcoStatus determination in River EcoClassification: Index of Habitat Integrity (Section 1, Technical manual) Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT330/08.

Mucina, L and Rutherford, MC (eds). (2006). The Vegetation of South Africa, Lesotho and Swaziland. Strelizia 19. South African National Biodiversity Institute, Pretoria.

Noss, RF. (1990). Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4:355-364.

O'Keeffe, JH, Hughes, DA and Tharme, R. (2002). Linking ecological responses to altered flows, for use in enviromental flow assessments: the Flow Stress-Response method. Proceedings of the International Association of Theoretical and Applied Limnology, 28, 84-92.

Rountree, K and du Preez, L. (in prep). Geomorphology Driver Assessment Index. Joint Water Research Commission and Department of Water Affairs and Forestry report. Water Research Commission, Pretoria, South Africa.

SANBI POSA. (2009). Plants of southern Africa: An online checklist. Version 3.0.

Scherman Colloty and Associates. (2013). Review and update of the 1999 EIS/PES of South African rivers including expansion to priority tributaries and wetlands according to quaternary catchments: WMAs 12 and 15.

Scott, LEP, Skelton, PH, Booth, AJ, Verheust, L, Harris, R and Dooley, J. (2006). Atlas of Southern African Freshwater Fishes. Smithiana Publication, Monograph 2. The South African Institute for Aquatic Biodiversity, Grahamstown, South Africa.

Skead, CJ (compiler). (2009). Historical plant incidence in southern Africa. Strelizia 24. South African National Biodiversity Institute, Pretoria.

Thirion, C. (2007). Module E: Macroinvertebrate Response Assessment Index in River EcoClassification: Manual for EcoStatus Determination (version 2). Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT330/08.

14 APPENDIX A: ECO-HYDRAULICS

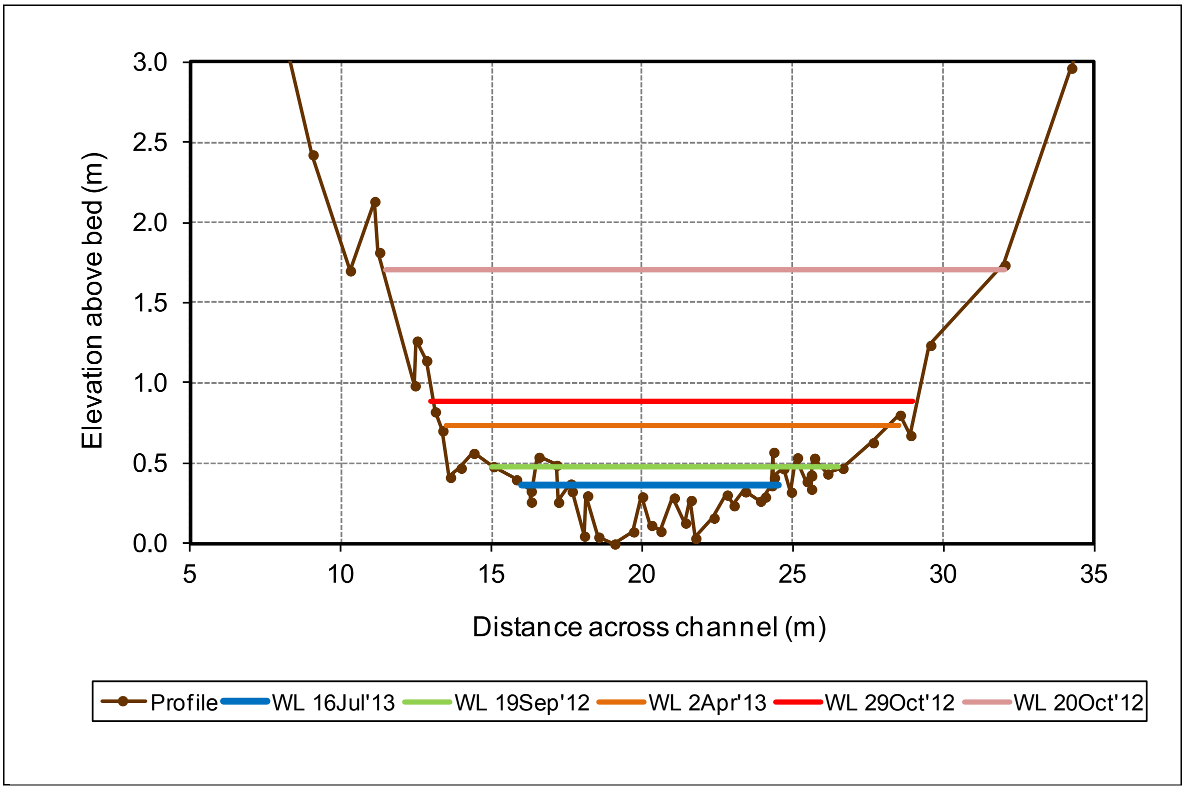
14.1 METHODOLOGY

The application of holistic methods for ecological flow determination (refer to Tharme, 1996) requires environmental water requirements (EWRs) to be expressed as discharge rates (including their temporal characteristics) through assessments of the presence of suitable habitat for certain biota at different flows. The interface between the way in which flow requirements are assessed and expressed is through the results of hydraulic measurements, analyses and modelling at sites along rivers. The primary product of these hydraulic analyses are relationships between discharge and the following determinants, which have been found over the course of numerous flow assessments, to be the most useful: depth (maximum and average), velocity (average), wetted perimeter, and width of the water surface. The discharge-depth (or rating) relationship is fundamental to hydraulic analysis, and is generally derived from a combination of measured and synthesized data (refer to Rowlston *et al*. (2000), Birkhead (1999), Jordanova *et al*. (2004), Hirschowitz *et al*. (2007) and Birkhead (2010) for descriptions of procedures for deriving hydraulic information for use in EWRs in South Africa). Once the rating relationship for a river section has been developed, the relationships between discharge and the other hydraulic parameters (listed above) may readily be computed using the cross-sectional geometry, and are generally provided in tabular format using look-up tables (refer to Section 14.4).

The cross-sectional profile plots and look-up tables comprise the "standard hydraulic data" used in EWR determinations in South Africa. Ecologists use these standard hydraulic data with the aid of site assessments and photographs to determine the quantity and quality of hydraulic habitat at different flows. Substantial experience and interpretation are required to provide assessments of site-based and reach-based biological habitats using cross-sectional surveys and the results of one-dimensional hydraulic analyses (biological habitat refers to the integration of the different components defining habitat, *e.g.* hydraulic, substrate and cover attributes for fish). Procedures have therefore been developed for using standard hydraulic information as the basis for quantifying hydraulic habitat for fish (refer to Hirschowitz *et al*. (2007) and Birkhead (2010) for an explanation of the method). The method allows the assessment of abundance of different flow classes to be applied more consistently in EWRs, and has been used in this study.

14.2 DATA COLLECTION

The initial field trip to the Koonap River sites took place in September 2012, when cross-sections, vegetation markers and water levels were surveyed, and discharge was measured (refer to Figure 14.1 and Table 15.1). Two further field trips to both sites took place in April and July 2013 to collect additional rating (stage-discharge) data; and an additional field visit to Site 1 took place in October 2012.



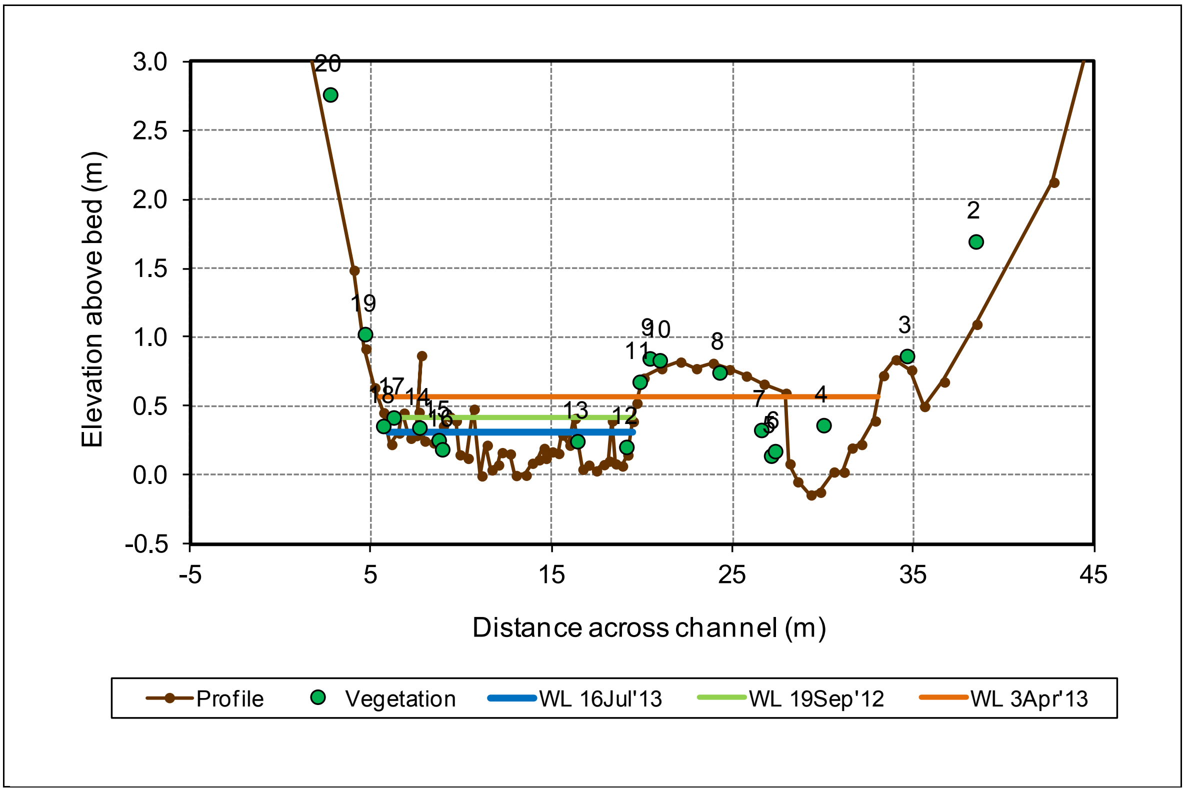


Figure 14.1 Cross-sectional profiles surveyed at EWR KOON 1 (top) and EWR KOON 2 (bottom) on the Koonap River

Table 14.1 Hydraulic data collected at EWR KOON 1 and EWR KOON 2 on the Koonap River

Site	Date	Discharge (m^3/s)	Depth (m)[1]
1	16/07/2013	0.20	0.36
	19/09/2012	1.0	0.48
	02/04/2013	2.2	0.73
	29/10/2012	3.7	0.89
	20/10/2012	20.6	1.70
2	16/07/2013	0.18	0.45
	19/09/2012	0.82	0.56
	03/04/2013	3.7	0.17

1 Relative to lowest elevation on the cross-sectional profiles.

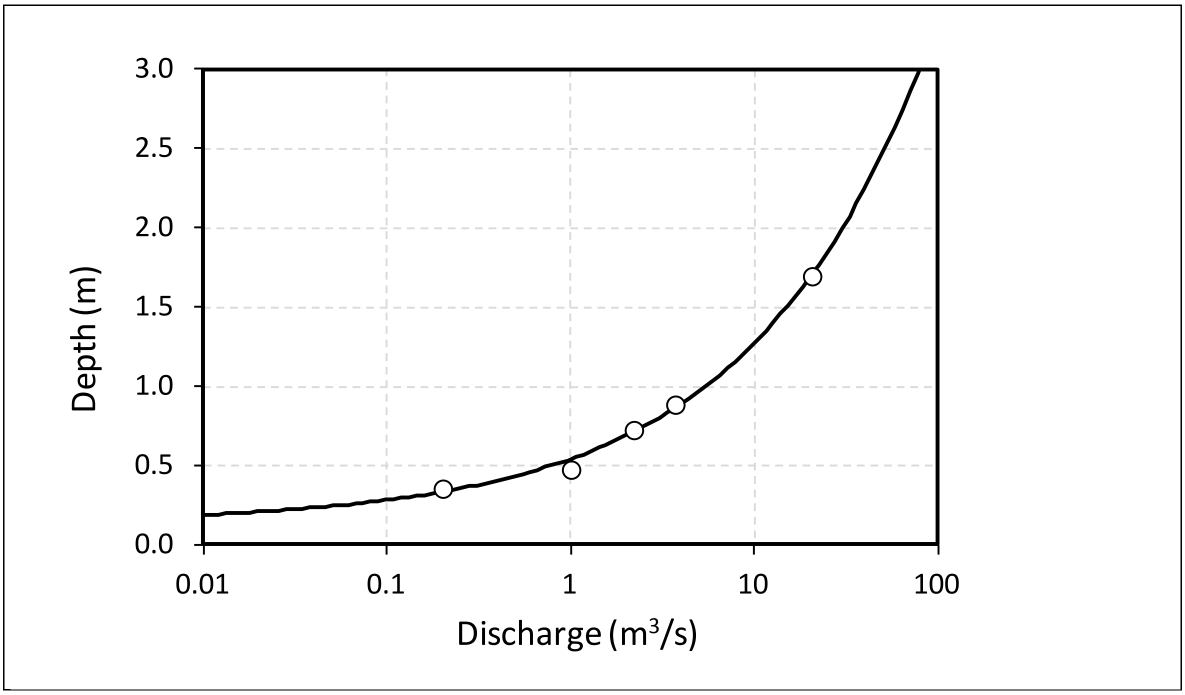
14.3 MODELLING

A continuous rating relationships were fitted by regression to the measured rating data collected at EWR KOON 1, and to extended (using Manning's resistance relationship) rating data at EWR KOON 2. The rating parameters are provided in Table 14.2 and the rating plots are provided in Figure 14.2.

14.4 RESULTS

Table 14.2 Rating coefficients in $y = aQ^b + c$ for the cross-section surveyed at Sites 1 and 2, where y is depth (m) and Q is discharge (m^3/s)

Site	*a*	*b*	*c*
EWR KOON 1	0.404	0.448	0.138
EWR KOON 2	0.160	0.530	0.257



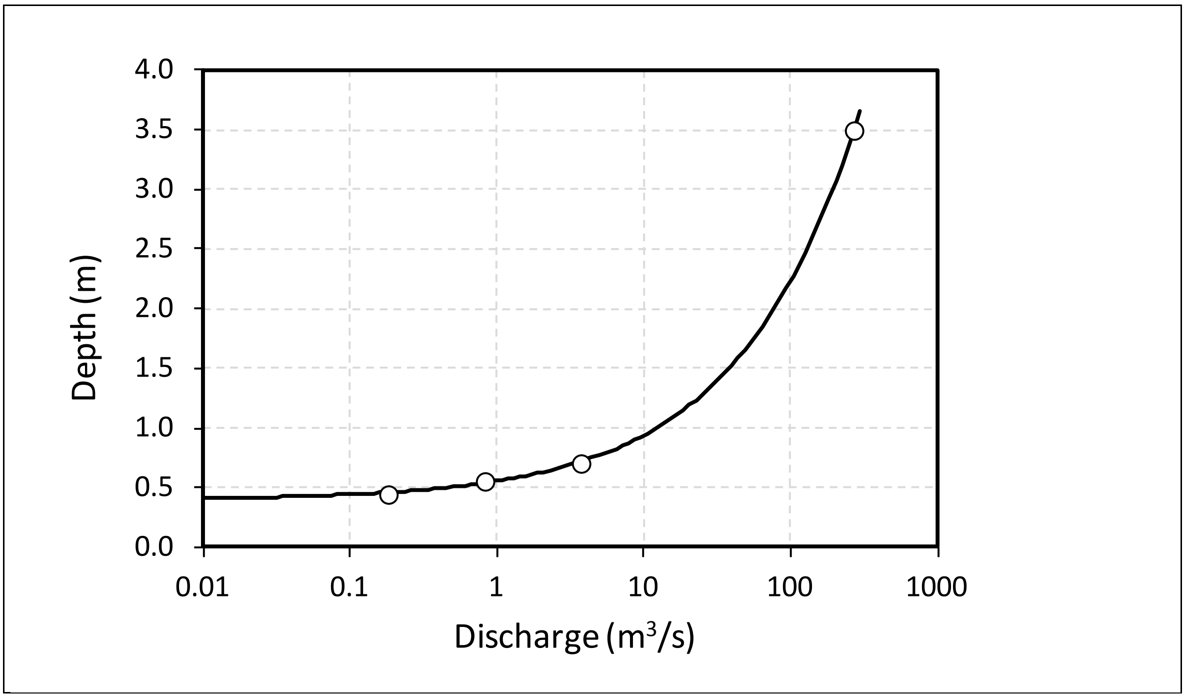


Figure 14.2 Rating relationships for the cross-sections at EWR KOON 1 (top) and EWR KOON 2 (bottom) on the Koonap River

The lookup table is provided in Table 14.3. Fish and macro-invertebrate flow classes are provided below:

SVS: Slow very shallow
SS: Slow shallow
SD: Slow deep
FVS: Fast very shallow
FS Fast shallow
FI: Fast intermediate
FD: Fast deep
VSCS: Very shallow over coarse substrate
SCS: Shallow over coarse substrate
FCS: Fast over coarse substrate
VFCS: Vey fast over coarse substrate
VSFS: Vey shallow over fine substrate
SFS: Shallow over fine substrate
FFS: Fast over fine substrate
VFFS: Very fast over fine substrate

Table 14.3 Lookup table providing relevant hydraulic parameters and flow classes used for ecological interpretation at EWR KOON 1 and EWR KOON 2 on the Koonap River

Max. depth (m)	Ave. depth (m)	Discharge (m^3/s)	Width (m)	Perimeter (m)	Ave. velocity (m/s)	Max. velocity (m/s)	Fish flow class (%)							Macro-invertebrate flow class (%)							
							SVS[1]	SS[2]	SD[3]	FVS[4]	FS[5]	FI[6]	FD[7]	VSCS[8]	SCS[9]	FCS[10]	VFCS[11]	VSFS[12]	SFS[13]	FFS[14]	VFFS[15]
EWR KOON 1																					
0.14	0.07	0.012	2.6	2.9	0.06	0.23	69	31	0	0	0	0	0	62	18	0	0	15	4	0	0
0.16	0.08	0.017	3.0	3.3	0.07	0.25	61	38	0	0	0	0	0	59	20	1	0	15	5	0	0
0.18	0.09	0.024	3.3	3.7	0.08	0.28	54	44	0	1	1	0	0	55	23	1	0	14	6	0	0
0.20	0.10	0.033	3.6	4.1	0.09	0.30	47	51	0	1	1	0	0	52	25	2	0	13	6	1	0
0.22	0.11	0.043	4.0	4.5	0.10	0.34	41	55	0	2	2	1	0	49	27	4	0	12	7	1	0
0.24	0.13	0.056	4.3	4.8	0.10	0.37	36	58	0	2	3	1	0	46	29	5	0	12	7	1	0
0.26	0.13	0.070	4.8	5.4	0.11	0.39	35	58	0	3	3	2	0	44	30	6	0	11	7	1	0
0.28	0.13	0.085	5.5	6.2	0.12	0.41	36	56	0	3	3	2	0	43	31	6	0	11	8	2	0
0.30	0.14	0.10	6.2	7.1	0.12	0.43	36	55	0	3	3	3	0	41	32	7	0	10	8	2	0
0.32	0.15	0.13	6.7	7.6	0.14	0.46	37	52	0	4	2	3	1	39	33	8	0	10	8	2	0
0.34	0.16	0.16	7.1	8.1	0.15	0.51	34	54	0	5	3	3	2	36	34	9	1	9	8	2	0
0.36	0.17	0.26	7.5	8.5	0.21	0.70	26	50	0	8	6	6	4	27	34	15	4	7	8	4	1
0.38	0.18	0.32	7.7	8.9	0.23	0.75	21	51	0	8	7	7	6	26	33	17	5	6	8	4	1
0.40	0.20	0.38	8.0	9.3	0.24	0.81	15	53	0	7	10	7	8	24	31	20	5	6	8	5	1
0.42	0.20	0.45	8.5	9.8	0.26	0.87	14	50	0	8	11	8	9	23	29	22	6	6	7	6	2
0.44	0.21	0.52	9.1	10.6	0.27	0.89	13	50	0	8	12	7	11	22	28	23	7	5	7	6	2
0.46	0.21	0.60	10.1	11.7	0.29	0.94	16	43	0	11	10	7	12	20	27	25	7	5	7	6	2
0.48	0.21	0.69	11.0	12.6	0.30	0.99	17	40	0	13	8	9	13	20	26	26	8	5	6	7	2
0.50	0.22	0.78	11.7	13.4	0.31	0.99	16	39	0	13	7	9	14	19	26	26	9	5	7	7	2
0.52	0.22	0.88	12.5	14.3	0.32	1.03	17	35	2	14	7	9	15	18	25	27	10	5	6	7	2
0.54	0.23	0.99	13.3	15.2	0.33	1.06	16	33	3	14	7	11	15	17	25	28	10	4	6	7	3
0.56	0.24	1.1	13.7	15.7	0.33	1.08	14	34	4	13	9	10	17	17	24	28	11	4	6	7	3
0.58	0.26	1.2	13.9	15.8	0.34	1.10	10	35	6	10	11	9	19	17	24	28	11	4	6	7	3
0.60	0.28	1.3	14.0	16.0	0.35	1.12	8	35	6	8	14	7	22	16	24	29	12	4	6	7	3

Max. depth (m)	Ave. depth (m)	Discharge (m^3/s)	Width (m)	Perimeter (m)	Ave. velocity (m/s)	Max. velocity (m/s)	Fish flow class (%)							Macro-invertebrate flow class (%)							
							SVS[1]	SS[2]	SD[3]	FVS[4]	FS[5]	FI[6]	FD[7]	VSCS[8]	SCS[9]	FCS[10]	VFCS[11]	VSFS[12]	SFS[13]	FFS[14]	VFFS[15]
0.62	0.29	1.5	14.1	16.1	0.36	1.13	5	35	8	6	15	7	24	15	23	29	12	4	6	7	3
0.64	0.31	1.6	14.3	16.3	0.37	1.16	3	35	8	4	15	9	27	15	23	30	13	4	6	7	3
0.66	0.33	1.8	14.4	16.4	0.38	1.18	2	34	9	3	14	10	28	14	22	30	14	3	6	7	4
0.68	0.34	1.9	14.5	16.6	0.39	1.20	2	31	11	3	11	13	30	13	22	30	15	3	5	7	4
0.70	0.36	2.1	14.7	16.8	0.39	1.21	2	30	11	3	9	14	32	13	21	30	16	3	5	8	4
0.72	0.37	2.3	14.9	17.0	0.40	1.23	2	29	11	2	7	15	35	12	21	30	17	3	5	8	4
0.74	0.39	2.4	15.2	17.3	0.41	1.26	2	26	11	4	4	17	35	12	20	30	18	3	5	8	5
0.76	0.40	2.6	15.4	17.5	0.42	1.28	2	24	12	4	3	16	39	11	20	30	19	3	5	7	5
0.78	0.42	2.8	15.6	17.8	0.43	1.30	3	21	13	5	2	12	44	11	19	30	20	3	5	8	5
0.80	0.43	3.0	15.9	18.0	0.44	1.30	2	21	14	3	3	9	47	11	19	30	20	3	5	8	5
0.82	0.45	3.2	15.9	18.1	0.45	1.33	2	18	16	3	4	7	50	10	18	30	21	3	5	8	5
0.84	0.47	3.4	16.0	18.2	0.46	1.34	1	18	16	3	4	5	54	10	18	29	23	2	5	7	6
0.86	0.49	3.7	16.0	18.2	0.47	1.36	1	17	16	2	4	3	56	10	18	29	23	2	4	7	6
0.88	0.50	3.9	16.1	18.3	0.48	1.38	1	16	16	1	4	4	58	9	17	29	24	2	4	7	6
0.90	0.52	4.1	16.1	18.3	0.49	1.41	1	15	16	2	4	3	59	9	17	28	26	2	4	7	7
0.92	0.54	4.4	16.2	18.4	0.50	1.42	0	15	17	0	4	3	60	9	17	28	27	2	4	7	7
0.94	0.56	4.6	16.2	18.5	0.51	1.45	0	13	17	1	3	4	62	8	16	27	29	2	4	7	7
0.96	0.58	4.9	16.2	18.5	0.52	1.46	0	11	19	0	3	4	63	8	16	27	29	2	4	7	7
0.98	0.60	5.2	16.3	18.6	0.53	1.48	0	9	20	0	2	5	64	8	16	26	30	2	4	7	8
1.00	0.61	5.4	16.3	18.7	0.54	1.51	0	8	20	1	1	4	65	8	15	26	32	2	4	6	8
1.02	0.63	5.7	16.4	18.8	0.55	1.52	0	6	22	0	1	5	66	8	15	25	32	2	4	6	8
1.04	0.65	6.0	16.5	18.9	0.56	1.53	0	5	22	1	1	4	67	7	14	25	33	2	4	6	8
1.06	0.67	6.3	16.6	19.0	0.57	1.55	0	4	22	1	1	4	68	7	14	25	34	2	4	6	9
1.08	0.68	6.6	16.6	19.1	0.58	1.57	0	4	22	1	1	1	70	7	14	24	35	2	4	6	9
1.10	0.70	6.9	16.7	19.2	0.59	1.60	1	4	21	2	1	1	71	7	13	23	36	2	4	6	9
1.12	0.72	7.3	16.8	19.3	0.60	1.62	0	4	21	1	2	1	72	7	13	23	37	2	3	6	10
1.14	0.73	7.6	16.9	19.4	0.61	1.63	0	3	20	1	2	1	71	6	13	22	37	2	3	6	10
1.16	0.75	7.9	17.0	19.6	0.62	1.64	0	3	20	1	2	1	73	6	13	22	38	2	3	6	10

Max. depth (m)	Ave. depth (m)	Discharge (m^3/s)	Width (m)	Perimeter (m)	Ave. velocity (m/s)	Max. velocity (m/s)	Fish flow class (%)							Macro-invertebrate flow class (%)							
							SVS[1]	SS[2]	SD[3]	FVS[4]	FS[5]	FI[6]	FD[7]	VSCS[8]	SCS[9]	FCS[10]	VFCS[11]	VSFS[12]	SFS[13]	FFS[14]	VFFS[15]
1.18	0.76	8.3	17.1	19.7	0.64	1.65	1	3	20	2	1	1	73	6	12	22	39	2	3	6	11
1.20	0.78	8.6	17.2	19.9	0.65	1.67	1	3	20	2	1	1	73	6	12	21	39	2	3	6	11
1.22	0.79	9.0	17.3	20.0	0.66	1.70	1	2	19	2	2	1	73	6	12	20	40	2	3	6	11
1.24	0.81	9.4	17.4	20.2	0.67	1.72	1	2	19	2	2	1	73	5	11	20	41	2	3	6	12
1.26	0.82	9.8	17.6	20.4	0.68	1.73	1	2	19	2	3	2	73	5	11	20	42	2	3	6	12
1.28	0.83	10.2	17.7	20.5	0.69	1.74	0	2	19	2	2	2	73	5	11	19	42	2	3	6	12
1.30	0.85	10.6	17.8	20.6	0.70	1.77	1	2	18	3	3	1	73	5	10	19	43	2	3	6	13
1.32	0.86	11.0	18.0	20.8	0.71	1.78	1	2	17	3	2	2	73	5	10	18	43	2	3	6	13
1.34	0.88	11.4	18.1	20.9	0.72	1.78	0	2	17	2	3	2	74	5	10	18	44	1	3	6	13
1.36	0.89	11.8	18.2	21.0	0.73	1.79	0	2	17	2	3	3	74	5	10	18	44	1	3	6	14
1.38	0.90	12.3	18.4	21.2	0.74	1.82	1	2	16	3	3	2	74	5	9	17	45	1	3	5	14
1.40	0.92	12.7	18.5	21.3	0.75	1.82	0	2	16	2	3	2	74	4	9	17	45	1	3	5	14
1.42	0.93	13.2	18.6	21.4	0.76	1.83	0	2	16	2	3	2	74	4	9	17	45	1	3	5	15
1.44	0.95	13.6	18.7	21.6	0.77	1.85	1	2	15	3	3	2	74	4	9	16	46	1	3	5	15
1.46	0.96	14.1	18.9	21.7	0.78	1.87	1	2	15	3	3	3	74	4	9	16	46	1	3	5	16
1.48	0.97	14.6	19.0	21.8	0.79	1.86	0	2	15	2	3	3	75	4	8	16	46	1	3	5	16
1.50	0.99	15.1	19.1	22.0	0.80	1.88	0	2	14	2	3	2	77	4	8	15	47	1	3	5	16
1.52	1.00	15.6	19.2	22.1	0.81	1.91	0	2	14	2	3	2	76	4	8	15	47	1	3	5	17
1.54	1.01	16.1	19.4	22.3	0.82	1.91	0	2	14	2	3	3	77	4	8	15	47	1	3	5	17
1.56	1.03	16.6	19.5	22.4	0.83	1.93	0	2	13	2	3	3	77	4	8	15	48	1	3	5	17
1.58	1.04	17.1	19.6	22.5	0.84	1.97	0	2	13	2	3	3	76	4	7	14	48	1	3	5	18
1.60	1.05	17.7	19.7	22.7	0.85	1.97	0	2	13	2	3	3	76	4	7	14	48	1	3	5	18
1.62	1.07	18.2	19.9	22.8	0.86	1.96	0	2	13	2	3	3	78	4	7	14	48	1	3	5	18
1.64	1.08	18.7	20.0	22.9	0.87	1.98	0	2	12	2	3	3	78	3	7	13	49	1	3	5	19
1.66	1.09	19.3	20.1	23.1	0.88	2.01	0	2	12	2	3	3	78	3	7	13	49	1	3	5	19
1.68	1.11	19.9	20.3	23.2	0.89	2.00	0	2	12	2	3	3	79	3	7	13	49	1	3	5	19
1.70	1.12	20.5	20.4	23.3	0.90	2.04	0	2	12	2	3	3	79	3	6	13	49	1	3	5	20
1.72	1.13	21.1	20.6	23.5	0.91	2.07	0	2	11	3	3	2	78	3	6	12	50	1	3	5	20

Max. depth (m)	Ave. depth (m)	Discharge (m^3/s)	Width (m)	Perimeter (m)	Ave. velocity (m/s)	Max. velocity (m/s)	Fish flow class (%)							Macro-invertebrate flow class (%)							
							SVS[1]	SS[2]	SD[3]	FVS[4]	FS[5]	FI[6]	FD[7]	VSCS[8]	SCS[9]	FCS[10]	VFCS[11]	VSFS[12]	SFS[13]	FFS[14]	VFFS[15]
1.74	1.14	21.7	20.8	23.8	0.92	2.06	0	2	11	2	3	3	79	3	6	12	49	1	3	5	20
1.76	1.15	22.3	20.9	23.9	0.93	2.09	0	2	11	3	3	2	79	3	6	12	50	1	3	5	21
1.78	1.16	22.9	21.0	24.1	0.94	2.11	1	1	11	4	2	2	79	3	6	11	50	1	3	5	21
1.80	1.17	23.5	21.2	24.2	0.95	2.10	0	1	11	3	2	2	80	3	6	11	50	1	3	5	21
1.82	1.19	24.1	21.3	24.4	0.95	2.13	1	1	10	4	2	2	80	3	6	11	50	1	2	5	22
1.84	1.20	24.8	21.4	24.5	0.96	2.13	0	1	10	3	3	2	80	3	6	11	50	1	2	5	22
1.86	1.21	25.4	21.6	24.7	0.97	2.18	0	1	10	3	3	2	80	3	5	11	50	1	2	5	22
1.88	1.23	26.1	21.7	24.8	0.98	2.18	0	1	10	2	3	3	81	3	5	11	50	1	2	5	23
1.90	1.24	26.8	21.8	25.0	0.99	2.20	0	1	10	2	3	3	80	3	5	10	50	1	2	5	23
1.92	1.25	27.5	21.9	25.1	1.00	2.21	0	1	10	2	3	3	80	3	5	10	50	1	2	5	23
1.94	1.27	28.2	22.0	25.3	1.01	2.21	0	1	10	1	3	3	81	3	5	10	50	1	2	5	24
1.96	1.28	28.9	22.1	25.4	1.02	2.22	0	1	10	2	3	3	82	3	5	10	51	1	2	5	24
1.98	1.29	29.6	22.3	25.6	1.03	2.23	0	1	9	2	2	3	82	2	5	10	51	1	2	5	24
2.00	1.31	30.3	22.4	25.7	1.04	2.24	0	1	9	2	2	3	82	2	5	10	51	1	2	5	24
2.02	1.32	31.0	22.5	25.9	1.05	2.26	0	1	9	3	3	3	82	2	5	9	51	1	2	5	25
2.04	1.33	31.8	22.6	26.0	1.05	2.24	0	1	9	2	2	3	82	2	5	9	51	1	2	5	25
2.06	1.34	32.5	22.7	26.2	1.06	2.29	0	1	9	2	2	3	83	2	5	9	50	1	2	5	25
2.08	1.36	33.3	22.9	26.3	1.07	2.31	0	1	9	2	2	3	83	2	5	9	51	1	2	5	26
2.10	1.37	34.0	23.0	26.4	1.08	2.35	0	1	9	2	3	3	82	2	4	9	51	1	2	5	26
2.12	1.38	34.8	23.1	26.6	1.09	2.36	0	1	9	3	3	3	83	2	4	9	51	1	2	5	26
2.14	1.40	35.6	23.2	26.7	1.10	2.38	0	1	8	3	2	2	83	2	4	9	51	1	2	4	26
2.16	1.41	36.4	23.3	26.8	1.11	2.40	0	1	8	3	2	2	83	2	4	8	51	1	2	4	27
2.18	1.43	37.2	23.3	26.9	1.12	2.41	0	1	8	2	2	2	83	2	4	8	51	1	2	4	27
2.20	1.45	38.0	23.4	26.9	1.12	2.42	0	1	8	2	2	2	84	2	4	8	51	1	2	4	27
2.22	1.46	38.9	23.5	27.0	1.13	2.43	0	1	8	2	2	2	84	2	4	8	51	1	2	4	27
2.24	1.48	39.7	23.5	27.1	1.14	2.43	0	1	8	2	2	2	85	2	4	8	51	1	2	4	27
2.26	1.49	40.5	23.6	27.2	1.15	2.42	0	1	8	1	1	2	86	2	4	8	51	1	2	4	28
2.28	1.51	41.4	23.7	27.3	1.16	2.44	0	1	8	1	1	2	87	2	4	8	51	1	2	4	28

Max. depth (m)	Ave. depth (m)	Discharge (m^3/s)	Width (m)	Perimeter (m)	Ave. velocity (m/s)	Max. velocity (m/s)	Fish flow class (%)							Macro-invertebrate flow class (%)							
							SVS[1]	SS[2]	SD[3]	FVS[4]	FS[5]	FI[6]	FD[7]	VSCS[8]	SCS[9]	FCS[10]	VFCS[11]	VSFS[12]	SFS[13]	FFS[14]	VFFS[15]
2.30	1.52	42.3	23.7	27.3	1.17	2.48	0	1	8	1	2	2	86	2	4	8	51	1	2	4	28
2.32	1.54	43.2	23.8	27.4	1.18	2.50	0	1	8	1	2	2	86	2	4	8	51	1	2	4	28
2.34	1.55	44.0	23.9	27.5	1.19	2.51	0	1	8	1	1	2	87	2	4	8	51	1	2	4	28
2.36	1.57	44.9	24.0	27.6	1.20	2.52	0	1	8	1	1	2	87	2	4	8	51	1	2	4	29
2.38	1.59	45.8	24.0	27.7	1.20	2.53	0	1	8	1	1	2	87	2	4	7	51	1	2	4	29
2.40	1.60	46.8	24.1	27.7	1.21	2.56	0	1	8	2	2	2	87	2	4	7	51	1	2	4	29
2.42	1.62	47.7	24.2	27.8	1.22	2.57	0	1	8	2	1	1	87	2	4	7	51	1	2	4	29
2.44	1.63	48.6	24.2	27.9	1.23	2.57	0	1	8	2	1	1	88	2	3	7	51	1	2	4	29
2.46	1.65	49.6	24.3	28.0	1.24	2.58	0	1	7	2	1	1	88	2	3	7	51	1	2	4	30
2.48	1.66	50.5	24.4	28.1	1.25	2.57	0	0	7	1	1	1	89	2	3	7	51	1	2	4	30
2.50	1.68	51.5	24.4	28.1	1.26	2.60	0	1	7	1	1	1	89	2	3	7	51	1	2	4	30
2.52	1.69	52.5	24.5	28.2	1.27	2.63	0	1	7	1	1	1	89	2	3	7	51	1	2	4	30
2.54	1.71	53.5	24.5	28.3	1.27	2.65	0	0	7	1	1	2	89	2	3	7	51	1	2	4	30
2.56	1.73	54.5	24.6	28.3	1.28	2.67	0	0	7	1	1	2	89	2	3	7	51	1	2	4	30
2.58	1.74	55.5	24.7	28.4	1.29	2.69	0	0	7	1	1	2	89	2	3	6	51	1	2	4	31
2.60	1.76	56.5	24.7	28.5	1.30	2.70	0	0	7	1	1	2	90	2	3	6	51	1	2	4	31
2.62	1.77	57.5	24.8	28.6	1.31	2.71	0	0	7	1	1	2	90	2	3	6	51	1	2	4	31
2.64	1.79	58.6	24.8	28.6	1.32	2.72	0	0	7	1	1	2	90	2	3	6	51	1	2	4	31
2.66	1.80	59.6	24.9	28.7	1.33	2.76	0	0	7	1	1	2	89	2	3	6	52	1	2	4	31
2.68	1.82	60.7	25.0	28.8	1.34	2.76	0	0	7	1	1	1	90	1	3	6	52	1	2	4	32
2.70	1.84	61.7	25.0	28.9	1.34	2.77	0	0	7	1	1	1	90	1	3	6	52	1	2	4	32
2.72	1.85	62.8	25.1	28.9	1.35	2.78	0	0	7	1	1	1	90	1	3	6	52	1	2	4	32
2.74	1.87	63.9	25.1	29.0	1.36	2.80	0	0	7	1	1	1	90	1	3	6	51	1	2	4	32
2.76	1.88	65.0	25.2	29.1	1.37	2.82	0	0	6	1	1	1	90	1	3	6	51	1	2	4	32
2.78	1.90	66.1	25.3	29.2	1.38	2.85	0	0	6	1	1	1	90	1	3	6	52	1	2	4	32
2.80	1.91	67.3	25.3	29.2	1.39	2.87	0	0	6	1	1	1	90	1	3	6	52	1	2	4	33
2.82	1.93	68.4	25.4	29.3	1.40	2.89	0	0	6	1	1	1	90	1	3	6	52	1	2	4	33
2.84	1.94	69.5	25.5	29.4	1.41	2.88	0	0	6	0	1	1	91	1	3	6	51	1	2	4	33

Max. depth (m)	Ave. depth (m)	Discharge (m^3/s)	Width (m)	Perimeter (m)	Ave. velocity (m/s)	Max. velocity (m/s)	Fish flow class (%)							Macro-invertebrate flow class (%)							
							SVS[1]	SS[2]	SD[3]	FVS[4]	FS[5]	FI[6]	FD[7]	VSCS[8]	SCS[9]	FCS[10]	VFCS[11]	VSFS[12]	SFS[13]	FFS[14]	VFFS[15]
2.86	1.96	70.7	25.5	29.4	1.41	2.91	0	0	6	0	1	1	91	1	3	6	51	1	2	4	33
2.88	1.97	71.9	25.6	29.5	1.42	2.91	0	0	6	0	1	1	92	1	3	5	51	1	2	4	33
2.90	1.99	73.0	25.6	29.6	1.43	2.93	0	0	6	0	1	1	92	1	3	5	51	1	2	3	33
2.92	2.00	74.2	25.7	29.7	1.44	2.95	0	0	6	0	0	1	92	1	3	5	51	1	2	3	34
2.94	2.02	75.4	25.8	29.7	1.45	2.96	0	0	6	0	0	1	92	1	3	5	51	1	2	3	34
2.96	2.04	76.6	25.8	29.8	1.46	2.98	0	0	6	0	0	1	92	1	2	5	51	1	2	3	34
2.98	2.05	77.8	25.9	29.9	1.47	2.99	0	0	6	0	0	1	92	1	2	5	51	1	2	3	34
3.00	2.06	79.1	26.0	30.0	1.48	3.03	0	0	6	1	1	1	91	1	2	5	51	1	2	3	34
EWR KOON 2																					
0.26	0.13	0.0010	9.4	10.3	0.00	0.00	35	65	0	0	0	0	0	70	0	0	0	30	0	0	0
0.28	0.14	0.026	10.1	11.1	0.02	0.06	30	70	0	0	0	0	0	70	0	0	0	30	0	0	0
0.30	0.16	0.084	10.7	11.8	0.05	0.18	29	71	0	0	0	0	0	57	13	0	0	25	5	0	0
0.32	0.17	0.17	11.1	12.3	0.09	0.33	26	70	0	1	1	1	0	45	22	3	0	19	10	1	0
0.34	0.18	0.29	11.4	12.7	0.14	0.48	22	66	0	3	3	4	1	34	28	8	0	14	12	3	0
0.36	0.20	0.44	11.7	13.1	0.19	0.64	13	66	0	3	6	8	3	26	29	12	3	11	13	5	1
0.38	0.21	0.61	12.1	13.7	0.24	0.79	12	58	0	5	7	11	8	22	27	17	5	9	12	7	2
0.40	0.23	0.81	12.5	14.2	0.29	0.94	8	51	0	6	11	11	13	18	24	22	7	8	10	9	3
0.42	0.23	1.0	13.1	14.8	0.34	1.49	5	26	0	7	10	12	15	13	16	23	19	5	7	10	8
0.44	0.19	1.3	18.2	20.1	0.38	1.16	17	29	0	20	8	10	17	12	20	26	12	5	8	11	5
0.46	0.21	1.6	18.4	20.4	0.41	1.31	14	26	0	21	8	10	20	11	17	26	16	5	7	11	7
0.48	0.22	1.9	18.6	20.6	0.45	1.38	13	25	0	21	8	9	24	10	16	25	19	4	7	11	8
0.50	0.24	2.2	18.8	20.8	0.48	1.52	12	22	1	23	6	11	27	9	15	23	23	4	6	10	10
0.52	0.26	2.6	19.1	21.2	0.52	1.57	5	27	1	10	20	10	29	8	15	22	25	3	6	9	11
0.54	0.27	2.9	19.4	21.6	0.55	1.66	3	25	2	7	22	10	31	7	14	21	28	3	6	9	12
0.56	0.29	3.3	19.8	22.0	0.59	1.77	2	23	3	6	22	9	34	7	13	19	31	3	5	8	13
0.58	0.30	3.8	20.1	22.4	0.62	1.80	2	22	4	5	23	9	37	7	12	19	32	3	5	8	14
0.60	0.32	4.2	20.5	22.8	0.65	1.89	2	18	5	7	22	8	38	6	11	18	35	3	5	8	15
0.62	0.33	4.7	21.2	23.5	0.68	1.92	2	16	5	7	19	11	40	6	11	17	37	2	5	7	16

Max. depth (m)	Ave. depth (m)	Discharge (m^3/s)	Width (m)	Perimeter (m)	Ave. velocity (m/s)	Max. velocity (m/s)	Fish flow class (%)							Macro-invertebrate flow class (%)							
							SVS[1]	SS[2]	SD[3]	FVS[4]	FS[5]	FI[6]	FD[7]	VSCS[8]	SCS[9]	FCS[10]	VFCS[11]	VSFS[12]	SFS[13]	FFS[14]	VFFS[15]
0.64	0.34	5.2	21.9	24.3	0.71	1.90	2	14	6	8	4	25	41	5	10	17	37	2	4	7	16
0.66	0.34	5.7	22.6	25.1	0.73	2.01	3	12	6	11	4	23	41	5	10	15	40	2	4	7	17
0.68	0.36	6.3	23.2	25.7	0.76	2.06	2	11	6	10	6	24	41	5	9	15	42	2	4	6	18
0.70	0.37	6.8	23.8	26.4	0.78	2.09	3	10	6	12	5	21	44	4	9	14	43	2	4	6	18
0.72	0.38	7.4	24.5	27.1	0.81	2.02	2	9	6	10	7	8	57	4	8	14	43	2	4	6	19
0.74	0.38	8.0	25.4	28.1	0.83	2.04	2	9	6	10	8	5	60	4	8	14	44	2	3	6	19
0.76	0.39	8.7	26.4	29.1	0.85	2.11	2	8	6	12	9	4	59	4	8	13	46	2	3	6	20
0.78	0.39	9.3	27.4	30.2	0.87	2.15	2	7	6	12	11	4	58	4	7	12	47	2	3	5	20
0.80	0.38	10.0	29.7	32.5	0.89	2.10	3	7	5	17	9	5	54	4	7	13	47	2	3	5	20
0.82	0.37	10.7	32.0	34.9	0.90	2.16	3	6	5	20	9	5	51	3	7	12	48	1	3	5	20
0.84	0.39	11.5	32.5	35.4	0.91	2.17	3	6	5	19	10	7	50	3	7	12	48	1	3	5	21
0.86	0.41	12.2	32.7	35.6	0.92	2.16	2	7	5	15	12	9	51	3	6	12	49	1	3	5	21
0.88	0.42	13.0	32.8	35.7	0.94	2.16	2	7	5	10	16	8	53	3	6	11	49	1	3	5	21
0.90	0.44	13.8	32.9	35.8	0.95	2.18	1	7	5	8	16	8	55	3	6	11	50	1	3	5	21
0.92	0.46	14.6	33.0	36.0	0.96	2.16	1	5	6	6	15	8	57	3	6	11	50	1	3	5	22
0.94	0.48	15.5	33.1	36.1	0.97	2.17	1	5	7	4	15	9	59	3	6	11	51	1	2	5	22
0.96	0.50	16.3	33.2	36.2	0.99	2.21	0	5	6	3	14	11	61	3	5	11	51	1	2	5	22
0.98	0.52	17.2	33.4	36.3	1.00	2.20	0	5	6	1	12	13	62	3	5	10	52	1	2	4	22
1.00	0.53	18.1	33.5	36.5	1.01	2.21	0	5	6	0	10	14	65	3	5	10	52	1	2	4	22
1.02	0.55	19.1	33.6	36.6	1.03	2.26	0	4	6	2	8	14	66	2	5	10	53	1	2	4	23
1.04	0.57	20.0	33.7	36.7	1.04	2.26	0	4	6	2	5	14	68	2	5	10	53	1	2	4	23
1.06	0.59	21.0	33.8	36.8	1.05	2.26	0	4	6	2	3	13	72	2	5	10	53	1	2	4	23
1.08	0.61	22.0	33.9	36.9	1.07	2.22	0	4	6	1	2	12	76	2	5	10	53	1	2	4	23
1.10	0.62	23.0	34.0	37.0	1.08	2.27	0	3	6	2	1	10	78	2	4	9	54	1	2	4	23
1.12	0.64	24.0	34.1	37.2	1.10	2.30	0	3	6	2	1	8	79	2	4	9	54	1	2	4	23
1.14	0.66	25.1	34.2	37.3	1.11	2.33	0	3	6	2	1	6	82	2	4	9	55	1	2	4	23
1.16	0.68	26.2	34.3	37.4	1.12	2.35	0	3	6	2	1	3	85	2	4	9	55	1	2	4	24
1.18	0.70	27.3	34.4	37.5	1.14	2.38	0	3	6	2	1	2	87	2	4	9	55	1	2	4	24

Max. depth (m)	Ave. depth (m)	Discharge (m^3/s)	Width (m)	Perimeter (m)	Ave. velocity (m/s)	Max. velocity (m/s)	Fish flow class (%)							Macro-invertebrate flow class (%)							
							SVS[1]	SS[2]	SD[3]	FVS[4]	FS[5]	FI[6]	FD[7]	VSCS[8]	SCS[9]	FCS[10]	VFCS[11]	VSFS[12]	SFS[13]	FFS[14]	VFFS[15]
1.20	0.71	28.4	34.5	37.6	1.15	2.41	0	2	6	2	1	1	87	2	4	8	56	1	2	4	24
1.22	0.73	29.6	34.6	37.7	1.17	2.41	0	2	6	1	1	1	89	2	4	8	56	1	2	4	24
1.24	0.75	30.7	34.8	37.9	1.18	2.43	0	2	6	1	1	1	89	2	4	8	56	1	2	3	24
1.26	0.77	31.9	34.9	38.0	1.19	2.47	0	2	6	2	1	1	88	2	4	8	57	1	2	3	24
1.28	0.79	33.1	35.0	38.1	1.21	2.54	0	1	6	2	1	1	89	2	3	8	57	1	1	3	24
1.30	0.80	34.4	35.1	38.2	1.22	2.52	0	1	6	2	1	1	89	2	3	8	57	1	1	3	25
1.32	0.82	35.6	35.2	38.3	1.23	2.54	0	1	6	2	1	1	89	2	3	8	57	1	1	3	25
1.34	0.84	36.9	35.3	38.4	1.25	2.53	0	0	7	1	1	1	90	2	3	7	58	1	1	3	25
1.36	0.86	38.2	35.4	38.5	1.26	2.56	0	0	6	1	1	1	90	2	3	7	58	1	1	3	25
1.38	0.87	39.5	35.5	38.7	1.28	2.58	0	0	6	1	1	2	90	2	3	7	58	1	1	3	25
1.40	0.89	40.8	35.6	38.8	1.29	2.61	0	0	6	1	1	2	90	2	3	7	58	1	1	3	25
1.42	0.91	42.2	35.7	38.9	1.30	2.64	0	0	6	1	1	2	90	1	3	7	59	1	1	3	25
1.44	0.92	43.6	35.8	39.0	1.32	2.68	0	0	6	2	1	2	90	1	3	7	59	1	1	3	25
1.46	0.94	45.0	35.9	39.1	1.33	2.70	0	0	6	2	1	2	90	1	3	7	59	1	1	3	25
1.48	0.96	46.4	36.0	39.2	1.34	2.71	0	0	6	1	1	2	91	1	3	7	59	1	1	3	25
1.50	0.98	47.9	36.1	39.4	1.36	2.73	0	0	5	1	1	2	91	1	3	7	59	1	1	3	25
1.52	0.99	49.3	36.2	39.5	1.37	2.79	0	0	5	2	1	1	90	1	3	6	60	1	1	3	26
1.54	1.01	50.8	36.4	39.6	1.38	2.80	0	0	5	1	1	1	91	1	3	6	60	1	1	3	26
1.56	1.03	52.3	36.5	39.7	1.40	2.82	0	0	5	1	1	1	91	1	3	6	60	1	1	3	26
1.58	1.04	53.8	36.6	39.8	1.41	2.84	0	0	5	2	1	1	91	1	3	6	60	1	1	3	26
1.60	1.06	55.4	36.7	40.0	1.42	2.85	0	0	5	1	1	1	92	1	3	6	60	1	1	3	26
1.62	1.08	56.9	36.8	40.1	1.44	2.90	0	0	5	2	1	1	91	1	3	6	60	1	1	3	26
1.64	1.09	58.5	36.9	40.2	1.45	2.90	0	0	5	1	1	2	91	1	3	6	60	0	1	3	26
1.66	1.11	60.1	37.0	40.3	1.46	2.96	0	0	5	2	1	2	91	1	2	6	61	0	1	2	26
1.68	1.13	61.8	37.1	40.4	1.48	2.95	0	0	5	1	1	2	92	1	2	6	61	0	1	2	26
1.70	1.14	63.4	37.3	40.6	1.49	3.02	0	0	5	2	1	2	91	1	2	6	61	0	1	2	26
1.72	1.16	65.1	37.4	40.7	1.50	3.02	0	0	5	1	1	2	92	1	2	6	61	0	1	2	26
1.74	1.18	66.8	37.5	40.8	1.51	3.09	0	0	4	2	2	2	91	1	2	5	61	0	1	2	26

Max. depth (m)	Ave. depth (m)	Discharge (m^3/s)	Width (m)	Perimeter (m)	Ave. velocity (m/s)	Max. velocity (m/s)	Fish flow class (%)							Macro-invertebrate flow class (%)							
							SVS[1]	SS[2]	SD[3]	FVS[4]	FS[5]	FI[6]	FD[7]	VSCS[8]	SCS[9]	FCS[10]	VFCS[11]	VSFS[12]	SFS[13]	FFS[14]	VFFS[15]
1.76	1.19	68.5	37.6	40.9	1.53	3.10	0	0	5	1	1	2	92	1	2	5	61	0	1	2	26
1.78	1.21	70.2	37.7	41.1	1.54	3.16	0	0	4	1	1	1	91	1	2	5	61	0	1	2	26
1.80	1.23	72.0	37.8	41.2	1.55	3.16	0	0	4	1	1	1	92	1	2	5	61	0	1	2	26
1.82	1.24	73.7	37.9	41.3	1.56	3.19	0	0	4	1	1	1	91	1	2	5	62	0	1	2	26
1.84	1.26	75.5	38.0	41.4	1.58	3.19	0	0	4	1	1	1	92	1	2	5	62	0	1	2	26
1.86	1.28	77.3	38.2	41.5	1.59	3.25	0	0	4	1	1	1	91	1	2	5	62	0	1	2	27
1.88	1.29	79.2	38.3	41.7	1.60	3.25	0	0	4	1	1	1	92	1	2	5	62	0	1	2	27
1.90	1.31	81.0	38.4	41.8	1.61	3.29	0	0	4	1	1	1	91	1	2	5	62	0	1	2	27
1.92	1.32	82.9	38.5	41.9	1.63	3.29	0	0	4	1	1	1	92	1	2	5	62	0	1	2	27
1.94	1.34	84.8	38.6	42.0	1.64	3.30	0	0	4	1	1	1	92	1	2	5	62	0	1	2	27
1.96	1.36	86.7	38.7	42.1	1.65	3.34	0	0	4	1	1	2	92	1	2	5	62	0	1	2	27
1.98	1.37	88.6	38.8	42.3	1.66	3.39	0	0	4	1	2	2	91	1	2	5	62	0	1	2	27
2.00	1.39	90.6	38.9	42.4	1.68	3.39	0	0	4	1	1	2	92	1	2	5	62	0	1	2	27
2.02	1.40	92.5	39.1	42.5	1.69	3.41	0	0	4	1	2	2	91	1	2	5	62	0	1	2	27
2.04	1.42	94.5	39.2	42.6	1.70	3.45	0	0	4	1	1	2	91	1	2	5	62	0	1	2	27
2.06	1.44	96.5	39.3	42.7	1.71	3.47	0	0	4	1	2	2	91	1	2	5	63	0	1	2	27
2.08	1.45	98.6	39.4	42.9	1.72	3.47	0	0	4	1	1	2	92	1	2	5	63	0	1	2	27
2.10	1.47	100.6	39.5	43.0	1.74	3.53	0	0	4	1	2	2	91	1	2	4	63	0	1	2	27
2.12	1.48	102.7	39.6	43.1	1.75	3.52	0	0	4	1	1	2	92	1	2	4	63	0	1	2	27
2.14	1.50	104.8	39.7	43.2	1.76	3.59	0	0	4	1	2	2	91	1	2	4	63	0	1	2	27
2.16	1.52	106.9	39.8	43.3	1.77	3.58	0	0	4	1	1	2	92	1	2	4	63	0	1	2	27
2.18	1.53	109.0	39.8	43.4	1.78	3.61	0	0	4	1	1	1	92	1	2	4	63	0	1	2	27
2.20	1.55	111.2	39.9	43.4	1.79	3.66	0	0	4	1	1	1	92	1	2	4	63	0	1	2	27
2.22	1.57	113.3	40.0	43.5	1.81	3.68	0	0	4	1	1	1	92	1	2	4	63	0	1	2	27
2.24	1.59	115.5	40.0	43.6	1.82	3.66	0	0	4	1	1	1	93	1	2	4	63	0	1	2	27
2.26	1.60	117.7	40.1	43.7	1.83	3.68	0	0	4	0	1	2	94	1	2	4	63	0	1	2	27
2.28	1.62	120.0	40.2	43.8	1.84	3.70	0	0	4	0	1	2	94	1	2	4	63	0	1	2	27
2.30	1.64	122.2	40.3	43.8	1.85	3.75	0	0	4	1	1	2	93	1	2	4	63	0	1	2	27

Max. depth (m)	Ave. depth (m)	Discharge (m^3/s)	Width (m)	Perimeter (m)	Ave. velocity (m/s)	Max. velocity (m/s)	Fish flow class (%)							Macro-invertebrate flow class (%)							
							SVS[1]	SS[2]	SD[3]	FVS[4]	FS[5]	FI[6]	FD[7]	VSCS[8]	SCS[9]	FCS[10]	VFCS[11]	VSFS[12]	SFS[13]	FFS[14]	VFFS[15]
2.32	1.66	124.5	40.3	43.9	1.86	3.74	0	0	4	0	1	2	94	1	2	4	63	0	1	2	27
2.34	1.67	126.8	40.4	44.0	1.88	3.80	0	0	4	1	1	2	93	1	2	4	63	0	1	2	27
2.36	1.69	129.1	40.5	44.1	1.89	3.79	0	0	4	0	1	2	94	1	2	4	63	0	1	2	27
2.38	1.71	131.4	40.5	44.2	1.90	3.83	0	0	4	1	1	2	93	1	2	4	63	0	1	2	27
2.40	1.72	133.7	40.6	44.2	1.91	3.82	0	0	4	0	0	2	94	1	2	4	63	0	1	2	27
2.42	1.74	136.1	40.7	44.3	1.92	3.89	0	0	4	1	1	1	94	1	2	4	64	0	1	2	27
2.44	1.76	138.5	40.7	44.4	1.93	3.90	0	0	4	0	0	1	95	1	2	4	64	0	1	2	27
2.46	1.78	140.9	40.8	44.5	1.95	3.97	0	0	4	1	1	1	94	1	2	4	64	0	1	2	27
2.48	1.79	143.3	40.9	44.6	1.96	3.96	0	0	4	0	0	1	95	1	2	4	64	0	1	2	27
2.50	1.81	145.7	40.9	44.6	1.97	4.02	0	0	3	1	1	1	94	1	2	4	64	0	1	2	27
2.52	1.83	148.2	41.0	44.7	1.98	4.01	0	0	3	0	0	1	95	1	2	4	64	0	1	2	27
2.54	1.84	150.7	41.1	44.8	1.99	4.03	0	0	3	0	0	1	95	1	2	4	64	0	1	2	27
2.56	1.86	153.2	41.1	44.9	2.00	4.10	0	0	3	1	1	1	94	1	2	4	64	0	1	2	27
2.58	1.88	155.7	41.2	45.0	2.01	4.08	0	0	3	0	0	1	95	1	2	4	64	0	1	2	27
2.60	1.89	158.3	41.3	45.0	2.02	4.12	0	0	3	1	1	1	94	1	2	3	64	0	1	1	27
2.62	1.91	160.8	41.4	45.1	2.04	4.12	0	0	3	0	0	1	95	1	2	3	64	0	1	1	27
2.64	1.93	163.4	41.4	45.2	2.05	4.19	0	0	3	1	1	1	94	1	2	3	64	0	1	1	27
2.66	1.94	166.0	41.5	45.3	2.06	4.18	0	0	3	0	0	1	95	1	2	3	64	0	1	1	27
2.68	1.96	168.6	41.6	45.4	2.07	4.25	0	0	3	1	1	1	94	1	2	3	64	0	1	1	28
2.70	1.98	171.2	41.6	45.4	2.08	4.23	0	0	3	0	0	1	95	1	2	3	64	0	1	1	28
2.72	1.99	173.9	41.7	45.5	2.09	4.30	0	0	3	1	1	1	95	1	2	3	64	0	1	1	28
2.74	2.01	176.6	41.8	45.6	2.10	4.28	0	0	3	0	0	1	96	1	2	3	64	0	1	1	28
2.76	2.03	179.3	41.8	45.7	2.11	4.33	0	0	3	0	1	1	95	1	2	3	64	0	1	1	28
2.78	2.04	182.0	41.9	45.8	2.12	4.25	0	0	3	0	0	1	96	1	2	3	64	0	1	1	28
2.80	2.06	184.7	42.0	45.8	2.14	4.32	0	0	3	0	0	1	95	1	2	3	64	0	1	1	28
2.82	2.08	187.4	42.0	45.9	2.15	4.29	0	0	3	0	0	1	96	1	2	3	64	0	1	1	28
2.84	2.09	190.2	42.1	46.0	2.16	4.29	0	0	3	0	0	1	96	1	2	3	64	0	1	1	28
2.86	2.11	193.0	42.2	46.1	2.17	4.32	0	0	3	0	0	1	96	1	2	3	64	0	1	1	28

14.5 CONFIDENCES IN THE HYDRAULIC CHARACTERISATIONS

For EWR KOON 1, the recommended low flows are in the range 0.003 to 0.004 m^3/s (drought, 90%) and 0.017 to 0.052 m^3/s (maintenance, 60%), and the floods range from 2 to 40 m^3/s. The confidence in the hydraulic characterisations for low flows is low (1) and for high flows is medium/high (4). This is because the lowest and highest observed discharges are 0.20 and 20 m^3/s, respectively. For KOON EWR 2, the recommended low flows are in the range 0.004 to 0.047 m^3/s (drought, 90%) and 0.025 to 0.103 m^3/s (maintenance, 60%), and the floods range from 4 to 60 m^3/s. The confidence in the hydraulic characterisations for low flows is low/medium (2) and for high flows is medium (3). This is because the lowest and highest observed discharges are 0.18 and 3.7 m^3/s, respectively, and the presence of filamentous algae influences flow resistance estimation, particularly at low flows.

Additional rating data are required at lower discharges (less than 0.1 m^3/s) to improve the low flow confidences at both sites.

14.6 REFERENCES

Birkhead, AL. 1999. The procedure for generating hydraulic data for the Intermediate and Comprehensive Ecological Reserve (Quantity), Appendix R17. Water Resource Protection Policy Implementation, Resource Directed Measures for protection of Water Resources, Volume 3: River Ecosystems (Version 1.0). http://www.dwaf.gov.za/documents.asp

Birkhead, AL. 2010. The role of Ecohydraulics in the South African Ecological Reserve. In: Ecohydraulics for South African Rivers: A Review and Guide, 264 pp. James, C.S. and King, J.M. (eds), Water Research Commission report no. TT 453/10, Pretoria, South Africa.

Hirschowitz, PM, Birkhead, AL, and James, CS. 2007. Hydraulic modelling for ecological studies for South African Rivers. WRC Report No. 1508/1/07, Water Research Commission, Pretoria. 250pp. http://www.wrc.org.za/publications/reports_htm

Jordanova, AA, Birkhead, AL, James, CS, and Kleynhans, CL. 2004. Hydraulics for determination of the ecological Reserve for rivers. Report to the Water Research Commission on the project “Hydraulic analyses for the determination of the ecological Reserve for rivers”. WRC Report no. 1174/0/1.

Rowlston, B, Jordanova, AA, and Birkhead AL. 2000. Hydraulics In: Environmental flow assessment for rivers: Manual for the Building Block Methodology, King, J.M., Tharme, R.E. and de Villiers, M.S., (eds), Water Research Commission report No.TT 131/00, Pretoria, South Africa.

Tharme, RE. 1996. Review of international methodologies for the quantification of the instream flow requirements of rivers. Water law review. Final report for policy development. Commissioned by the Department of Water Affairs and Forestry, Pretoria. Freshwater Research Unit, University of Cape Town, Cape Town. 116pp.

15 APPENDIX B: DIATOMS

15.1 INTRODUCTION

Benthic diatoms were used in this study as indicators of biological water quality. Diatoms typically reflect water quality conditions over the past three days and are ecologically important because of their role as primary producers, which form the base of the aquatic food web, and because they usually account for the highest number of species among the primary producers in aquatic systems (Leira and Sabater 2005). Diatoms are photosynthetic unicellular organisms and are found in almost all aquatic and semi-aquatic habitats. They have been shown to be reliable indicators of specific water quality problems such as organic pollution, eutrophication, acidification and metal pollution (Tilman *et al*. 1982, Dixit *et al*. 1992, Cattaneo *et al*. 2004), as well as for general water quality (AFNOR, 2000).

15.2 TERMINOLOGY

Terminology used in this specialist appendix is outlined in Taylor *et al*. (2007a) and summarised below.

Trophy	
Dystrophic	Rich in organic matter, usually in the form of suspended plant colloids, but of a low nutrient content.
Oligotrophic	Low levels or primary productivity, containing low levels of mineral nutrients required by plants.
Mesotrophic	Intermediate levels of primary productivity, with intermediate levels of mineral nutrients required by plants.
Eutrophic	High primary productivity, rich in mineral nutrients required by plants.
Hypereutrophic	Very high primary productivity, constantly elevated supply of mineral nutrients required by plants.
Mineral content	
Very electrolyte poor	< 50 µS/cm
Electrolyte-poor (low electrolyte content)	50 - 100 µS/cm
Moderate electrolyte content	100 - 500 µS/cm
Electrolyte-rich (high electrolyte content)	> 500 µS/cm
Brackish (very high electrolyte content)	> 1000 µS/cm
Saline	6000 µS/cm
Pollution (Saprobity)	
Unpolluted to slightly polluted	BOD <2, O_2 deficit <15% (oligosaprobic)
Moderately polluted	BOD <4, O_2 deficit <30% (β-mesosaprobic)
Critical level of pollution	BOD <7 (10), O_2 deficit <50% (β-ά-mesosaprobic)
Strongly polluted	BOD <13, O_2 deficit <75% (ά-mesosaprobic)
Very heavily polluted	BOD <22, O_2 deficit <90% (ά-meso-polysaprobic)
Extremely polluted	BOD >22, O_2 deficit >90% (polysaprobic)

15.3 METHODS

15.3.1 Sampling

Sampling methods were followed as outlined in Taylor *et al*. (2007a) which were designed and refined as part of the Diatom Assessment Protocol, a Water Research Commission initiative.

15.3.2 Slide preparation and diatom enumeration

Preparation of diatom slide followed the Hot HCl and $KMnO_4$ method as outlined in Taylor *et al*. (2007a). A Nikon Eclipse E100 microscope with phase contrast optics (1000x) was used to identify diatom valves on slides. A count of 400 valves per sample or more was enumerated for all the sites based on the findings of Schoeman (1973) and Battarbee (1986) in order to produce semi-quantitative data from which ecological conclusions can be drawn (Taylor *et al*., 2007a). Nomenclature followed Krammer and Lange-Bertalot (1986-91) and diatom index values were calculated with the database programme OMNIDIA (Lecointe *et al*., 1993).

15.3.3 Diatom-based water quality indices

The specific water quality tolerances of diatoms have been resolved into different diatom-based water quality indices, used around the world. Most indices are based on a weighted average equation (Zelinka and Marvan, 1961). In general, each diatom species used in the calculation of the index is assigned two values; the first value (s value) reflects the tolerance or affinity of the particular diatom species to a certain water quality (good or bad) while the second value (v value) indicates how strong (or weak) the relationship is (Taylor, 2004). These values are then weighted by the abundance of the particular diatom species in the sample (Lavoie *et al*., 2006; Taylor, 2004; Besse, 2007). The main difference between indices is in the indicator sets (number of indicators and list of taxa) used in calculations (Eloranta and Soininen, 2002).

These indices form the foundation for developing computer software to estimate biological water quality. OMNIDIA (Lecointe *et al*., 1993) is one such software package; it has been approved by the European Union and is used with increasing frequency in Europe and has been used for this study. The program is a taxonomic and ecological database of 7500 diatom species, and it contains indicator values and degrees of sensitivity for given species. It permits the user to perform rapid calculations of indices of general pollution, saprobity and trophic state, indices of species diversity, as well as of ecological systems (Szczepocka, 2007).

15.4 DATA ANALYSIS

15.4.1 Diatom-based water quality score

The European numerical diatom index, the Specific Pollution sensitivity Index (SPI) was used to interpret results. De la Rey *et al*. (2004) concluded that the SPI reflects certain elements of water quality with a high degree of accuracy due to the broad species base of the SPI. The interpretation of the SPI scores was adjusted during 2011 (Taylor and Koekemoer, in press) and the new adjusted class limits are provided in Table 16.1. The new adjustments will affect diatom-derived Ecological Categories from previous studies and therefore all previous results have been adjusted accordingly.

Table 15.1 Adjusted class limit boundaries for the SPI index applied in this study

Interpretation of index scores		
Ecological Category (EC)	**Class**	**Index Score (SPI Score)**
A	High quality	18 - 20
A/B		17 - 18
B	Good quality	15 - 17
B/C		14 - 15
C	Moderate quality	12 - 14
C/D		10 - 12
D	Poor quality	8 - 10
D/E		6 - 8
E	Bad quality	5 - 6

Interpretation of index scores		
Ecological Category (EC)	**Class**	**Index Score (SPI Score)**
E/F		4 - 5
F		<4

15.4.2 Diatom based Ecological classification

Ecological characterisation of the samples was based on Van Dam *et al.* (1994). This work includes the preferences of 948 freshwater and brackish water diatom species in terms of pH, nitrogen, oxygen, salinity, humidity, saprobity and trophic state as provided by OMNIDIA (Le Cointe *et al*., 1993). The results from the Trophic Diatom Index (TDI) (Kelly and Whitton, 1995) were also taken into account as this index provides the percentage pollution tolerant diatom valves (PTVs) in a sample and was developed for monitoring sewage outfall (orthophosphate-phosphorus concentrations), and not general stream quality. The presence of more than 20% PTVs shows significant organic impact.

15.5 RESULTS

A summary of the diatom results are provided in Table 16.2 and the diatom based ecological classification based on Van Dam *et al*. (1994) for diatom based water quality is given in Table 16.3 and includes the presence of PTVs.

Table 15.2 Results of diatom analysis results for the Koonap River

Site	No species	SPI score	Class	Category	PTV (%)
EWR KOON 1	39	12.5	Moderate quality	C	24.3
EWR KOON 2	44	13.8	Moderate quality	C	10

Table 15.3 Generic diatom based ecological classification for the Koonap River

Site	pH	Salinity	Organic nitrogen	Oxygen levels	Pollution levels	Trophic status
EWR KOON 1	Alkaline	Fresh brackish	Elevated concentrations of organically bound nitrogen	Fairly high (>75% saturation)	Moderately polluted	Eutrophic
EWR KOON 2	Alkaline	Fresh brackish	Elevated concentrations of organically bound nitrogen	Fairly high (>75% saturation)	Moderately polluted	Eutrophic

15.6 DISCUSSION

The results of the diatom analyses are provided below. Note: Species contributing 5% or more to the total count were classified as dominant species and are listed in Section 16.8. Dominant species of the diatom samples collected at EWR KOON 1 and EWR KOON 2 are listed in Table 16.4

Table 15.4 Dominant species present at EWR KOON 1 and EWR KOON 2

Species	Abbr	EWR KOON 1	EWR KOON 2
Amphora pediculus (Kützing) Grunow	APED		5
Cocconeis pediculus Ehrenberg	CPED	7.75	23
Cocconeis placentula Ehrenberg	CPLA	6.25	14.25

Nitzschia dissipata (Kützing) Grunow	NDIS	18	5.5
Nitzschia intermedia Hantzsch	NINT	13.75	
Navicula tripunctata (OF Müller) Bory	NTPT	26.5	
Reimeria uniseriata Sala Guerrero & Ferrario	RUNI		7.25
Stephanodiscus hantzschii Grunow	SHAN		8

15.6.1 EWR KOON 1

The biological water quality at this site was moderate with a SPI score of 12.5 (C Ecological Category) (Table 3.1). The diatom based ecological classification (from Van Dam *et al*., 1994; Table 3.2) indicated that nutrient levels were elevated and this was evident from the dominance of *Cocconeis placentula.* The genus *Cocconeis* has a broad ecological range and is found in most running waters except where nutrients are low or acidic conditions prevail (Taylor *et al.*, 2007b) and according to Fore and Grafe (2002), *C. placentula* prefer alkaline, eutrophic conditions. It is abundant on rocks, but is also found on other surfaces such as filamentous algae and macrophytes (Kelly *et al*., 2001).

Nitzschia dissipata was dominant, indicating hard water (calcium based salinity), and favouring alkaline conditions (Taylor, *pers comm*.). *Navicula tripunctata* is a good indicator of eutrophic conditions and is tolerant to waters of moderate to high electrolyte content and critical levels of pollution. *Nitzschia intermedia,* which was also dominant, has similar preferences to *N. tripunctata* although its tolerance for pollution is lower.

Salinity and organic pollution levels were elevated at levels that were becoming problematic and PTVs made up 24% of the total count. The diatom community was characterized by species with an affinity for moderate water quality with higher organic pollution levels. Indicators of anthropogenic impact specifically relating to sewage were present and included *Amphora pediculus*, *Navicula germainii*, *Navicula gregaria* and *Navicula schroeteri* var. *symmetrica* as well as *Navicula veneta*

15.6.2 EWR KOON 2

There was an improvement in diatom based water quality downstream in the Koonup River at EWR KOON 2. The biological water quality at this site was moderate with a SPI score of 13.8 (C Ecological Category) (Table 3.1). The improvement could mainly be attributed to improvement in organic pollution levels with PTVs making up 10% of the total count.

Although the diatom based water quality was better than at EWR KOON 1 a notable increased gradient in salinity and nutrients was observed between the two sites. Nutrient levels were higher at EWR 2 which was reflected by the greater dominance of *Cocconeis* species. The dominant *Stephanodiscus hantzschii* and sub-dominant *Stephanodiscus minutulus* are found in polluted waters of high electrolyte content and was an indication of increased salinity levels. The dominance of *Reimeria uniseriata* indicated increased turbidity levels (Taylor *et al.*, 2007b). The high abundance of *A. pediculus* also indicated that pollution levels were increasing but that the diatom community as a whole was still reacting to these increased levels.

15.7 CONCLUSIONS

The Koonap River is characterised by moderate water quality. In the upper reaches, in the vicinity of EWR 1 organic pollution levels are problematic while nutrient and salinity levels are generally elevated. High organic pollution levels are mainly due to sewage effluent entering the river at Adelaide. The biological water quality remains relatively stable throughout the Koonap River although higher nutrient and salinity levels occur in the vicinity of EWR 2. The increased gradient of nutrients and salinity is most probably related to irrigation return flows. No valve deformities were noted indicating that metal toxicity was below detection limits at the time of sampling.

15.8 DIATOM SPECIES LISTS

The lists of dominant diatom species collected at various wetland sites during 2013. Species are listed alphabetically.

Species	Abbr	KOON 1	KOON 2
Achnanthidium sp.	ADCS		2
Achnanthidium eutrophilum (Lange-Bertalot) Lange-Bertalot	ADEU	1	
Achnanthidium minutissima Kützing (Czarnecki)	AMIN	3	1
Achnanthidium minutissima var. *saprophilum* (Kobayasi & Mayama) Round and Bukhtiyarova	AMSA	1	
Amphora pediculus (Kützing) Grunow	APED	15	20
Bacillaria paradoxa Gmelin	BPAR		1
Cyclostephanos dubius (Fricke) Round	CDUB		2
Cyclotella meneghiniana Kützing	CMEN		1
Caloneis molaris (Grunow) Krammer	CMOL	1	1
Cocconeis pediculus Ehrenberg	CPED	31	92
Cocconeis placentula Ehrenberg	CPLA	25	57
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow	CPLE		2
Cymbella tumida (Brébisson) Van Heurck	CTUM	1	2
Diploneis oblongella (Naegeli) Cleve-Euler	DOBL		1
Diatoma vulgaris Bory	DVUL		12
Epithemia adnata (Kützing) Brébisson	EADN	1	2
Encyonopsis microcephala (Grunow) Krammer	ENCM	1	
Encyonema minutum (Hilse) DG Mann	ENMI		1
Eolimna minima (Grunow) Lange-Bertalot	EOMI	1	
Eolimna subminuscula (Manguin) Lange-Bertalot	ESBM	1	1
Fragilaria biceps (Kützing) Lange-Bertalot	FBCP		2
Fallacia monoculata (Hustedt) DG Mann	FMOC	1	
Fragilaria parasitica (W Smith) Grunow	FPAR	1	
Gomphonema affine Kützing	GAFF		1
Gomphonema angustum Agardh	GANT		2
Gomphonema minutum (Agardh) Agardh	GMIN	2	
Gomphonema species	GOMS	2	
Gomphonema parvulum (Kützing) Kützing	GPAR	12	1
Gomphonema pumilum var. *rigidum* Reichardt & Lange-Bertalot	GPRI	1	
Mayamaea atomus var. *permitis* (Hustedt) Lange-Bertalot	MAPE		1
Melosira varians Agardh	MVAR	8	8
Nitzschia amphibia Grunow	NAMP	3	
Navicula antonii Lange-Bertalot	NANT	9	16
Navicula capitatoradiata Germain	NCPR	1	4

Species	Abbr	KOON 1	KOON 2
Navicula cryptotenella Lange-Bertalot	NCTE	3	8
Nitzschia dissipata (Kützing) Grunow	NDIS	72	22
Navicula germainii Wallace	NGER	2	
Navicula gregaria Donkin	NGRE	1	
Nitzschia frustulum (Kützing) Grunow	NIFR	7	12
Nitzschia intermedia Hantzsch	NINT	55	1
Nitzschia linearis (Agardh) W Smith	NLIN	11	9
Navicula microcari Lange-Bertalot	NMCA		3
Nitzschia paleacea (Grunow) Grunow	NPAE		1
Nitzschia palea (Kützing) W. Smith	NPAL	1	
Navicula radiosa Kützing	NRAD		1
Navicula rostellata Kützing	NROS	1	8
Navicula schroeteri var. *symmetrica* (Patrick) Lange-Bertalot	NSSY	4	
Navicula tripunctata (OF Müller) Bory	NTPT	106	13
Navicula veneta Kützing	NVEN	2	
Nitzschia species	NZSS	5	9
Planothidium frequentissima (Lange-Bertalot) Round & Bukhityarova	PLFR		1
Planothidium rostrata (Oestrup) Round & Bukhityarova	PRST		1
Rhoicosphenia curvata (Kützing) Grunow	RCUR	1	
Reimeria uniseriata Sala Guerrero & Ferrario	RUNI	3	29
Stephanodiscus hantzschii Grunow	SHAN		32
Stephanodiscus minutulus (Kützing) Cleve and Möller	STMI		11
Tryblionella apiculata Gregory	TAPI	3	4
Tryblionella coarctata D.G. Mann	TCOA		1
Tryblionella hungarica (Grunow) DG Mann	THUN		1
Tryblionella levidensis WM Smith	TLEV	1	0
Total count		**400**	**400**

15.9 REFERENCES

AFNOR (2000). Norme Française NF T 90–354. Détermination de l'Indice Biologique Diatomées IBD. Association Française de Normalisation, 63 pp.

Battarbee, RW. (1986). Diatom Analysis. In Berglund BE (ed) Handbook of Holocene Paleoecology and Paleohydrology. John Wiley & Sons Ltd. Chichester. Great Briton. pp 527-570.

Besse A. (2007). *Integrated Project to evaluate the Impacts of Global Change on European Freshwater Ecosystems:* Task 4 - Generation of an indicator value database for European freshwater species. Euro-limpacs. Project No. GOCE-CT-2003-505540. ALTERRA, Green World Research, Wageningen, Netherlands.

Cattaneo, A, Couillard, Y, Wunsam, S, and Courcelles, M. (2004). Diatom taxonomic and morphological changes as indicators of metal pollution and recovery in Lac Dufault Québec, *Canada. Journal of Paleolimnology* **32**: 163-175.

Dixit, SS, Smol, JP, Kingston, JC & Charles, DF. (1992). Diatoms: Powerful indicators of environmental change. Environmental Science and Technology 26: 23–33.

De la Rey, PA, Taylor, JC, Laas, A, Van Rensburg, L & Vosloo, A. (2004). Determining the possible application value of diatoms as indicators of general water quality: A comparison with SASS 5. *Water SA* **30**: 325-332.

Eloranta P and Soininen J. (2002). Ecological status of Finnish rivers evaluated using benthic diatom communities. *J. Appl. Phycol*. **14**: 1-7.

Fore, LS and Grafe, C. (2002). Using diatoms to assess the biological condition of large rivers in Idaho (U.S.A.). *Freshwater Biology (2002) 47, 2015–2037.*
Europe. *Journal of Applied Phycology* **10**: 215-224.

Kelly MG, Whitton BA. (1995). The Trophic Diatom Index: a new index for monitoring eutrophication in rivers, *Journal of Applied Phycology* 7, 433- 444.

Kelly, MG, Adams, C, Graves, AC, Jamieson, J, Krokowski, J, Lyncett, EB, Murry-Bligh, J, Pritchard, S and Wilkins, C. (2001). The Trophic Diatom Index: A user's manual. Revised Edition. Environmental Agency Technical Report E2/TR2.

Krammer, K and Lange-Bertalot, H. (1986-1991). Bacillario-phyceae. Süßwasserflora von Mitteleuropa *2* (1-4). Spektrum Akademischer Verlag, Heidelberg. Berlin.

Lavoie I, Campeau S, Grenier M and Dillon PJ. (2006). A diatom-based index for the biological assessment of eastern Canadian rivers: an application of correspondence analysis (CA). *Can. J. Fish. Aquat. Sci.* **63**(8): 1793–1811.

Lecointe, C, Coste, M and Prygiel, J. (1993). "Omnidia": Software for taxonomy, calculation of diatom indices and inventories management. Hydrobiologia 269/270: 509-513.

Leira, M and Sabater, S. (2005). Diatom assemblages distribution in Catalan rivers, NE Spain, in relation to chemical and physiographical factors. Water Research **39**: 73-82

Schoeman, FR. (1973). A systematical and ecological study of the diatom flora of Lesotho with special reference to water quality. V&R Printers, Pretoria, South Africa.

Szczepocka E. (2007). Benthic diatoms from the outlet section of the Bzura River. International Journal of Oceanography and Hydrobiology **36**(1): 255-260.

Taylor, JC. (2004). *The Application of Diatom-Based Pollution Indices in the Vaal Catchment*. Unpublished M.Sc. thesis, North-West University, Potchefstroom Campus, Potchefstroom.

Taylor, JC, Harding, WR and Archibald, CGM. (2007a). A methods manual for the collection, preparation and analysis of diatom samples. Water Research Commission Report TT281/07. Water Research Commission. Pretoria.

Taylor, JC, Harding, WR and Archibald, CGM. (2007b). An illustrated guide to some common diatom species from South Africa. Water Research Commission Report TT282/07. Water Research Commission. Pretoria.

Tilman, D, Kilham, SS, & Kilham, P. (1982). Phytoplankton community ecology: The role of limiting nutrients. Annual Review of Ecology and Systematics 13: 349–372.

Van Dam, Mertens A and Sinkeldam J. (1994). A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. Netherlands Journal of Aquatic Ecology 28(1): 177-133.

Zelinka M and Marvan P (1961) Zur Prikisierung der biologischen Klassifikation der Reinheit fliessender Gewasser. Archiv. *Hydrobiol*. **57**: 389-407.

16 APPENDIX C: RDERM - REVISED DESKTOP MODEL OUTPUTS

A report is generated as part of the RDERM to provide:

- the hydrology summary;
- the parameters that were adjusted from the default;
- and the final output results (EWR rules) for all categories.

This report is provided for EWR KOON 1 and EWR KOON 2 in the following sections.

16.1 EWR KOON 1

16.1.1 Hydrology data summary

Natural Flows:					Present Day Flows:				
Area (km^2)	MAR	Ann.SD	Q75	Ann. CV	Area (km^2)	MAR	Ann.SD	Q75	Ann. CV
	($m^3 * 10^6$)					($m^3 * 10^6$)			
0.0	62.93	64.14	0.88	1.02	0	52.04	62.89	0.06	1.21
% Zero flows	0.0				% Zero flows	3.3			
Baseflow Parameters:			A	0.97	Baseflow Parameters:			A	0.97
			B	0.44				B	0.44
BFI				0.32	BFI				0.21
Hydro Index				13	Hydro Index				23.9

MONTH	MEAN	SD	CV	MONTH	MEAN	SD	CV
	($m^3 * 10^6$)				($m^3 * 10^6$)		
Oct	4.06	10.9	2.69	Oct	3	10.87	3.62
Nov	6.59	13.8	2.09	Nov	5.45	13.66	2.5
Dec	6.64	10.99	1.66	Dec	5.34	10.75	2.01
Jan	4.39	7.94	1.81	Jan	3.1	7.59	2.45
Feb	5.87	10.11	1.72	Feb	4.64	9.83	2.12
Mar	10.61	24.12	2.27	Mar	9.46	24.11	2.55
Apr	6.26	11.55	1.84	Apr	5.53	11.44	2.07
May	5.12	12.27	2.4	May	4.56	12.17	2.67
Jun	3.13	5.76	1.84	Jun	2.68	5.72	2.13
Jul	2.82	5.69	2.02	Jul	2.34	5.64	2.41
Aug	4.08	11.19	2.74	Aug	3.42	11.1	3.25
Sep	3.35	7.19	2.15	Sep	2.52	7.12	2.83

Critical months:	Wet Season	Mar	Dry Season	Oct
Max. baseflows (m^3/s)	1.13		0.6	

16.1.2 Hydraulics data summary

Geomorph. Zone	3
Flood Zone	2
Max. Channel width (m)	21.74
Max. Channel Depth (m)	1.5
Observed Channel XS and rating curve used: (Gradients and Roughness n values calibrated)	
Max. Gradient	0.03
Min. Gradient	0.017

Gradient Shape Factor	9
Max. Mannings n	0.3
Min. Mannings n	0.16
n Shape Factor	20
Max. Channel Discharge (m3/s) between 49.576 and 15.268	

16.1.3 Flow - stressor response data summary

Table of initial SHIFT factors for the Stress Frequency Curves		
Category	**High SHIFT**	**Low SHIFT**
A	0.1	0.1
A/B	0.15	0.15
B	0.2	0.2
B/C	0.3	0.275
C	0.4	0.35
C/D	0.5	0.4
D	0.6	0.5
Perenniality Rules: Non-Perennial Allowed		
Alignment of maximum stress to Present Day stress C Category Aligned		
Table of flows (m^3/s) v stress index		
Stress	**Wet Season Flow**	**Dry Season Flow**
1	1.052	0.546
2	0.918	0.476
3	0.639	0.288
4	0.481	0.232
5	0.352	0.129
6	0.242	0.104
7	0.14	0.078
8	0.093	0.052
9	0.047	0.026
10	0	0

16.1.4 High flow estimation summary details

No High flows when natural high flows are < 24% of total flows							
Maximum high flows are 250% greater than normal high flows							
Table of normal high flow requirements (Mill. m^3)							
Category	**A**	**A/B**	**B**	**B/C**	**C**	**C/D**	**D**
Annual	9.985	9.245	8.537	7.858	7.209	6.587	5.992
Oct	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0
Dec	0.753	0.698	0.644	0.593	0.544	0.497	0.452
Jan	0.633	0.586	0.541	0.498	0.457	0.418	0.38
Feb	2.136	1.978	1.826	1.681	1.542	1.409	1.282
Mar	4.526	4.191	3.869	3.562	3.268	2.986	2.716
Apr	1.937	1.793	1.656	1.524	1.398	1.278	1.162
May	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0

16.1.5 Final Reserve summary details

Long term mean flow requirements (Mill. m³ and %MAR)				
Category	Low Flows		Total Flows	
	Mill. m³	%MAR	Mill. m³	%MAR
A	8.46	13.4	18.265	29
A/B	7.282	11.6	16.361	26
B	6.099	9.7	14.482	23
B/C	4.358	6.9	12.075	19.2
C	2.997	4.8	10.076	16
C/D	2.198	3.5	8.667	13.8
D	1.411	2.2	7.296	11.6

16.1.6 Flow duration and Reserve assurance tables

Columns are FDC percentage points:										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Natural Total flow duration curve (mill. m³)										
Oct	8.236	3.388	2.142	1.64	1.32	1.128	0.962	0.772	0.64	0.329
Nov	22.18	8.274	2.73	1.972	1.31	1.072	0.91	0.77	0.578	0.278
Dec	18.672	11.254	7.066	2.856	1.72	1.164	0.872	0.664	0.5	0.23
Jan	15.478	5.276	2.976	1.666	1.23	0.888	0.744	0.634	0.512	0.199
Feb	19.124	7.522	4.058	2.662	1.89	1.134	0.8	0.644	0.5	0.238
Mar	19.06	13.684	8.868	6.19	4.01	2.144	1.586	1.094	0.672	0.462
Apr	16.018	6.018	4.278	3.678	2.1	1.504	1.102	0.924	0.722	0.387
May	13.962	3.384	2.054	1.552	1.32	1.14	1.06	0.9	0.732	0.463
Jun	9.14	2.44	1.93	1.374	1.28	1.138	1.05	0.918	0.752	0.55
Jul	5.014	2.516	1.896	1.522	1.38	1.118	1.026	0.91	0.718	0.579
Aug	7.718	2.638	1.874	1.464	1.25	1.02	0.922	0.844	0.712	0.491
Sep	7.164	2.728	1.84	1.522	1.24	1.05	0.886	0.72	0.626	0.379
Natural Baseflow flow duration curve (mill. m³)										
Oct	2.426	1.59	1.364	1.171	1.12	0.949	0.834	0.718	0.603	0.329
Nov	4.047	2.219	1.401	1.25	1.044	0.924	0.838	0.735	0.572	0.278
Dec	4.648	2.373	1.84	1.412	1.25	0.973	0.82	0.627	0.5	0.23
Jan	3.82	1.774	1.374	1.102	0.922	0.818	0.682	0.574	0.449	0.199
Feb	3.666	1.904	1.433	1.205	1.02	0.933	0.731	0.602	0.492	0.237
Mar	4.042	2.967	2.254	1.869	1.324	1.05	0.904	0.795	0.565	0.368
Apr	4.027	2.194	1.692	1.435	1.18	1.03	0.888	0.741	0.522	0.349
May	4.07	1.79	1.544	1.247	1.062	0.948	0.856	0.742	0.534	0.353
Jun	2.867	1.796	1.354	1.186	1.01	0.937	0.867	0.738	0.543	0.399
Jul	2.878	1.89	1.59	1.199	1.05	0.931	0.878	0.749	0.57	0.484
Aug	2.684	1.867	1.491	1.213	1.02	0.9	0.854	0.763	0.569	0.476
Sep	2.182	1.675	1.436	1.199	1.053	0.899	0.83	0.71	0.568	0.379
Category Low Flow Assurance curves (mill. m³)										
A Category										
Oct	1.309	0.802	0.614	0.382	0.314	0.287	0.27	0.26	0.255	0.252
Nov	2.267	1.333	0.645	0.435	0.417	0.34	0.302	0.301	0.287	0.22
Dec	2.501	1.552	0.988	0.61	0.518	0.325	0.291	0.266	0.254	0.199
Jan	2.125	1.029	0.701	0.487	0.385	0.319	0.252	0.241	0.229	0.182
Feb	2.071	1.196	0.648	0.41	0.38	0.317	0.248	0.224	0.222	0.172

Columns are FDC percentage points:										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Mar	2.622	2.106	1.443	1.013	0.71	0.497	0.365	0.323	0.298	0.285
Apr	2.387	1.305	0.833	0.609	0.431	0.409	0.324	0.294	0.275	0.263
May	2.38	1.116	0.747	0.496	0.434	0.326	0.309	0.307	0.29	0.273
Jun	1.757	1.019	0.688	0.441	0.409	0.343	0.309	0.296	0.291	0.291
Jul	1.556	1.072	0.748	0.451	0.435	0.358	0.321	0.316	0.316	0.316
Aug	1.512	1.047	0.71	0.471	0.43	0.347	0.321	0.316	0.311	0.31
Sep	1.367	0.894	0.65	0.44	0.42	0.334	0.301	0.301	0.294	0.272
A/B Category										
Oct	1.107	0.7	0.464	0.316	0.274	0.246	0.229	0.219	0.214	0.211
Nov	2.049	1.114	0.513	0.354	0.353	0.279	0.254	0.254	0.24	0.183
Dec	2.246	1.303	0.829	0.508	0.436	0.273	0.248	0.224	0.213	0.166
Jan	1.923	0.853	0.574	0.404	0.326	0.262	0.215	0.203	0.192	0.152
Feb	1.868	1.003	0.52	0.336	0.322	0.26	0.212	0.188	0.186	0.144
Mar	2.433	1.753	1.257	0.875	0.591	0.386	0.315	0.274	0.249	0.237
Apr	2.172	1.092	0.687	0.509	0.367	0.332	0.277	0.248	0.23	0.219
May	2.172	0.932	0.604	0.405	0.368	0.273	0.264	0.259	0.243	0.228
Jun	1.566	0.845	0.568	0.374	0.346	0.282	0.264	0.249	0.242	0.242
Jul	1.373	0.887	0.604	0.386	0.368	0.293	0.275	0.265	0.264	0.264
Aug	1.33	0.867	0.57	0.392	0.364	0.284	0.274	0.266	0.259	0.259
Sep	1.218	0.738	0.518	0.375	0.356	0.274	0.253	0.253	0.246	0.226
B Category										
Oct	0.848	0.615	0.338	0.277	0.233	0.205	0.188	0.178	0.172	0.169
Nov	1.719	0.954	0.392	0.306	0.292	0.232	0.206	0.206	0.194	0.147
Dec	1.873	1.119	0.682	0.439	0.359	0.228	0.206	0.181	0.172	0.133
Jan	1.627	0.735	0.448	0.348	0.27	0.218	0.179	0.165	0.155	0.122
Feb	1.566	0.857	0.404	0.288	0.266	0.216	0.176	0.153	0.15	0.115
Mar	2.067	1.533	1.1	0.747	0.476	0.329	0.266	0.225	0.201	0.188
Apr	1.844	0.938	0.552	0.44	0.306	0.276	0.232	0.203	0.186	0.175
May	1.839	0.799	0.472	0.351	0.304	0.227	0.218	0.21	0.196	0.182
Jun	1.306	0.729	0.451	0.315	0.286	0.234	0.219	0.202	0.194	0.194
Jul	1.123	0.767	0.474	0.322	0.304	0.244	0.229	0.211	0.211	0.211
Aug	1.084	0.748	0.441	0.332	0.301	0.236	0.226	0.217	0.207	0.207
Sep	1.001	0.637	0.396	0.312	0.294	0.228	0.205	0.205	0.199	0.181
B/C Category										
Oct	0.672	0.368	0.269	0.203	0.156	0.126	0.107	0.096	0.09	0.087
Nov	1.314	0.705	0.299	0.224	0.197	0.155	0.116	0.112	0.102	0.074
Dec	1.436	0.846	0.526	0.319	0.243	0.146	0.123	0.099	0.091	0.067
Jan	1.242	0.509	0.341	0.252	0.182	0.146	0.109	0.091	0.082	0.061
Feb	1.2	0.627	0.309	0.21	0.179	0.145	0.108	0.085	0.079	0.058
Mar	1.595	1.227	0.855	0.532	0.326	0.234	0.17	0.129	0.105	0.093
Apr	1.412	0.688	0.423	0.319	0.206	0.189	0.144	0.115	0.098	0.088
May	1.402	0.563	0.361	0.255	0.205	0.147	0.129	0.113	0.103	0.091
Jun	0.996	0.507	0.344	0.225	0.193	0.157	0.131	0.111	0.1	0.097
Jul	0.852	0.537	0.363	0.225	0.205	0.163	0.138	0.115	0.107	0.107
Aug	0.822	0.52	0.337	0.241	0.203	0.158	0.134	0.123	0.108	0.104
Sep	0.756	0.431	0.302	0.223	0.198	0.153	0.124	0.111	0.105	0.091
C Category										
Oct	0.489	0.289	0.2	0.129	0.079	0.046	0.026	0.014	0.008	0.005
Nov	1.04	0.541	0.223	0.145	0.125	0.078	0.035	0.02	0.01	0.002

Columns are FDC percentage points:										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Dec	1.129	0.653	0.392	0.209	0.156	0.063	0.041	0.022	0.009	0.002
Jan	0.98	0.377	0.254	0.167	0.116	0.075	0.04	0.02	0.008	0.002
Feb	0.949	0.482	0.231	0.137	0.114	0.074	0.039	0.019	0.008	0.002
Mar	1.279	0.967	0.634	0.352	0.231	0.138	0.075	0.034	0.009	0
Apr	1.124	0.526	0.314	0.209	0.125	0.102	0.056	0.027	0.01	0.002
May	1.121	0.424	0.269	0.168	0.13	0.066	0.041	0.022	0.011	0.003
Jun	0.774	0.377	0.256	0.148	0.123	0.079	0.044	0.024	0.01	0.002
Jul	0.655	0.399	0.271	0.147	0.13	0.082	0.049	0.025	0.011	0.003
Aug	0.631	0.386	0.251	0.159	0.129	0.08	0.042	0.029	0.011	0.003
Sep	0.589	0.315	0.225	0.146	0.126	0.078	0.044	0.023	0.011	0.003
C/D Category										
Oct	0.341	0.237	0.138	0.06	0.004	0	0	0	0	0
Nov	0.857	0.445	0.157	0.077	0.06	0.021	0	0	0	0
Dec	0.918	0.537	0.287	0.131	0.078	0.008	0	0	0	0
Jan	0.817	0.31	0.182	0.106	0.055	0.02	0	0	0	0
Feb	0.784	0.397	0.165	0.074	0.055	0.02	0	0	0	0
Mar	1.099	0.8	0.468	0.271	0.145	0.049	0	0	0	0
Apr	0.944	0.433	0.227	0.132	0.051	0.031	0.001	0	0	0
May	0.937	0.349	0.192	0.096	0.062	0.011	0	0	0	0
Jun	0.626	0.31	0.184	0.082	0.059	0.021	0	0	0	0
Jul	0.515	0.327	0.194	0.078	0.063	0.022	0	0	0	0
Aug	0.492	0.317	0.178	0.089	0.062	0.021	0	0	0	0
Sep	0.466	0.259	0.159	0.078	0.061	0.021	0	0	0	0
D Category										
Oct	0.269	0.163	0.061	0	0	0	0	0	0	0
Nov	0.615	0.301	0.076	0.018	0.017	0	0	0	0	0
Dec	0.664	0.362	0.166	0.052	0.021	0	0	0	0	0
Jan	0.588	0.212	0.099	0.044	0.016	0	0	0	0	0
Feb	0.563	0.269	0.083	0.022	0.016	0	0	0	0	0
Mar	0.787	0.529	0.304	0.162	0.04	0	0	0	0	0
Apr	0.677	0.293	0.126	0.057	0.014	0	0	0	0	0
May	0.67	0.238	0.1	0.03	0.018	0	0	0	0	0
Jun	0.455	0.212	0.102	0.028	0.017	0	0	0	0	0
Jul	0.373	0.223	0.1	0.026	0.018	0	0	0	0	0
Aug	0.356	0.217	0.09	0.03	0.018	0	0	0	0	0
Sep	0.336	0.177	0.078	0.025	0.018	0	0	0	0	0
Category Total Flow Assurance curves (mill. m^3)										
A Category										
Oct	1.309	0.802	0.614	0.382	0.314	0.287	0.27	0.26	0.255	0.252
Nov	2.267	1.333	0.645	0.435	0.417	0.34	0.302	0.301	0.287	0.22
Dec	4.07	2.673	1.861	1.382	1.272	1.03	0.855	0.594	0.261	0.199
Jan	3.444	1.971	1.435	1.135	1.018	0.912	0.726	0.517	0.235	0.182
Feb	6.52	4.373	3.123	2.596	2.516	2.316	1.847	1.155	0.239	0.172
Mar	12.049	8.838	6.687	5.647	5.235	4.733	3.752	2.296	0.335	0.285
Apr	6.42	4.186	3.077	2.592	2.367	2.221	1.773	1.138	0.291	0.263
May	2.38	1.116	0.747	0.496	0.434	0.326	0.309	0.307	0.29	0.273
Jun	1.757	1.019	0.688	0.441	0.409	0.343	0.309	0.296	0.291	0.291
Jul	1.556	1.072	0.748	0.451	0.435	0.358	0.321	0.316	0.316	0.316
Aug	1.512	1.047	0.71	0.471	0.43	0.347	0.321	0.316	0.311	0.31

Columns are FDC percentage points:										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Sep	1.367	0.894	0.65	0.44	0.42	0.334	0.301	0.301	0.294	0.272
A/B Category										
Oct	1.107	0.7	0.464	0.316	0.274	0.246	0.229	0.219	0.214	0.211
Nov	2.049	1.114	0.513	0.354	0.353	0.279	0.254	0.254	0.24	0.183
Dec	3.699	2.341	1.637	1.223	1.134	0.926	0.77	0.528	0.219	0.166
Jan	3.145	1.725	1.253	1.004	0.912	0.81	0.653	0.459	0.197	0.152
Feb	5.987	3.945	2.811	2.361	2.299	2.111	1.692	1.05	0.202	0.144
Mar	11.161	7.987	6.113	5.165	4.782	4.308	3.451	2.101	0.284	0.237
Apr	5.907	3.759	2.765	2.345	2.16	2.01	1.619	1.03	0.245	0.219
May	2.172	0.932	0.604	0.405	0.368	0.273	0.264	0.259	0.243	0.228
Jun	1.566	0.845	0.568	0.374	0.346	0.282	0.264	0.249	0.242	0.242
Jul	1.373	0.887	0.604	0.386	0.368	0.293	0.275	0.265	0.264	0.264
Aug	1.33	0.867	0.57	0.392	0.364	0.284	0.274	0.266	0.259	0.259
Sep	1.218	0.738	0.518	0.375	0.356	0.274	0.253	0.253	0.246	0.226
B Category										
Oct	0.848	0.615	0.338	0.277	0.233	0.205	0.188	0.178	0.172	0.169
Nov	1.719	0.954	0.392	0.306	0.292	0.232	0.206	0.206	0.194	0.147
Dec	3.215	2.077	1.429	1.098	1.003	0.831	0.688	0.462	0.177	0.133
Jan	2.754	1.541	1.076	0.903	0.811	0.724	0.584	0.401	0.16	0.122
Feb	5.37	3.573	2.52	2.157	2.092	1.925	1.543	0.949	0.165	0.115
Mar	10.126	7.289	5.584	4.709	4.346	3.951	3.162	1.912	0.233	0.188
Apr	5.293	3.401	2.47	2.135	1.962	1.825	1.471	0.925	0.199	0.175
May	1.839	0.799	0.472	0.351	0.304	0.227	0.218	0.21	0.196	0.182
Jun	1.306	0.729	0.451	0.315	0.286	0.234	0.219	0.202	0.194	0.194
Jul	1.123	0.767	0.474	0.322	0.304	0.244	0.229	0.211	0.211	0.211
Aug	1.084	0.748	0.441	0.332	0.301	0.236	0.226	0.217	0.207	0.207
Sep	1.001	0.637	0.396	0.312	0.294	0.228	0.205	0.205	0.199	0.181
B/C Category										
Oct	0.672	0.368	0.269	0.203	0.156	0.126	0.107	0.096	0.09	0.087
Nov	1.314	0.705	0.299	0.224	0.197	0.155	0.116	0.112	0.102	0.074
Dec	2.671	1.728	1.213	0.926	0.836	0.701	0.567	0.357	0.095	0.067
Jan	2.28	1.25	0.919	0.762	0.68	0.613	0.482	0.308	0.086	0.061
Feb	4.701	3.127	2.257	1.931	1.86	1.718	1.366	0.818	0.093	0.058
Mar	9.014	6.526	4.982	4.179	3.888	3.567	2.836	1.682	0.134	0.093
Apr	4.587	2.956	2.189	1.88	1.73	1.615	1.284	0.779	0.11	0.088
May	1.402	0.563	0.361	0.255	0.205	0.147	0.129	0.113	0.103	0.091
Jun	0.996	0.507	0.344	0.225	0.193	0.157	0.131	0.111	0.1	0.097
Jul	0.852	0.537	0.363	0.225	0.205	0.163	0.138	0.115	0.107	0.107
Aug	0.822	0.52	0.337	0.241	0.203	0.158	0.134	0.123	0.108	0.104
Sep	0.756	0.431	0.302	0.223	0.198	0.153	0.124	0.111	0.105	0.091
C Category										
Oct	0.489	0.289	0.2	0.129	0.079	0.046	0.026	0.014	0.008	0.005
Nov	1.04	0.541	0.223	0.145	0.125	0.078	0.035	0.02	0.01	0.002
Dec	2.262	1.462	1.022	0.766	0.7	0.573	0.448	0.259	0.014	0.002
Jan	1.932	1.057	0.784	0.635	0.573	0.502	0.382	0.219	0.012	0.002
Feb	4.161	2.775	2.018	1.716	1.656	1.517	1.193	0.691	0.021	0.002
Mar	8.084	5.828	4.42	3.697	3.498	3.196	2.52	1.458	0.036	0
Apr	4.036	2.606	1.934	1.641	1.523	1.41	1.102	0.636	0.021	0.002
May	1.121	0.424	0.269	0.168	0.13	0.066	0.041	0.022	0.011	0.003

Columns are FDC percentage points:										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Jun	0.774	0.377	0.256	0.148	0.123	0.079	0.044	0.024	0.01	0.002
Jul	0.655	0.399	0.271	0.147	0.13	0.082	0.049	0.025	0.011	0.003
Aug	0.631	0.386	0.251	0.159	0.129	0.08	0.042	0.029	0.011	0.003
Sep	0.589	0.315	0.225	0.146	0.126	0.078	0.044	0.023	0.011	0.003
C/D Category										
Oct	0.341	0.237	0.138	0.06	0.004	0	0	0	0	0
Nov	0.857	0.445	0.157	0.077	0.06	0.021	0	0	0	0
Dec	1.954	1.277	0.863	0.64	0.575	0.473	0.372	0.217	0.004	0
Jan	1.687	0.932	0.666	0.534	0.473	0.411	0.313	0.182	0.003	0
Feb	3.719	2.492	1.797	1.517	1.464	1.339	1.055	0.614	0.012	0
Mar	7.318	5.241	3.928	3.328	3.13	2.843	2.234	1.301	0.024	0
Apr	3.605	2.333	1.708	1.441	1.329	1.227	0.957	0.557	0.01	0
May	0.937	0.349	0.192	0.096	0.062	0.011	0	0	0	0
Jun	0.626	0.31	0.184	0.082	0.059	0.021	0	0	0	0
Jul	0.515	0.327	0.194	0.078	0.063	0.022	0	0	0	0
Aug	0.492	0.317	0.178	0.089	0.062	0.021	0	0	0	0
Sep	0.466	0.259	0.159	0.078	0.061	0.021	0	0	0	0
D Category										
Oct	0.269	0.163	0.061	0	0	0	0	0	0	0
Nov	0.615	0.301	0.076	0.018	0.017	0	0	0	0	0
Dec	1.606	1.034	0.69	0.515	0.474	0.423	0.339	0.197	0.004	0
Jan	1.379	0.778	0.54	0.433	0.396	0.356	0.284	0.166	0.003	0
Feb	3.233	2.176	1.568	1.335	1.298	1.2	0.959	0.559	0.01	0
Mar	6.445	4.57	3.451	2.943	2.756	2.542	2.033	1.184	0.022	0
Apr	3.098	2.022	1.473	1.247	1.176	1.088	0.87	0.507	0.009	0
May	0.67	0.238	0.1	0.03	0.018	0	0	0	0	0
Jun	0.455	0.212	0.102	0.028	0.017	0	0	0	0	0
Jul	0.373	0.223	0.1	0.026	0.018	0	0	0	0	0
Aug	0.356	0.217	0.09	0.03	0.018	0	0	0	0	0
Sep	0.336	0.177	0.078	0.025	0.018	0	0	0	0	0

16.2 EWR KOON 2

16.2.1 Hydrology data summary

Natural Flows:					Present Day Flows:				
Area (km^2)	MAR	Ann.SD	Q75	Ann. CV	Area (km^2)	MAR	Ann.SD	Q75	Ann. CV
	($m^3 * 10^6$)					($m^3 * 10^6$)			
0.0	77.54	85.07	0.9	1.1	0	65.3	83.47	0.03	1.28
% Zero flows	0.0				% Zero flows	3.3			
Baseflow Parameters:			A	0.97	Baseflow Parameters:			A	0.97
			B	0.44				B	0.44
BFI				0.29	BFI				0.21
Hydro Index				14.8	Hydro Index				25.5

MONTH	MEAN	SD	CV	MONTH	MEAN	SD	CV
	($m^3 * 10^6$)				($m^3 * 10^6$)		
Oct	5.34	16.37	3.07	Oct	4.16	16.27	3.91
Nov	8.31	17.79	2.14	Nov	7.01	17.52	2.5
Dec	8.46	14.67	1.73	Dec	6.96	14.33	2.06
Jan	5.44	9.75	1.79	Jan	3.99	9.31	2.33
Feb	7.39	12.87	1.74	Feb	5.97	12.46	2.09
Mar	14.68	37.41	2.55	Mar	13.31	37.25	2.8
Apr	7.93	15.55	1.96	Apr	7.1	15.36	2.16
May	5.56	13.67	2.46	May	4.95	13.54	2.73
Jun	3.26	6.15	1.89	Jun	2.79	6.09	2.18
Jul	2.95	6.23	2.11	Jul	2.44	6.13	2.51
Aug	4.51	13.35	2.96	Aug	3.8	13.18	3.46
Sep	3.71	8.04	2.17	Sep	2.81	7.91	2.81

Critical months:	Wet Season	Mar	Dry Season	Oct
Max. baseflows (m^3/s)	1.41		0.651	

16.2.2 Hydraulics data summary

Geomorph. Zone	4
Flood Zone	2
Max. Channel width (m)	28.07
Max. Channel Depth (m)	1.5
Observed Channel XS and rating curve used: (Gradients and Roughness n values calibrated)	
Max. Gradient	0.016
Min. Gradient	0.016
Gradient Shape Factor	10
Max. Mannings n	0.15
Min. Mannings n	0.07
n Shape Factor	35
Max. Channel Discharge (m^3/s) between 59.329 and 55.362	

16.2.3 Flow - stressor response data summary

Table of initial SHIFT factors for the Stress Frequency Curves		
Category	**High SHIFT**	**Low SHIFT**
A	0.1	0.05
A/B	0.15	0.075
B	0.2	0.1
B/C	0.3	0.125
C	0.4	0.15
C/D	0.5	0.2
D	0.6	0.3
Perenniality Rules: Wet season perennial forced		
Alignment of maximum stress to Present Day stress C Category Aligned		
Table of flows (m^3/s) v stress index		
Stress	**Wet Season Flow**	**Dry Season Flow**
1	1.421	0.706
2	1.279	0.655
3	1.167	0.592
4	0.965	0.501
5	0.713	0.393
6	0.585	0.198
7	0.415	0.126
8	0.198	0.095
9	0.106	0.063
10	0.053	0.032

16.2.4 High flow estimation summary details

No High flows when natural high flows are < 24% of total flows							
Maximum high flows are 290% greater than normal high flows							
Table of normal high flow requirements (Mill. m^3)							
Category	**A**	**A/B**	**B**	**B/C**	**C**	**C/D**	**D**
Annual	13.414	12.361	11.359	10.406	9.501	8.64	7.822
Oct	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0
Dec	1.189	1.096	1.007	0.923	0.842	0.766	0.694
Jan	1.172	1.08	0.993	0.909	0.83	0.755	0.684
Feb	2.741	2.525	2.321	2.126	1.941	1.765	1.598
Mar	5.929	5.464	5.021	4.6	4.2	3.819	3.458
Apr	2.382	2.195	2.017	1.848	1.687	1.534	1.389
May	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0
Sep	0	0	0	0	0	0	0

16.2.5 Final Reserve summary details

Long term mean flow requirements (Mill. m^3 and %MAR)				
Category	Low Flows		Total Flows	
	Mill. m^3	%MAR	Mill. m^3	%MAR
A	10.698	13.8	24.286	31.3
A/B	9.778	12.6	22.299	28.8
B	8.91	11.5	20.417	26.3
B/C	7.76	10	18.301	23.6
C	6.917	8.9	16.541	21.3
C/D	5.928	7.6	14.679	18.9
D	4.495	5.8	12.419	16

16.2.6 Flow duration and Reserve assurance tables

Columns are FDC percentage points:										
	10	20	30	40	50	60	70	80	90	99
Natural Total flow duration curve (mill. m^3)										
Oct	11.41	4.268	2.36	1.712	1.43	1.168	1.008	0.772	0.642	0.329
Nov	24.59	9.598	3.996	2.364	1.45	1.172	0.95	0.83	0.612	0.278
Dec	25.652	13.32	8.084	4.02	1.99	1.348	0.898	0.682	0.548	0.23
Jan	20.41	6.106	3.524	2.072	1.49	0.994	0.808	0.662	0.536	0.199
Feb	23.578	9.954	4.92	3.438	2.25	1.434	0.866	0.708	0.532	0.238
Mar	27.416	16.746	10.582	7.044	5.03	2.838	1.714	1.266	0.69	0.462
Apr	19.502	7.376	5.108	4.246	2.34	1.586	1.166	0.93	0.732	0.387
May	17.2	3.588	2.158	1.586	1.33	1.15	1.082	0.908	0.732	0.463
Jun	9.912	2.522	1.93	1.374	1.28	1.156	1.062	0.918	0.752	0.55
Jul	5.076	2.516	1.896	1.522	1.39	1.118	1.026	0.91	0.718	0.579
Aug	7.918	2.662	1.88	1.482	1.25	1.02	0.922	0.844	0.712	0.491
Sep	8.156	3.244	1.852	1.558	1.27	1.05	0.886	0.72	0.626	0.379
Natural Baseflow flow duration curve (mill. m^3)										
Oct	2.767	1.727	1.462	1.294	1.137	0.967	0.844	0.723	0.611	0.329
Nov	4.376	2.707	1.553	1.361	1.102	0.951	0.882	0.764	0.586	0.278
Dec	6.079	2.757	2.059	1.555	1.359	0.99	0.867	0.647	0.548	0.23
Jan	4.202	2.117	1.551	1.228	1.021	0.88	0.75	0.596	0.458	0.199
Feb	4.869	2.89	1.816	1.371	1.167	0.998	0.772	0.651	0.502	0.237
Mar	5.15	3.77	2.823	2.243	1.469	1.231	1.01	0.834	0.57	0.369
Apr	5.023	2.611	2.012	1.598	1.29	1.099	0.922	0.822	0.535	0.349
May	4.468	1.912	1.654	1.306	1.11	0.978	0.894	0.743	0.561	0.353
Jun	3.002	1.831	1.465	1.224	1.069	0.977	0.876	0.785	0.551	0.4
Jul	2.878	1.916	1.6	1.217	1.1	0.964	0.894	0.751	0.571	0.484
Aug	2.692	1.898	1.547	1.222	1.029	0.923	0.857	0.764	0.58	0.476
Sep	2.681	1.736	1.491	1.216	1.1	0.907	0.832	0.713	0.568	0.379
Category Low Flow Assurance curves (mill. m^3)										
A Category										
Oct	1.385	0.71	0.307	0.195	0.117	0.067	0.038	0.021	0.012	0.007
Nov	2.403	1.337	0.392	0.248	0.203	0.122	0.113	0.113	0.106	0.049
Dec	2.898	1.513	0.838	0.423	0.319	0.108	0.107	0.106	0.099	0.045
Jan	2.26	1.044	0.472	0.373	0.224	0.132	0.093	0.093	0.086	0.044
Feb	2.348	1.4	0.498	0.242	0.172	0.091	0.09	0.09	0.084	0.042
Mar	3.038	2.369	1.658	1.048	0.471	0.275	0.199	0.153	0.127	0.114

Columns are FDC percentage points:										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Apr	2.69	1.431	0.698	0.422	0.285	0.165	0.117	0.117	0.1	0.067
May	2.42	0.982	0.431	0.255	0.235	0.12	0.118	0.117	0.108	0.074
Jun	1.519	0.848	0.46	0.377	0.223	0.113	0.113	0.112	0.103	0.071
Jul	1.486	0.872	0.415	0.366	0.235	0.126	0.117	0.115	0.108	0.074
Aug	1.469	0.862	0.371	0.346	0.23	0.139	0.118	0.118	0.111	0.079
Sep	1.413	0.757	0.343	0.34	0.227	0.133	0.112	0.111	0.105	0.058
A/B Category										
Oct	1.618	1.264	0.717	0.395	0.301	0.262	0.238	0.225	0.218	0.214
Nov	2.686	1.871	0.824	0.462	0.406	0.291	0.248	0.235	0.227	0.186
Dec	3.243	2.063	1.284	0.685	0.603	0.284	0.246	0.215	0.212	0.172
Jan	2.537	1.582	0.912	0.579	0.434	0.283	0.224	0.194	0.185	0.15
Feb	2.627	1.894	0.907	0.446	0.365	0.259	0.213	0.188	0.18	0.144
Mar	3.302	2.82	1.932	1.408	0.834	0.457	0.324	0.261	0.235	0.223
Apr	2.98	1.967	1.137	0.709	0.548	0.349	0.27	0.246	0.215	0.213
May	2.702	1.511	0.878	0.475	0.461	0.286	0.257	0.24	0.232	0.221
Jun	1.762	1.344	0.819	0.573	0.435	0.28	0.245	0.238	0.238	0.238
Jul	1.705	1.388	0.86	0.57	0.457	0.301	0.258	0.258	0.258	0.258
Aug	1.684	1.375	0.811	0.553	0.446	0.301	0.255	0.252	0.252	0.252
Sep	1.609	1.222	0.758	0.543	0.441	0.286	0.241	0.23	0.227	0.222
B Category										
Oct	1.562	1.165	0.531	0.327	0.263	0.222	0.198	0.184	0.176	0.173
Nov	2.608	1.741	0.659	0.391	0.338	0.246	0.205	0.194	0.185	0.15
Dec	3.15	1.925	1.109	0.595	0.497	0.241	0.204	0.176	0.173	0.139
Jan	2.462	1.461	0.743	0.509	0.362	0.239	0.184	0.159	0.15	0.121
Feb	2.551	1.768	0.75	0.379	0.31	0.219	0.175	0.155	0.146	0.116
Mar	3.226	2.677	1.823	1.278	0.663	0.383	0.264	0.218	0.192	0.179
Apr	2.898	1.833	0.967	0.612	0.457	0.294	0.222	0.204	0.175	0.172
May	2.625	1.394	0.707	0.402	0.384	0.242	0.213	0.197	0.189	0.178
Jun	1.701	1.237	0.674	0.506	0.363	0.238	0.203	0.194	0.192	0.192
Jul	1.649	1.275	0.69	0.501	0.381	0.255	0.214	0.208	0.208	0.208
Aug	1.629	1.264	0.643	0.483	0.372	0.253	0.21	0.203	0.203	0.203
Sep	1.558	1.121	0.598	0.476	0.367	0.241	0.198	0.188	0.185	0.178
B/C Category										
Oct	1.473	0.982	0.396	0.261	0.19	0.145	0.118	0.102	0.094	0.09
Nov	2.511	1.543	0.486	0.313	0.255	0.176	0.136	0.136	0.131	0.093
Dec	3.029	1.723	0.935	0.496	0.38	0.164	0.13	0.127	0.123	0.085
Jan	2.366	1.263	0.568	0.429	0.275	0.176	0.13	0.113	0.107	0.076
Feb	2.456	1.584	0.587	0.304	0.233	0.151	0.123	0.109	0.104	0.073
Mar	3.148	2.515	1.722	1.136	0.505	0.299	0.215	0.168	0.142	0.129
Apr	2.8	1.636	0.793	0.494	0.349	0.218	0.156	0.147	0.124	0.11
May	2.528	1.199	0.529	0.322	0.291	0.166	0.141	0.141	0.134	0.115
Jun	1.614	1.054	0.522	0.43	0.275	0.165	0.135	0.135	0.127	0.12
Jul	1.571	1.085	0.512	0.422	0.289	0.183	0.14	0.139	0.134	0.13
Aug	1.553	1.074	0.467	0.403	0.283	0.186	0.143	0.142	0.137	0.129
Sep	1.489	0.95	0.428	0.397	0.279	0.178	0.139	0.135	0.131	0.109
C Category										
Oct	1.385	0.71	0.307	0.195	0.117	0.067	0.038	0.021	0.012	0.007
Nov	2.403	1.337	0.392	0.248	0.203	0.122	0.113	0.113	0.106	0.049
Dec	2.898	1.513	0.838	0.423	0.319	0.108	0.107	0.106	0.099	0.045

Columns are FDC percentage points:										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Jan	2.26	1.044	0.472	0.373	0.224	0.132	0.093	0.093	0.086	0.044
Feb	2.348	1.4	0.498	0.242	0.172	0.091	0.09	0.09	0.084	0.042
Mar	3.038	2.369	1.658	1.048	0.471	0.275	0.199	0.153	0.127	0.114
Apr	2.69	1.431	0.698	0.422	0.285	0.165	0.117	0.117	0.1	0.067
May	2.42	0.982	0.431	0.255	0.235	0.12	0.118	0.117	0.108	0.074
Jun	1.519	0.848	0.46	0.377	0.223	0.113	0.113	0.112	0.103	0.071
Jul	1.486	0.872	0.415	0.366	0.235	0.126	0.117	0.115	0.108	0.074
Aug	1.469	0.862	0.371	0.346	0.23	0.139	0.118	0.118	0.111	0.079
Sep	1.413	0.757	0.343	0.34	0.227	0.133	0.112	0.111	0.105	0.058
C/D Category										
Oct	1.225	0.466	0.242	0.122	0.04	0	0	0	0	0
Nov	2.174	1.063	0.316	0.174	0.149	0.103	0.101	0.099	0.091	0.039
Dec	2.624	1.226	0.738	0.331	0.25	0.099	0.096	0.093	0.086	0.036
Jan	2.039	0.771	0.393	0.298	0.168	0.092	0.081	0.081	0.075	0.036
Feb	2.126	1.15	0.42	0.171	0.107	0.078	0.078	0.078	0.073	0.035
Mar	2.785	2.094	1.535	0.894	0.42	0.252	0.179	0.136	0.111	0.099
Apr	2.448	1.157	0.605	0.331	0.214	0.117	0.099	0.099	0.086	0.055
May	2.19	0.714	0.351	0.18	0.174	0.103	0.102	0.101	0.093	0.062
Jun	1.346	0.597	0.394	0.306	0.166	0.096	0.096	0.096	0.089	0.059
Jul	1.322	0.612	0.338	0.291	0.176	0.102	0.101	0.1	0.093	0.06
Aug	1.308	0.602	0.296	0.271	0.173	0.104	0.103	0.103	0.096	0.065
Sep	1.267	0.535	0.269	0.267	0.171	0.097	0.096	0.096	0.091	0.047
D Category										
Oct	0.842	0.311	0.158	0.039	0	0	0	0	0	0
Nov	1.678	0.787	0.222	0.109	0.109	0.085	0.084	0.083	0.077	0.033
Dec	2.02	0.925	0.577	0.205	0.186	0.081	0.08	0.078	0.072	0.03
Jan	1.561	0.534	0.287	0.192	0.12	0.078	0.069	0.068	0.063	0.03
Feb	1.653	0.873	0.313	0.085	0.077	0.069	0.068	0.067	0.061	0.029
Mar	2.211	1.733	1.25	0.622	0.337	0.217	0.154	0.115	0.094	0.083
Apr	1.922	0.87	0.465	0.22	0.156	0.1	0.085	0.084	0.073	0.047
May	1.691	0.486	0.249	0.125	0.124	0.087	0.086	0.086	0.079	0.052
Jun	0.979	0.393	0.289	0.201	0.118	0.082	0.082	0.081	0.075	0.049
Jul	0.978	0.404	0.239	0.186	0.126	0.085	0.084	0.084	0.079	0.051
Aug	0.97	0.395	0.203	0.172	0.124	0.087	0.087	0.087	0.081	0.055
Sep	0.956	0.359	0.179	0.169	0.122	0.082	0.082	0.081	0.077	0.04
Category Total Flow Assurance curves (mill. m^3)										
A Category										
Oct	1.666	1.359	0.919	0.476	0.341	0.301	0.279	0.266	0.259	0.255
Nov	2.762	1.989	0.999	0.548	0.484	0.344	0.294	0.282	0.269	0.222
Dec	6.048	3.959	2.811	1.989	1.903	1.445	1.181	0.774	0.261	0.205
Jan	5.285	3.436	2.406	1.844	1.684	1.436	1.145	0.743	0.229	0.179
Feb	8.954	6.086	4.162	3.303	3.169	2.868	2.306	1.42	0.236	0.172
Mar	16.907	11.788	8.784	7.542	6.934	6.084	4.837	2.905	0.327	0.267
Apr	8.496	5.632	4	3.226	3.025	2.647	2.106	1.337	0.276	0.255
May	2.778	1.618	1.06	0.563	0.543	0.335	0.305	0.286	0.275	0.264
Jun	1.82	1.441	0.966	0.645	0.513	0.333	0.29	0.285	0.284	0.284
Jul	1.759	1.49	1.04	0.647	0.539	0.359	0.309	0.308	0.308	0.308
Aug	1.737	1.477	0.988	0.634	0.526	0.359	0.304	0.302	0.302	0.301
Sep	1.658	1.312	0.929	0.618	0.519	0.342	0.289	0.273	0.269	0.265

Columns are FDC percentage points:										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
A/B Category										
Oct	1.618	1.264	0.717	0.395	0.301	0.262	0.238	0.225	0.218	0.214
Nov	2.686	1.871	0.824	0.462	0.406	0.291	0.248	0.235	0.227	0.186
Dec	5.744	3.694	2.518	1.794	1.699	1.31	1.066	0.693	0.221	0.172
Jan	5.002	3.19	2.128	1.673	1.514	1.294	1.032	0.665	0.193	0.15
Feb	8.389	5.652	3.75	3.004	2.891	2.622	2.103	1.288	0.2	0.144
Mar	15.769	10.952	8.083	6.942	6.298	5.57	4.414	2.643	0.28	0.223
Apr	7.989	5.234	3.609	2.933	2.743	2.403	1.913	1.202	0.233	0.213
May	2.702	1.511	0.878	0.475	0.461	0.286	0.257	0.24	0.232	0.221
Jun	1.762	1.344	0.819	0.573	0.435	0.28	0.245	0.238	0.238	0.238
Jul	1.705	1.388	0.86	0.57	0.457	0.301	0.258	0.258	0.258	0.258
Aug	1.684	1.375	0.811	0.553	0.446	0.301	0.255	0.252	0.252	0.252
Sep	1.609	1.222	0.758	0.543	0.441	0.286	0.241	0.23	0.227	0.222
B Category										
Oct	1.562	1.165	0.531	0.327	0.263	0.222	0.198	0.184	0.176	0.173
Nov	2.608	1.741	0.659	0.391	0.338	0.246	0.205	0.194	0.185	0.15
Dec	5.448	3.424	2.243	1.615	1.504	1.183	0.958	0.615	0.181	0.139
Jan	4.727	2.938	1.86	1.514	1.354	1.168	0.926	0.592	0.159	0.121
Feb	7.846	5.222	3.363	2.729	2.631	2.391	1.912	1.166	0.165	0.116
Mar	14.682	10.15	7.475	6.364	5.684	5.082	4.022	2.406	0.233	0.179
Apr	7.501	4.836	3.239	2.655	2.475	2.182	1.732	1.083	0.191	0.172
May	2.625	1.394	0.707	0.402	0.384	0.242	0.213	0.197	0.189	0.178
Jun	1.701	1.237	0.674	0.506	0.363	0.238	0.203	0.194	0.192	0.192
Jul	1.649	1.275	0.69	0.501	0.381	0.255	0.214	0.208	0.208	0.208
Aug	1.629	1.264	0.643	0.483	0.372	0.253	0.21	0.203	0.203	0.203
Sep	1.558	1.121	0.598	0.476	0.367	0.241	0.198	0.188	0.185	0.178
B/C Category										
Oct	1.473	0.982	0.396	0.261	0.19	0.145	0.118	0.102	0.094	0.09
Nov	2.511	1.543	0.486	0.313	0.255	0.176	0.136	0.136	0.131	0.093
Dec	5.134	3.096	1.973	1.431	1.303	1.028	0.821	0.529	0.13	0.085
Jan	4.441	2.616	1.592	1.35	1.185	1.027	0.811	0.509	0.114	0.076
Feb	7.307	4.749	2.981	2.457	2.359	2.141	1.715	1.036	0.121	0.073
Mar	13.643	9.361	6.901	5.794	5.105	4.604	3.657	2.173	0.179	0.129
Apr	7.017	4.386	2.874	2.365	2.197	1.947	1.54	0.953	0.139	0.11
May	2.528	1.199	0.529	0.322	0.291	0.166	0.141	0.141	0.134	0.115
Jun	1.614	1.054	0.522	0.43	0.275	0.165	0.135	0.135	0.127	0.12
Jul	1.571	1.085	0.512	0.422	0.289	0.183	0.14	0.139	0.134	0.13
Aug	1.553	1.074	0.467	0.403	0.283	0.186	0.143	0.142	0.137	0.129
Sep	1.489	0.95	0.428	0.397	0.279	0.178	0.139	0.135	0.131	0.109
C Category										
Oct	1.385	0.71	0.307	0.195	0.117	0.067	0.038	0.021	0.012	0.007
Nov	2.403	1.337	0.392	0.248	0.203	0.122	0.113	0.113	0.106	0.049
Dec	4.819	2.767	1.786	1.276	1.161	0.897	0.737	0.473	0.106	0.045
Jan	4.154	2.28	1.407	1.214	1.054	0.909	0.714	0.455	0.093	0.044
Feb	6.777	4.289	2.683	2.208	2.113	1.908	1.543	0.936	0.1	0.042
Mar	12.62	8.619	6.386	5.301	4.67	4.205	3.341	1.983	0.161	0.114
Apr	6.54	3.942	2.597	2.131	1.973	1.745	1.38	0.852	0.114	0.067
May	2.42	0.982	0.431	0.255	0.235	0.12	0.118	0.117	0.108	0.074
Jun	1.519	0.848	0.46	0.377	0.223	0.113	0.113	0.112	0.103	0.071

Columns are FDC percentage points:										
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**99**
Jul	1.486	0.872	0.415	0.366	0.235	0.126	0.117	0.115	0.108	0.074
Aug	1.469	0.862	0.371	0.346	0.23	0.139	0.118	0.118	0.111	0.079
Sep	1.413	0.757	0.343	0.34	0.227	0.133	0.112	0.111	0.105	0.058
C/D Category										
Oct	1.225	0.466	0.242	0.122	0.04	0	0	0	0	0
Nov	2.174	1.063	0.316	0.174	0.149	0.103	0.101	0.099	0.091	0.039
Dec	4.372	2.366	1.601	1.107	1.016	0.815	0.669	0.427	0.092	0.036
Jan	3.762	1.895	1.243	1.063	0.923	0.798	0.646	0.41	0.081	0.036
Feb	6.154	3.777	2.408	1.958	1.872	1.73	1.399	0.848	0.087	0.035
Mar	11.499	7.778	5.834	4.762	4.239	3.826	3.037	1.8	0.142	0.099
Apr	5.949	3.441	2.333	1.885	1.749	1.553	1.248	0.768	0.099	0.055
May	2.19	0.714	0.351	0.18	0.174	0.103	0.102	0.101	0.093	0.062
Jun	1.346	0.597	0.394	0.306	0.166	0.096	0.096	0.096	0.089	0.059
Jul	1.322	0.612	0.338	0.291	0.176	0.102	0.101	0.1	0.093	0.06
Aug	1.308	0.602	0.296	0.271	0.173	0.104	0.103	0.103	0.096	0.065
Sep	1.267	0.535	0.269	0.267	0.171	0.097	0.096	0.096	0.091	0.047
D Category										
Oct	0.842	0.311	0.158	0.039	0	0	0	0	0	0
Nov	1.678	0.787	0.222	0.109	0.109	0.085	0.084	0.083	0.077	0.033
Dec	3.603	1.957	1.358	0.907	0.879	0.73	0.599	0.38	0.078	0.03
Jan	3.12	1.551	1.057	0.884	0.804	0.718	0.58	0.366	0.069	0.03
Feb	5.299	3.251	2.112	1.704	1.675	1.565	1.264	0.764	0.075	0.029
Mar	10.1	6.879	5.143	4.124	3.794	3.453	2.741	1.622	0.122	0.083
Apr	5.091	2.938	2.029	1.627	1.545	1.4	1.124	0.69	0.084	0.047
May	1.691	0.486	0.249	0.125	0.124	0.087	0.086	0.086	0.079	0.052
Jun	0.979	0.393	0.289	0.201	0.118	0.082	0.082	0.081	0.075	0.049
Jul	0.978	0.404	0.239	0.186	0.126	0.085	0.084	0.084	0.079	0.051
Aug	0.97	0.395	0.203	0.172	0.124	0.087	0.087	0.087	0.081	0.055
Sep	0.956	0.359	0.179	0.169	0.122	0.082	0.082	0.081	0.077	0.04

APPENDIX F: ESTUARY RESERVE REPORT

Feasibility Study for Foxwood Dam (WP10580)

An Assessment of the Potential Impacts of the Foxwood Dam on the Great Fish Estuary

Draft

water affairs
Department
Water Affairs
REPUBLIC OF SOUTH AFRICA

AN ASSESSMENT OF THE POTENTIAL IMPACTS OF THE FOXWOOD DAM ON THE GREAT FISH ESTUARY

This report was authored, on behalf of Arup (Pty) Ltd, by:

Lara van Niekerk
CSIR
PO Box 320, Stellenbosch, 7599

Tel: + 27 21 888 2491
Email: Lvnieker@csir.co.za

CSIR Report Number CSIR/NRE/ECOS/ER/2014/004/B.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DEADP	Department of Environment, Agriculture and Development Planning
DWA	Department of Water Affairs
EIA	Environmental Impact Assessment
m	metre
MAR	Mean Annual run-off
MSL	Mean Sea Level
$x10^6m^3$	Million cubic metres

1 Scope

This scoping study was commissioned by Rivers for Africa to determine the potential impacts of the Foxwood dam development on the Great Fish Estuary.

The study will rely on the findings of a Rapid Reserve for the Great Fish Estuary (Van Niekerk et al. 2013) commissioned by Coastal and Environmental Services to determine the Ecological Reserve for the Estuary. This study will summarise the Present Ecological Status (health state), the Recommended Ecological Category (the future state of health) and the quantity and quality of freshwater inflows and other conditions required to maintain this. The analysis involves estimating the characteristics of the system in its original condition as well us under a range of potential future scenarios.

The Ecological Freshwater requirement studies on the estuaries will follow the methods as described in DWAF (2008): Resource Directed Measures for Protection of Water Resources: Methodologies for the determination of ecological water requirements for estuaries. Version 2.

2 Study Area

The 650 km Great Fish River enters the Indian Ocean at 33°29'38.08"S, 27° 8'10.61"E. The river system has a catchment of approximately 30 300 km^2 and a natural mean annual runoff of 513.29 x 10^6 m^3. The estuary is nearly permanently open and maintained by enhanced freshwater inputs from an interbasin transfer scheme bringing water from the Orange River. The geographical boundaries of the Great Fish Estuary (Figure 2.1) study area are defined as follows:

Downstream boundary:	33°29'38.08"S, 27° 8'10.61"E
Upstream boundary:	33°23'59.83"S, 27° 1'29.89"E 27° 1'29.89"E
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank

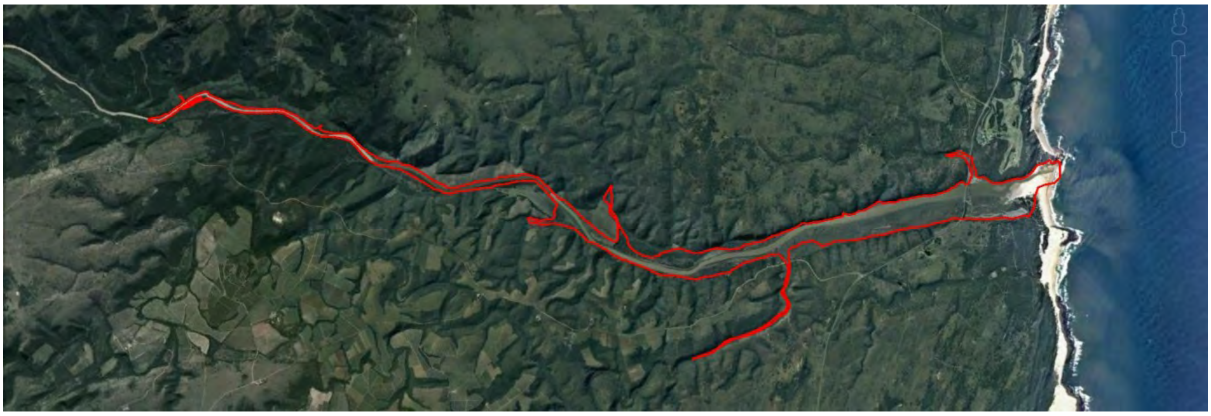


Figure 2.1. Geographical boundaries of the Great Fish Estuary (Source: Google Earth)

3 Present Ecological Status of the Great Fish Estuary

The Estuarine Health Index (EHI) scores allocated to the various abiotic and biotic health parameters for the Great Fish Estuary and the overall Present Ecological Status (PES) for the system under the present state are calculated from the overall EHI score (Table 3.1). The EHI score for the Great Fish Estuary in its present state was estimated to be 71 (i.e. 70% similar to natural condition, which translates into a Present Ecological Status (PES) of C (summarised in Table 3.2).

Table 3.1 Estuarine Health Score (EHI) for the Great Fish Estuary, the estimated Estuarine Health Score with non-flow related impacts removed, and confidence levels.

Variable	Weight	Health score/100	Health score net of 50% of non-flow related impacts	Confidence
Hydrology	25	79	79	Low
Hydrodynamics and mouth condition	25	90	90	Low
Water quality	25	56.6	65	Low
Physical habitat alteration	25	88	88	Medium
Habitat health score		**78**	**80**	**Low**
Microalgae	20	43	53	Medium
Macrophytes	20	77	77	Medium
Invertebrates	20	50	60	Medium
Fish	20	70	80	Medium
Birds	20	75	75	Low
Biotic health score		**63**	**69**	**Medium**
ESTUARY HEALTH SCORE		**71**	**75**	
PRESENT ECOLOGICAL STATUS		**C**	**B/C**	
OVERALL CONFIDENCE				**Low**

The Great Fish Estuary is presently in a C Category which is largely attributed to the following three factors:

1. Elevated base flows as a result of agricultural return flow and possibly allocated water not been taken up by the relevant water users;
2. Increase nutrient input as a result of poor agricultural practises; and
3. Overexploitation of the living resources (especially linefish species such as dusky kob *A. japonicus*) in the estuary).

Table 3.2 PES scores and descriptions

EHI score	Present Ecological Status	General description
91 – 100	A	Unmodified, natural
76 – 90	B	Largely natural with few modifications
61 – 75	**C**	**Moderately modified**
41 – 60	D	Largely modified
21 – 40	E	Highly degraded
0 – 20	F	Extremely degraded

Rough estimates of the contribution of non-flow related impacts on the level of degradation of each component led to an adjusted health score of 80, which would raise the PES to a B category. This suggests that non-flow impacts have played a significant role in the degradation of the estuary to a C, but that flow-related impacts are the main cause of its degradation. Acknowledging that it would be impossible to remove all non-flow related impacts from the system, the Present State hydrological regime was revaluated in conjunction with a 50% decrease in nutrient loading and fishing pressures. This lead to an adjusted health score of 75, which would raise the PES to a B/C category.

Thus the highest priority is to address the quantity and quality of influent water. Of the non-flow-related impacts, water quality problem as a result of poor agricultural practises and over fishing in the estuary was found to be the most important factor that influenced the health of the system.

4 Importance of the Great Fish Estuary

The Estuary Importance Score (EIS) for the estuary takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account. Biodiversity importance, in turn is based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. These importance scores ideally refer to the system in its natural condition. The scores have been determined for all South African estuaries, apart from functional importance, which is scored by the specialists in the workshop.

In this case, the functional importance of the estuary was deemed to be very high (100), because of the following:

- 16 (38%) of the fish species recorded in the Great Fish Estuary are southern African endemics;
- The Great Fish Estuary is one of the most important nursery areas in South Africa for both dusky kob *A. japonicus* and spotted grunter *P. commersonnii*; and
- Large numbers of catadromous anguillid eels and mullet recruit up the Great Fish River, with the former occupying almost the entire catchment and the latter found mainly in the lower catchment (up to 110 km from the estuary).

The EIS for the Great Fish Estuary, based on its present state, was therefore estimated to be 92 (Table 4.1), i.e., the estuary is rated as "Highly Important" (Table 4.2).

Table 4.1 Importance scores (EIS) for the Great Fish Estuary

Criterion	Weight	Score
Estuary Size	15	100
Zonal Rarity Type	10	20
Habitat Diversity	25	100
Biodiversity Importance	25	98
Functional Importance	25	100
Weighted Estuary Importance Score		**92**

Table 4.2 Estuarine importance scores (EIS) and significance

Importance score	Description
81 – 100	**Highly important**
61 – 80	Important
0 – 60	Of low to average importance

5 Recommended Ecological Category (REC)

The Recommended Ecological Category (REC) represents the level of protection assigned to an estuary. The first step is to determine the 'minimum' EC, based on its PES. The relationship between EHI Score, PES and minimum REC is set out in Table 5.1.

Table 5.1 Relationship between the EHI, PES and minimum ERC

EHI SCORE	PES	DESCRIPTION	MINIMUM EC
91 – 100	A	Unmodified, natural	A
76 – 90	B	Largely natural with few modifications	B
61 – 75	C	Moderately modified	C
41 – 60	D	Largely modified	D
21 – 40	E	Highly degraded	-
0 – 20	F	Extremely degraded	-

The PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of **importance** and level of **protection or desired** protection of a particular estuary (Table 5.2.

Table 5.2 Estuary protection status and importance, and the basis for assigning a recommended ecological reserve category

Protection status and importance	REC	Policy basis
Protected area	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health
Desired Protected Area		
Highly important	PES + 1, min B	Highly important estuaries should be in an A or B category
Important	PES + 1, min C	Important estuaries should be in an A, B or C category
Of low to average importance	PES, min D	Estuaries to remain in a D category

* BAS = Best Attainable State

The PES for the Great Fish is a C. The estuary is rated as "Highly Important", and it is a designated as a desired protected area in the Biodiversity Plan for the National Biodiversity Assessment (Turpie *et al*., 2012). Thus the **Recommended Ecological Category** for the estuary is an A or it's **Best Attainable State which is estimated as a Category B/C.**

6 Recommended ecological flow requirement for the Great Fish Estuary

For a high confidence study, the **'Recommended Ecological Flow Requirement' scenario,** is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the recommended Ecological Category. Where any component of the health score is less than 40, then modifications to flow and measures to address anthropogenic impacts must be found that will rectify this. The Best Attainable State for the estuary is a **B/C Category**. The only way to achieve a B/C is to maintain the present state flow distribution with the following mitigation measures:

- Apply agricultural practises that would assist with a reduction in return flow, a decrease in related nutrient loading, and control sediment erosion in the catchment;
- Reduction in, or complete removal of, fishing pressure through a range of measures such as a night ban on fishing; implementing a catch-and-release policy; special bag limits; and or closed periods;
- Effective management of Fort Beaufort and Cradock Waste Water Treatment Works; and
- Revisiting the operation rules of the Orange Transfer Scheme as in some cases allocated water seems to be released for use but not required/taken up by the licences holder.

It should be noted, however, that some of these proposed mitigation measures would be difficult to achieve in the short term, such as the reduction in the fishing pressure. It is therefore strongly recommended that an Estuarine Management Plan be developed for the Great Fish Estuary as required by the ICM act.

The flow requirements for the estuary are the same as those described for Present State. A summary of the monthly flows for these two scenarios is presented in Table 6.1.

Table 6.1 Summary of the monthly flow (in m3/s) distribution under the Present State

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%ile	22.4	33.4	47.3	35.5	49.8	70.2	41.7	18.6	8.3	6.4	11.4	18.9
80%ile	10.4	21.0	24.5	15.6	28.5	36.8	21.5	7.2	3.3	4.3	4.2	7.6
70%ile	7.9	11.3	13.4	11.6	17.6	22.1	13.7	5.2	2.4	3.5	4.0	4.9
60%ile	6.3	7.0	8.7	8.0	13.5	14.1	10.0	3.9	2.1	3.2	3.7	3.8
50%ile	5.2	5.9	6.5	6.8	9.2	10.5	7.7	3.1	1.9	3.2	3.5	3.5
40%ile	4.6	5.3	4.6	5.2	7.8	8.7	5.7	3.0	1.8	3.1	3.4	3.4
30%ile	4.4	4.4	4.0	4.4	6.4	7.2	4.3	2.8	1.7	3.0	3.3	3.3
20%ile	4.1	4.1	3.5	4.2	5.5	5.5	3.7	2.7	1.7	3.0	3.2	3.2
10%ile	4.0	3.8	3.3	3.9	4.7	4.6	3.3	2.6	1.6	2.9	3.2	3.2
1%ile	3.8	3.7	3.2	3.8	4.5	3.8	3.1	2.5	1.5	2.8	3.1	3.0

7 Evaluation of Future Scenario

Four scenarios (Scenario 1 – 4) were evaluated in detail as part of a rapid Great Fish Ecological Water Requirement study in 2013 (Van Niekerk et al. 2013). These scenarios are listed here for comparative reasons as they allow for a calibration between the Reference Conditions, Present State and the new Scenario 5. Scenario 5 was evaluated in terms of is relative impact as determined by the disturbing of the abiotic states and related expected biotic impacts (Table 7.1).

Table 7.1 Summary of the scenarios evaluated in this study

Scenario name	Description	MAR (million m^3)	Percentage remaining
Natural	Reference Condition	513.29	100.0
Present	**Present Day**	**463.30**	**90.3**
Scenario 1	With 30 Ml/day abstraction for water treatment (which could include some desalination), includes a 2.5 m high abstraction weir and abstraction works on the left bank of the river.	452.30	88.1
Scenario 2	**Foxwood Dam**	**434.64**	**84.7**
Scenario 3	With full delivery from Orange Transfer scheme	490.47	95.6
Scenario 4	No input from Orange Transfer scheme	322.84	62.9
Scenario 5 (new)	**Foxwood Maximum development**	**453.57**	**88.4**

Based on historical data and projected future flow modifications four typical abiotic conditions were identified for the Great Fish Estuary (Table 7.2).

Table 7.2 Typical abiotic conditions linked to projected river inflow

State	Description	Flow range (m^3/s)
1	Closed, marine dominated	<1
2	Strong marine influence (open mouth)	1-5
3	Brackish (open mouth)	5-10
4	Freshwater dominated (open mouth)	>10

Table 7.3 provides a summary of the percentage occurrence of the abiotic states under Natural Conditions, Present State and Scenario 1 to 5. The table shows that the change in the occurrence of abiotic states under Scenario 5 is similar to that of Scenario 2, with a slight improvement in the occurrence of State 2 (Strong marine influence). (See Appendix A for more detail on the occurrence of the abiotic states under the various flow scenarios.)

Table 7.3 Percentage occurrence of abiotic states under Refrence Conditions, Present State and Scenario 1 to 5.

	Natural	Present	Sc1	Sc2	Sc3	Sc4	Sc5
State 1 (Closed)	4.9	**0.0**	0.0	**0.0**	0.0	49.0	**0.0**
State 2	49.3	**52.0**	54.6	**55.4**	49.5	22.9	**52.5**
State 3	14.2	**21.3**	19.5	**19.9**	21.4	9.2	**21.6**
State 4	31.6	**26.8**	25.9	**24.7**	29.1	18.8	**25.9**
Years Estuary can close	10	**0**	0	**0**	0	0	**0**
% Years closed	12	**0**	0	**0**	0	0	**0**

8 Ecological Categories associated with runoff scenarios

The individual EHI scores, as well as the corresponding ecological category under the different scenarios are provided in Table 8.1. The estuary is currently in a C Category. Based on the findings of the rapid EWR study and the occurrence of the abiotic states under the five scenarios the following insights can be drawn:

- *Scenario 1:* The Great Fish Estuary will only deteriorate slightly in health under Scenario 1 (expected to remain in a C Category). In contrast, the river reach upstream of the estuary is expected to significantly decline in health largely due to two factors: 1) An abstraction weir that acts as a barrier to migratory fish; and 2) the possible release of sediment pulses from the sand traps during low flow periods. This type of flushing holds a significant risk to migratory fish species such as eels and fresh water mullet which will be aggregating below the abstraction weir.
- *Scenario 2:* The estuary will only deteriorate slightly in health under Scenario 2 and is expected to remain in a C Category.
- *Scenario 3:* The health of the estuary will remain similar to Present State under Scenario 3.
- *Scenario 4:* The estuary will deteriorate significantly under Scenario 4 to a D Category.
- *Scenario 5:* The estuary will only deteriorate slightly in health under Scenario 5 and is expected to remain in a C Category.

Table 8.1 EHI score and corresponding Ecological Category under the different runoff scenarios

Component	Present	1	2	3	4	5
ESTUARY HEALTH SCORE	**71**	**68**	**69**	**71**	**46**	**70 - 69**
PRESENT ECOLOGICAL STATUS	**C**	**C**	**C**	**C**	**D**	**C**

Therefore none of the future runoff scenarios presented as part of this study or the Rapid Reserve (van Niekerk et al. 2013) meets the Recommended Ecological Category of B/C. **Scenario 5 will maintain the PES albeit at a slightly reduce condition (1 – 2 % reduction in ecological condition), but will not meet the REC of a B/C.**

9 References

Department of Water Affairs and Forestry (DWAF). 2008. Water Resource Protection and Assessment Policy Implementation Process. Resource Directed Measures for protection of water resources: Methodology for the Determination of the Ecological Water Requirements for Estuaries. Version 2. Pretoria.

Turpie JK and Clark BM. 2007. The health status, conservation importance, and economic value of temperate South African estuaries and development of a regional conservation plan. Report

Turpie JK Adams JB, Joubert A., Harrison TD, Colloty BM, Maree RC, Whitfield AK, Wooldridge TH, Lamberth SJ, Taljaard, S. and van Niekerk L. 2002. Assessment of the conservation priority status of South African estuaries for use in management and water allocation. *Water SA* 28, 191-206.

Van Niekerk, L, Taljaard, S, Adams, JB, Huizinga, P, Turpie, JK, Whitfield, AK and Wooldridge, TH 2013. Determination of the Ecological Reserve for the Great Fish Estuary on a Rapid level. Draft report commissioned by Coastal and Environmental Services. CSIR Report CSIR/NRE/ECOS/ER/2013/0096/B.

10 Appendix A: Distribution of abiotic states

To assess the occurrence and duration of the different abiotic states selected for the estuary during the different scenarios, a number of techniques were used:

- Summary tables of the occurrence of different flows at increments of the 10%ile are listed separately to provide a quick comprehensive overview; and
- Colour coding (indicated above) was used to visually highlight the occurrence of the various abiotic states under different scenarios.

A statistical analysis of the monthly-simulated runoff data in m^3/s for Reference condition, Present State and Scenario 1 to 5 is provided below in Table 9.1. While Figures 9.1 to 9.4 provide a graphic illustrations of the percentages monthly and annual occurrences of the various abiotic states under the various flow scenarios.

Table 9.1 Summary of the monthly flow (in m^3/s) distribution under natural, present and Scenario 1 to 5

Scenario

Reference Condition

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%ile	24.0	56.8	58.6	47.4	62.1	82.2	48.1	21.2	11.1	5.9	11.7	22.9
80%ile	11.4	25.0	36.1	28.2	34.3	45.3	24.3	8.8	3.7	3.7	3.1	8.6
70%ile	8.0	13.1	19.1	15.6	23.0	28.3	15.5	6.1	2.9	2.6	2.6	4.2
60%ile	5.3	7.2	11.9	11.1	17.1	18.8	12.0	3.7	2.2	2.2	2.0	3.0
50%ile	3.8	6.3	9.0	7.1	12.2	14.3	8.2	2.7	1.9	1.8	1.8	2.3
40%ile	2.9	5.0	5.0	4.5	7.9	10.8	5.5	2.3	1.7	1.6	1.5	1.7
30%ile	1.9	4.0	3.3	3.5	6.3	8.7	4.2	1.6	1.5	1.3	1.3	1.4
20%ile	1.5	2.2	2.0	2.3	3.5	5.8	2.7	1.4	1.3	1.2	1.1	1.1
10%ile	1.2	1.5	1.4	1.2	1.9	3.5	1.8	1.2	1.2	1.1	1.0	1.0
1%ile	0.6	1.1	0.7	0.6	0.9	1.2	1.1	0.8	1.0	0.8	0.8	0.6

Present

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%ile	22.4	33.4	47.3	35.5	49.8	70.2	41.7	18.6	8.3	6.4	11.4	18.9
80%ile	10.4	21.0	24.5	15.6	28.5	36.8	21.5	7.2	3.3	4.3	4.2	7.6
70%ile	7.9	11.3	13.4	11.6	17.6	22.1	13.7	5.2	2.4	3.5	4.0	4.9
60%ile	6.3	7.0	8.7	8.0	13.5	14.1	10.0	3.9	2.1	3.2	3.7	3.8
50%ile	5.2	5.9	6.5	6.8	9.2	10.5	7.7	3.1	1.9	3.2	3.5	3.5
40%ile	4.6	5.3	4.6	5.2	7.8	8.7	5.7	3.0	1.8	3.1	3.4	3.4
30%ile	4.4	4.4	4.0	4.4	6.4	7.2	4.3	2.8	1.7	3.0	3.3	3.3
20%ile	4.1	4.1	3.5	4.2	5.5	5.5	3.7	2.7	1.7	3.0	3.2	3.2
10%ile	4.0	3.8	3.3	3.9	4.7	4.6	3.3	2.6	1.6	2.9	3.2	3.2
1%ile	3.8	3.7	3.2	3.8	4.5	3.8	3.1	2.5	1.5	2.8	3.1	3.0

1

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%ile	22.0	33.0	47.0	35.2	49.4	69.8	41.3	18.2	7.9	6.0	11.0	18.5
80%ile	10.0	20.7	24.2	15.3	28.1	36.4	21.1	6.8	2.9	3.9	3.8	7.2
70%ile	7.6	11.0	13.1	11.3	17.3	21.8	13.3	4.8	2.1	3.2	3.6	4.5
60%ile	6.0	6.7	8.3	7.6	13.2	13.7	9.6	3.5	1.7	2.9	3.3	3.5
50%ile	4.8	5.5	6.1	6.4	8.9	10.1	7.4	2.8	1.6	2.8	3.1	3.2
40%ile	4.2	4.9	4.3	4.9	7.5	8.4	5.4	2.6	1.5	2.7	3.0	3.0
30%ile	4.0	4.1	3.7	4.1	6.1	6.9	3.9	2.4	1.4	2.7	3.0	2.9
20%ile	3.8	3.8	3.2	3.8	5.2	5.1	3.3	2.3	1.3	2.7	2.9	2.9
10%ile	3.7	3.5	2.9	3.6	4.4	4.3	3.0	2.3	1.2	2.6	2.8	2.8
1%ile	3.5	3.3	2.8	3.4	4.2	3.5	2.8	2.1	1.1	2.5	2.7	2.7

2

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%ile	21.1	30.4	44.5	33.9	46.0	63.9	40.5	17.8	7.2	5.4	8.2	15.7
80%ile	9.4	19.1	22.5	14.7	27.3	35.3	20.5	6.0	2.5	3.4	3.7	6.7
70%ile	7.4	10.5	11.3	11.0	16.9	21.0	12.0	4.5	1.8	2.9	3.5	4.2
60%ile	5.9	6.6	8.1	7.6	13.0	12.5	9.2	3.4	1.5	2.8	3.2	3.4
50%ile	4.7	5.5	6.1	6.3	8.9	9.7	6.8	2.6	1.5	2.7	3.0	3.1
40%ile	4.2	4.9	4.3	4.7	7.3	8.2	5.1	2.5	1.4	2.7	3.0	3.0
30%ile	4.0	4.0	3.7	4.1	6.1	6.7	3.9	2.4	1.3	2.6	2.9	2.9
20%ile	3.8	3.8	3.2	3.8	5.1	5.1	3.3	2.3	1.3	2.6	2.8	2.8
10%ile	3.6	3.5	2.9	3.6	4.3	4.2	2.9	2.2	1.2	2.5	2.8	2.8
1%ile	3.5	3.3	2.8	3.4	4.2	3.4	2.7	2.1	1.1	2.5	2.7	2.7

3

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%ile	23.6	40.2	51.3	38.7	56.0	74.9	42.8	18.8	8.5	6.3	11.8	20.0
80%ile	11.3	23.1	27.5	23.1	31.1	40.3	23.9	7.9	3.4	4.2	4.6	7.9
70%ile	8.6	11.7	14.5	12.3	21.2	25.6	14.4	5.6	2.7	3.4	4.4	5.0
60%ile	6.8	7.4	9.0	8.8	16.1	16.2	11.3	4.0	2.3	3.1	4.1	3.9
50%ile	5.5	6.3	7.2	7.1	11.1	13.1	8.3	3.2	2.1	3.0	3.9	3.7
40%ile	5.0	5.6	5.1	5.6	8.4	10.2	6.1	3.0	2.0	3.0	3.8	3.5
30%ile	4.7	4.6	4.1	4.9	7.2	8.8	4.9	2.9	1.9	2.9	3.8	3.4
20%ile	4.4	4.4	3.7	4.4	6.0	6.6	3.8	2.8	1.8	2.9	3.7	3.3
10%ile	4.3	4.0	3.4	4.2	5.1	4.8	3.2	2.7	1.7	2.8	3.6	3.3
1%ile	4.1	3.8	3.2	4.0	4.8	4.0	2.9	2.5	1.5	2.7	3.5	3.1

4

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%ile	18.0	25.8	39.7	30.5	38.1	59.8	33.5	15.6	6.1	3.4	6.1	11.5
80%ile	5.8	15.9	19.7	9.0	18.1	28.3	16.2	4.8	1.5	1.4	0.9	3.2
70%ile	3.3	6.7	7.9	5.3	11.4	15.1	8.6	2.1	0.8	0.7	0.7	1.4
60%ile	1.9	2.5	4.5	3.5	6.6	8.1	5.6	1.1	0.7	0.6	0.5	0.7
50%ile	1.0	1.6	2.6	2.2	3.4	5.5	4.3	0.8	0.6	0.4	0.2	0.4
40%ile	0.4	1.1	1.1	1.0	2.2	3.9	2.1	0.7	0.3	0.2	0.1	0.0
30%ile	0.2	0.7	0.8	0.6	1.2	2.7	1.0	0.5	0.1	0.1	0.0	0.0
20%ile	0.0	0.4	0.4	0.3	0.9	1.2	0.7	0.1	0.0	0.0	0.0	0.0
10%ile	0.0	0.0	0.0	0.0	0.0	0.6	0.3	0.0	0.0	0.0	0.0	0.0
1%ile	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

5

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%ile	21.3	30.8	44.8	35.2	47.0	66.2	41.4	18.3	8.0	6.6	9.2	18.8
80%ile	10.2	19.5	22.4	15.2	28.9	36.6	21.2	7.0	3.0	4.3	4.2	7.5
70%ile	7.7	10.8	11.6	11.3	17.1	21.2	12.6	4.9	2.3	3.5	3.9	5.2
60%ile	6.2	7.0	8.4	7.9	13.4	13.2	9.5	3.8	1.9	3.1	3.6	3.8
50%ile	5.1	5.8	6.6	6.7	9.2	10.1	7.2	3.0	1.8	3.0	3.4	3.5
40%ile	4.5	5.2	4.6	5.0	7.5	8.4	5.4	2.9	1.8	3.0	3.3	3.4
30%ile	4.3	4.4	4.0	4.5	6.5	7.1	4.2	2.7	1.7	3.0	3.3	3.3
20%ile	4.1	4.1	3.5	4.2	5.5	5.3	3.6	2.6	1.6	2.9	3.2	3.2
10%ile	4.0	3.8	3.3	4.0	4.7	4.5	3.3	2.6	1.5	2.9	3.1	3.1
1%ile	3.8	3.7	3.2	3.8	4.5	3.8	3.1	2.5	1.4	2.8	3.1	3.0

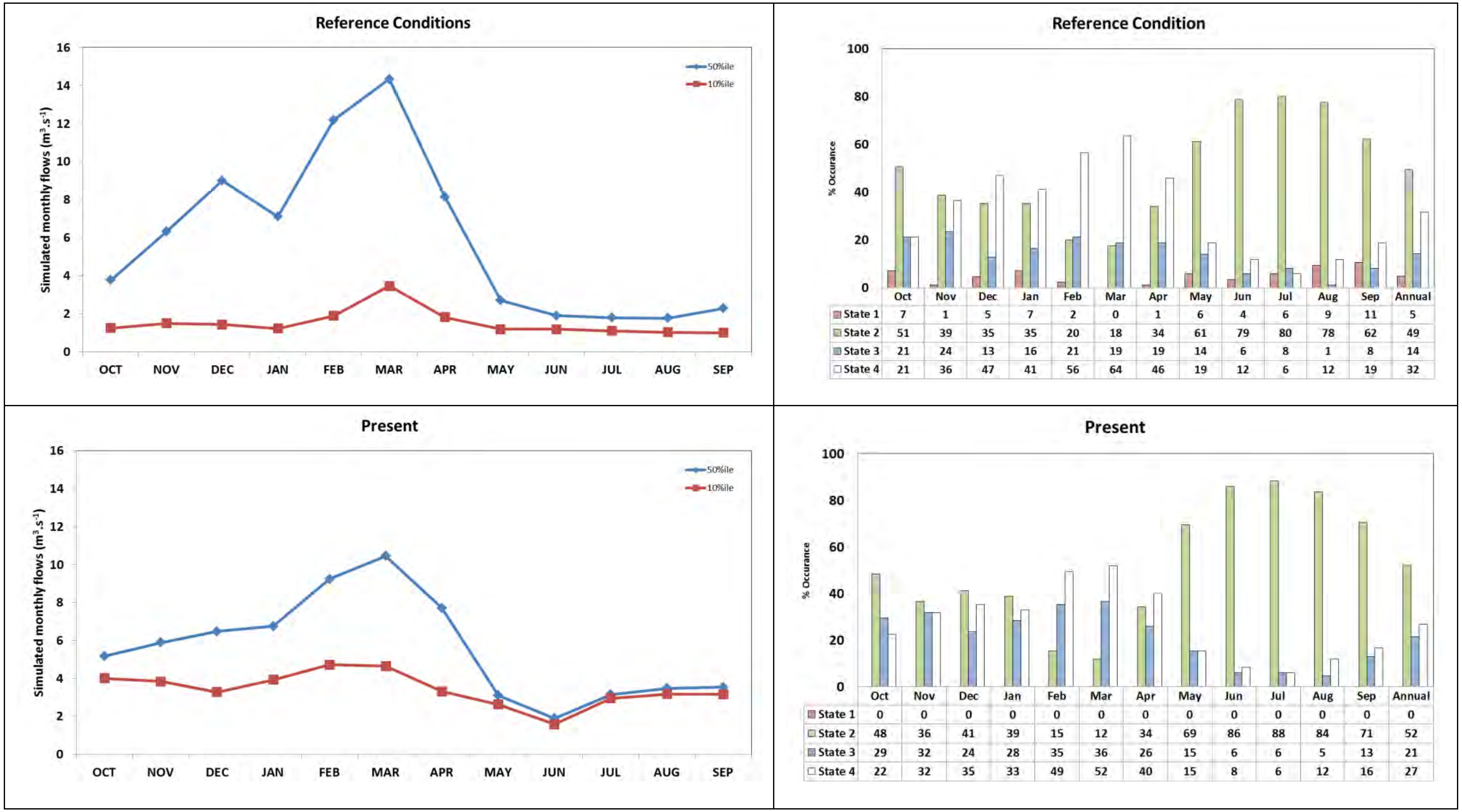


Figure 9.1. Graphic illustrations of the median (50 percentile) and drought conditions (10 percentile) and a summary of the percentages monthly and annual occurrences of the various abiotic states under the Refrence Condition and Present State..

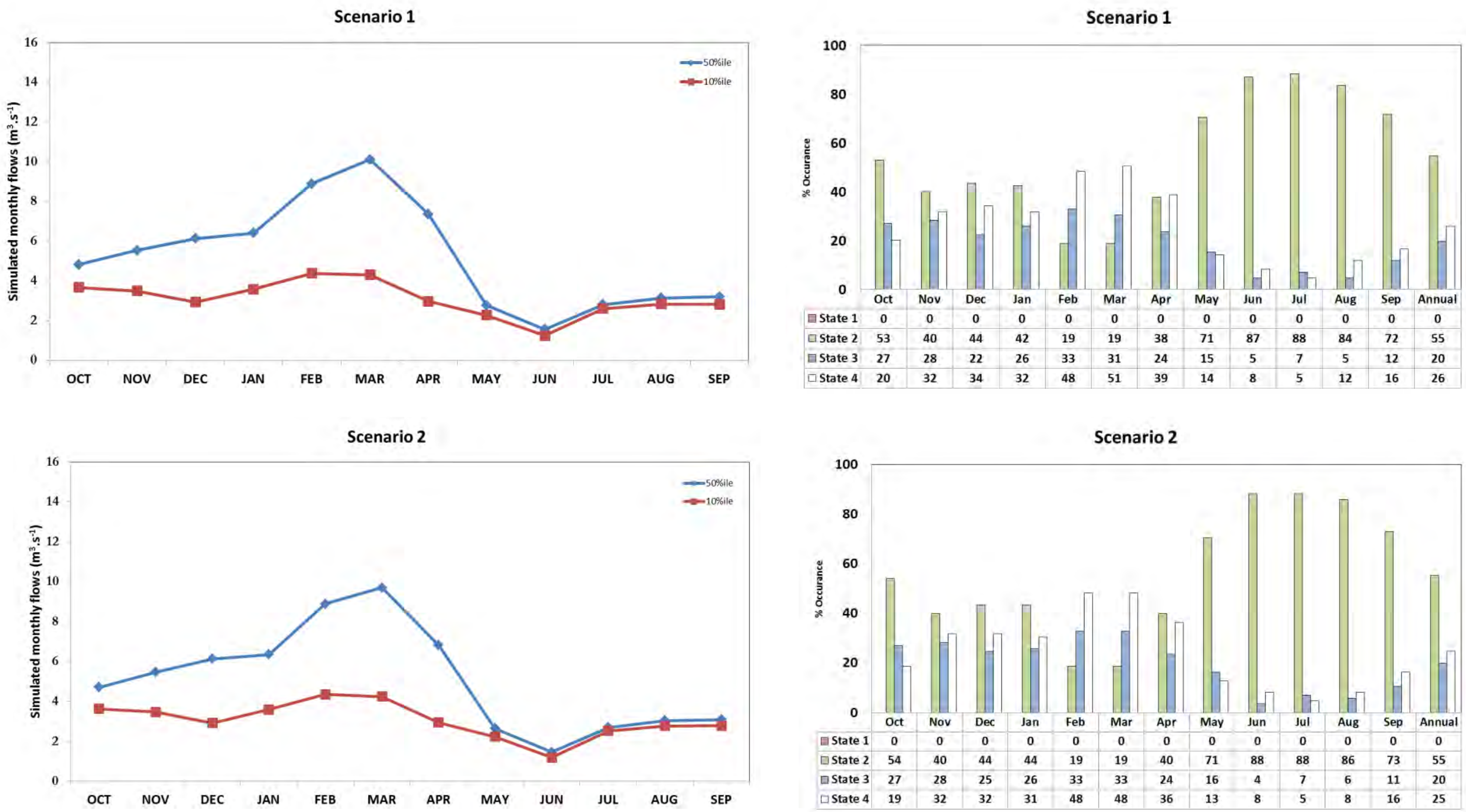
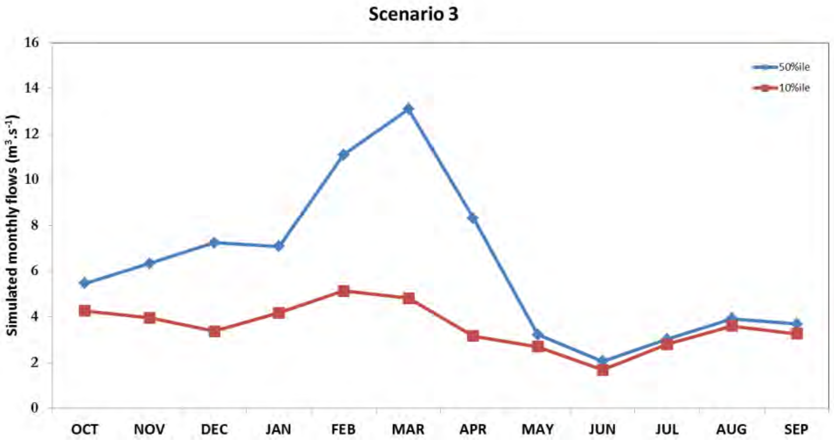
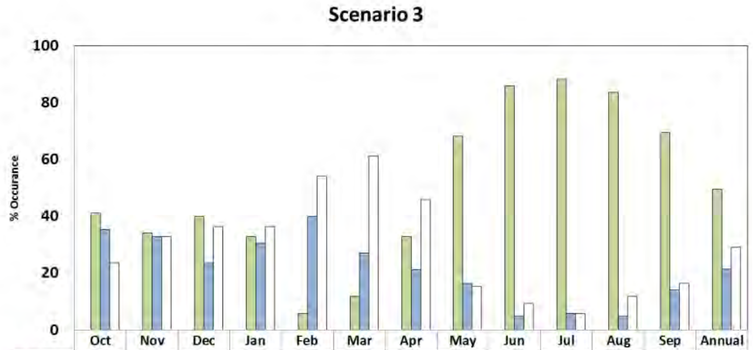
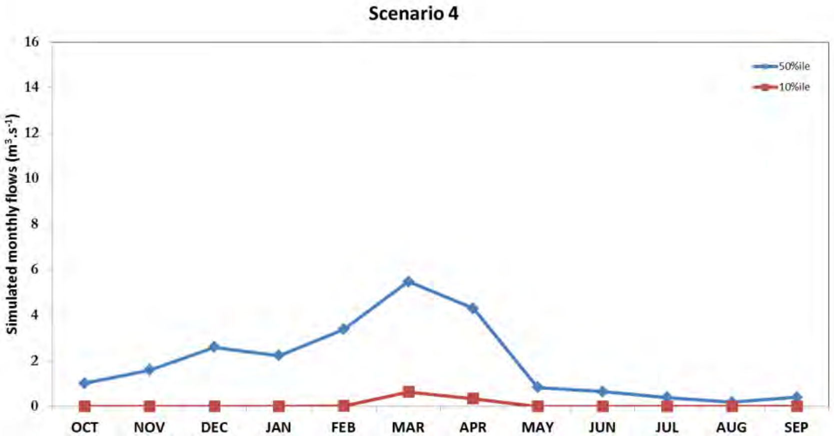


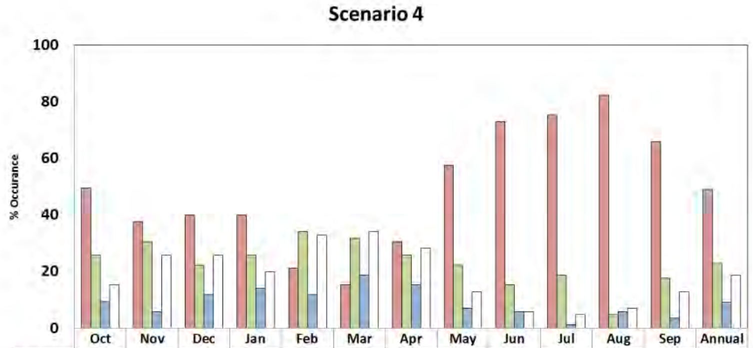
Figure 9.2. Graphic illustrations of the median (50 percentile) and drought conditions (10 percentile) and a summary of the percentages monthly and annual occurrences of the various abiotic states under Scenario 1 and 2.





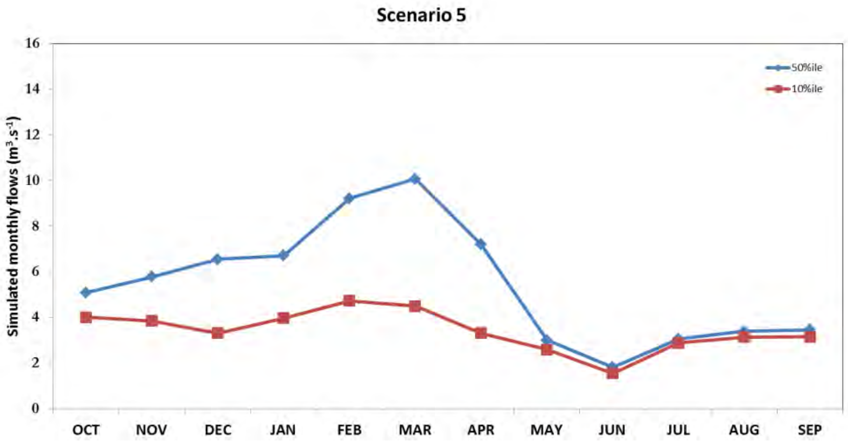
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	41	34	40	33	6	12	33	68	86	88	84	69	50
State 3	35	33	24	31	40	27	21	16	5	6	5	14	21
State 4	24	33	36	36	54	61	46	15	9	6	12	16	29

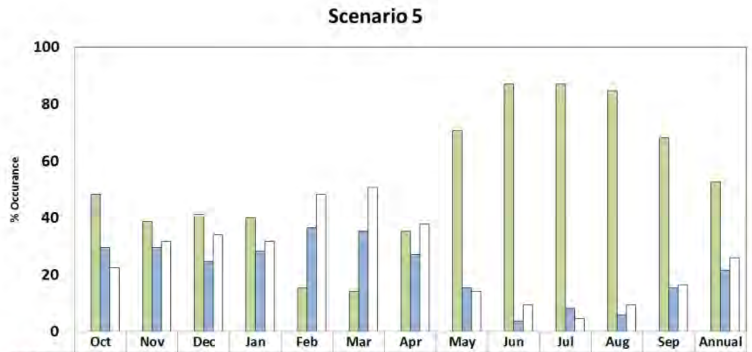




	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
State 1	49	38	40	40	21	15	31	58	73	75	82	66	49
State 2	26	31	22	26	34	32	26	22	15	19	5	18	23
State 3	9	6	12	14	12	19	15	7	6	1	6	4	9
State 4	15	26	26	20	33	34	28	13	6	5	7	13	19

Figure 9.3. Graphic illustrations of the median (50 percentile) and drought conditions (10 percentile) and a summary of the percentages monthly and annual occurrences of the various abiotic states under Scenario 3 and 4.



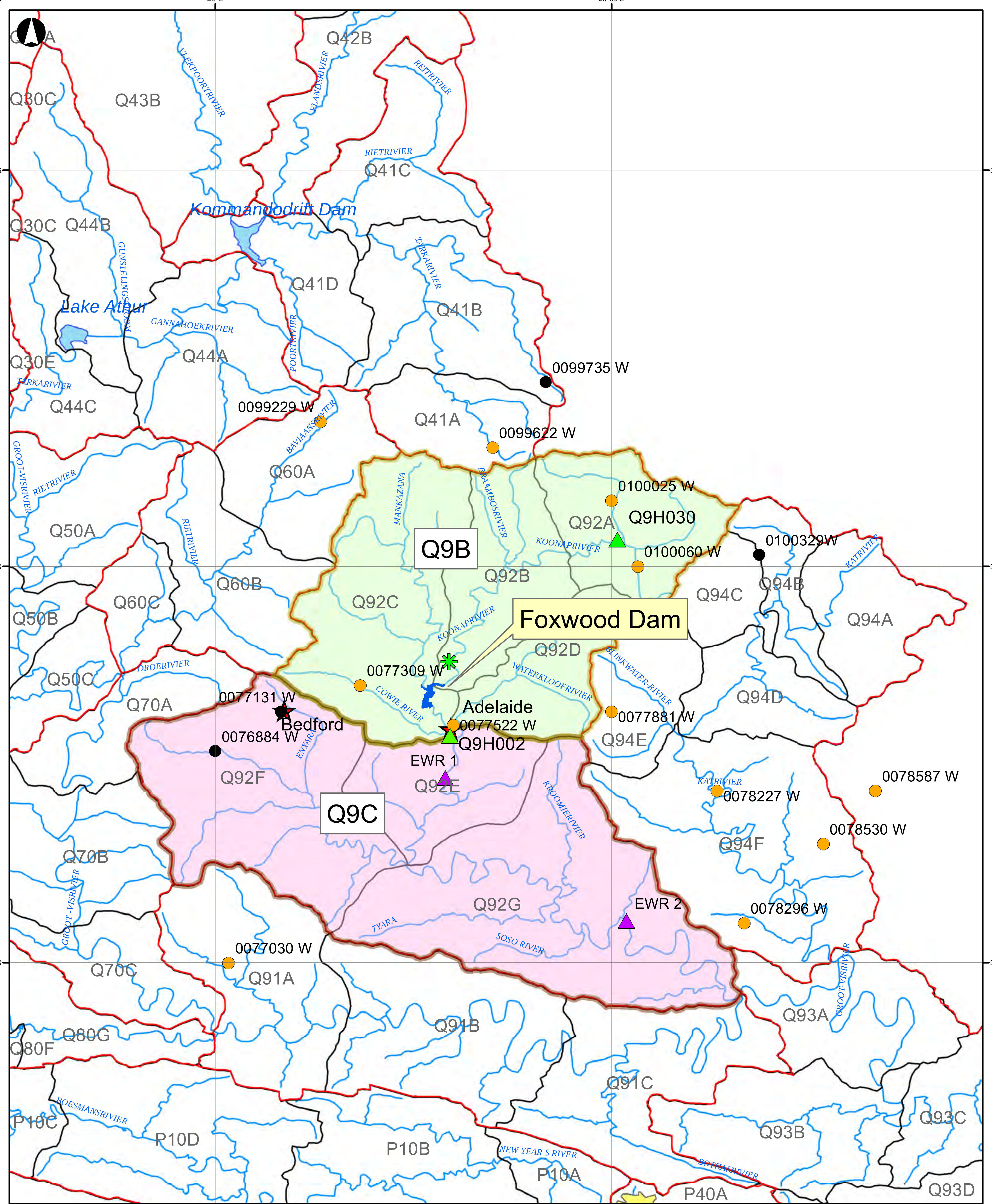


	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
State 1	0	0	0	0	0	0	0	0	0	0	0	0	0
State 2	48	39	41	40	15	14	35	71	87	87	85	68	53
State 3	29	29	25	28	36	35	27	15	4	8	6	15	22
State 4	22	32	34	32	48	51	38	14	9	5	9	16	26

Figure A.4. Graphic illustrations of the median (50 percentile) and drought conditions (10 percentile) and a summary of the percentages monthly and annual occurrences of the various abiotic states under Scenario 5.

APPENDIX G:REPORT DRAWINGS

A3



Legend

- Off-Take Weir
- Flow Gauge
- Closed Rain Gauge
- Open Rain Gauge
- EWR Site
- Rivers
- Foxwood Dam Site
- Q9B Rain Zone
- Q9C Rain Zone
- Tertiary Catchment Boundary
- Quaternary Catchment Boundary
- Existing Dams
- Towns

Issue	Date	By	Chkd	Appd
0B	2014-10-31	MC	AB	JAH

ARUP

water & sanitation
Department: Water and Sanitation
REPUBLIC OF SOUTH AFRICA

10 High Street Melrose Arch,
Johannesburg South Africa
Tel +27 11 218 7600 Fax +27 86 674 8513
www.arup.com

Client
Department of Water and Sanitation

Job Title
Feasibility Study for Foxwood Dam

Kilometers
0 2.25 4.5 9 13.5 18 22.5

Koonap (Q92) Sub-catchment showing Rainzones, Raingauge and Flow Gauges

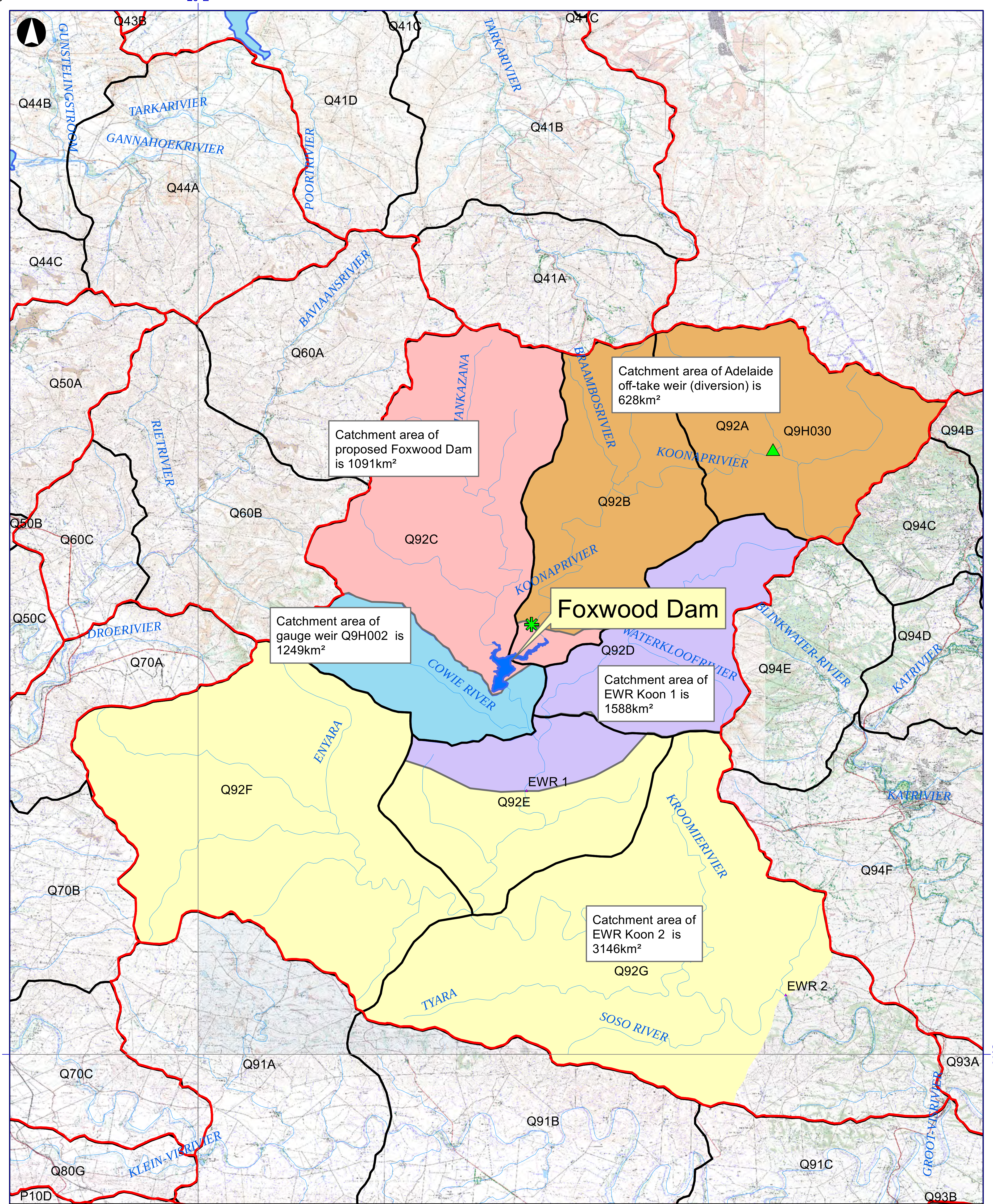
Scale at A3
1:500,000

Job No	Drawing Status
225739-00	**Preliminary**

Drawing No	Issue
225739-HYD-0202	**0B**

MXD Location

A3



26°E

Legend

- Existing Dams
- Off-Take Weir
- Flow Gauge
- EWR Sites
- Rivers
- Foxwood Dam Estimated Inundation Area
- Tertiary Catchment Boundary
- Quaternary Catchment Boundary
- OffTake_Weir_Catchment_Area
- Foxwood_Dan_Catchment_Area
- Flow_Gauge_Catchment_Area
- EWR Koon 1
- EWR Koon 2

0A	2014-10-31	MC	AB	JH
Issue	Date	By	Chkd	Appd

ARUP

water & sanitation — Department: Water and Sanitation, REPUBLIC OF SOUTH AFRICA

10 High Street Melrose Arch,
Johannesburg South Africa
Tel +27 11 218 7600 Fax +27 86 674 8513
www.arup.com

Client
Department of Water and Sanitation

Job Title
Feasibility Study for Foxwood Dam

Kilometers
0 2.25 4.5 9 13.5 18

Foxwood Dam Catchment Areas

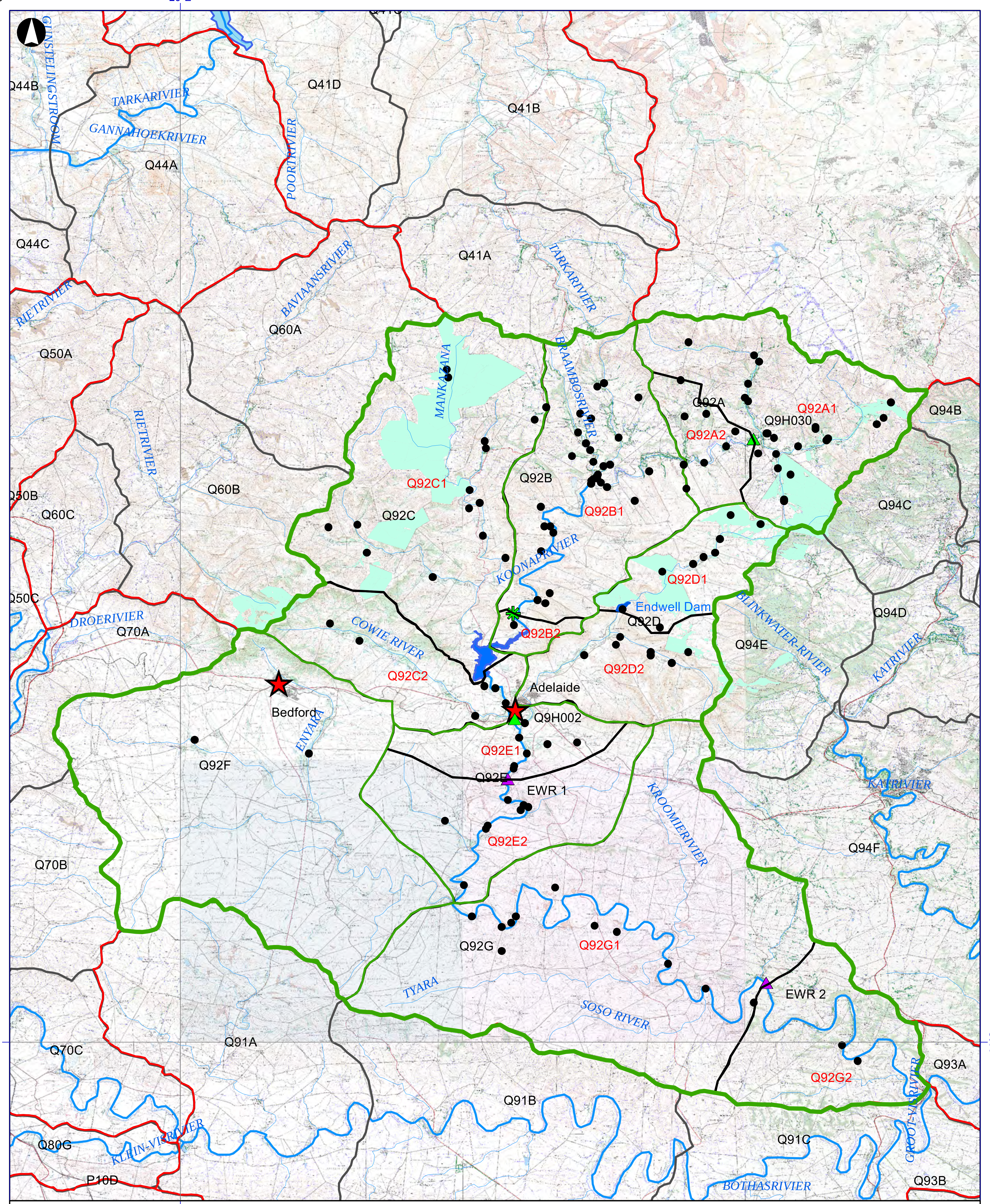
Scale at A3
1:350,000

Job No	Drawing Status
225739-00	**Preliminary**

Drawing No	Issue
225739-HYD-0203	**0A**

MXD Location

A3



Legend

- Irrigation Points
- EWR Sites
- Flow Gauge
- Off-Take Weir
- Rivers
- Q92 Tertiary Catchment Boundary
- Q92 Quaternary Catchment Boundary
- Foxwood Dam Estimated Inundation Area
- Quaternary Catchment Boundary
- Alien Invasive Plants
- Existing Dams

0A	2014-10-31	MC	AB	JAH
Issue	Date	By	Chkd	Appd

ARUP

water & sanitation
Department: Water and Sanitation
REPUBLIC OF SOUTH AFRICA

10 High Street Melrose Arch,
Johannesburg South Africa
Tel +27 11 218 7600 Fax +27 86 674 8513
www.arup.com

Client
Department of Water and Sanitation

Job Title
Feasibility Study for Foxwood Dam

Kilometers
0 2.25 4.5 9 13.5 18

Koonap Catchment
Landuse Hydrology

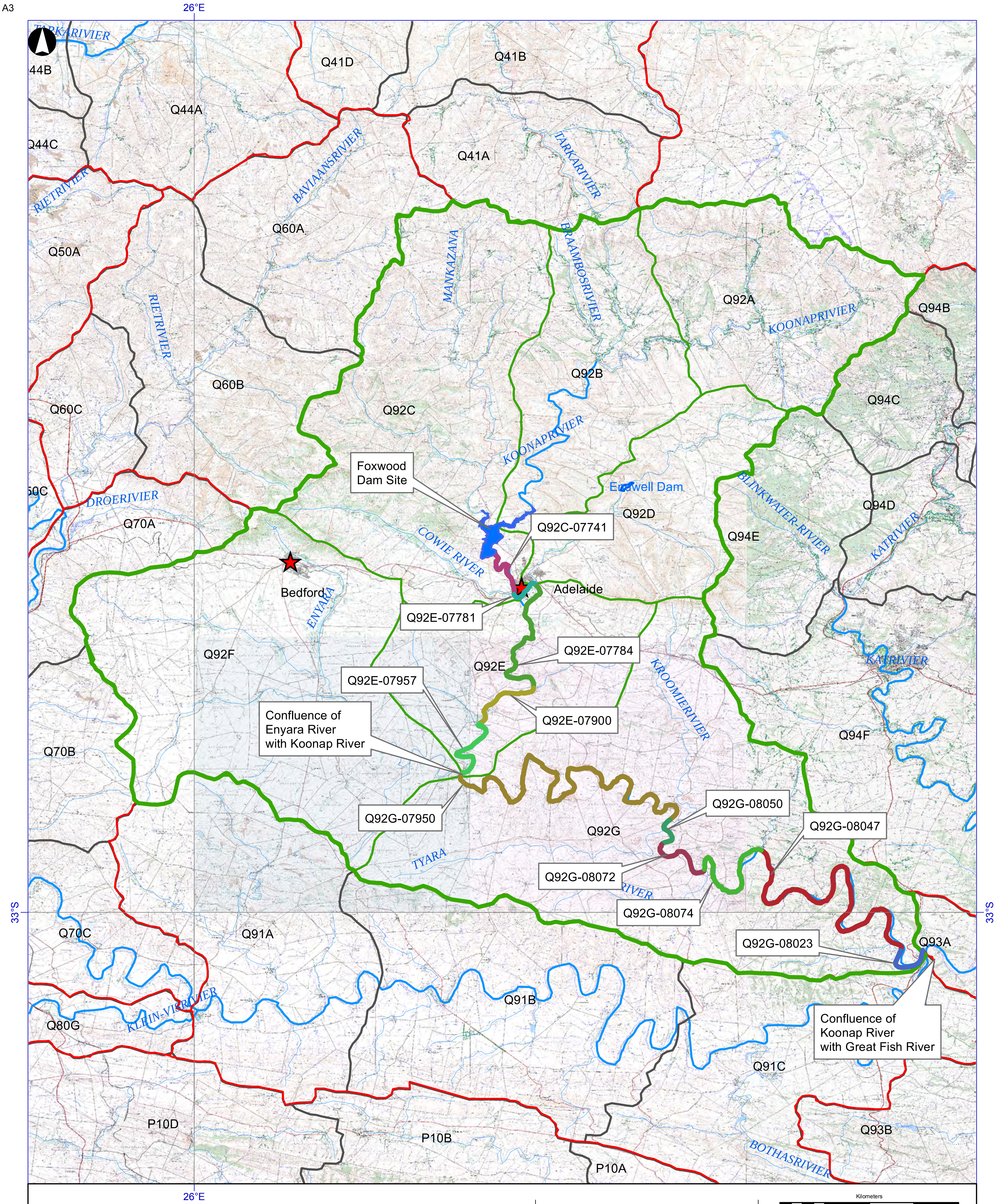
Scale at A3
1:350,000

Job No	Drawing Status
225739-00	**Preliminary**

Drawing No	Issue
225739-HYD-0204	**0A**

MXD Location

A3



Legend

- Rivers
- Q92 Tertiary Catchment Boundary
- Q92 Quaternary Catchment Boundary
- Tertiary Catchment Boundary
- Quaternary Catchment Boundary
- Existing Dams
- Foxwood Dam Estimated Inundation Area

0A	2014-10-31	MC	JB	JAH
Issue	Date	By	Chkd	Appd

ARUP

water & sanitation
Department: Water and Sanitation
REPUBLIC OF SOUTH AFRICA

10 High Street Melrose Arch,
Johannesburg South Africa
Tel +27 11 218 7600 Fax +27 86 674 8513
www.arup.com

Client
Department of Water and Sanitation

Job Title
Feasibility Study for Foxwood Dam

Kilometers
0 2.25 4.5 9 13.5 18

Locality of Subquaternary Reaches on Koonap River Downstream of Foxwood Dam

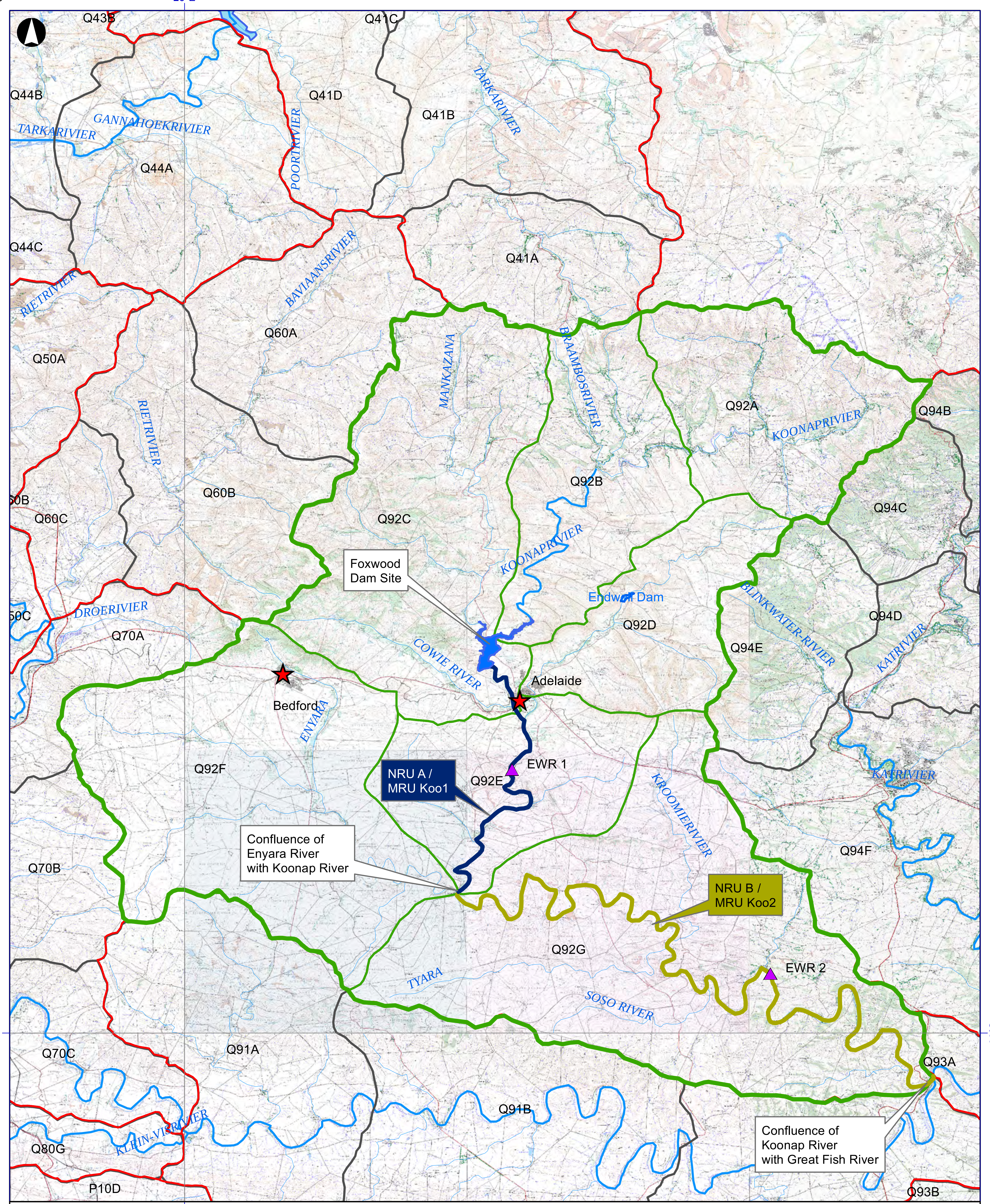
Scale at A3
1:350,000

Job No	Drawing Status
225739-00	**Preliminary**

Drawing No	Issue
225739-HYD-0206	**0A**

MXD Location

A3



Legend

- EWR Sites
- Rivers
- NRU A / MRU Koo1
- NRU B / MRU Koo2
- Q92 Tertiary Catchment Boundary
- Q92 Quaternary Catchment Boundary
- Tertiary Catchment Boundary
- Quaternary Catchment Boundary
- Existing Dams
- Foxwood Dam Estimated Inundation Area

0A	2014-10-31	YO	JB	JAH
Issue	Date	By	Chkd	Appd

ARUP

water & sanitation
Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

10 High Street Melrose Arch,
Johannesburg South Africa
Tel +27 11 218 7600 Fax +27 86 674 8513
www.arup.com

Client
Department of Water and Sanitation

Job Title
Feasibility Study for Foxwood Dam

Kilometers
0 2.25 4.5 9 13.5 18

Ecological Water Requirements Natural and Management Resource Units

Scale at A3
1:350,000

Job No	Drawing Status
225739-00	**Preliminary**

Drawing No	Issue
225739-HYD-0205	**0A**

MXD Location