Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the MOKOLO CATCHMENT, LIMPOPO PROVINCE

PROJECT NO: WP 9132

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VOLUME 2: SPECIALIST APPENDICES

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ECOCLASSIFICATION REPORT: FINAL

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26/8/3/10/14/007	Intermediate Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Limpopo Water Management Area, Mpumalanga. Mokolo River System: Desktop Estimation report
26/8/3/10/14/008	**Intermediate Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Limpopo Water Management Area, Mpumalanga. Mokolo River System: EcoClassification report**
26/8/3/10/14/009	Intermediate Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Limpopo Water Management Area, Mpumalanga. Mokolo River System: EWR scenario report
26/8/3/10/14/010	Intermediate Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Limpopo Water Management Area, Mpumalanga. Mokolo River System: Ecological, Goods & Services and Socio-Economic consequences of various Operational Scenarios.
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26/8/3/10/14/013	Intermediate Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Limpopo Water Management Area, Mpumalanga. Mokolo River System: Training audit and report
26/8/3/10/14/014	Intermediate Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Limpopo Water Management Area, Mpumalanga. Mokolo River System: Main report
26/8/3/10/14/015	Intermediate Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Limpopo Water Management Area, Mpumalanga. Mokolo River System: Wetland report
26/8/3/10/12/016	Intermediate Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Limpopo Water Management Area, Mpumalanga. Mokolo River System: Electronic information and data
26/8/3/10/14/017	Intermediate Reserve Determination Study for the Surface and Groundwater Resources in the Mokolo Catchment, Limpopo Province: Ground Water – Surface Water Interaction Report

Bold indicates this report

REFERENCES

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ABBREVIATIONS AND ACRONYMS

ASPT	Average Score Per Taxon
Conf	Confidence
D:RQS	Directorate: Resource Quality Services
DO	Dissolved Oxygen
DWAF	Department of Water Affairs and Forestry
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirements
EWR	Ecological Water Requirements
F	Flow related
FRAI	Fish Response Assessment Index
FROC	Fish Frequency of Occurrence
FD	Fast Deep
FS	Fast Shallow
HAI	Hydrology Assessment Index
IIHI	Index of Instream Habitat Integrity
IRHI	Index of Riparian Habitat Integrity
ISP	Internal Strategic Perspective
mamsl	Metres above mean sea level
MIRAI	Macro Invertebrate Response Assessment Index
MRU	Management Resource Unit
NF	Non Flow related
NRHP	National River Health Programme
NRU	Natural Resource Unit
PAI	Physico-Chemical Driver Assessment Index
PES	Present Ecological State
RAU	Resource Assessment Unit
RC	Reference Condition
REC	Recommended Ecological Category
RHP	River Health Programme
RU	Resource Unit
SAIAB	South African Institute of Aquatic Biodiversity
SANBI	South African National Biodiversity Institute
SASS5	South African Scoring System version 5
SD	Standard deviation (Water quality)
SD	Slow Deep
SPI	Specific Pollution sensitivity Index
SPI	Specific Pollution Index
SRP	Soluble Reactive Phosphate
SS	Slow Shallow
STW	Sewage Treatment Works
TEACHA	Tool for Ecological Aquatic Chemical Habitat Assessment
TIN	Total Inorganic Nitrogen
VEGRAI	Riparian Vegetation Response Assessment Index
WARMS	Water Resource Management System
WMA	Water Management Area
WQSU	Water Quality Sub-Unit
WWTW	Waste Water Treatment Works

APPENDIX A: HYDROLOGY AND WATER RESOURCES OF THE MOKOLO SYSTEM

Hydrology: Prof DA Hughes, Institute for Water Research
Water Resources: Mr S Mallory, Water for Africa

A1 HYDROLOGY OF THE MOKOLO CATCHMENT

A1.1 INTRODUCTION

The location of the EWR sites, the quaternary catchment boundaries and rivers are provided in Figure A1.

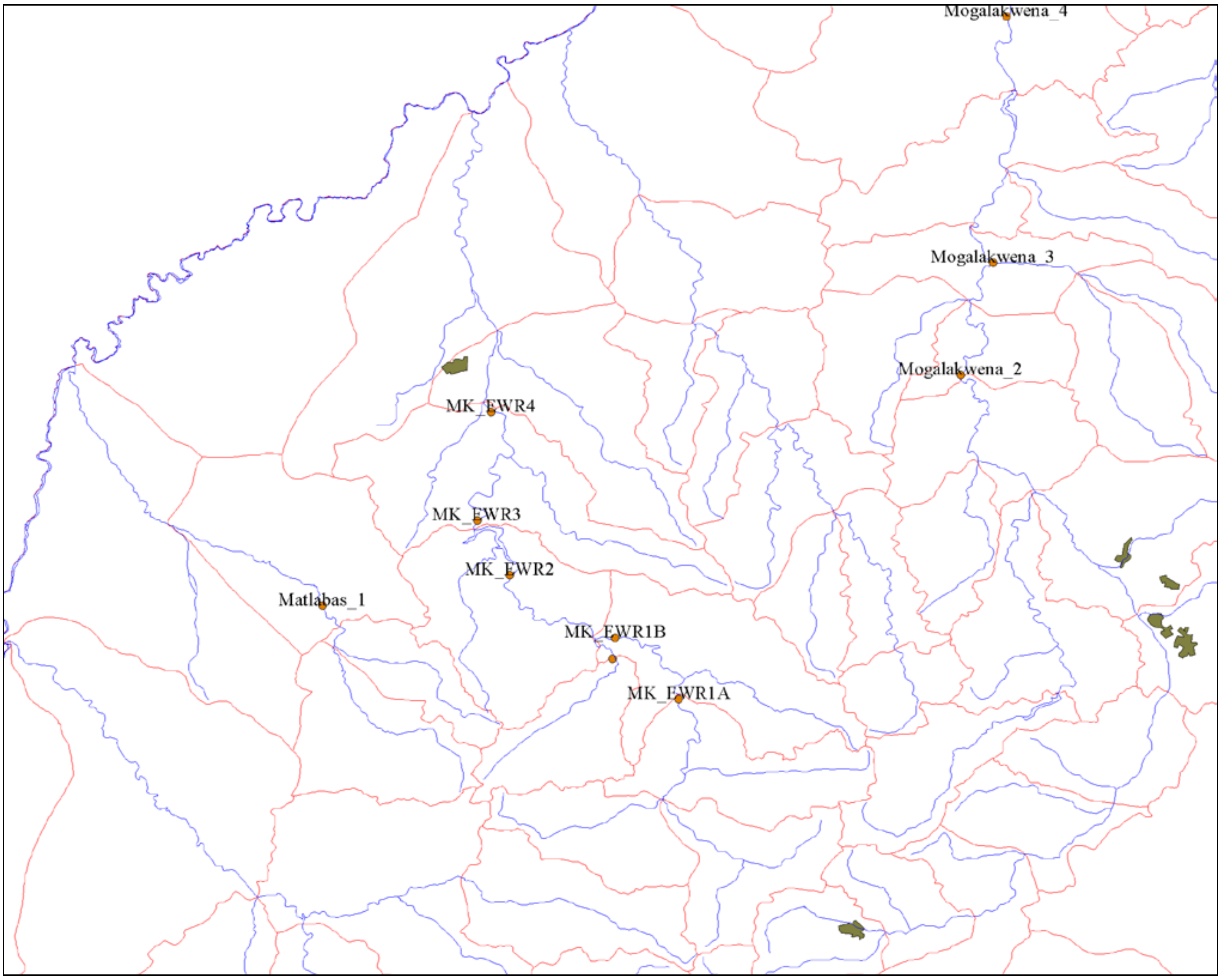


Figure A1 Locality of EWR sites and quaternary catchments

A1.2 DWAF STREAMFLOW GAUGES

The available DWAF daily data from stream flow gauging sites are referred to in the following sections where available and appropriate. Additional gauges may be identified and the data prepared before the workshop.

A1.3 PRESENT DAY HYDROLOGICAL IMPACTS

The natural and present day time series of monthly flows were provided by the systems modelers and these have not yet been compared with the observed records as part of the assessment of the present day hydrological impacts. The Hydrological Assessment Index (HAI) details for the sites are given in Tables A1 to A5, while flow duration curves are compared in Figures A2 to A6 to support some of the conclusions. The confidence ratings are based on the interpretation of the simulated data and not on the quality of the simulated data. These confidence values may therefore be modified at a later date when there has been more time to look at the observed data.

A1.3.1 HAI for MK_EWR 1A – Mokolo River at Vaalwater

Large reductions in low and moderate flows (Figure A2) resulting in high values for several of the rating values (Table A1). While the present day flows do not reach zero, they are very close and therefore the 'Zero Flow' rating has been set to 2.0.

Table A1 HAI details for MK_IWR1A

Hydrology metrics	Rating	Confidence
LOW FLOWS	5.0	4.00
ZERO FLOW DURATION	2.0	4.00
SEASONALITY	0.0	4.00
MODERATE EVENTS	3.0	4.00
EVENT HYDROLOGY(HIGH FLOWS-FLOODS)	0.0	4.00

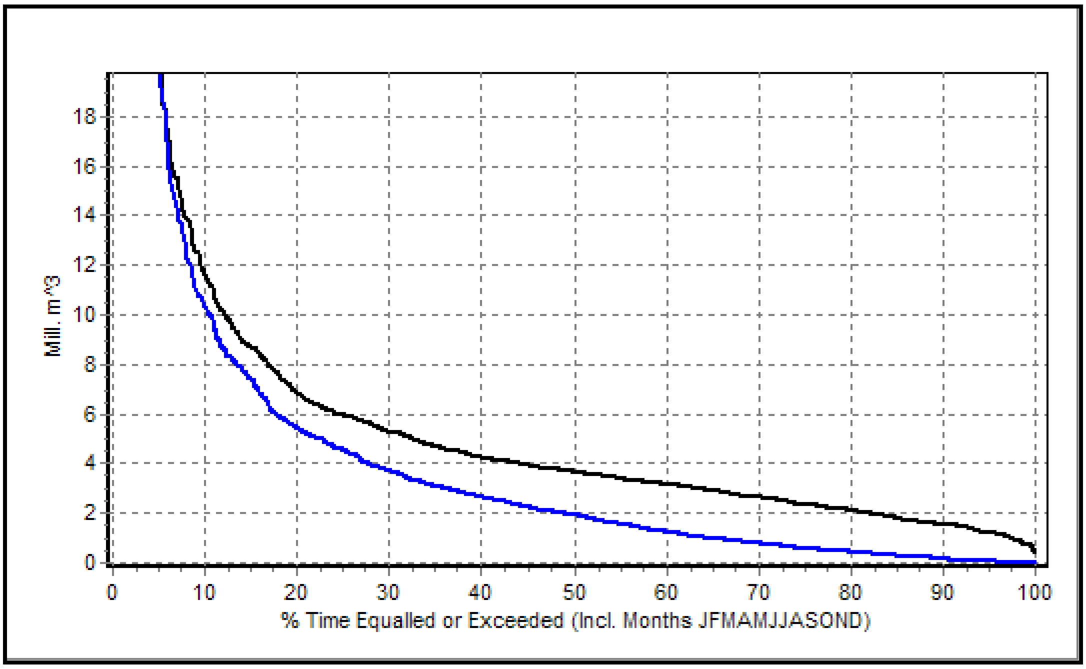


Figure A2 Annual monthly flow duration curves (data 1920 to 2003) for site MK_EWR 1A (Black = Natural, Blue = Present Day)

A1.3.2 HAI for MK_EWR 1B – Mokolo River at Tobacco

These results (Figure A3 and Table A2) are very similar to EWR 1A, but the zero flow impact is now a lot greater.

Table A2 HAI details for Site MK_EWR 1B

Hydrology metrics	Rating	Confidence
LOW FLOWS	5.00	4.00
ZERO FLOW DURATION	4.00	4.00
SEASONALITY	0.00	4.00
MODERATE EVENTS	3.00	4.00
EVENT HYDROLOGY(HIGH FLOWS-FLOODS)	0.00	4.00

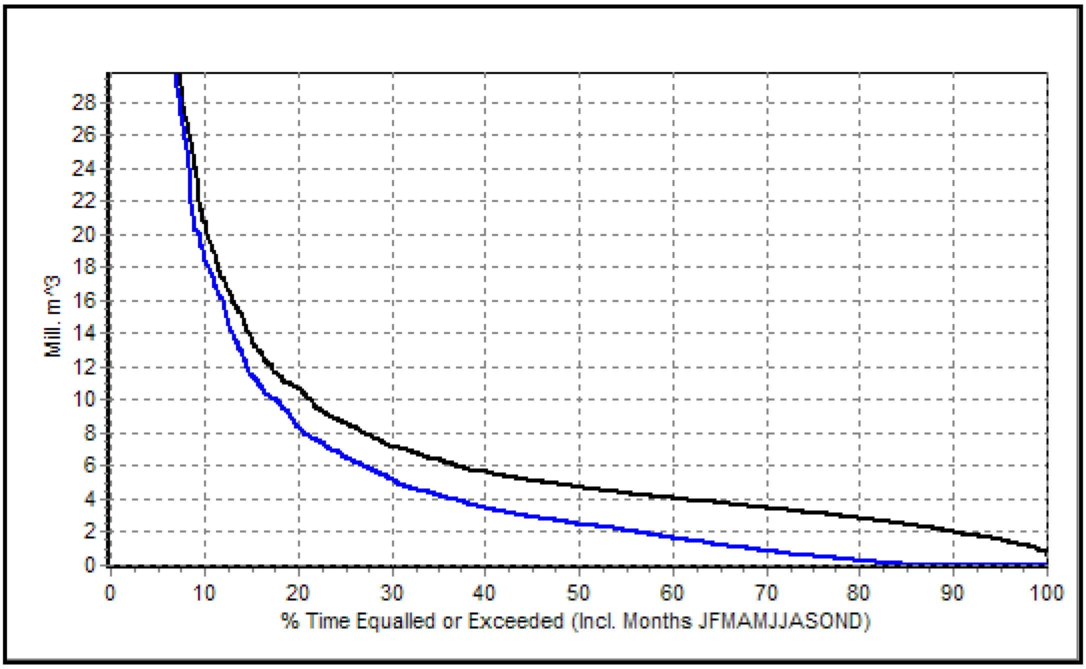


Figure A3 Annual monthly flow duration curves (data 1920 to 2003) for site MK_EWR 1B (Black = Natural, Blue = Present Day)

A1.3.3 HAI for MK_EWR2 – Mokolo River at Ka'ingo

Very similar to site MK_EWR 1B and the results are given in Table A3 and Figure A4.

Table A3 HAI details for Site MK_EWR2

Hydrology metrics	Rating	Confidence
LOW FLOWS	5.00	4.00
ZERO FLOW DURATION	4.00	4.00
SEASONALITY	0.00	4.00
MODERATE EVENTS	3.00	4.00
EVENT HYDROLOGY(HIGH FLOWS-FLOODS)	0.00	3.00

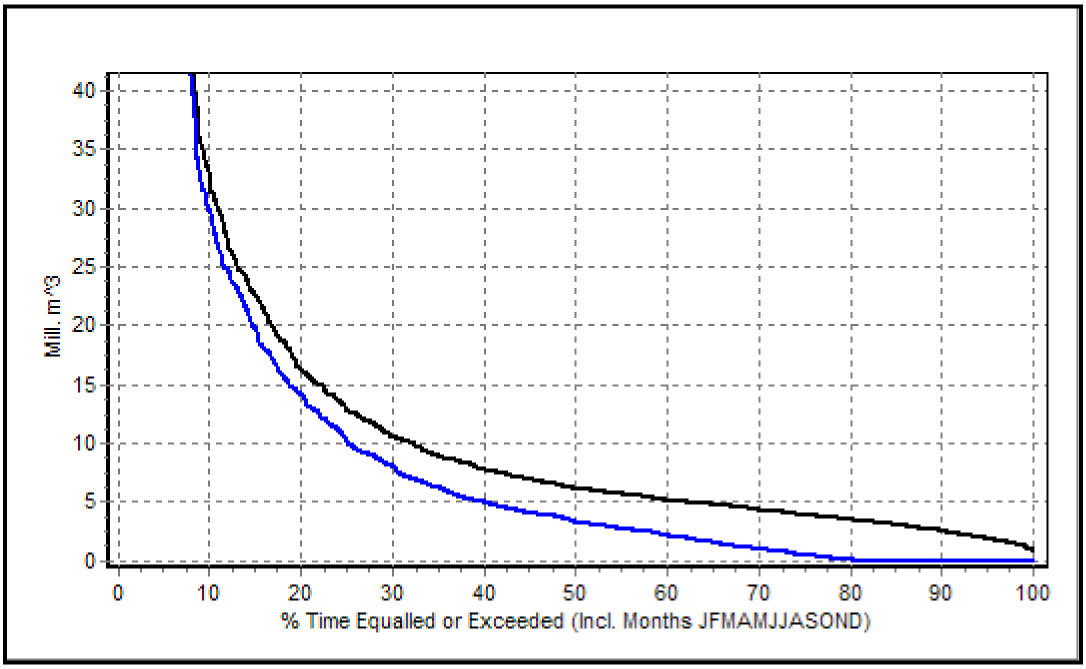


Figure A4 Annual monthly flow duration curves (data 1920 to 2003) for site MK_EWR 2 (Black = Natural, Blue = Present Day)

A1.3.4 HAI for MK_EWR3 – Mokolo River at Gorge

Very similar to the previous two sites (with possibly an even bigger impact on moderate events) and the results are given in Table A4 and Figure A5.

Table A4 HAI details for Site MK_EWR 3

Hydrology metrics	Rating	Confidence
LOW FLOWS	5.00	4.00
ZERO FLOW DURATION	4.00	4.00
SEASONALITY	0.00	4.00
MODERATE EVENTS	4.00	3.00
EVENT HYDROLOGY(HIGH FLOWS-FLOODS)	0.00	4.00

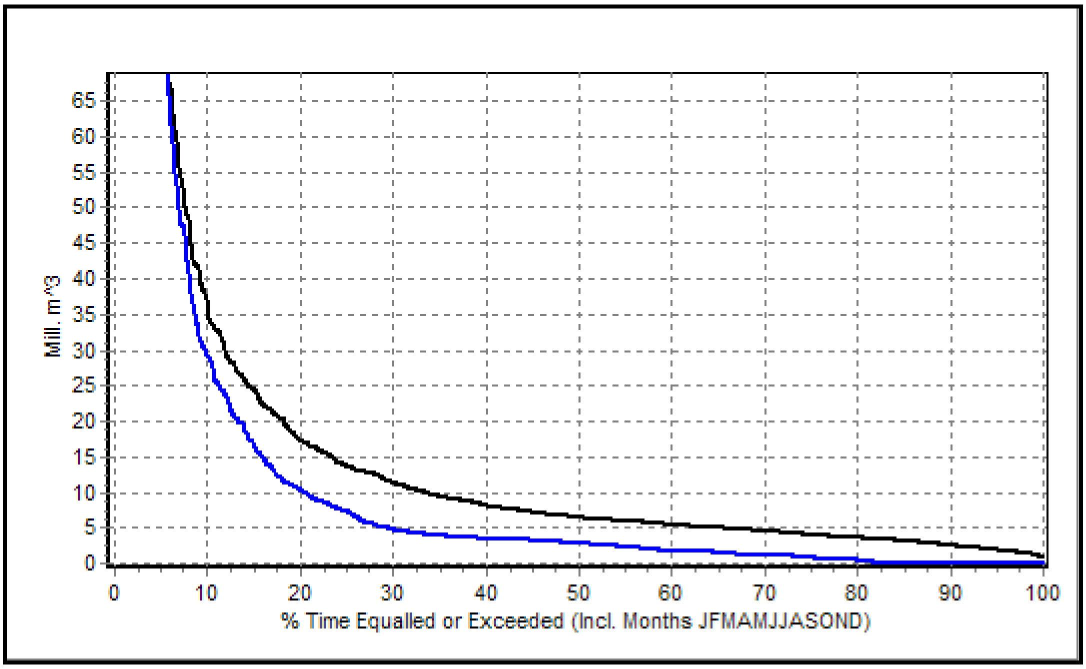


Figure A5 Annual monthly flow duration curves (data 1920 to 2003) for site MK_EWR 3 (Black = Natural, Blue = Present Day)

A1.3.5 HAI for MK_EWR 4 – Mokolo River at Malalatau

Very similar to the previous site (with possibly a smaller impact on zero flow duration) and the results are given in Table A5 and Figure A6.

Table A5 HAI details for Site MK_EWR 4

Hydrology metrics	Rating	Confidence
LOW FLOWS	5.00	4.00
ZERO FLOW DURATION	2.00	4.00
SEASONALITY	0.00	4.00
MODERATE EVENTS	4.00	3.00
EVENT HYDROLOGY(HIGH FLOWS-FLOODS)	0.00	4.00

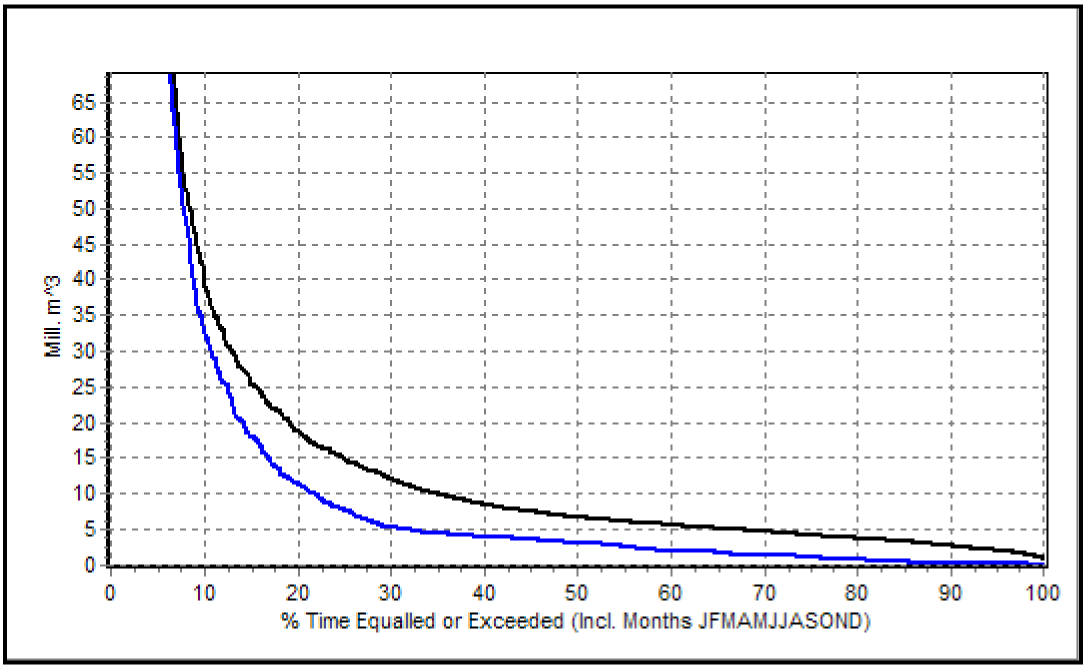


Figure A6 Annual monthly flow duration curves (data 1920 to 2003) for site MK_EWR 4 (Black = Natural, Blue = Present Day)

A1.4 Conclusions and observations

Figure A7 shows the time series for site MK_EWR 3, which illustrates that nearly all the impacts occur during dry years and that these are highly cyclical. This may have some impact on the way in which the HAI ratings are interpreted.

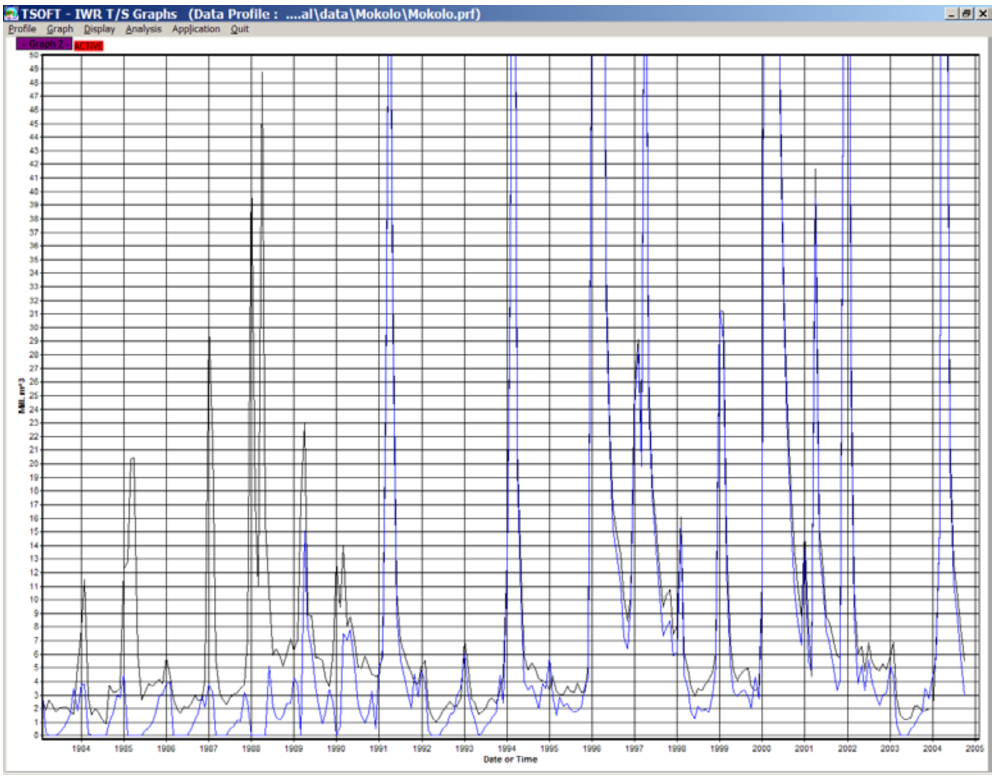


Figure A7 Monthly time series of simulated natural (Black) and present day (Blue) flows

A2 HYDROLOGY AND WATER RESOURCES OF THE MOKOLO CATCHMENT

A2.1 HYDROLOGY

The Mokolo catchment is the only catchment in the Limpopo WMA with significant water resources. This is due to the relative high rainfall in the upper reaches of the catchment, as high as 660 mm/annum in places.

Hydology

Capture WR90 default

Node Numbe	Node name	Flow file	WR90 Reference	Proportion	Catchment Area	MAP (mm)	Rain Zone	MAE (mm)	Evaporation zo
1	DummyDamA42A	A42A	X21F	0.3	79.3	640.0	A4C	1700	01D
2	NodeA42A	A42A	X21F	0.7	317.4	640.0	A4C	1700	01D
3	DummyDamA42B	A42B	X21G	0.5	34.7	660.0	A4C	1700	01D
4	NodeA42B	A42B	X21G	0.5	312.6	660.0	A4C	1700	01D
5	DummyDamA42C	A42C	X21H	0.4	217.4	656.0	A4C	1700	01D
6	NodeA42C	A42C	X21H	0.6	11.4	656.0	A4C	1700	01D
7	DummyDamA42E	A42E	X21J	0.3	354.6	605.0	A4D	1700	01D
8	NodeA42E	A42E	X21K	0.7	245.1	605.0	A4D	1700	01D
9	DummyDamA42D	A42D	X21A	0.4	53.0	667.0	A4D	1700	01D
10	NodeA42D	A42D	X21A	0.6	211.9	667.0	A4D	1700	01D
11	Mokolo Dam	A42F	X21B	1	18.9	577.0	A4D	1800	01D
12	Node A42G	A42G	X21B	1	359.4	551.0	A4E	1900	01D
13	Node A42H	A42H	X21C	1	248.8	518.0	A4E	1900	01D
14	Node A42J	A42J	X21C	1	62.2	428.0	A4E	1950	01D

Figure A8 WR 90 information on the catchment

The mean annual runoff of the catchment is estimated to be 315 million m^3/annum based on the latest available hydrology carried out by BKS in 1993. An update of the hydrology has been in progress for nearly two years now. A draft report is available and this is being sourced.

A2.2 WATER REQUIREMENTS

By far the largest water user is the irrigation sector, with an estimated requirement of 68 million m^3/annum. This is located mostly upstream of the Mokolo Dam. The irrigators are supplied mostly from farm dams, of which are many. The irrigation quota from the Mokolo Dam itself is only about 10 million m^3/annum. Irrigators are supplied by means of releases into the Mokolo River and the losses associated with this are thought to be large.

The other two large water allocations are 9,9 million m^3/ annum to the Grootgeluk mine and 7.3 million m^3/annum to the Matimba power station. Other small users are the towns of Lephelale and Vaalwater which together use approximately 2 million m^3/ annum and rural water use of 2 million m^3/ annum, probably mostly from boreholes.

Inflow summary

Node Numbe	Node name	MARnat (Inc)	MARnat (Cum)	Imports	Return flow in	MAR (Present Day)
1	DummyDamA42A	7.766	7.766	0.000	0.000	7.766
2	NodeA42A	18.121	25.887	0.000	0.000	22.055
3	DummyDamA42B	12.986	12.986	0.000	0.000	12.986
4	NodeA42B	12.986	25.971	0.000	0.000	16.491
5	DummyDamA42C	13.624	13.624	0.000	0.000	13.624
6	NodeA42C	20.435	85.918	0.000	0.000	64.755
7	DummyDamA42E	21.354	21.354	0.000	0.000	21.354
8	NodeA42E	49.825	157.096	0.000	0.000	128.834
9	DummyDamA42D	18.606	18.606	0.000	0.000	18.606
10	NodeA42D	27.908	46.514	0.000	0.000	39.248
11	Mokolo Dam	36.792	240.403	0.000	0.000	190.164
12	Node A42G	39.968	280.371	0.000	0.000	211.587
13	Node A42H	27.745	308.116	0.000	0.000	239.332
14	Node A42J	7.423	315.539	0.000	0.000	246.756

Figure A9 Water requirements of the Mokolo catchment

A2.3 INFRASTRUCTURE

There are a large number of farm dams in the catchments upstream of the Mokolo Dam. These are mostly smaller than 50 000 m^3 and hence are mostly not registered by the DWAF's Dam Safety office. Obtaining accurate estimates of the number of dams, their capacities and surface areas is therefore difficult but it is assumed that the updated hydrological study will have done this.

The large Mokolo Dam (formerly the Hans Strydom Dam) has a full supply capacity of 146 million m^3. If it were not for the large number of farm dams and irrigation upstream of the Mokolo Dam, this dam would have a yield of about 70 million m^3/annum, but according to the BKS report (1993) the abstractions for irrigation have reduced the yield to only about 23 million m^3/a.

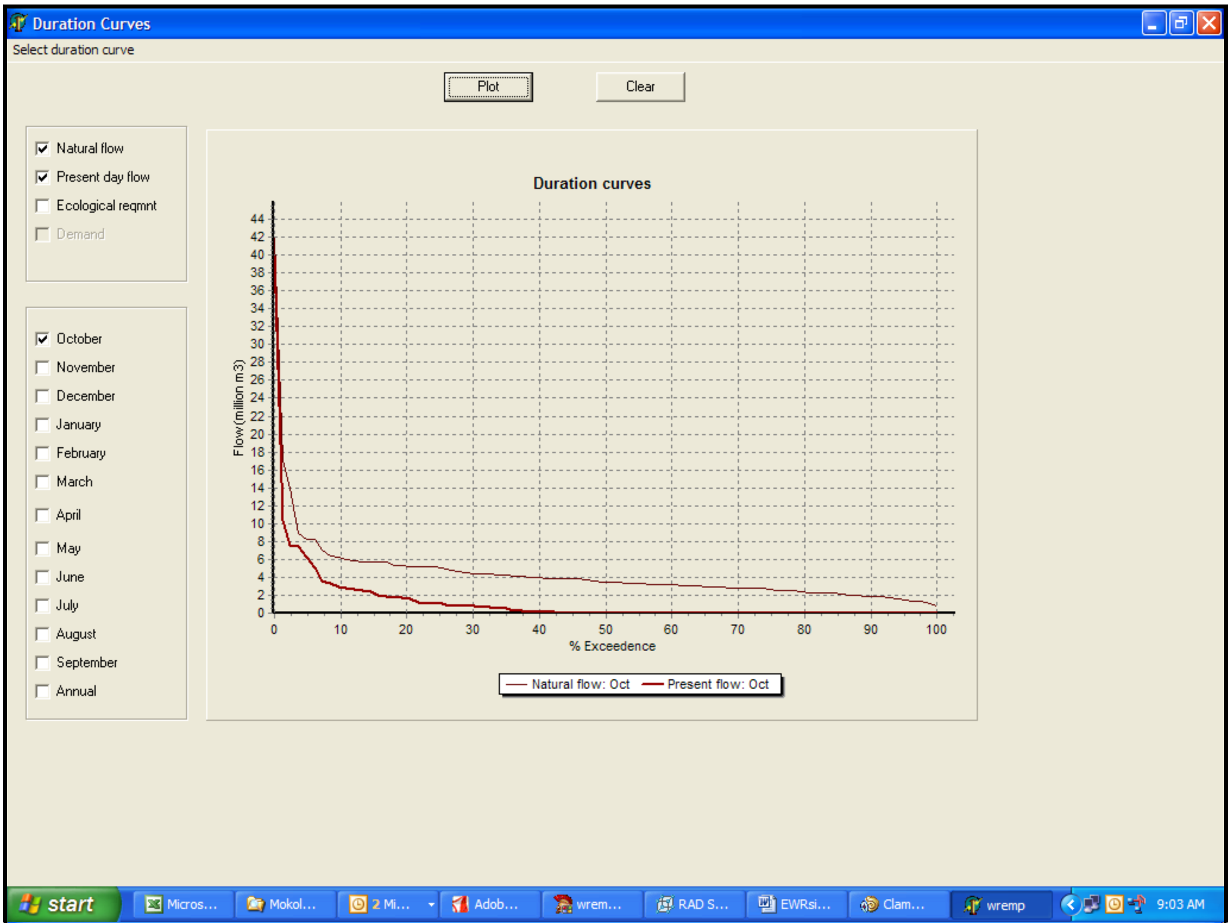
A2.4 SUMMARY OF HYDROLOGY PER SITE

A summary of the system hydrology is provided below.

EWR 1A: VAALWATER		
Are there reliable gauges near to the site?		Yes: A4H002 not far downstream of site
How long a record is available?		1948 to 2002
Does it measure low flows accurately?		Yes
Will it record zero flows accurately?		Probably
What are the highest flows it can record before it drowns out?		6 m^3/s
Rate your confidence in your modelled naturalised hydrology and provide reasons (1 (low) – 5 (high))		4 = relatively high confidence. A good calibration was obtained against a reliable gauge and the water use upstream of the gauge is fairly well understood.
Rate your confidence in your modelled present day hydrology and provide reasons (1 (low) – 5 (high))		3 = medium confidence. Some uncertainty as to how much irrigators abstract.
Are there major differences between observed hydrology & modelled present hydrology. Why? If present hydrology reflects recent changes, provide info. If changes have been gradual, note that.		There has probably been an increase in flow over the past 10 years due to a decrease in irrigation upstream of the gauge.
BASE (LOW) FLOWS	Have base flows changed from natural? (in volume, and/or time and/or distribution)	Yes Volume is less. Baseflow fully utilised by irrigators most of time.
	Are the changes an increase or decrease?	Decrease.
	Are the changes continuous through the year or only in specific seasons/months?	Continuous but more severe in winter.
	Have the natural seasonal distribution changed and if yes, how and why?	Not much change in seasonal distribution. Possible later onset of spring freshettes due to numerous farm dams.
	Why has the base flow changed, i.e. what is the water being used for.	Used for irrigation, mostly abstracted from farm dams. Farm dams also reduce the baseflow due to evaporation losses.
	What (in m^3/s) is the natural range of baseflows (lowest to highest). If possible, provide for the wet season, and dry season.	
	What (in m^3/s) is the present day range of baseflows (lowest to highest). If possible, provide for the wet season, and dry season.	
MODERATE FLOODS (HIGH FLOWS)	Has the frequency of floods changed from natural?	Probably not. Lots of dams but they are all small.
	Are the changes an increase or a decrease? If an increase, is it due to dam releases, urban runoff, or something else.	Increase/Decrease.
	Are there any changes in seasonality of the floods? And if yes, how.	No.
	Why has the flooding regime changed?	
LARGE FLOODS (HIGH FLOWS)	Has the frequency of floods changed from natural?	No.
	Are the changes an increase or a decrease? If an increase, is it due to dam releases, urban runoff, or something else.	Increase/Decrease.
	Are there any changes in seasonality of the floods? And if yes, how.	Yes/No.
	Why have the flooding changed?	
Have any frequency analysis of floods been undertaken and if so, what are the flood peaks (in m^3/s). E.g. 1:2 = X m3/s etc		No
Any general comments or anything else one should take note of?		

Figure A10 Duration curves for EWR 1A: February and October

EWR 1B: TOBACCO		
	Are there reliable gauges near to the site?	The A4H002 covers most of this site and is a reliable gauge. The A42E catchment which contributes to flow at EWR1B is not gauged.
	How long a record is available?	1948 to 2002
	Does it measure low flows accurately?	Yes.
	Will it record zero flows accurately?	Probably.
	What are the highest flows it can record before it drowns out?	6 m^3/s
	Rate your confidence in your modelled naturalised hydrology and provide reasons (1 (low) – 5 (high))	3 = relatively high confidence. A good calibration was obtained against a reliable gauge and the water use upstream of the gauge is fairly well understood. There is some uncertainty about the contribution of the A42E catchment.
	Rate your confidence in your modelled present day hydrology and provide reasons (1 (low) – 5 (high))	3 = medium confidence. Some uncertainty as to how much irrigators abstract.
	Are there major differences between observed hydrology & modelled present hydrology. Why? If present hydrology reflects recent changes, provide info. If changes have been gradual, note that.	There has probably been an increase in flow over the past 10 years due to a decrease in irrigation upstream of the gauge.
BASE (LOW) FLOWS	Have base flows changed from natural? (in volume, and/or time and/or distribution)	Yes. Volume is less. Baseflow fully utilised by irrigators most of time.
	Are the changes an increase or decrease?	Decrease.
	Are the changes continuous through the year or only in specific seasons/months?	Continuous but more severe in winter.
	Have the natural seasonal distribution changed and if yes, how and why?	Not much change in seasonal distribution. Possible later onset of spring freshettes due to numerous farm dams.
	Why has the base flow changed, i.e. what is the water being used for.	Used for irrigation, mostly abstracted from farm dams. Farm dams also reduce the baseflow due to evaporation losses.
	What (in m^3/s) is the natural range of baseflows (lowest to highest). If possible, provide for the wet season, and dry season.	
	What (in m^3/s) is the present day range of baseflows (lowest to highest). If possible, provide for the wet season, and dry season.	
MODERATE FLOODS (HIGH FLOWS)	Has the frequency of floods changed from natural?	Probably not. Lots of dams but they are all small.
	Are the changes an increase or a decrease? If an increase, is it due to dam releases, urban runoff, or something else.	Increase/Decrease.
	Are there any changes in seasonality of the floods? And if yes, how.	No.
	Why has the flooding regime changed?	
LARGE FLOODS (HIGH FLOWS)	Has the frequency of floods changed from natural?	No.
	Are the changes an increase or a decrease? If an increase, is it due to dam releases, urban runoff, or something else.	Increase/Decrease.
	Are there any changes in seasonality of the floods? And if yes, how.	Yes/No.
	Why have the flooding changed?	
	Have any frequency analysis of floods been undertaken and if so, what are the flood peaks (in m^3/s). E.g. 1:2 = X m^3/s etc.	No.
	Any general comments or anything else one should take note of?	



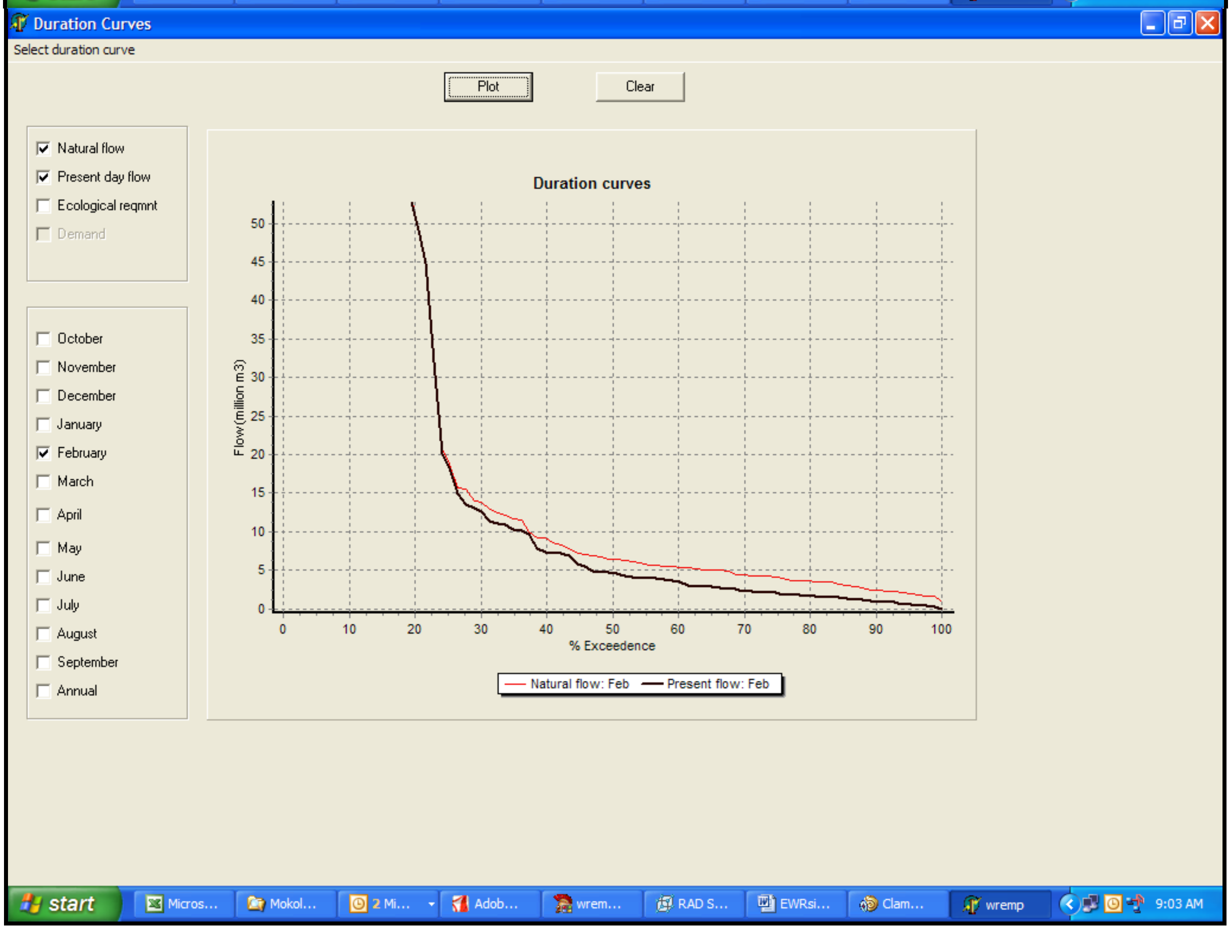


Figure A11 Duration curves for EWR 1B: February and October

EWR 2: KA'INGO		
Are there reliable gauges near to the site?		The A4H005 gauge is just downstream of the EWR 2 site and is considered reliable.
How long a record is available?		1962 to present.
Does it measure low flows accurately?		Yes.
Will it record zero flows accurately?		Probably.
What are the highest flows it can record before it drowns out?		Unknown.
Rate your confidence in your modelled naturalised hydrology and provide reasons (1 (low) – 5 (high))		4 = relatively high confidence. A good calibration was obtained against a reliable gauge and the water use upstream of the gauge is fairly well understood.
Rate your confidence in your modelled present day hydrology and provide reasons (1 (low) – 5 (high))		3 = medium confidence. Some uncertainty as to how much irrigators abstract.
Are there major differences between observed hydrology & modelled present hydrology. Why? If present hydrology reflects recent changes, provide info. If changes have been gradual, note that.		There has probably been an increase in flow over the past 10 years due to a decrease in irrigation upstream of the gauge.
BASE (LOW) FLOWS	Have base flows changed from natural? (in volume, and/or time and/or distribution)	Yes Volume is less. Baseflow fully utilised by irrigators most of time.
	Are the changes an increase or decrease?	Decrease.
	Are the changes continuous through the year or only in specific seasons/months?	Continuous but more severe in winter.
	Have the natural seasonal distribution changed and if yes, how and why?	Not much change in seasonal distribution. Possible later onset of spring freshettes due to numerous farm dams.
	Why has the base flow changed, i.e. what is the water being used for.	Used for irrigation, mostly abstracted from farm dams. Farm dams also reduce the baseflow due to evaporation losses.
	What (in m^3/s) is the natural range of baseflows (lowest to highest). If possible, provide for the wet season, and dry season.	
	What (in m^3/s) is the present day range of baseflows (lowest to highest). If possible, provide for the wet season, and dry season.	
MODERATE FLOODS (HIGH FLOWS)	Has the frequency of floods changed from natural?	Probably not. Lots of dams but they are all small.
	Are the changes an increase or a decrease? If an increase, is it due to dam releases, urban runoff, or something else.	Increase/Decrease.
	Are there any changes in seasonality of the floods? And if yes, how.	No.
	Why has the flooding regime changed?	
LARGE FLOODS (HIGH FLOWS)	Has the frequency of floods changed from natural?	No.
	Are the changes an increase or a decrease? If an increase, is it due to dam releases, urban runoff, or something else.	Increase/Decrease.
	Are there any changes in seasonality of the floods? And if yes, how.	Yes/No.
	Why have the flooding changed?	
Have any frequency analysis of floods been undertaken and if so, what are the flood peaks (in m^3/s). E.g. 1:2 = X m^3/s etc.		No.
Any general comments or anything else one should take note of?		

Figure A12 Duration curves for EWR 2: February and October

EWR 3: GORGE		
Are there reliable gauges near to the site?		The reservoir storage record (A4R001) provides a reasonably reliable gauge for EWR 3. Some incremental inflows d/s of the Mokolo Dam not recorded but these are minimal. There are also releases made from the dam to irrigators downstream of the dam. It is not known if these releases are recorded and if so how accurate these records are.
How long a record is available?		1980 to present.
Does it measure low flows accurately?		No.
Will it record zero flows accurately?		No.
What are the highest flows it can record before it drowns out?		The spillway is too high to ever submerge. The spillway is rated up to 2253 m^3/s.
Rate your confidence in your modelled naturalised hydrology and provide reasons (1 (low) – 5 (high))		2.5 = limited confidence. Uncertainty as to timing and quantity of releases from the dam.
Rate your confidence in your modelled present day hydrology and provide reasons (1 (low) – 5 (high))		1.5 = low confidence. Uncertainty as to timing and quantity of releases from the dam.
Are there major differences between observed hydrology & modelled present hydrology. Why? If present hydrology reflects recent changes, provide info. If changes have been gradual, note that.		A major change is 1980 when the dam was constructed. Not much change since then.
BASE (LOW) FLOWS	Have base flows changed from natural? (in volume, and/or time and/or distribution)	Yes. Both volume and distribution.
	Are the changes an increase or decrease?	Decrease, but with occasional slug releases from the dam for irrigators d/s of the dam.
	Are the changes continuous through the year or only in specific seasons/months?	The change is throughout the year.
	Have the natural seasonal distribution changed and if yes, how and why?	Releases from the dam occur sporadically on request from the irrigators. These releases are not large and are less than the natural baseflow. Based on the estimated cropping pattern releases are required from September through to the end of December.
	Why has the base flow changed, i.e. what is the water being used for.	Used for irrigation, mostly abstracted from farm dams. Farm dams also reduce the baseflow due to evaporation losses. Also storage in the Mokolo Dam has drastically changed the baseflow.
	What (in m^3/s) is the natural range of baseflows (lowest to highest). If possible, provide for the wet season, and dry season.	
	What (in m^3/s) is the present day range of baseflows (lowest to highest). If possible, provide for the wet season, and dry season.	
MODERATE FLOODS (HIGH FLOWS)	Has the frequency of floods changed from natural?	Yes. The Mokolo Dam has reduced the frequency of small to moderate floods.
	Are the changes an increase or a decrease? If an increase, is it due to dam releases, urban runoff, or something else.	Decrease.
	Are there any changes in seasonality of the floods? And if yes, how.	Later onset of small to moderate floods.
	Why has the flooding regime changed?	Storage created by the Mokolo Dam.
LARGE FLOODS (HIGH FLOWS)	Has the frequency of floods changed from natural?	No.
	Are the changes an increase or a decrease? If an increase, is it due to dam releases, urban runoff, or something else.	Increase/Decrease.
	Are there any changes in seasonality of the floods? And if yes, how.	Yes/No.
	Why have the flooding changed?	
Have any frequency analysis of floods been undertaken and if so, what are the flood peaks (in m^3/s). E.g. 1:2 = X m^3/s etc.		No.
Any general comments or anything else one should take note of?		

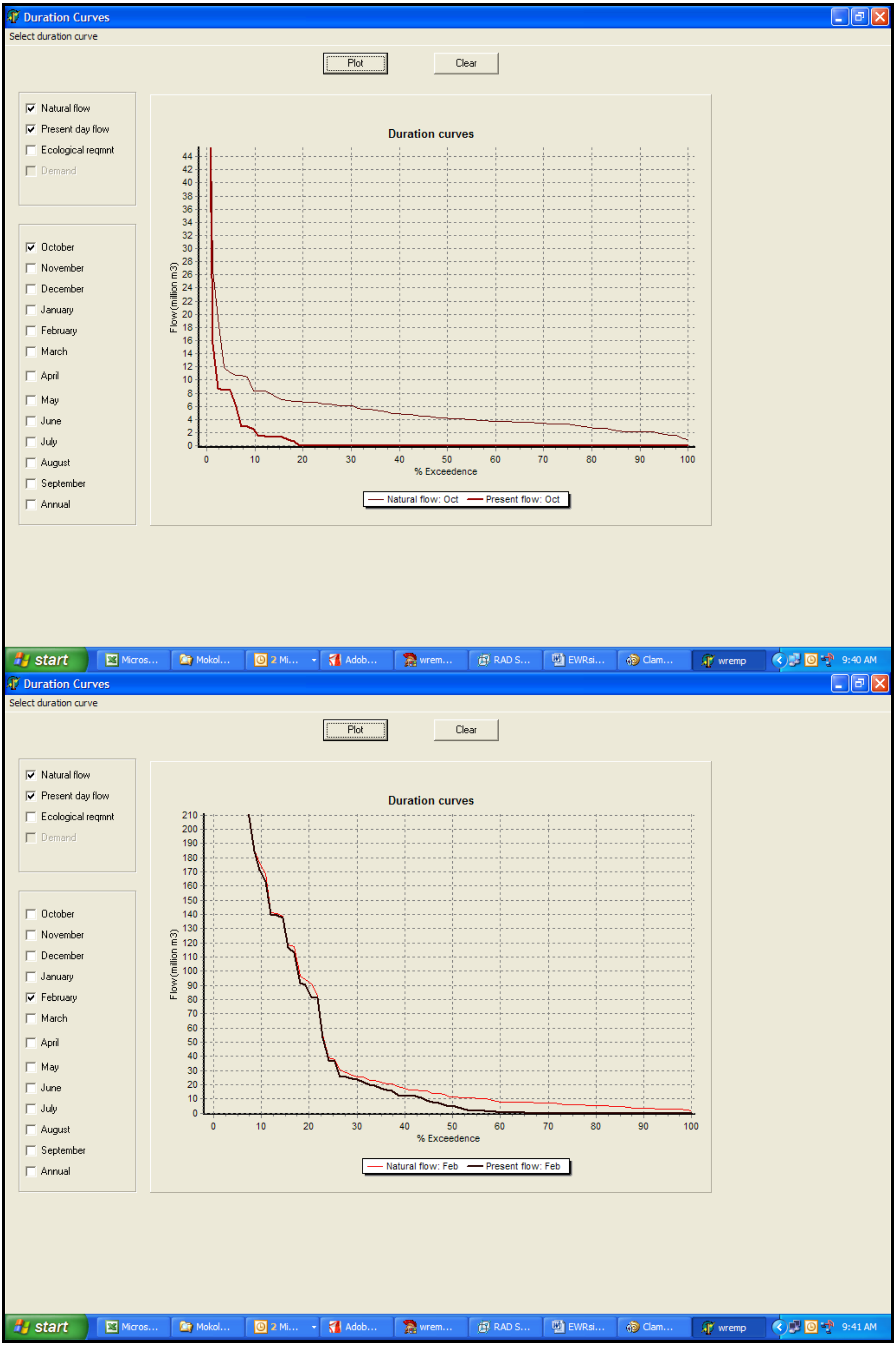


Figure A13 Duration curves for EWR 3 and 4: February and October

EWR 4: MALALATAU		
Are there reliable gauges near to the site?		The reservoir storage record (A4R001) provides a reasonably reliable gauge for EWR 4. Some incremental inflows d/s of the Mokolo Dam not recorded but these are minimal. There are also releases made from the dam to irrigators downstream of the dam. It is not known if these releases are recorded and if so how accurate these records are.
How long a record is available?		1980 to present.
Does it measure low flows accurately?		No.
Will it record zero flows accurately?		No.
What are the highest flows it can record before it drowns out?		The spillway is too high to ever submerge. The spillway is rated up to 2253 m^3/s.
Rate your confidence in your modelled naturalised hydrology and provide reasons (1 (low) – 5 (high))		2.5 = limited confidence. Uncertainty as to timing and quantity of releases from the dam.
Rate your confidence in your modelled present day hydrology and provide reasons (1 (low) – 5 (high))		1.5 = low confidence. Uncertainty as to timing and quantity of releases from the dam.
Are there major differences between observed hydrology & modelled present hydrology. Why? If present hydrology reflects recent changes, provide info. If changes have been gradual, note that.		A major change is 1980 when the dam was constructed. Not much change since then.
BASE (LOW) FLOWS	Have base flows changed from natural? (in volume, and/or time and/or distribution)	Yes. Both volume and distribution.
	Are the changes an increase or decrease?	Decrease, but with occasional slug releases from the dam for irrigators downstream of the dam.
	Are the changes continuous through the year or only in specific seasons/months?	The change is throughout the year.
	Have the natural seasonal distribution changed and if yes, how and why?	Releases from the dam occur sporadically on request from the irrigators. These releases are not large and are less than the natural baseflow. Based on the estimated cropping pattern releases are required from September through to the end of December.
	Why has the base flow changed, i.e. what is the water being used for.	Used for irrigation, mostly abstracted from farm dams. Farm dams also reduce the baseflow due to evaporation losses. Also storage in the Mokolo Dam has drastically changed the baseflow.
	What (in m^3/s) is the natural range of baseflows (lowest to highest). If possible, provide for the wet season, and dry season.	
	What (in m^3/s) is the present day range of baseflows (lowest to highest). If possible, provide for the wet season, and dry season.	
MODERATE FLOODS (HIGH FLOWS)	Has the frequency of floods changed from natural?	Yes. The Mokolo Dam has reduced the frequency of small to moderate floods.
	Are the changes an increase or a decrease? If an increase, is it due to dam releases, urban runoff, or something else.	Decrease.
	Are there any changes in seasonality of the floods? And if yes, how.	Later onset of small to moderate floods.
	Why has the flooding regime changed?	Storage created by the Mokolo Dam.
LARGE FLOODS (HIGH FLOWS)	Has the frequency of floods changed from natural?	No.
	Are the changes an increase or a decrease? If an increase, is it due to dam releases, urban runoff, or something else.	Increase/Decrease.
	Are there any changes in seasonality of the floods? And if yes, how.	Yes/No.
	Why have the flooding changed?	
Have any frequency analysis of floods been undertaken and if so, what are the flood peaks (in m^3/s). E.g. 1:2 = X m^3/s etc.		No.
Any general comments or anything else one should take note of?		

APPENDIX B: INSTREAM AND RIPARIAN HABITAT INTEGRITY

Ms MD Louw, Water for Africa

B1 MOKOLO SYSTEM INSTREAM HABITAT INTEGRITY

The Instream Index of Habitat Integrity (IIHI) and the Riparian Index of Habitat Integrity (RIHI) is based on the methods outlined in Kleynhans *et al*., 2008.

B1.1 DATA AVAILABILITY

The Instream Habitat Integrity (IHI) undertaken was largely ground-based. Where high resolution Google Earth imagery was available, this was used. No recent or good quality IHI DVDs were available. The following data was used to assess the IHI:

- Personal ground-based observations.
- Local knowledge.
- Hydrological assessments.
- Water quality assessments.
- Land cover assessments (DWAF).
- Google Earth (mostly high resolution).
- Various maps.

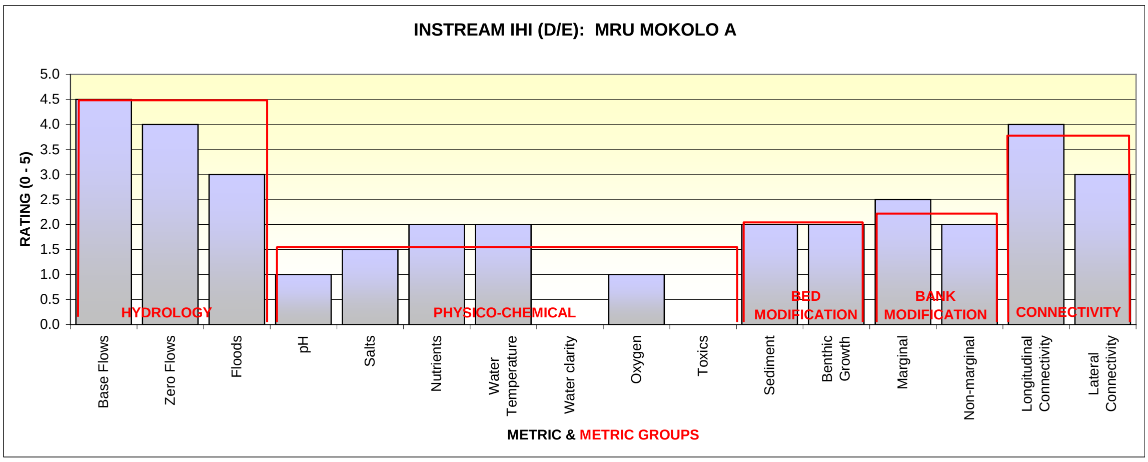
Confidence of Data = 4: The confidence in the data is high due to the systems local knowledge, high quality of Google Earth imagery available for large sections of the study area and a reconnaissance site visit was undertaken.

B1.2 REFERENCE CONDITION

Reference conditions are not explicitly described in the IHI at this stage. The model is based on an evaluation of impacts (scale and severity) and this forms the basis of the ratings supplied which measure change from natural.

B1.3 MRU MOKOLO A

The Instream and Riparian IHI results are illustrated in Figure B1 and summarised in Table B1.



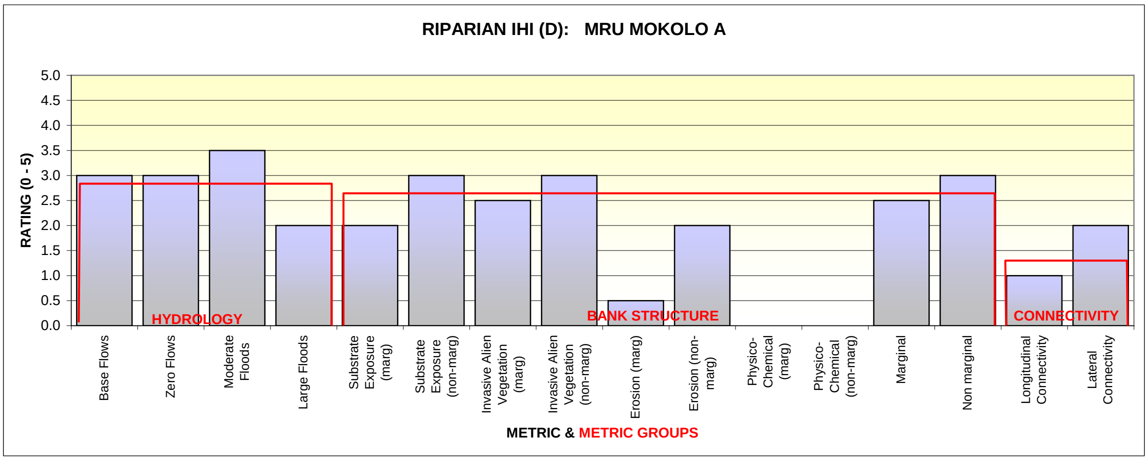


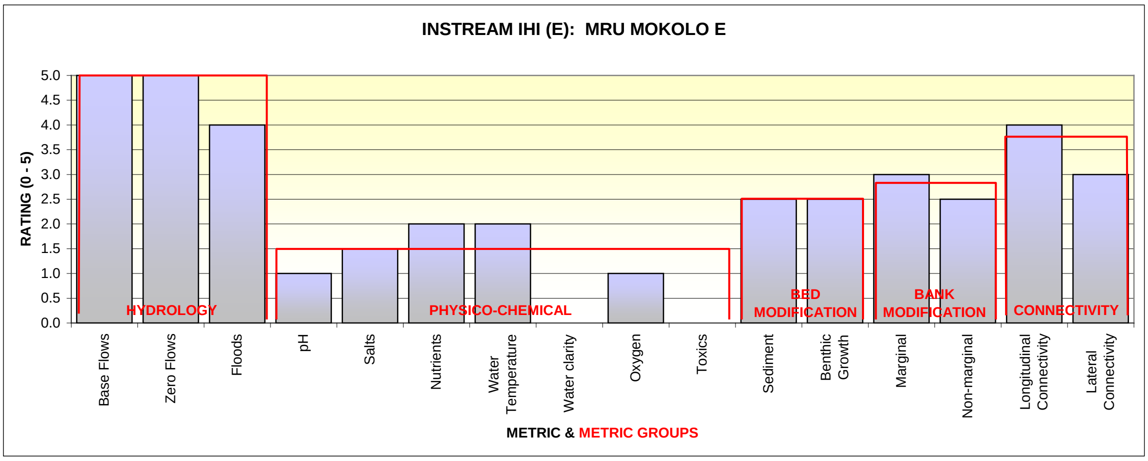
Figure B1 MRU MOKOLO A: Instream and Riparian IHI

Table B1 A summary of the causes and sources for the change in reference condition for MRU Mokolo A

PES	Causes	Sources	Flow/Non Flow related	Confidence
INSTREAM				
D/E	Abstraction and zero flow situations	Farming (farm dams)	Flow-related	3.2
	Connectivity due to zero flows (longitudinal) and small dams	Farming	Non-flow related Flow related	
RIPARIAN				
D/E	Zero flow situations	Farming activities	Flow related	3.2
	Change in floods due to number of dams in the system	Farming activities	Flow related	
	Alien vegetation	Catchment disturbance	Non-flow related	
	Exposure and removal of veg	Irrigation lands	Non-Flow-related	

B1.4 MRU MOKOLO E

The Instream and Riparian IHI results are illustrated in Figure B2 and summarised in Table B2.



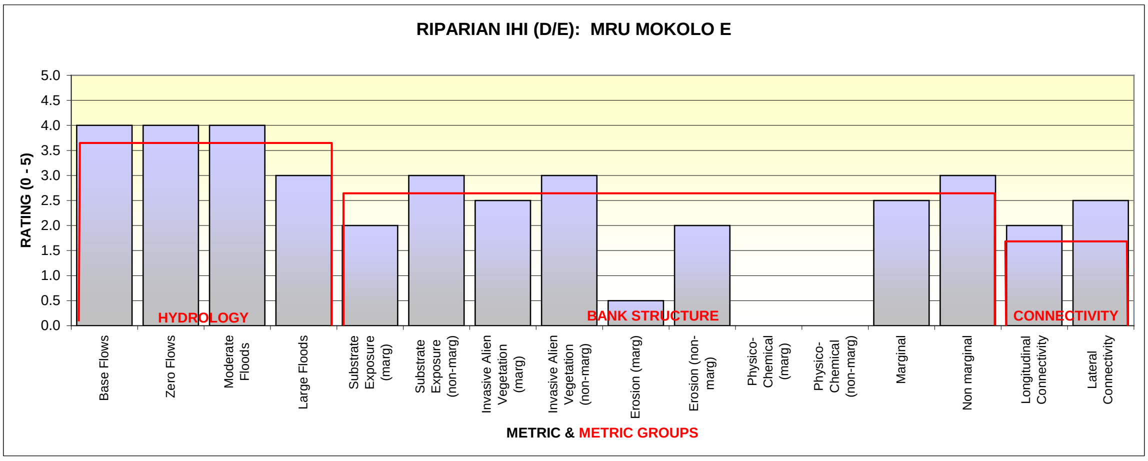


Figure B2 MRU Mokolo E: Instream and Riparian IHI

Table B2 A summary of the causes and sources for the change in reference condition for MRU E (Grootspruit)

PES	Causes	Sources	Flow/Non Flow related	Confidence
INSTREAM				
E	Abstraction and zero flow situations	Farming (farm dams)	Flow-related	3.2
	Connectivity due to zero flows (longitudinal) and many dams. Large proportion of the main river is dammed	Farming	Non-flow related Flow related	
RIPARIAN				
E	Zero flow situations	Farming activities	Flow related	3.2
	Change in floods due to number of dams in the system	Farming activities	Flow related	
	Alien vegetation	Catchment disturbance	Non-flow related	
	Exposure and removal of veg	Irrigation lands	Non-Flow-related	
	Connectivity (lateral into wetlands)	Farming activities (physical disturbance) and change in flooding regime	Non-Flow related Flow related	

B1.5 MRU MOKOLO B: EWR 1A

This reach stretches from the confluence of the Grootspruit and the Sand River to EWR 1A and falls within Mokolo MRU B. The Instream and Riparian IHI results are illustrated in Figure B3 and summarised in Table B3.

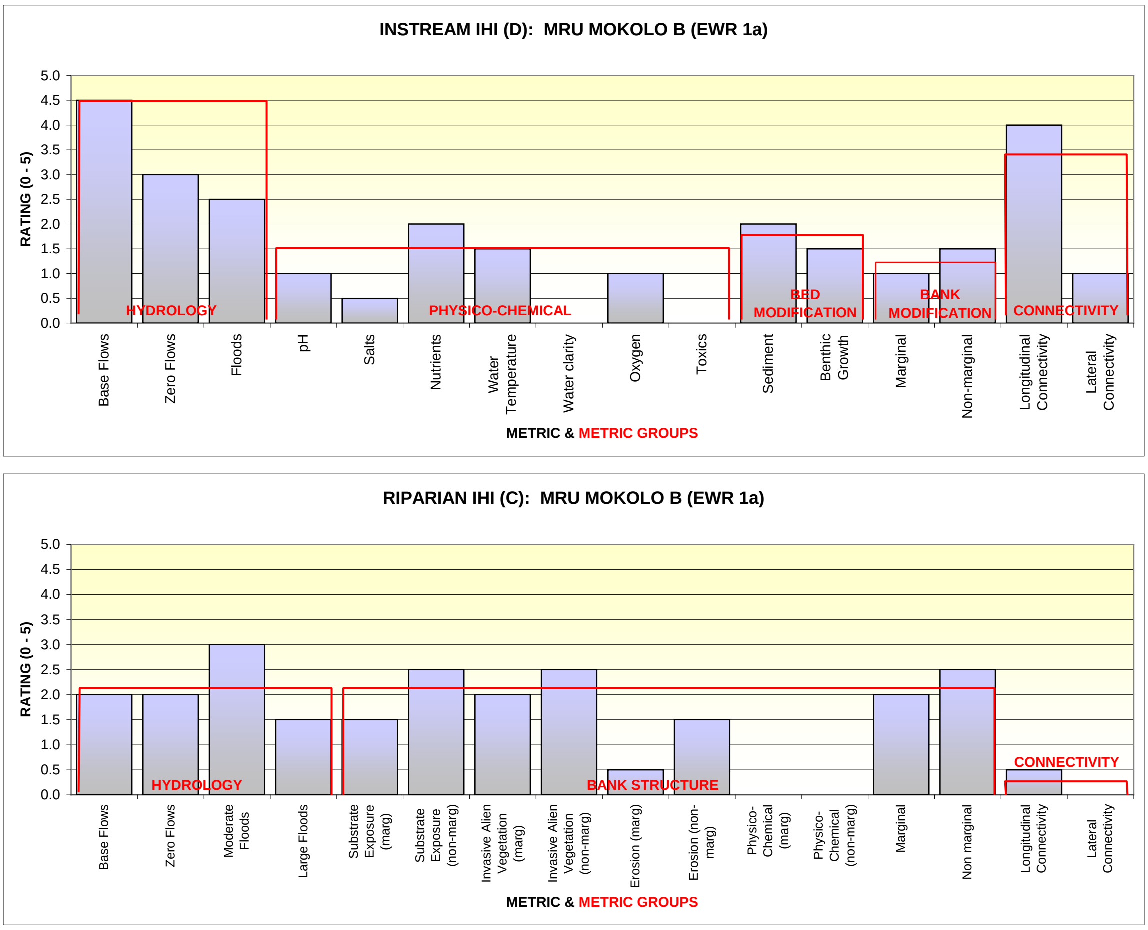


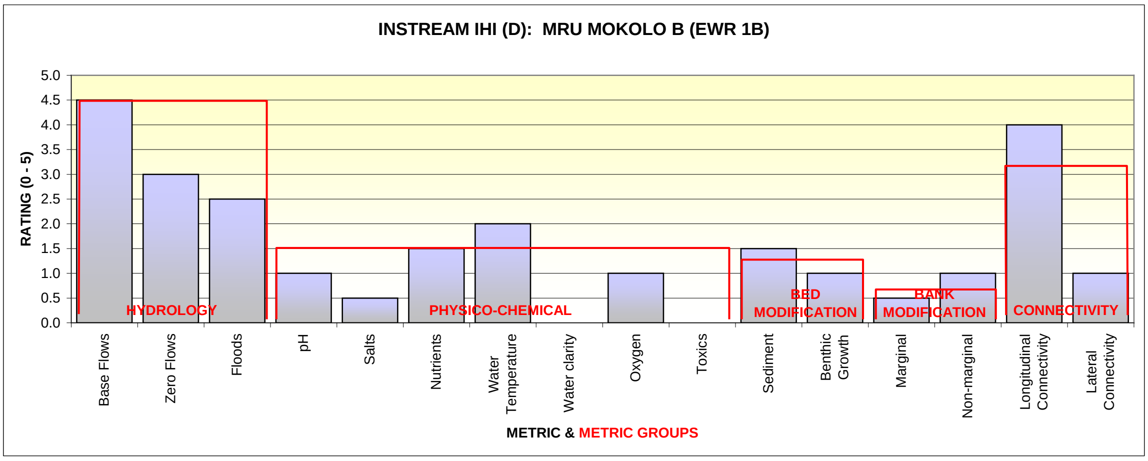
Figure B3 MRU Mokolo B (EWR 1A): Instream and Riparian IHI

Table B3 A summary of the causes and sources for the change in reference condition for EWR 1A

PES	Causes	Sources	Flow/Non Flow related	Confidence
		INSTREAM		
D	Abstraction and zero flow situations	Farming (farm dams)	Flow-related	3.2
	Connectivity due to zero flows (longitudinal) and small dams	Farming	Non-flow related Flow related	
		RIPARIAN		
C	Zero flow situations	Farming activities	Flow related	3.2
	Change in floods due to number of dams in the system	Farming activities	Flow related	
	Alien vegetation	Catchment disturbance	Non-flow related	
	Exposure and removal of veg	Irrigation lands	Non-Flow-related	

B1.6 MRU MOKOLO B: EWR 1B

This assessment is valid from EWR 1A to the Sterkstroom confluence. The Instream and Riparian IHI results are illustrated in Figure B4 and summarised in Table B4.



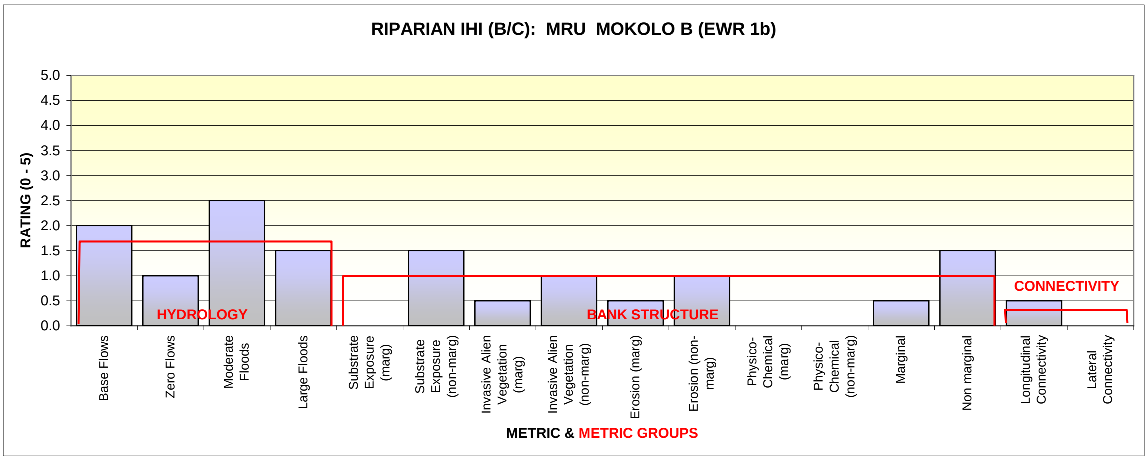


Figure B4 MRU MOKOLO B: Instream and Riparian IHI

Table B4 A summary of the causes and sources for the change in reference condition for EWR 1B

PES	Causes	Sources	Flow/Non Flow related	Confidence
INSTREAM				
D	Abstraction and zero flow situations	Farming (farm dams)	Flow-related	3.3
	Connectivity due to zero flows (longitudinal) and small dams	Farming	Non-flow related Flow related	
RIPARIAN				
B/C	Zero flow situations	Farming activities	Flow related	3.8
	Change in floods due to number of dams in the system	Farming activities	Flow related	
	Exposure and removal of veg	Irrigation lands	Non-Flow-related	

B1.7 MRU MOKOLO B.1: EWR 2

This IHI is undertaken from the confluence of the Sterk to the Mokolo Dam within MRU B. The Instream and Riparian IHI results are illustrated in Figure B6 and summarised in Table B6.

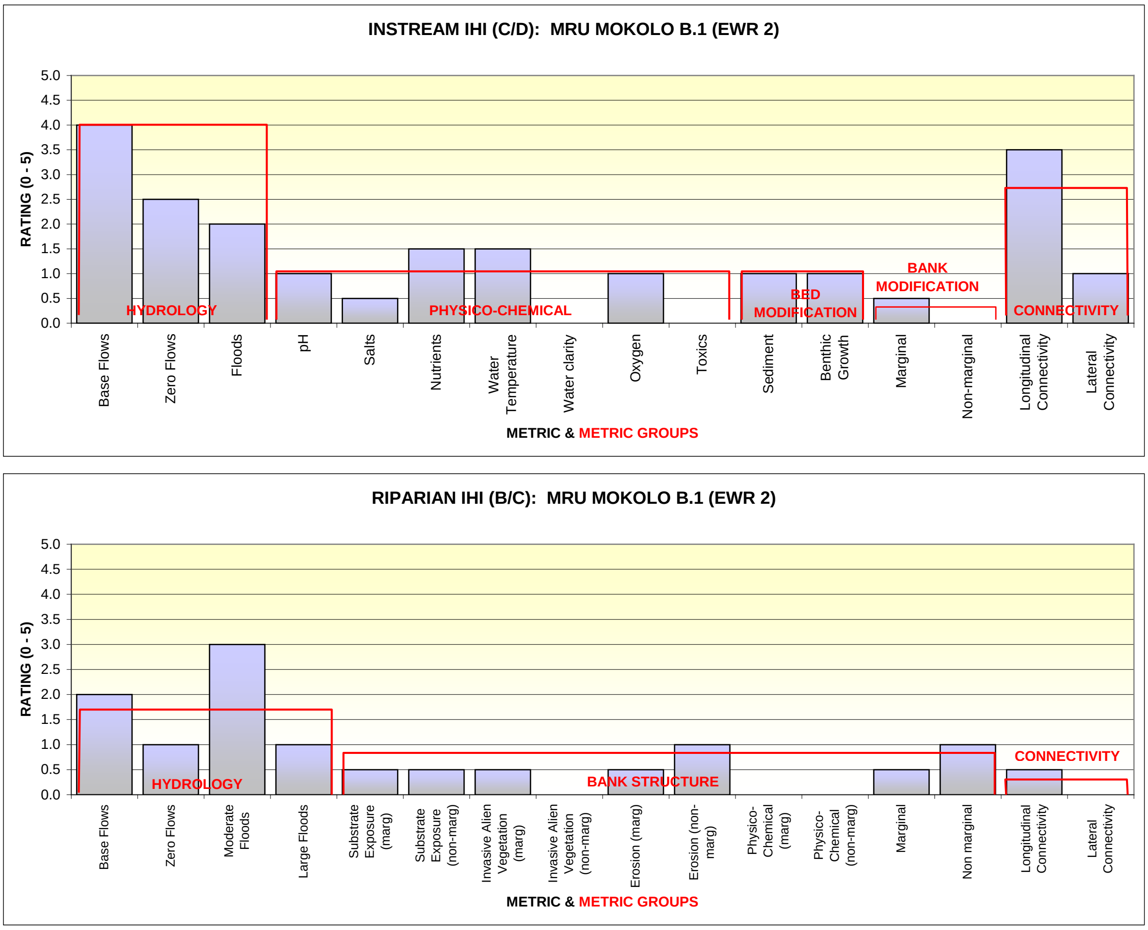


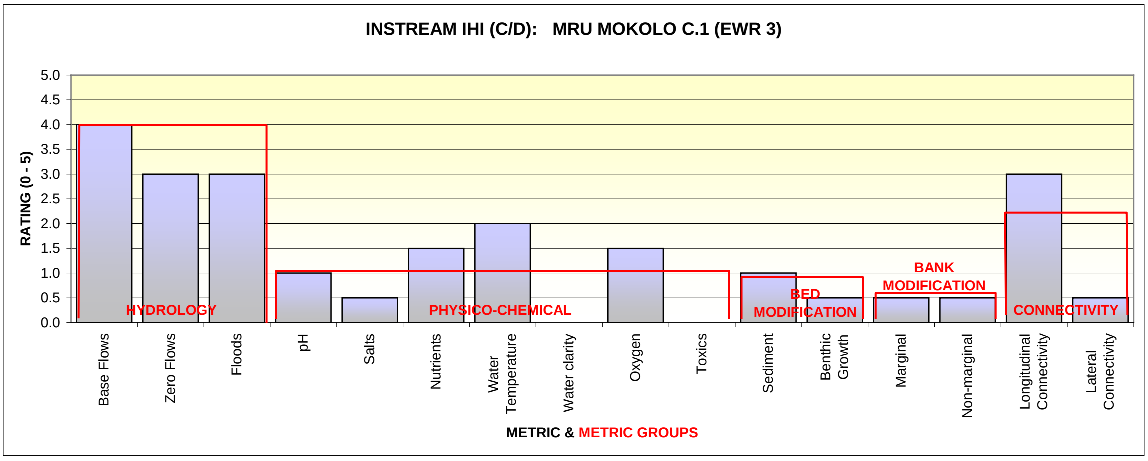
Figure B5 MRU MOKOLO B.1: Instream and Riparian IHI

Table B5 A summary of the causes and sources for the change in reference condition for EWR 2

PES	Causes	Sources	Flow/Non Flow related	Confidence
INSTREAM				
C/D	Abstraction and zero flow situations	Farming (farm dams)	Flow-related	3.5
	Connectivity due to zero flows (longitudinal) and small dams	Farming	Non-flow related Flow related	
RIPARIAN				
B/C	Zero flow situations	Farming activities	Flow related	3.3
	Change in floods due to number of dams in the system	Farming activities	Flow related	

B1.8 MRU MOKOLO C.1: EWR 3

The Instream and Riparian IHI results are illustrated in Figure B6 and summarised in Table B6.



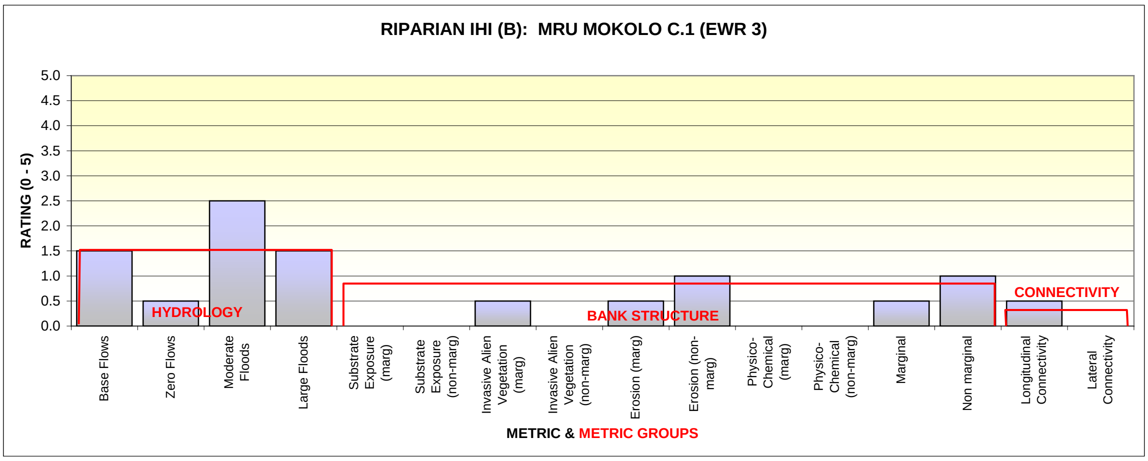


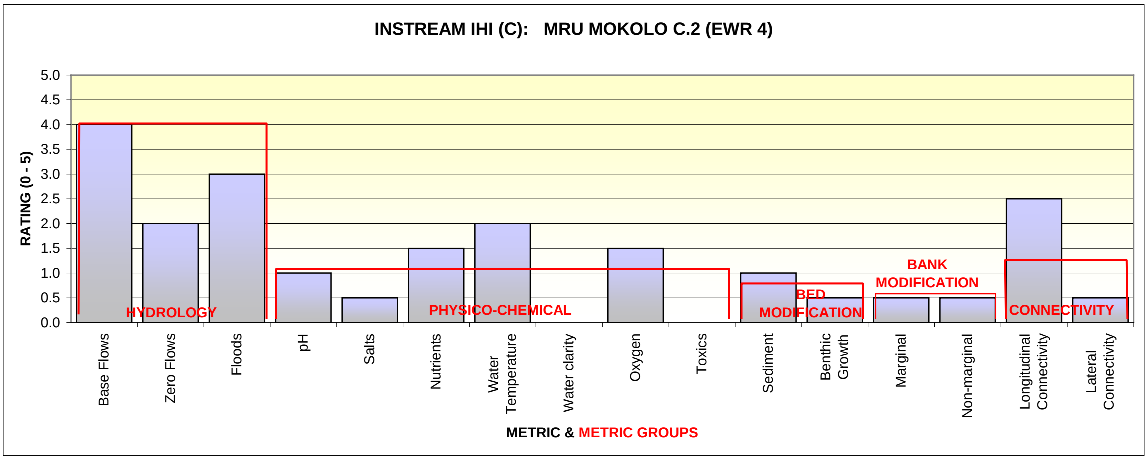
Figure B6 MRU MOKOLO C.1: Instream and Riparian IHI

Table B6 A summary of the causes and sources for the change in reference condition for EWR 3

PES	Causes	Sources	Flow/Non Flow related	Confidence
INSTREAM				
C/D	Changes in flow regime – basically zero flows, lack of floods, unseasonal releases	Mokolo Dam	Flow related	4
	Connectivity due to trickle for most of dry season	Mokolo operating releases	Flow related	
RIPARIAN				
B	Changes in the flooding regime	Mokolo Dam	Non-flow related	3.2

B1.9 MRU MOKOLO C.2: EWR 4

The Instream and Riparian IHI results are illustrated in Figure B7 and summarised in Table B7.



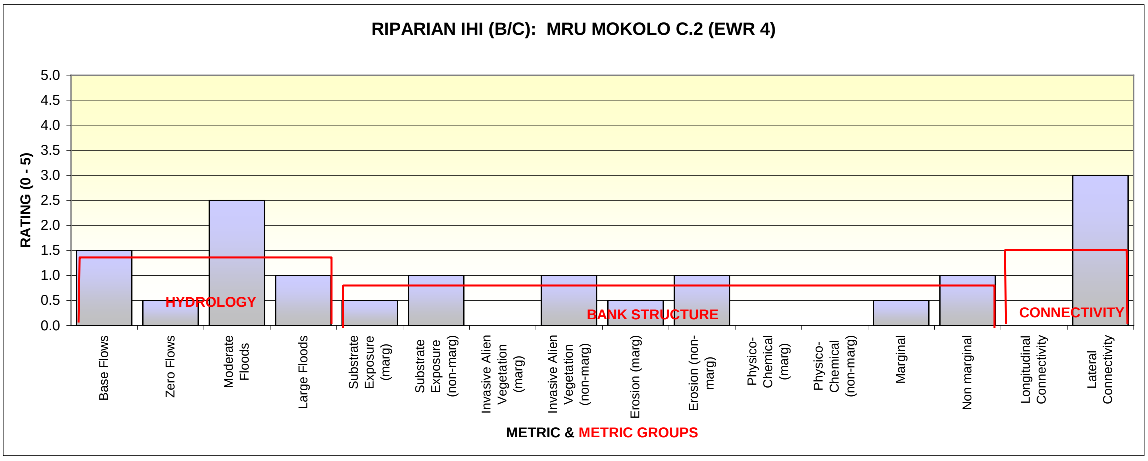


Figure B7 MRU MOKOLO C.2: Instream and Riparian IHI

Table B7 A summary of the causes and sources for the change in reference condition for EWR 4

PES	Causes	Sources	Flow/Non Flow related	Confidence
INSTREAM				
C	Changes in flow regime – basically zero flows, lack of floods, unseasonal releases	Mokolo Dam	Flow related	4
	Connectivity due to zero flows for most of dry season	Mokolo operating releases	Flow related	
RIPARIAN				
B/C	Changes in the flooding regime	Mokolo Dam	Non-flow related	3.3
	Connectivity in floodplain (changes in flooding regime)	Mokolo Dam	Flow related	

B1.10 MOKOLO RIVER INSTREAM IHI SUMMARY

The results are compared in the following tables and graphics.

Table B8 Ratings for the each MRU and EWR site – Mokolo System

INSTREAM IHI	MRU Mokolo A	MRU Mokolo E	MRU Mokolo B (EWR 1a)	MRU Mokolo B (EWR 1b)	MRU Mokolo B.1 (EWR2)	MRU Mokolo C.1 (EWR 3)	MRU Mokolo C.2 (EWR 4)
Base Flows	4.5	5.0	4.5	4.5	4.0	4.0	4.0
Zero Flows	4.0	5.0	3.0	3.0	2.5	3.0	2.0
Floods	3.0	4.0	2.5	2.5	2.0	3.0	3.0
HYDROLOGY RATING	**4.5**	**5.0**	**4.5**	**4.5**	**4.0**	**4.0**	**4.0**
pH	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Salts	1.5	1.5	0.5	0.5	0.5	0.5	0.5
Nutrients	2.0	2.0	2.0	1.5	1.5	1.5	1.5
Water Temperature	2.0	2.0	1.5	2.0	1.5	2.0	2.0
Water clarity	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oxygen	1.0	1.0	1.0	1.0	1.0	1.5	1.5
Toxics				0.0			
PC RATING	**1.5**	**1.5**	**1.5**	**1.5**	**1.0**	**1.0**	**1.0**
Sediment	2.0	2.5	2.0	1.5	1.0	1.0	1.0
Benthic Growth	2.0	2.5	1.5	1.0	1.0	0.5	0.5
BED RATING	**2.0**	**2.5**	**1.8**	**1.3**	**1.0**	**0.8**	**0.7**
Marginal	2.5	3.0	1.0	0.5	0.5	0.5	0.5
Non-marginal	2.0	2.5	1.5	1.0	0.0	0.5	0.5
BANK RATING	**2.3**	**2.8**	**1.2**	**0.7**	**0.3**	**0.5**	**0.5**
Longitudinal Connectivity	4.0	4.0	4.0	4.0	3.5	3.0	2.5
Lateral Connectivity	3.0	3.0	1.0	1.0	1.0	0.5	0.5
CONNECTIVITY RATING	**3.8**	**3.8**	**3.4**	**3.1**	**2.7**	**2.2**	**1.7**
INSTREAM IHI %	**42.0**	**36.0**	**46.7**	**51.3**	**59.7**	**61.8**	**64.2**
INSTREAM IHI EC	**D/E**	**E**	**D**	**D**	**C/D**	**C/D**	**C**
INSTREAM CONFIDENCE	**3.2**	**3.2**	**3.2**	**3.3**	**3.5**	**4.0**	**4.0**

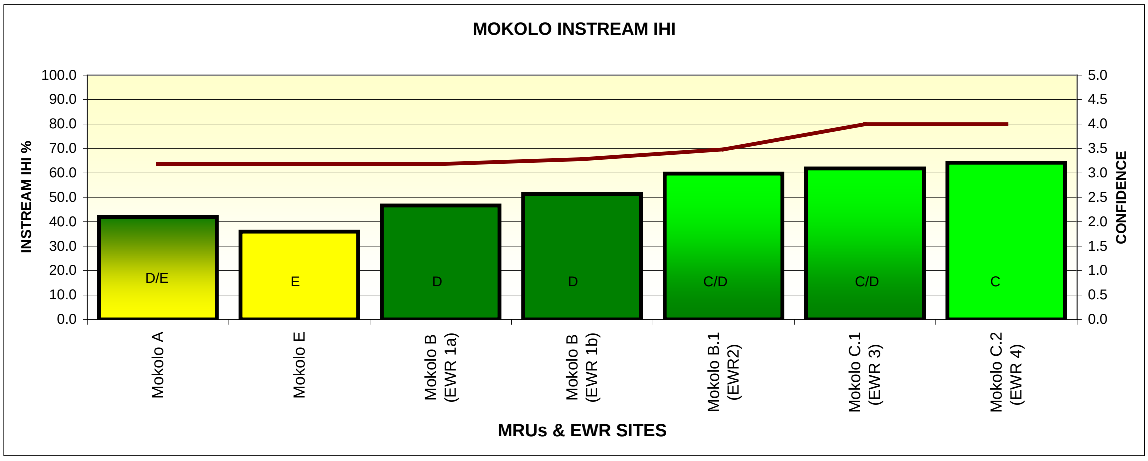


Figure B8 Summary of IHI Instream categories for the Mokolo System

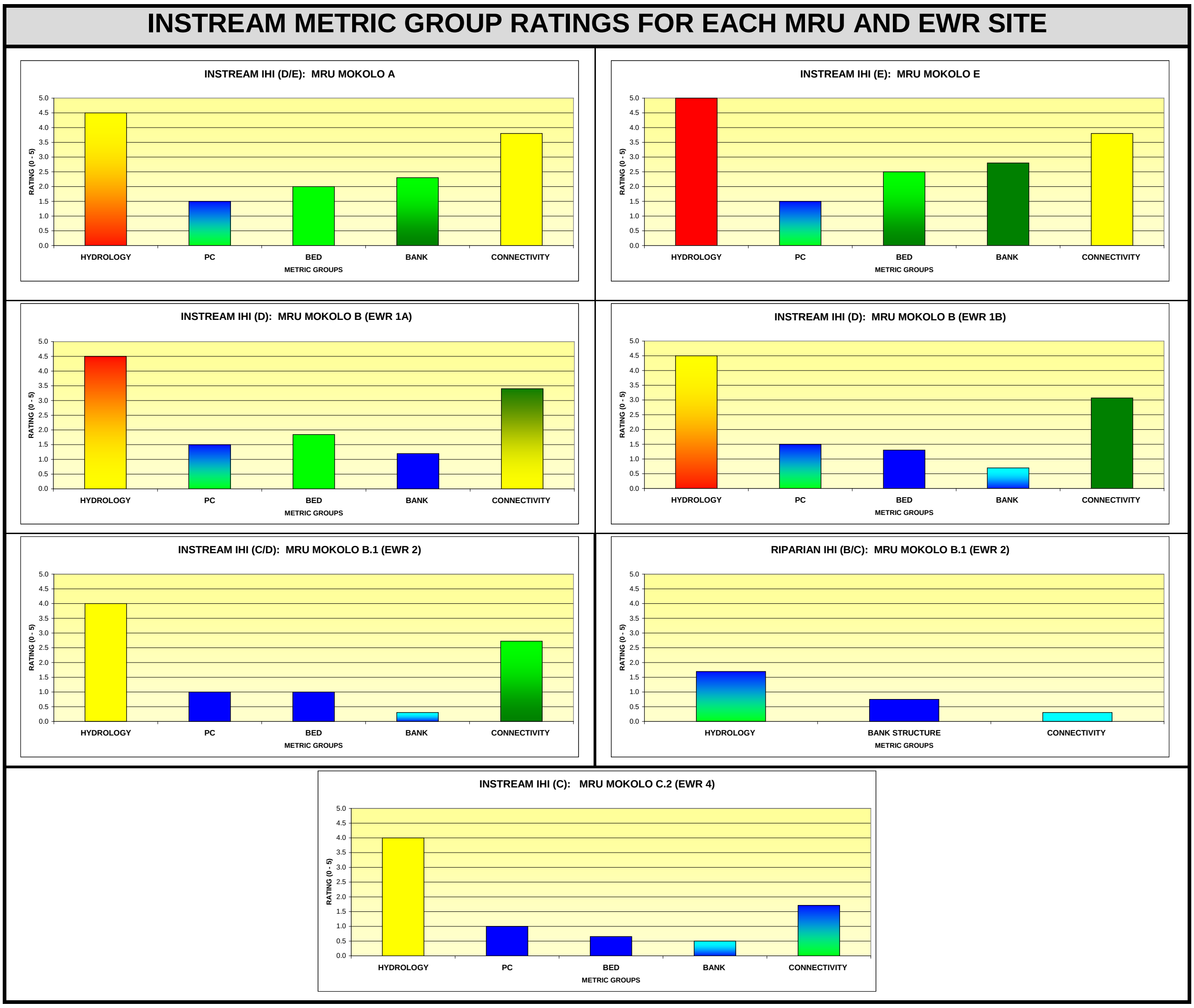


Figure B9 Instream Metric group ratings for each MRU and EWR site for the Mokolo

B1.11 MOKOLO RIVER RIPARIAN IHI SUMMARY

The results are compared in the following tables and graphics.

Table B9 Ratings for the each MRU and EWR site – Mokolo System

	MRU	MRU	MRU	MRU	MRU	MRU	MRU
RIPARIAN IHI	Mokolo A	Mokolo E	Mokolo B (EWR 1a)	Mokolo B (EWR 1b)	Mokolo B.1 (EWR2)	Mokolo C.1 (EWR 3)	Mokolo C.2 (EWR 4)
Base Flows	3.0	4.0	2.0	2.0	2.0	1.5	1.5
Zero Flows	3.0	4.0	2.0	1.0	1.0	0.5	0.5
Moderate Floods	3.5	4.0	3.0	2.5	3.0	2.5	2.5
Large Floods	2.0	3.0	1.5	1.5	1.0	1.5	1.0
HYDROLOGY RATING	**2.9**	**3.7**	**2.1**	**1.7**	**1.7**	**1.5**	**1.4**
Substrate Exposure (marg)	2.0	2.0	1.5	0.0	0.5	0.0	0.5
Substrate Exposure (non-marg)	3.0	3.0	2.5	1.5	0.5	0.0	1.0
Invasive Alien Vegetation (marg)	2.5	2.5	2.0	0.5	0.5	0.5	0.0
Invasive Alien Vegetation (non-marg)	3.0	3.0	2.5	1.0	0.0	0.0	1.0
Erosion (marg)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Erosion (non-marg)	2.0	2.0	1.5	1.0	1.0	1.0	1.0
Physico-Chemical (marg)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Physico-Chemical (non-marg)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marginal	2.5	2.5	2.0	0.5	0.5	0.5	0.5
Non marginal	3.0	3.0	2.5	1.5	1.0	1.0	1.0
BANK STRUCTURE RATING	**2.7**	**2.7**	**2.2**	**1.0**	**0.8**	**0.8**	**0.8**
Longitudinal Connectivity	1.0	2.0	0.5	0.5	0.5	0.5	0.0
Lateral Connectivity	2.0	2.5	0.0	0.0	0.0	0.0	3.0
CONNECTIVITY RATING	**1.3**	**2.2**	**0.3**	**0.3**	**0.3**	**0.3**	**1.5**
RIPARIAN IHI %	**51.1**	**41.5**	**64.9**	**78.3**	**80.7**	**82.1**	**77.5**
RIPARIAN IHI EC	**D**	**D/E**	**C**	**B/C**	**B/C**	**B**	**B/C**
RIPARIAN CONFIDENCE	**3.2**	**3.2**	**3.2**	**3.8**	**3.3**	**3.3**	**3.3**

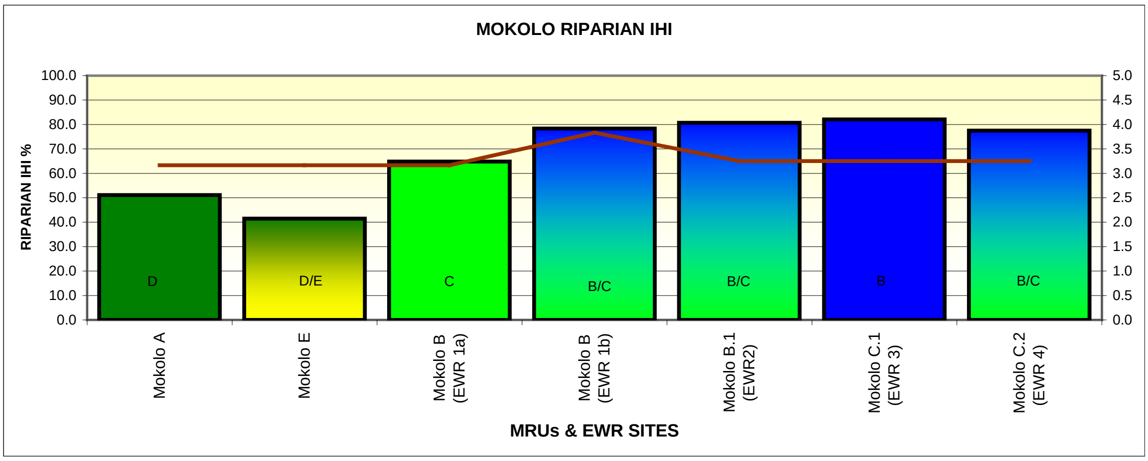


Figure B10 Summary of IHI Riparian categories

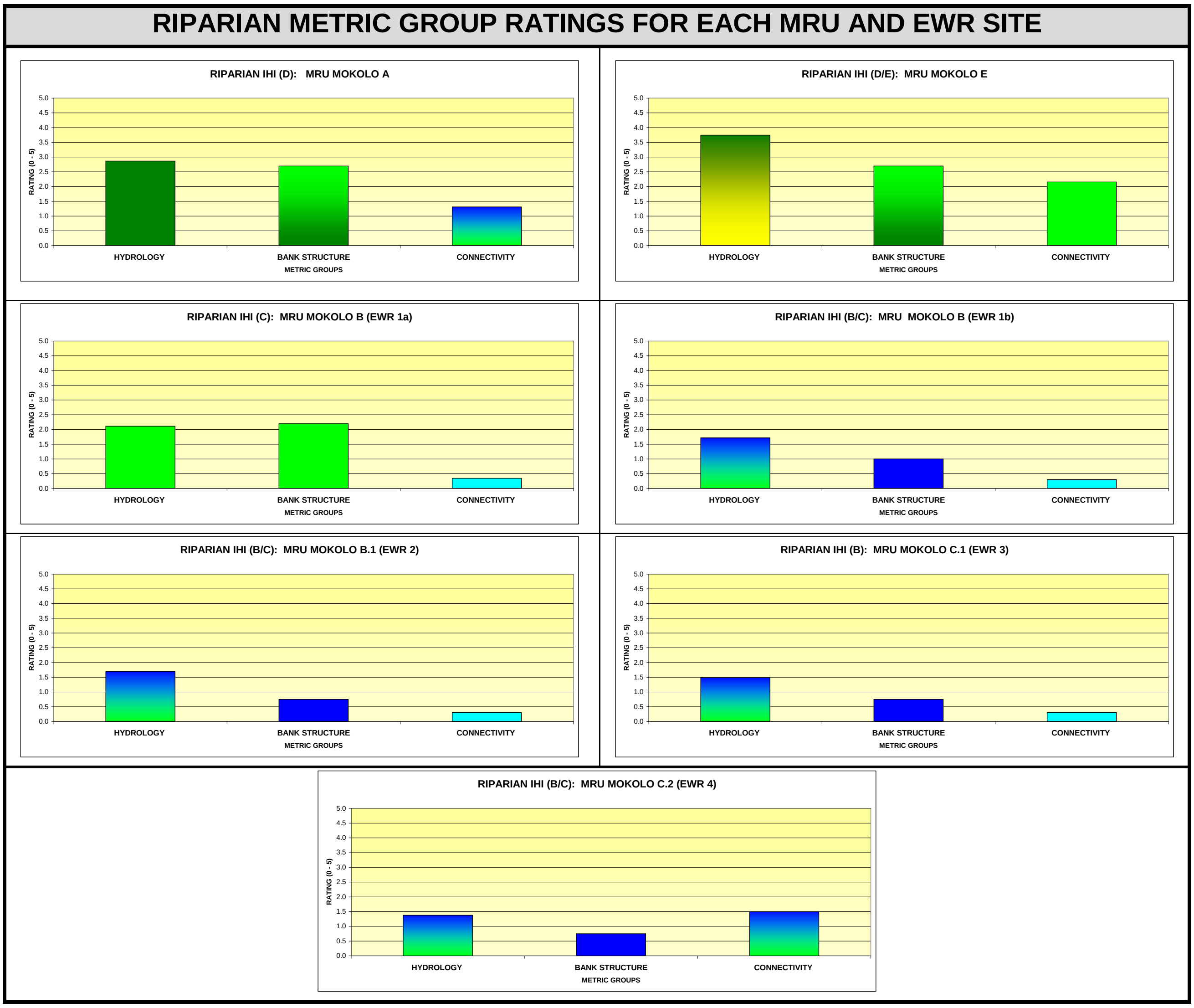


Figure B11 Riparian Metric group ratings for each MRU and EWR site

B2 REFERENCES

Kleynhans, C.J., Louw, M.D., and Graham, M. 2008. 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. TT 377-08.

APPENDIX C: GEOMORPHOLOGY

M Rountree, Fluvius Environmental Consultants

C1 EWR 1A: VAALWATER

C1.1 DATA AVAILABILITY

Data availability	Conf
Historical aerial photography (1949, 1956, 1965, 1984). Google Earth imagery of the site and catchment.	4

C1.2 REFERENCE CONDITIONS

Reference conditions	Conf
Under reference conditions there would have been less vegetation and a sandier macro-channel floor.	3

C1.3 PRESENT ECOLOGICAL STATE

C1.3.1 Site suitability

Morphology of the site	Braided section of the river (up- and downstream), although cross-section is primarily through a single thread section of the river. Site condition is very poor (localized disturbance, bank engineering) but the reach is better. Historically a braided (multiple-channel) reach which had a more open (i.e. less well vegetated) macro-channel floor than currently.		
PES	C (66.6 %)	**Confidence**	4

C1.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
C	4	Transport Capacity – moderate floods are slightly reduced; baseflows reduced.	Numerous farm dams; irrigation and abstractions.	F	3
		System connectivity.	Numerous weirs along the river; many farm dams in the tributaries.	NF	
		Sediment Supply – slight change in supply.	Sediment trapped in small farm dams; but compensated through erosion/increased sediment supplied from agricultural areas along the river.		

C1.4 TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C	Negative	C/D	5 years	Site and reach are continuing to adjust to the reduced flows.	2.5

C1.5 REC: B/C

PES	REC	Comments	Conf
C	C	With a higher baseflow, there will be some stabilisation of the active channel and associated marginal vegetation. This will promote scour of the channel and improve instream conditions. However this will not be sufficient to improve the condition of the geomorphology to a higher EC. The EC under this scenario will be a higher C category.	N/A

C1.6 AEC: C/D

PES	AEC	Comments	Conf
C	D	A reduction in scour and activation of the channel bed, and the activation of the seasonal channels and riparian areas will be reduced.	2

C2 EWR 1B: TOBACCO

C2.1 DATA AVAILABILITY

Data availability	Conf
Historical aerial photographs from Land Surveyors Offices. Google Earth imagery of the site and catchment. Information from the field assessment.	4

C2.2 REFERENCE CONDITIONS

Reference conditions	Conf
Reference state would have been a larger channel as higher flows would have been experienced. The bedrock nature of the site indicates that this site is extremely resistant to flow changes.	3

C2.3 PRESENT ECOLOGICAL STATE

C2.3.1 Site suitability

This provides an assessment of the suitability of the site for EWR determination studies	SCORES: 5	2	1	SCORE	Notes
Representivity of the site for the reach				4.0	
How well does the *morphology* of the site represent that of the reach?	Very well	Don't know	Poorly	4.0	
To what extent is the *condition* of the site representative of the general condition of the reach?	Representative	Don't know	Very different	4.0	
Morphological Cues				1.7	Bedrock influenced pool riffle reach. No terraces or benches which can be used for morphological cues.
Is the site a bedrock or alluvial dominated section?	Alluvial	Mixed	Bedrock	3.0	
Are there good morphological clues that can be related to flood levels?	Very good	Don't know	Bad	1.0	
If these are present, are the terraces paired?	Yes	Don't know	No	1.0	
Sediment Transport Modelling				4.0	Bedload system, and rapid PBMT modelling will be undertaken.
Is the river a bedload dominated system (i.e. is potential bed material tranpsort modelling suitable)	Yes	Don't know	No	4.0	
Is potential bed material transport modelling going to be undertaken at this site?	Yes	Don't know	No	4.0	
OVERALL SCORE:				**2.8**	

Morphology of the site	The bedrock influence of the site makes it very resistant to flow changes. Sediment has likely increased due to reduced flows/small floods.		
PES	C (74.63%)	**Confidence**	3.5

C2.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
C	3.5	Transport capacity – moderate floods are slightly reduced; baseflows seriously reduced.	Farm dams and irrigation abstractions have reduced flows.	F	3
		System connectivity.	Numerous weirs along the river; farm dams in the tributaries.	NF	
		Slight change in sediment supply.	Trapped in small farm dams; but compensated through erosion/increased sediment supplied from agricultural areas along the river.		

C2.4 TREND

PES	Trend	Trend PES	Time	Reasons	Conf
B/C	Stable	B/C		The site is bedrock controlled, so very non-responsive to flows changes.	2.5

C2.5 REC: B

PES	REC	Comments	Conf
C	B/C	This scenario will provide an opportunity for the bed sediments to be scoured, increasing mobility and interstitial spaces. This will promote scour of the channel and improve the instream condition, and will be sufficient to improve the condition of the geomorphology to a B/C EC.	2

C2.6 AEC: C/D

PES	AEC	Comments	Conf
C	C/D	The impact upon the morphology will be to further reduce scour and activation of the channel bed, and reduce activation of the seasonal channels and riparian areas.	2

C3 EWR 2: KA'INGO

C3.1 DATA AVAILABILITY

Data availability	Conf
Historical aerial photographs from Land Surveyors Offices. Google Earth imagery of the site and catchment. Information from the field assessment.	4

C3.2 REFERENCE CONDITIONS

Reference conditions	Conf
The current condition is fairly close to reference - fixed boulder and bedrock with cobbles and a fine sand component. The fines are likely to be a very important component of the bedload, given the consequences of accumulation (and loss of interstitial spaces) for biota.	3

C3.3 PRESENT ECOLOGICAL STATE

C3.3.1 Site suitability

This provides an assessment of the suitability of the site for EWR determination studies					Notes
	SCORES: 5	2	1	SCORE	
Representivity of the site for the reach				**4.0**	
How well does the *morphology* of the site represent that of the reach?	Very well	Don't know	Poorly	4.0	
To what extent is the *condition* of the site representative of the general condition of the reach?	Representative	Don't know	Very different	4.0	
Morphological Cues				**1.5**	Bedrock influenced pool riffle reach. No terraces or benches which can be used for morphological cues.
Is the site a bedrock or alluvial dominated section?	Alluvial	Mixed	Bedrock	2.5	
Are there good morphological clues that can be related to flood levels?	Very good	Don't know	Bad	1.0	
If these are present, are the terraces paired?	Yes	Don't know	No	1.0	
Sediment Transport Modelling				**5.0**	Bedload system, and rapid PBMT modelling will be undertaken.
Is the river a bedload dominated system (i.e. is potential bed material tranpsort modelling suitable)	Yes	Don't know	No	5.0	
Is potential bed material transport modelling going to be undertaken at this site?	Yes	Don't know	No	5.0	
OVERALL SCORE:				**3.0**	

Site description	Site is in a very good condition. The hydrology is heavily affected by low and zero flows, but the bedrock nature of this site is not sensitive to these changes.		
Morphology of the site	Bedrock pool-rapid site with fixed boulder and bedrock and cobbles, as well as a fine sand component.		
PES	B/C (79 %)	**Confidence**	3.5

C3.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
B/C	3.5	Transport capacity – moderate floods are slightly reduced while baseflows are seriously reduced.	Large flood events are considered to be unimpacted, but the moderate floods are reduced due to the headwater tributary dams. At this site, amelioration from other tributaries, and the larger catchment, has reduced this impact.	F	3
		System connectivity.	A few weirs along the river; and farm dams in the tributaries.	NF	
		Slight change in sediment supply.	Trapped in small farm dams; but increasingly compensated through erosion/increased sediment supplied from agricultural areas along the river.		

C3.4 TREND

PES	Trend	Trend PES	Time	Reasons	Conf
B/C	Stable	B/C		The site is bedrock controlled, and therefore very insensitive to flows changes.	2.5

C3.5 REC: B

PES	REC	Comments	Conf
B/C	B	This scenario will offer an opportunity for the bed sediments to be scoured, maintaining mobility and interstitial spaces. This will be sufficient to improve the condition of the geomorphology to a B EC from the current B/C category.	2

C3.6 AEC: C/D

PES	AEC	Comments	Conf
B/C	C	The impact upon the morphology will be to further reduce scour and activation of the channel bed, and reduce activation of the seasonal channels and riparian areas. This will lead to some embeddedness of the bed sediment and reduction of the size of the channel.	2

C4 EWR 3: GORGE

C4.1 DATA AVAILABILITY

Data availability	Conf
Historical aerial photographs from Land Surveyors Offices. Google Earth imagery of the site and catchment. Information from the field assessment.	4

C4.2 REFERENCE CONDITIONS

Reference conditions	Conf
The gross morphology is fairly close to reference condition, because the bedrock nature of the river within this gorge section has very little capacity for adjustment. The bed of the channel would have been composed of bedrock, fixed boulders and cobbles with highly mobile sand component.	3

C4.3 PRESENT ECOLOGICAL STATE

C4.3.1 Site suitability

This provides an assessment of the suitability of the site for EWR determination studies					Notes
	SCORES: 5	2	1	SCORE	
Representivity of the site for the reach				5.0	
How well does the *morphology* of the site represent that of the reach?	Very well	Don't know	Poorly	5.0	
To what extent is the *condition* of the site representative of the general condition of the reach?	Representative	Don't know	Very different	5.0	
Morphological Cues				1.3	Bedrock influenced pool riffle reach. No terraces or benches which can be used for morphological cues.
Is the site a bedrock or alluvial dominated section?	Alluvial	Mixed	Bedrock	2.0	
Are there good morphological clues that can be related to flood levels?	Very good	Don't know	Bad	1.0	
If these are present, are the terraces paired?	Yes	Don't know	No	1.0	
Sediment Transport Modelling				5.0	Bedload system, and rapid PBMT modelling will be undertaken.
Is the river a bedload dominated system (i.e. is potential bed material tranpsort modelling suitable)	Yes	Don't know	No	5.0	
Is potential bed material transport modelling going to be undertaken at this site?	Yes	Don't know	No	5.0	
OVERALL SCORE:				**3.2**	

Site description	The site is located immediately below the Mokolo Dam, and the site represents the gorge section of the river between the dam and EWR 4.		
Morphology of the site	The site is a bedrock pool-rapid site with fixed boulder and bedrock and cobbles, as well as a sand component. There are no alluvial terraces or benches at the site. Due to the dam cutting off the sediments upstream, the bed is armouring (fines scoured out, remaining only below the larger cobbles.		
PES	C (68 %)	**Confidence**	3.5

C4.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
C	3.5	Transport capacity – small floods are slightly reduced; while baseflows seriously reduced.	Large flood events are considered to be unimpacted, but the moderate floods are much reduced due to the Mokolo Dam. There are no tributaries and thus no opportunity for amelioration of the dam's impact.	F	3
		System connectivity.	The large Mokolo Dam is located immediately upstream of the site.	NF	

PES	Conf	Causes	Sources	F/NF	Conf
		Sediment supply is effectively cut off.	The Mokolo Dam cuts off all bedload supply, and there is little opportunity for replenishment as the tributaries are extremely small.		

C4.4 TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C	Negative	C		The site is bedrock controlled, and therefore very unresponsive to flow changes, but the continual loss of fines and subsequent armouring of the bed will continue to result in a coarsening of the site.	2.5

C4.5 REC: B

PES	REC	Comments	Conf
C	C	This scenario will offer an opportunity for the bed sediments to be scoured, maintaining mobility and interstitial spaces. However, as there is no opportunity to replenish the sediment supply which has been cut off by the dam, EC improvement will be within the C category.	N/A

C4.6 AEC: C/D

PES	AEC	Comments	Conf
C	C/D	The impact upon the morphology will be to further reduce scour and activation of the channel bed, and increase armouring and embeddedness.	2

C5 EWR 4: MALALATAU

C5.1 DATA AVAILABILITY

Data availability	Conf
Historical aerial photographs from Land Surveyors Offices. Google Earth imagery of the site and catchment. Information from the field assessment.	4

C5.2 REFERENCE CONDITIONS

Reference conditions	Conf
This site is an alluvial lowland river which has a floodplain adjacent to the channel. Where the tributaries flow on to the floodplain, there are usually wetland areas which develop in the depressions between the edge of the floodplain and the higher levee of the riparian zone along the main channel.	3

C5.3 PRESENT ECOLOGICAL STATE

C5.3.1 Site suitability

This provides an assessment of the suitability of the site for EWR determination studies	SCORES: 5	2	1	SCORE	Notes
Representivity of the site for the reach				**3.8**	
How well does the *morphology* of the site represent that of the reach?	Very well	Don't know	Poorly	3.5	Site is as the river exists the gorge - fairly representative, although still somewhat constrained. Coindition is slightly better than the downstream reach.
To what extent is the *condition* of the site representative of the general condition of the reach?	Representative	Don't know	Very different	4.0	
Morphological Cues				**3.0**	
Is the site a bedrock or alluvial dominated section?	Alluvial	Mixed	Bedrock	5.0	Bedrock influenced pool riffle reach. No terraces or benches which can be used for morphological cues.
Are there good morphological clues that can be related to flood levels?	Very good	Don't know	Bad	3.0	
If these are present, are the terraces paired?	Yes	Don't know	No	1.0	
Sediment Transport Modelling				**4.7**	
Is the river a bedload dominated system (i.e. is potential bed material tranpsort modelling suitable)	Yes	Don't know	No	4.0	Bedload system (but net depositional). Rapid PBMT modelling will be undertaken.
Is potential bed material transport modelling going to be undertaken at this site?	Yes	Don't know	No	5.0	
OVERALL SCORE:				**3.6**	

Site description	The site is located at the upstream end of the floodplain section of the river, as the river flows out from the gorge section.		
Morphology of the site	The site is an alluvial floodplain area, although the channel is not meandering across the entire floodplain. Wetland areas are present. Due to the dam cutting off the sediments upstream, the bed is armouring and there is likely to be an increase in gravels as the bed coarsens.		
PES	C/D (61.46%)	**Confidence**	3

C5.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
C/D	3.5	Transport capacity – small floods are slightly reduced; while baseflows seriously reduced.	Large flood events are considered to be unimpacted, but the moderate floods are much reduced due to the Mokolo Dam. There are no tributaries and thus no opportunity for amelioration of the dam's impact.	F	3
		System connectivity.	The large Mokolo Dam is located immediately upstream of the site.	NF	

PES	Conf	Causes	Sources	F/NF	Conf
		Sediment supply is effectively cut off.	The Mokolo Dam cuts off all bedload supply, and there is little opportunity for replenishment as the tributaries are extremely small.		

C5.4 TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C/D	Negative	D	5-10 years	The site is alluvial and highly sensitive to the reduced sediment supply which has been caused by the Mokolo Dam. Removal of fines from the site will increase the proportion of gravels instream, and continue to cause incision of the channel.	2

C5.5 REC: B

PES	REC	Comments	Conf
C/D	C	It is not possible to stop or reverse the process of incision, since this is due to the reduced sediment supply, and exacerbated by the in-channel sand mining which is occurring in the reach. This scenario will offer an opportunity for the bed sediments to be scoured, maintaining mobility of the bed and interstitial spaces where gravels occur. However, as there is no opportunity to replenish the sediment supply which has been cut off by the Mokolo dam, the incision of the channel will continue, and may accelerate due to the increased floods. Improvement in condition is thus not likely to be large.	2

C5.6 AEC: C/D

PES	AEC	Comments	Conf
C/D	D	The impact upon the morphology will be to decrease channel bed activation and thus increase armouring and embeddedness, but possibly slow the rate of incision.	2

APPENDIX D: PHYSICO-CHEMICAL VARIABLES

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D1 INTRODUCTION

D1.1 CATCHMENT CONTEXT

The Mokolo River Catchment covers 8 387 km^2, stretching from the Waterberg Mountains through the upper reaches of the Sand River to its confluence with the Limpopo River. A number of tributaries are present in the catchment, e.g. the Tambotie River, Poer-se-Loop and the Rietspruit, with the topography of the area being relatively flat, i.e. 900 – 922 mamsl. The largest water user, particularly in the upper catchment, is agriculture, with crops such as tobacco, maize, sunflower, vegetables and fruit predominating. Approximately 87% of the present water use in the catchment is therefore taken up by agricultural activities along the Mokolo River, with the remaining 13% being committed to industry, mining, power generation and domestic water supply. The sub-catchment has very unreliable supplies of water and there seems to be little opportunity for expansion of the irrigated areas without the importation of additional water supplies (Midgley *et al*., 1999).

There are only two mining concerns in this sub-catchment (Ashton *et al.*, 2001), with large water users in this mining/industry sector including the Matimba Power Station and Kumba Resources' Grootgeluk coal mine, both situated outside Lephalale. Matimba is the world's largest dry cooling power station and Grootgeluk the largest coal mine in the country (Van Vuuren, 2006).

Name of mine	Commodity mined	Status	Relative size	Probable impact
Grootgeluk	Coal	Operating	Very large	Medium
Steenbokpan	Phosphate	Prospecting	Very small	Very low

All of the towns and settlements in the sub-catchment rely on water supplied from the water supply impoundments, from run-of-river abstraction points and, occasionally (in the lower reaches) from local boreholes. A few informal settlements have sprung up around the periphery of the minor towns in the sub-catchment. These settlements lack access to basic services such as clean water supplies and suitable sanitation systems. In addition, the large numbers of subsistence farmers in the north-eastern portion of the sub-catchment have to rely on boreholes and hand-dug wells for water supply (Ashton *et al.*, 2001).

Water uses and users were categorised during the water quality planning stage of the Water Resource Planning Systems project, as follows:

- Ecological Requirements
- Basic Human Needs
- Domestic use
- Agriculture - Stock watering
- Agriculture- Irrigation (i.e. including the tobacco farming located in quaternary drainage region A42J)
- Industrial - Category - 1 (including power generation)
- Industrial - Category - 3 (including the mining sector)
- Recreation - Full contact, intermediate, and non- contact

This categorization was done by reviewing the Internal Strategic Perspective (ISP) document produced for DWAF in 2004 and the Water Resource Management System (WARMS) database, discussions held with the Regional Office staff and site visits.

D1.1.1 Land cover

The following land cover information is taken from the Delineation Report for the study (DWAF, 2008a), and describes the land cover within the 500m buffer zone alongside the river.

- A42A (upper catchment): Dominated by natural thicket, bushland and bush clumps, with the second most predominant land use consisting of cultivated temporary commercial dryland. Land-use is extensively agricultural, with vegetable and fruit farming predominating.
- A42B and A42C: Dominated by natural woodland, degraded forest and woodland, natural thicket, bushland and bush clumps, woodland as well as cultivated temporary commercial dryland.
- A42D: This quaternary catchment is still in a minimally modified condition, with the predominant land use feature consisting of natural thicket, bushland and bush clumps as well as woodland.
- A42E: Land cover consists primarily of natural thicket, bushland, bush clumps and woodland, as well as degraded forest and woodland.
- Quaternary catchments A42F, A42G, A42H and A42J are still in a minimally modified condition, with the predominant land use feature consisting of natural thicket, bushland and bush clumps as well as woodland with modified land use consisting predominantly of cultivated temporary commercial dryland.

Plantation forestry is very limited in the Limpopo Water Management Area (WMA) and as a land use covers only a very small portion of the total surface area of the WMA. Irrigation takes place mostly upstream of Mokolo Dam (DWAF, 2004a), where farmers are reliant on farm dams, thus effectively moving much of the yield of the Mokolo Dam upstream where it is used to irrigate large areas. Surface water quality is fairly good upstream of Mokolo Dam. This dam was built in the 1970s primarily to serve the power station, and now also supplies the coal mine, downstream farmers and Lephalale.

D1.1.2 Water quality

Groundwater quality in much of the Mokolo area is generally poor due to the coal and gas fields and cannot be used for domestic use, although surface water quality is generally good (DWAF, 2004a). Coal mining activities are expected to impact on the surface water quality of the Mokolo catchment, although little data is available downstream of the Grootgeluk mine. These impacts would most likely be localized and consist almost entirely of minor acid mine drainage linked to the oxidation of pyrite in the coal (Ashton *et al.*, 2001). The following list indicates risk sources for surface and groundwater contamination (including submerged sediments) from mining and mineral processing operations. The extent of the impact is largely related to the types and persistence of pollutants in mine discharges (Pulles *et al.*, 1996).

- Underground stopes
- Surface rock and sand dumps

- Slimes dams and delivery pipelines
- Coal discard dumps
- Coal fines
- Rehabilitated opencast pits
- Plant areas
- Explosives residues

Pulles *et al.* (1996) identified the following sources of water pollution from South African coal and gold mines that are difficult to eliminate cost-effectively:

- Acidic saline conditions with mobilized dissolved metals and nutrient enrichment caused by pyrite oxidation and blasting residues
- Eutrophication, pH fluctuations and decreased oxygen content caused by sewage discharges
- Cyanide and radionuclide contamination of gold mine seepage water

The rapid and uncontrolled growth of informal settlements around Vaalwater and Alma may also impact on surface and groundwater quality in this area, but there is little evidence of impacts on surface water at present. The following activities can be expected to have an impact on water resources in the sub-catchment (DWAF, 2004a):

- Landfills and solid waste disposal sites at towns.
- Disposal of liquid (domestic) effluent at all towns.
- Minor volumes of urban runoff from towns.
- Seepage / discharge of cooling water from Matimba Power Station.
- Non-point domestic effluent from numerous small settlements and farms.
- Minor non-point impact from non-intensive commercial or subsistence agriculture.
- Non-point impacts of agricultural return flows from intensive irrigation areas.
- Litter and domestic garbage discarded alongside the roads.

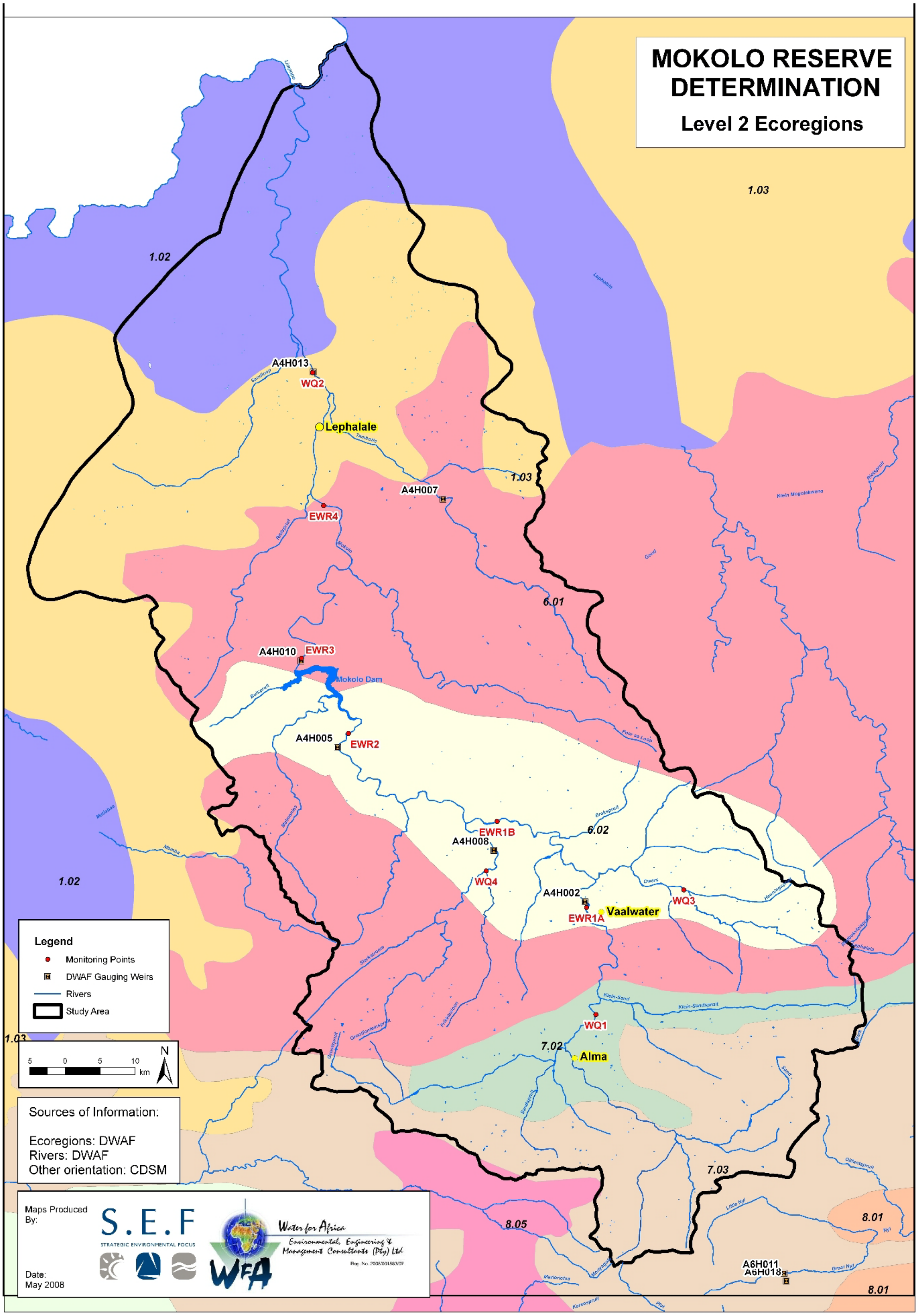


Figure D1 Locality map showing the position of the EWR sites, additional water quality sites and gauging weirs

D2 METHODS AND APPROACH

D2.1 DATA SELECTION

Table D1 Mokolo gauging weirs

Station	Place	Latitude	Longitude	Record date
A4H002Q01	Mokolo River at Zandrivier/Vaalwater	-24.282222	28.090278	6/12/1977 – 7/11/2007
A4H005Q01	Mokolo River at Dwaalhoek	-24.082778	27.773056	28/9/1971 – 15/5/2001
A4H007Q01	Tambotie River at Blakeney	-23.763056	27.908611	27/12/1977 – 12/7/2006
A4H008Q01	Sterkstroom River at Doornspruit	-24.215833	27.973611	28/9/1971 – 7/11/2007
A4H010Q01	Mokolo Dam on Mokolo River: downstream weir	-23.971389	27.726389	3/1/1984 – 24/8/2006
A4H011Q01	Mokolo Dam on Mokolo River: pipeline from dam	-23.975	27.725	29/3/1996 – 30/9/1997
A4H013Q01	Mokolo River at Moorddrift/Vught	-23.599167	27.741944	16/2/1994 – 4/7/2007
A6H011Q01	Groot-Nylrivier at Modderpoort	-24.7611	28.34556	14/2/1972 – 6/11/2007
A6H018Q01	Rasloop River at Modderpoort	-24.770833	28.348611	5/12/1977 – 6/11/2007

Table D2 Water quality data used for the EWR assessment

EWR site	Station	RC	PES	Frequency of monitoring
WQSU 1, 2, 3: Groot, Sand and upstream Mokolo rivers	A6H011Q01	1975 - 1977	2003 - 2007	Monthly
1A	A4H002Q01	1977 - 1979	2002 - 2007	Weekly to end 1982; 2-3x per month thereafter
1B	A4H002Q01	1977 - 1979	2002 - 2007	Weekly to end 1982; 2-3x per month thereafter
2	A4H005Q01	1977 - 1980	1998 - 2001	Generally weekly to every 2 weeks
3	A4H007Q01: RC A4H010Q01: PES	1977 - 1980	1992 - 1996	A4H007Q01: Weekly A4H010Q01: Monthly
4	A4H007Q01: RC A4H010Q01: PES	1977 - 1980	1992 - 1996	A4H007Q01: Weekly A4H010Q01: Monthly
WQSU 6: Mokolo River – floodplain (Rietspruit – Tambotie confluence)	A4H013Q01: PES	Benchmark tables	2000 - 2002	A4H013Q01: Monthly
WQSU 8: Mokolo River	A4H007Q01: RC A4H010Q01: PES	1977 - 1980	1992 - 1996	A4H007Q01: Weekly A4H010Q01: Monthly
WQSU 1: Mokolo River	A4H007Q01: RC A4H010Q01: PES	1977 - 1980	1992 - 1996	A4H007Q01: Weekly A4H010Q01: Monthly

Data used for the Water Quality Sub-Units (WQSU) not containing EWR sites are also shown in Table D2. The boundaries of these WQSUs can be seen in the delineation report for the study. Monitoring frequencies can also be seen in graphs produced for the relevant gauging weirs –see Section D8.

D2.2 WATER QUALITY ASSESSMENT

D2.2.1 Methods

Standard methods were used for this assessment, as outlined in the following publications.

- Methods manual of 2002 (DWAF, 2002).

- Methods updated from the DWAF (2002) document, and previously housed on the Ninham Shand web-site (http://projects.shands.co.za/Hydro/hydro/WQReserve/main.htm) and based on a workshop held in Grahamstown in 2003.
- EcoClassification Manual, version 1 (Kleynhans *et al.*, 2005), which includes the Physico-chemical driver Assessment Index (PAI) model, and instructions for the water quality assessment and completion of the PAI.
- TEACHA (Tool for Ecological Aquatic Chemical Habitat Assessment) programme version 1_32 and notes (prepared by S Jooste, DWAF: RQS) of April 2007.
- Palmer *et al.* (2004), which summarized available methods as at 2003/2004.
- Document by Palmer and colleagues on including Electrical Conductivity in Reserve assessments (DWAF, 2004b).

All methods (including the use of TEACHA as a data manipulation tool) have been compiled into a single document by Scherman Consulting (DWAF, 2008b).

TEACHA is an instrument to support decision-making in the Reserve process, and is a data manipulation tool. The primary output is the recommended water quality component of the Ecological Reserve with corresponding ion data to use in the setting of resource quality objectives. The use of this software presupposes that information is available and reliable. It is not an expert system and requires the availability of expertise to check that the outcome is correct and scientifically valid. It also has strict data input requirements, e.g. all salt ions have to be input or the model will not run. TEACHA was used for this assessment where possible, with data extracted from DWAF's Water Management System (WMS). The alternative approach to using TEACHA for data manipulation is to use a standard statistical package, such as Excel or Statistica, to produce summary statistics (e.g. median, 5th percentile, 95th percentile). Results produced by either method is input into the PAI model as ratings of 0 - 5 per metric, i.e. pH, Dissolved Oxygen (DO), salts, turbidity, toxics and nutrients. The relationship between the ratings of 0 - 5 and ecological categories A - F are shown in Table D3 below. The rank and weighting input to the PAI model is provided by the ecologist, as this assessment is linked to the type of river being assessed and the reaction of the biota in this system.

Table D3 The relationship between categories and ratings (modified from Kleynhans *et al.*, 2005; DWAF, 2008b)

Rating	Deviation from reference conditions	A - F Categories	Natural – Poor categories	Score
0	No change	A	Natural	≥ 92.01
		A/B		>87.4 and <92.01
1	Small change	B	Good	82.01 – 87.4
		B/C		>77.4 and <82.01
2	Moderate change	C		62.01 – 77.4
		C/D	Fair	>57.4 and <62.01
3	Large change	D		42.01 – 57.4
		D/E		>37.4 and <42.01
4	Serious change	E		22.01 – 37.4
		E/F	Poor	>17.4 and <22.01
5	Extreme change	F		0 - 17.4

The following variables were used for the assessment of water quality, according to the required methods:

Inorganic salts

- Sodium chloride (NaCl)
- Sodium sulphate (Na_2SO_4)
- Magnesium chloride ($MgCl_2$)
- Magnesium sulphate ($MgSO_4$)
- Calcium chloride ($CaCl_2$)
- Calcium sulphate ($CaSO_4$)
- Electrical Conductivity – used as a surrogate for aggregated salts when all ionic data are not available and TEACHA could not be used.

Note that salt ionic data, i.e. Ca, Na, Mg, Cl, SO_4, is run through TEACHA to generate aggregated salts. TEACHA has strict data input requirements, e.g. all salt ionic data is needed to generate aggregated salts. This data is normally sourced from the DWAF water quality monitoring points and available on DWAF's Water Management System (WMS).

Nutrients

- Total inorganic nitrogen or TIN (i.e. the N portion of all nitrogen sources, e.g. NO_2+NO_3+NH_4-N)
- Phosphate (PO_4^{3-} -P)

Systems variables

- pH.
- Temperature: Although temperature is considered particularly important in the instances of thermal impacts, it is also important to consider if the EWR site is located below a dam, or if changes in flow would result in extreme temperature changes in rivers.
- Dissolved oxygen.
- Turbidity.

As quantitative data (other than that measured in the field) were not available for DO, temperature and turbidity, a qualitative assessment was conducted for these variables (as outlined in the EcoStatus manual of Kleynhans *et al.* (2005) and DWAF (2008b)).

Toxic substances

Those listed in the South African Water Quality Guidelines for Aquatic Ecosystems (DWAF, 1996), which includes toxic metal ions, toxic organic substances, and/or substances selected from the chemical inventory of an effluent/discharge. The rating tables in DWAF (2008b) provide values for selected toxics.

D2.2.1 Data sources

A number of data sources were used for this assessment, as follows:

- Literature regarding current status and water quality issues prevalent in the catchment, e.g. RHP (2006), DWAF (2004a), Van Vuuren (2006) (Section D1 of this report).

- The perusal of 1: 50 000, and 1: 250 000 maps of the study area, depicting land use activities, point and diffuse sources of pollution, and catchment characteristics such as towns, tributaries, gauging weirs, etc.
- A field survey of the study area undertaken in March 2008. Water quality measurements were taken at specific points, including the EWR sites (Table D4). Periphyton samples were also taken for chlorophyll-a analysis by Prof Froneman of Rhodes University (Table D5), and diatom analysis was undertaken at Potchefstroom University (Appendix E; Table D6).
- Liaison with the DWAF head office and obtaining available water quality information from the DWAF-WMS (Water Management System) database.
- Water quality on CD (version 1.0); produced by the CSIR in 1999.

Table D4 In situ water quality data collected during the March 2008 field survey

Site	pH	Temperature (º C)	DO (mg/l)	DO (% sat)	Conductivity (mS/m)
EWR 1A	6.36	21.6	4.89	57.0	6.0
EWR 1A (January 2008)	5.77	22.3	7.37	84.9	5.2
EWR 1B (January 2008)	6.1	25.9	7.91	97.4	5.0
EWR 2	6.30	25.1	4.61	68.5	1.0
EWR 2 (January 2008)	5.47	25.1	7.37	89.0	3.7
EWR 3	6.35	25.0	4.39	64.7	3.0
EWR 4	5.83	27.3	4.09	62.2	3.0
WQSU 3 (WQ 1): Upper Mokolo River	5.96	21.5	3.73	51.8	7.0
WQSU 6 (WQ 2): Mokolo River below Lephalale	6.12	27.2	4.18	64.1	3.0
WQSU 7 (WQ 3): Dwars River	5.96	20.2	4.87	65.7	3.0
WQSU 7 (January 2008)	5.25	26.3	7.30	90.7	3.0
WQSU 8 (WQ 4): Sterkstroom River	5.34	20.8	4.70	64.6	0.0
WQSU 8 (January 2008)	4.1 (?)	24.8	7.52	90.5	1.2

Note that Dissolved Oxygen (DO) readings taken in March 2008 seem inaccurate, and pH values were generally lower than that of long-term data.

Table D5 Chlorophyll-a analysis for samples collected from the Mokolo study area

Site	Periphyton biomass (mg chl-a m^{-2}): Mean	Periphyton biomass (mg chl-a m^{-2}): Standard deviation
EWR 1A	21.58	6.07
EWR 2	25.54	13.82
EWR 3	17.28	5.68
WQSU 3 (WQ 1): Upper Mokolo River	16.53	5.96
WQSU 6 (WQ 2): Mokolo River below Lephalale	30.58	9.4
WQSU 7 (WQ 3): Dwars River	19.04	11.48
WQSU 8 (WQ 4): Sterkstroom River	18.68	8.92

Table D6 Diatom assessment for the Mokolo study area (from Appendix D)

Site	No. species	SPI	Interpretation of SPI index scores
EWR 1A	21	17.3	A/B: Good quality
EWR 1A (March 2008)	32	16.8	A/B: Good quality
EWR 1B	31	18.6	A: High quality
EWR 2	23	16.0	B: Good quality
EWR 2 (March 2008)	38	16.1	B: Good quality
EWR 3 (September 2007)	15	16.6	B: Good quality
EWR 3 (January 2008)	44	17.4	A: High quality
EWR 3 (March 2008)	28	18.4	A: High quality
EWR 4	34	17.8	A: High quality
EWR 4 (March 2008)	40	17.4	A: High quality
WQSU 3 (WQ 1): Upper Mokolo River	49	14.8	B: Good quality
WQSU 6 (WQ 2): Mokolo River below Lephalale	33	15.9	B: Good quality
WQSU 7 (WQ 3): Dwars River	61	15.5	B: Good quality
WQSU 8 (WQ 4): Sterkstroom River	32	18.8	A: High quality

D3 EWR 1A: VAALWATER

D3.1 DATA EVALUATION

Data availability	Conf
DWAF monitoring data was available for reference condition and PES. Limited phytoplankton, periphyton and diatoms was available (n = 1). No temperature, dissolved oxygen (DO) or turbidity data was available. Little metal data was available. Electrical conductivity (EC) was used instead of aggregated salts as TEACHA could not be used.	3

D3.2 REFERENCE CONDITIONS

Reference conditions	Conf
DWAF monitoring data was available. Water quality station A4H002Q01 was used to set reference conditions with n = 68, and data available from 1977 – 1979.	3

Water Quality Constituents		Value: RC
Inorganic salts (mg/L)	No data available.	
Nutrients (mg/L)	Soluble Reactive Phosphate (SRP)	0.011
	Total Inorganic Nitrogen (TIN)	0.080
Physical variables	pH (5th and 95th percentiles)	6.68 and 7.70
	Electrical conductivity (mS/m)	12.28
Toxics (mg/L)	Fluoride	0.10
	Ammonia	-

D3.3 PRESENT ECOLOGICAL STATE

The PAI and water quality tables, which are completed as part of the assessment and assigns the EcoStatus rating for water quality, are shown below as Tables D7 and D8.

Table D7 Water quality table for EWR 1A

RIVER	Mokolo River	**Water Quality Monitoring Points**	
WQSU	4	**RC**	A4H002Q01, ’77-’79, n = 68
EWR SITE	1A	**PES**	A4H002Q01, ’02-’07 (with 1 point in 2007), n = 48 (but 37 for F and SO_4)
Confidence assessment	Confidence in the assessment is **moderate**, as little DO, temp., turbidity or toxics data, although the gauging weir is close to the EWR site.		
Water Quality Constituents		**Value**	**Category (Rating) / Comment**
Inorganic salts (mg/L)	$MgSO_4$	-	TEACHA could not be used and EC used as surrogate
	Na_2SO_4	-	
	$MgCl_2$	-	
	$CaCl_2$	-	
	NaCl	-	
	$CaSO_4$	-	
Nutrients (mg/L)	SRP	0.0165	B (1): Benchmark category was recalibrated
	TIN	0.123	A (0)
Physical variables	pH (5th and 95th percentiles)	6.92 - 7.83	A (0)
	Temperature	-	No data, but few impacts expected. Catchment not pristine, so A/B (0.5) – qualitative assessment only
	Dissolved oxygen	-	

RIVER	Mokolo River		**Water Quality Monitoring Points**	
WQSU	4		**RC**	A4H002Q01, '77-'79, n = 68
EWR SITE	1A		**PES**	A4H002Q01, '02-'07 (with 1 point in 2007), n = 48 (but 37 for F and SO_4)
Confidence assessment		Confidence in the assessment is **moderate**, as little DO, temp., turbidity or toxics data, although the gauging weir is close to the EWR site.		
Water Quality Constituents			**Value**	**Category (Rating) / Comment**
	Turbidity (NTU)		-	No data, but loads not expected to be high. B (1) – qualitative assessment only
	Electrical conductivity (mS/m)		12.05	A (0)
Response variables	Chl-a: periphyton		EWR 1A: 21.58	C/D (2.5) (n=1)
	Chl-a: phytoplankton		-	-
	Biotic community composition: macroinvertebrate (ASPT) score		SASS: 127 ASPT: 5.3	C (62.3)
	Fish		70.3	C - largely flow-related
	Diatoms		EWR 1A: SPI = 17.3 and 16.8	A/B (0.5) (n = 2)
Toxics (mg/L)	Fluoride		0.18	A (0)
	Ammonia		0.001	A (0)
OVERALL SITE CLASSIFICATION (from PAI)			**B/C (80.0)**	

Table D8 PAI table for EWR 1A

METRIC	RATING	THRESHOLD EXCEEDED?	CONF	DEFAULT WEIGHTS	ADJUSTED RANKS	ADJUSTED WEIGHTS
pH	0.00	N	4.00	50.00		50.00
Salts	0.00	NONE SPECIFIED	4.00	50.00		50.00
Nutrients	2.00	NONE SPECIFIED	3.00	65.00		65.00
Water Temperature	0.50	N	3.00	55.00		55.00
Water clarity	1.00	NONE SPECIFIED	2.00	55.00		55.00
Oxygen	0.50	N	3.00	75.00		75.00
Toxics	2.00	N	3.00	100.00		100.00
PC MODIFICATION RATING WITH THRESHOLD APPLIED (MAX)	1.00	MEAN CONF →	3.14			
CALCULATED PC MODIFICATION RATING WITHOUT THRESHOLD AND WITH DEFAULT WEIGHTS	1.00					
CALCULATED P-C RATING WITHOUT THRESHOLD AND BASED ON ADJUSTED WEIGHTS	1.00					
FINAL PC MODIFICATION RATING	1.00					
P-C CATEGORY %	P-C CATEGORY					
80.00	B					

D3.3.1 PES causes and sources

PES	Conf	Causes	Sources	F[1]/NF[2]	Conf[3]
B/C	3	Elevated nutrients. Pesticide and other toxicant use expected due to land use.	Irrigation and urban activities.	NF	4
		Turbidity levels expected to be slightly elevated due to clearing for farming.	Farming.		
		Oxygen and temperature expected to fluctuate due to variable flows.	Abstractions and dams in system.	F	

1: Flow related 2: Non Flow related 3: Confidence

D3.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
B/C	Stable	B/C		Present day flows follow the same pattern as natural flows, although zero flows are now experienced, suggesting that the system has adapted to variability.	3

D3.5 REC: B/C

PES	REC	Comments	Conf
B/C	A/B	No zero flows would result in improved nutrient and toxics status. This assumes that the improvement in flows be sufficient to significantly dilute toxics and nutrient build-up, and increase the assimilative capacity of the river in this reach.	3

D3.6 AEC: D

PES	AEC	Comments	Conf
B/C	C	Lower zero flows and longer periods of zero and low flows would result in a concentration of nutrients and toxics. Temperatures would increase and oxygen levels would drop slightly. A small increase in salinity may take place due to less dilution.	3

D4 EWR 1B: TOBACCO

D4.1 DATA EVALUATION

Data availability	Conf
DWAF monitoring data was available for reference condition and PES with modifications to the PAI table for EWR 1B – particularly based on on-site indicators and changing land use. Limited phytoplankton, periphyton and diatoms was available (n = 1). No temperature, DO or turbidity data was available. Little metal data was available. Electrical conductivity (EC) was used instead of aggregated salts as TEACHA could not be used.	3

D4.2 REFERENCE CONDITIONS

Reference conditions	Conf
DWAF monitoring data was available. Water quality station A4H002Q01was used to set reference conditions with n = 68, and data available from 1977 – 1979.	3

Water Quality Constituents		Value: RC
Inorganic salts (mg/L)	No data available.	
Nutrients (mg/L)	Soluble Reactive Phosphate (SRP)	0.011
	Total Inorganic Nitrogen (TIN)	0.080
Physical variables	pH (5th and 95th percentiles)	6.68 and 7.70
	Electrical conductivity (mS/m)	12.28
Toxics (mg/L)	Fluoride	0.10
	Ammonia	-

D4.3 PRESENT ECOLOGICAL STATE

The PAI and water quality tables, which are completed as part of the assessment and assigns the EcoStatus rating for water quality, are shown below as Tables D9 and D10.

Table D9 Water quality table for EWR 1B

RIVER	Mokolo River	**Water Quality Monitoring Points**	
WQSU	4	**RC**	A4H002Q01, ’77 - ’79, n = 68
EWR SITE	1B	**PES**	A4H002Q01, ’02-’07 (with 1 point in 2007), n = 48 (but 37 for F and SO_4)
Confidence assessment	Confidence in the assessment is **moderate**, as little DO, temp., turbidity or toxics data. Data from A4H002Q01 is used for EWR 1A and B, with modifications to the PAI table – particularly based on on-site indicators.		
Water Quality Constituents		**Value**	**Category (Rating) / Comment**
Inorganic salts (mg/L)	$MgSO_4$	-	TEACHA could not be used and EC used as surrogate
	Na_2SO_4	-	
	$MgCl_2$	-	
	$CaCl_2$	-	
	NaCl	-	
	$CaSO_4$	-	
Nutrients (mg/L)	SRP	0.0165	B (1): Benchmark category was recalibrated
	TIN	0.123	A (0)
Physical variables	pH (5th and 95th percentiles)	6.92 – 7.83	A (0)
	Temperature	-	No data, but few impacts expected. Catchment not pristine, so B (1) due to the impact of zero flows – qualitative
	Dissolved oxygen	-	

RIVER		Mokolo River	Water Quality Monitoring Points	
WQSU		4	**RC**	A4H002Q01, '77 - '79, n = 68
EWR SITE		1B	**PES**	A4H002Q01, '02-'07 (with 1 point in 2007), n = 48 (but 37 for F and SO_4)
Confidence assessment		Confidence in the assessment is **moderate**, as little DO, temp., turbidity or toxics data. Data from A4H002Q01 is used for EWR 1A and B, with modifications to the PAI table – particularly based on on-site indicators.		
Water Quality Constituents		**Value**	**Category (Rating) / Comment**	
			assessment only	
	Turbidity (NTU)	-	No data, but loads not expected to be high. B (1) – qualitative assessment only	
	Electrical conductivity (mS/m)	12.05	A (0)	
Response variables	Chl-a: periphyton	WQ site 3 (Dwars): 19.04 (high SD)	C (2) (n=1)	
	Chl-a: phytoplankton	-	-	
	Biotic community composition: macroinvertebrate (ASPT) score	SASS: 130 ASPT: 5.4 (Jan '08) SASS: 188 ASPT: 6.1 (June '08)	B/C	
	Fish	72.4	C	
	Diatoms	EWR 1B: SPI = 18.8 WQ site 3 (Dwars): 15.9	A (0) (n=1) B (1) (n=2)	
Toxics (mg/L)	Fluoride	0.18	A (0)	
	Ammonia	0.001	A (0)	
OVERALL SITE CLASSIFICATION (from PAI)		**B/C (80.8%)**		

Note that the diatom and chlorophyll-a results for the Dwars River (WQ site 3) were used as this site is in the same Management Resource Unit (MRU) as the EWR site.

Table D10 PAI table for EWR 1B

METRIC	RATING	THRESHOLD EXCEEDED?	CONF	DEFAULT WEIGHTS	ADJUSTED RANKS	ADJUSTED WEIGHTS
pH	0.00	N	4.00	50.00		50.00
Salts	0.00	NONE SPECIFIED	4.00	50.00		50.00
Nutrients	1.50	NONE SPECIFIED	3.00	65.00		60.00
Water Temperature	1.00	N	3.00	60.00		65.00
Water clarity	1.00	NONE SPECIFIED	2.00	50.00		50.00
Oxygen	1.00	N	3.00	75.00		75.00
Toxics	1.50	N	3.00	100.00		100.00
PC MODIFICATION RATING WITH THRESHOLD APPLIED (MAX)	0.96	MEAN CONF →	3.14			
CALCULATED PC MODIFICATION RATING WITHOUT THRESHOLD AND WITH DEFAULT WEIGHTS	0.96					
CALCULATED P-C RATING WITHOUT THRESHOLD AND BASED ON ADJUSTED WEIGHTS	0.96					
FINAL PC MODIFICATION RATING	0.96					
P-C CATEGORY %	P-C CATEGORY					
80.80	B					

D4.3.1 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
B/C	3	Elevated nutrients. Pesticide and other toxicant use expected due to land use.	Land-use is extensively agricultural, with vegetable, maize and fruit farming predominating in the upper catchment, so pesticide use anticipated. Pole-treating activities (CCA-wax) are also found upstream of Vaalwater town. Other impacts include urban activities associated with Vaalwater, resulting in some toxicant load.	NF	4
		Turbidity levels expected to be slightly elevated due to clearing for farming.			
		Oxygen and temperature expected to fluctuate due to variable flows.	Flows are very variable, with reductions in low and moderate flows. Present day flows follow the same pattern as natural flows, although zero flows are now experienced, suggesting that the system has adapted to variability.	F	

D4.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C	Stable	C		Present day flows follow the same pattern as natural flows, although zero flows are now experienced, suggesting that the system has adapted to variability.	3

D4.5 REC: B

PES	REC	Comments	Conf
B/C	B	No zero flows would result in improved nutrient and toxics status. This assumes that the improvement in flows be sufficient to significantly dilute toxics and nutrient build-up, and increase the assimilative capacity of the river in this reach.	3

D4.6 AEC: C/D

PES	AEC	Comments	Conf
B/C	C	Lower zero flows and longer periods of zero and low flows would result in a concentration of nutrients and toxics. Temperatures would increase and oxygen levels would drop slightly.	3

D5 EWR 2: KA'INGO

D5.1 DATA EVALUATION

Data availability	Conf
DWAF monitoring data was available for reference condition and PES. Limited phytoplankton, periphyton and diatoms was available (n = 1). No temperature, DO or turbidity data was available. Little metal data was available. Electrical conductivity (EC) was used instead of aggregated salts as TEACHA could not be used.	2.5

D5.2 REFERENCE CONDITIONS

Reference conditions	Conf
DWAF monitoring data was available. Water quality station A4H005Q01was used to set reference conditions with n = 85, and data available from 1977 – 1980.	3

Water Quality Constituents		Value: RC
Inorganic salts (mg/L)	No data available.	
Nutrients (mg/L)	SRP	0.011
	TIN	0.06
Physical variables	pH (5th and 95th percentiles)	6.00 and 7.25
	Electrical conductivity (mS/m)	9.09
Toxics (mg/L)	Fluoride	0.19
	Ammonia	-

D5.3 PRESENT ECOLOGICAL STATE

The PAI and water quality tables, which are completed as part of the assessment and assigns the EcoStatus rating for water quality, are shown below as Tables D11 and D12.

Table D11 Water quality table for EWR 2

RIVER	Mokolo River	**Water Quality Monitoring Points**	
WQSU	4	**RC**	A4H005Q01, '77 - '80, n = 85 (but 163 for EC)
EWR SITE	2	**PES**	A4H005Q01, '98 - '01, n = 39 (but 47 for TIN)
Confidence assessment	Confidence in the assessment is **low.** Little DO, temp., turbidity or toxics data are available, and although the gauging weir is close to the EWR site, present state data is only available up until 2001.		
Water Quality Constituents		**Value**	**Category (Rating) / Comment**
Inorganic salts (mg/L)	$MgSO_4$	-	TEACHA could not be used and EC used as surrogate
	Na_2SO_4	-	
	$MgCl_2$	-	
	$CaCl_2$	-	
	NaCl	-	
	$CaSO_4$	-	
Nutrients (mg/L)	SRP	0.0059	A (0): Benchmark category was recalibrated – RC data very variable
	TIN	0.02	A (0). RC data very variable
Physical variables	pH (5th and 95th percentiles)	7.46 - 7.87	A (0): Benchmark category recalibrated for lower A category
	Temperature	-	No data, but few impacts expected.

RIVER	Mokolo River	**Water Quality Monitoring Points**	
WQSU	4	**RC**	A4H005Q01, '77 - '80, n = 85 (but 163 for EC)
EWR SITE	2	**PES**	A4H005Q01, '98 - '01, n = 39 (but 47 for TIN)
Confidence assessment	Confidence in the assessment is **low.** Little DO, temp., turbidity or toxics data are available, and although the gauging weir is close to the EWR site, present state data is only available up until 2001.		
Water Quality Constituents		**Value**	**Category (Rating) / Comment**
	Dissolved oxygen	-	Some temperature and DO fluctuations may occur at low flows - B (1) – qualitative assessment only
	Turbidity (NTU)	-	No data, but loads not expected to be high. A/B (0.5) – qualitative assessment only
	Electrical conductivity (mS/m)	9.4	A (0)
Response variables	Chl-a: periphyton	EWR 2: 25.54 WQ site 4: 18.68 (high SD)	D (3) (n=1). SD high across 3 replicates C (2) (n=1)
	Chl-a: phytoplankton	-	-
	Biotic community composition: macroinvertebrate (ASPT) score	Jan '08: SASS – 82; ASPT - 5.1 March '08: SASS - 126 ; ASPT - 6.6	C
	Fish	65.1	C
	Diatoms	EWR 2: SPI=16.1 WQ site 4: 18.8	B (1) (n=2) A (0) (n=1)
Toxics (mg/L)	Fluoride	0.15	A (0)
	Ammonia	0.002	A (0)
OVERALL SITE CLASSIFICATION (from PAI)		**B (84.2)**	

Note that the diatom and chlorophyll-a results for the Sterkstroom River (WQ site 4) were used for this site as this is an important tributary in this river reach. Sterkstroom water quality data was assessed, and indicates an A category.

Table D12 PAI table for EWR 2

METRIC	RATING	THRESHOLD EXCEEDED?	CONF	DEFAULT WEIGHTS	ADJUSTED RANKS	ADJUSTED WEIGHTS
pH	0.00	N	4.00	50.00		50.00
Salts	0.00	NONE SPECIFIED	4.00	50.00		50.00
Nutrients	1.50	NONE SPECIFIED	3.00	65.00		60.00
Water Temperature	1.00	N	3.00	60.00		65.00
Water clarity	0.50	NONE SPECIFIED	3.00	50.00		50.00
Oxygen	1.00	N	3.00	75.00		75.00
Toxics	1.00	N	3.00	100.00		100.00
PC MODIFICATION RATING WITH THRESHOLD APPLIED (MAX)	0.79	MEAN CONF →	3.29			
CALCULATED PC MODIFICATION RATING WITHOUT THRESHOLD AND WITH DEFAULT WEIGHTS	0.79					
CALCULATED P-C RATING WITHOUT THRESHOLD AND BASED ON ADJUSTED WEIGHTS	0.79					
FINAL PC MODIFICATION RATING	0.79					
P-C CATEGORY %	P-C CATEGORY					
84.20	B					

D5.3.1 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
B	2	Elevated nutrients. Pesticide and other toxicant use expected due to land use.	Agriculture.	NF	3
		Turbidity levels expected to be slightly elevated due to clearing for farming.			
		Oxygen and temperature expected to fluctuate due to variable flows.	Abstraction.	F	

D5.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
B	Stable	B		Present day flows follow the same pattern as natural flows, although zero flows are now experienced, suggesting that the system has adapted to variability.	3

D5.5 REC: B

PES	REC	Comments	Conf
B	A/B	The EC will be maintained, but improved flows will result in improved water quality in terms of nutrients, toxics, temperature and oxygen.	3

D5.6 AEC: C/D

PES	AEC	Comments	Conf
B	C	This scenario would result in a concentration of nutrients and toxics. Temperatures would increase and oxygen levels would drop slightly.	3

D6 EWR 3: GORGE

D6.1 DATA EVALUATION

Data availability	Conf
Data from A4H007Q01 was used for RC and A4H010Q01 for PES. Limited phytoplankton, periphyton and diatoms was available (n = 1). No temperature, DO or turbidity data was available. Little metal data was available. Electrical conductivity (EC) was used instead of aggregated salts as TEACHA could not be used.	2

D6.2 REFERENCE CONDITIONS

Reference conditions	Conf
DWAF monitoring data was available. Water quality station A4H007Q01was used to set reference conditions with n = 82, and data available from 1977 – 1980.	3

Water Quality Constituents		Value: RC
Inorganic salts (mg/L)	No data available.	
Nutrients (mg/L)	Soluble Reactive Phosphate (SRP)	0.007
	Total Inorganic Nitrogen (TIN)	0.065
Physical variables	pH (5th and 95th percentiles)	5.14 and 6.70
	Electrical conductivity (mS/m)	15 and 24
Toxics (mg/L)	Fluoride	6.77
	Ammonia	0.160

C5.7 PRESENT ECOLOGICAL STATE

The PAI and water quality tables, which are completed as part of the assessment and assigns the EcoStatus rating for water quality, are shown below as Table D13 and D14.

Table D13 Water quality table for EWR 3

RIVER	Mokolo River	**Water Quality Monitoring Points**	
WQSU	5	**RC**	A4H007Q01, '77 - '80, n = 82
EWR SITE	3	**PES**	A4H010Q01, '92 - '96, n = 27 (but 19 for temp. and 6 for NH_3)
Confidence assessment	Confidence in the assessment is **low** as little DO, temp., turbidity or toxics data are available. Although the gauging weir is close to the EWR site, present state data only until 1996. RC data sourced from A4H007Q01 on the Tambotie River (same EcoRegion level II).		
Water Quality Constituents		**Value**	**Category (Rating) / Comment**
Inorganic salts (mg/L)	$MgSO_4$	-	TEACHA could not be used and EC used as surrogate
	Na_2SO_4	-	
	$MgCl_2$	-	
	$CaCl_2$	-	
	NaCl	-	
	$CaSO_4$	-	
Nutrients (mg/L)	SRP	0.015	A (0): Benchmark category was recalibrated – Data very variable
	TIN	0.067	A (0). Data very variable
Physical variables	pH (5th and 95th percentiles)	7.2 and 7.76	B (1): RC data 5.14 (5th percentile) and 6.7 (95th percentile) – reliability?

RIVER	Mokolo River	Water Quality Monitoring Points	
WQSU	5	RC	A4H007Q01, '77 - '80, n = 82
EWR SITE	3	PES	A4H010Q01, '92 - '96, n = 27 (but 19 for temp. and 6 for NH_3)
Confidence assessment	Confidence in the assessment is **low** as little DO, temp., turbidity or toxics data are available. Although the gauging weir is close to the EWR site, present state data only until 1996. RC data sourced from A4H007Q01 on the Tambotie River (same EcoRegion level II).		

Water Quality Constituents		Value	Category (Rating) / Comment
	Temperature (10th and 90th percentiles)	12 - 25	Little data, but site downstream Mokolo Dam (even if multi-level offtake, probably bottom release due to low flows in the dam), so dam impacts on temperature and DO expected. C (2)
	Dissolved oxygen	-	
	Turbidity (NTU)	-	No data, but loads not expected to be high. A/B (0.5) – qualitative assessment only
	Electrical conductivity (mS/m)	10.87	A (0)
Response variable	Chl-a: periphyton	17.28	C (2) (n=1)
	Chl-a: phytoplankton	-	-
	Biotic community composition: macroinvertebrate (ASPT) score	SASS:130 ASPT: 5.0 SASS: 149 ASPT: 5.7	C
	Fish	65.8	C
	Diatoms	SPI=16.6 (Sept 07) SPI=17.4 (Jan 08) SPI=18.4 (Mar 08)	B (1) (n=3) A (0) A (0)
Toxics (mg/L)	Fluoride	0.278	A (0)
	Ammonia	0.001	A (0)
OVERALL SITE CLASSIFICATION (from PAI)		B/C (79.2)	

Table D14 PAI table for EWR 3

METRIC	RATING	THRESHOLD EXCEEDED?	CONF	DEFAULT WEIGHTS	ADJUSTED RANKS	ADJUSTED WEIGHTS
pH	1.00	N	2.00	50.00		50.00
Salts	0.00	NONE SPECIFIED	4.00	50.00		50.00
Nutrients	0.50	NONE SPECIFIED	3.00	65.00		60.00
Water Temperature	2.50	N	3.00	60.00		65.00
Water clarity	0.50	NONE SPECIFIED	3.00	50.00		50.00
Oxygen	2.00	N	3.00	75.00		75.00
Toxics	0.50	N	3.00	100.00		100.00
PC MODIFICATION RATING WITH THRESHOLD APPLIED (MAX)	1.02	MEAN CONF →	3.00			
CALCULATED PC MODIFICATION RATING WITHOUT THRESHOLD AND WITH DEFAULT WEIGHTS	1.02					
CALCULATED P-C RATING WITHOUT THRESHOLD AND BASED ON ADJUSTED WEIGHTS	1.04					
FINAL PC MODIFICATION RATING	1.04					
P-C CATEGORY %	P-C CATEGORY					
79.20	C					

D6.2.1 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
B/C	2	Elevated nutrients and sedimentation. Pesticide and other toxicant use expected due to land use.	Agriculture and land use activities.	NF	4
		Oxygen and temperature expected to fluctuate due to variable flows.	Mokolo Dam.	F	

D6.3 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
B/C	Stable	B/C		The water quality state is stable and has adapted to the constant variability generated by dam operations.	3

D6.4 REC: B

PES	REC	Comments	Conf
B/C	B	Increased multi-level releases from dam thereby increasing low flows. A decrease in water temperature variability, increase in oxygen concentrations and increase in the assimilative capacity of the river is expected.	**3**

D6.5 AEC: C/D

PES	AEC	Comments	Conf
B	C	Decrease in releases and removal of low flow releases will likely result in an increase in water temperature variability, with longer periods of high temperatures and low oxygen concentrations. Toxics and nutrients would concentrate.	3

D7 EWR 4: MALALATAU

D7.1 DATA EVALUATION

Data availability	Conf
Data from A4H007Q01 was used for RC (on Tambotie River) and A4H010Q01 for PES. Data from A4H010Q01 was used for EWR 3 and 4, with modifications to the PAI table – particularly based on on-site indicators and the influence of Poer-se-loop tributary joining the Mokolo River between the two sites. Present state data only until 1996 and RC data sourced from A4H007Q01 on the Tambotie River (same EcoRegion level II). No temperature, DO or turbidity data was available. Little metal data was available. Electrical conductivity (EC) was used instead of aggregated salts as TEACHA could not be used.	2

D7.2 REFERENCE CONDITIONS

Reference conditions	Conf
DWAF monitoring data was available. Water quality station A4H007Q01was used to set reference conditions with n = 82, and data available from 1977 – 1980. Refer to Table 5.4.	3

Water Quality Constituents		Value: RC
Inorganic salts (mg/L)	No data available.	
Nutrients (mg/L)	Soluble Reactive Phosphate (SRP)	0.007
	Total Inorganic Nitrogen (TIN)	0.065
Physical variables	pH (5th and 95th percentiles)	5.14 and 6.70
	Electrical conductivity (mS/m)	15 and 24
Toxics (mg/L)	Fluoride	6.77
	Ammonia	0.160

D7.3 PRESENT ECOLOGICAL STATE

The PAI and water quality tables, which are completed as part of the assessment and assigns the EcoStatus rating for water quality, are shown below as Tables D15 and D16.

Table D15 Water quality table for EWR 4

RIVER	Mokolo River	**Water Quality Monitoring Points**	
WQSU	5	**RC**	A4H007Q01, '77 - '80, n = 82
EWR SITE	4	**PES**	A4H010Q01, '92-'96, n = 27 (but 19 for temp. and 6 for NH_3)
Confidence assessment	Confidence in the assessment is **low** as little DO, temp., turbidity or toxics data are available. Data from A4H010Q01 is used for EWR 3 and 4, with modifications to the PAI table – particularly based on on-site indicators and the influence of Poer-se-loop tributary joining the Mokolo River between the two sites. Present state data only until 1996 and RC data sourced from A4H007Q01 on the Tambotie River (same EcoRegion level II).		
Water Quality Constituents		**Value**	**Category (Rating) / Comment**
Inorganic salts (mg/L)	$MgSO_4$	-	TEACHA could not be used and EC used as surrogate
	Na_2SO_4	-	
	$MgCl_2$	-	
	$CaCl_2$	-	
	NaCl	-	
	$CaSO_4$	-	

RIVER	Mokolo River	**Water Quality Monitoring Points**	
WQSU	5	**RC**	A4H007Q01, ’77 - ’80, n = 82
EWR SITE	4	**PES**	A4H010Q01, ’92-’96, n = 27 (but 19 for temp. and 6 for NH_3)
Confidence assessment	Confidence in the assessment is **low** as little DO, temp., turbidity or toxics data are available. Data from A4H010Q01 is used for EWR 3 and 4, with modifications to the PAI table – particularly based on on-site indicators and the influence of Poer-se-loop tributary joining the Mokolo River between the two sites. Present state data only until 1996 and RC data sourced from A4H007Q01 on the Tambotie River (same EcoRegion level II).		

Water Quality Constituents		**Value**	**Category (Rating) / Comment**
Nutrients (mg/L)	SRP	0.015	A (0): Benchmark category was recalibrated – Data very variable
	TIN	0.067	A (0). Data very variable
Physical variables	pH (5th and 95th percentiles)	7.2 - 7.76	B (1): RC data 5.14 (5th percentile) and 6.7 (95th percentile) – reliability?
	Temperature	-	No data, but no impacts expected. Small temperature and DO fluctuations may occur - B (1) – qualitative assessment only
	Dissolved oxygen	-	
	Turbidity (NTU)	-	No data, but loads not expected to be too high and river generally clear. A (0) – qualitative assessment only
	Electrical conductivity (mS/m)	10.87	A (0)
Response variable	Chl-a: periphyton	-	-
	Chl-a: phytoplankton	-	-
	Biotic community composition: macroinvertebrate (ASPT) score	SASS: 126 ASPT: 4.8	C
	Fish	63.73	C
	Diatoms	Sept ’07: SPI=17.8 March ’08: SPI=17.4	A (0) (n=2)
Toxics (mg/L)	Fluoride	0.278	A (0)
	Ammonia	0.001	A (0)
OVERALL SITE CLASSIFICATION (from PAI)		**B (86.8)**	

Table D16 PAI table for EWR 4

METRIC	RATING	THRESHOLD EXCEEDED?	CONF	DEFAULT WEIGHTS	ADJUSTED RANKS	ADJUSTED WEIGHTS
pH	1.00	N	2.00	**60.00**		**60.00**
Salts	0.00	NONE SPECIFIED	4.00	**50.00**		**50.00**
Nutrients	0.50	NONE SPECIFIED	3.00	**70.00**		**60.00**
Water Temperature	1.50	N	3.00	**60.00**		**70.00**
Water clarity	0.00	NONE SPECIFIED	3.00	**50.00**		**50.00**
Oxygen	1.00	N	3.00	**65.00**		**70.00**
Toxics	0.50	N	3.00	**100.00**		**100.00**
PC MODIFICATION RATING WITH THRESHOLD APPLIED (MAX)	**0.66**	**MEAN CONF →**	**3.00**			
CALCULATED PC MODIFICATION RATING WITHOUT THRESHOLD AND WITH DEFAULT WEIGHTS	**0.66**					
CALCULATED P-C RATING WITHOUT THRESHOLD AND BASED ON ADJUSTED WEIGHTS	**0.68**					
FINAL PC MODIFICATION RATING	**0.66**					
P-C CATEGORY %	**P-C CATEGORY**					
86.80	**B**					

D7.3.1 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
B	2	Pesticide and other toxicant use expected due to land use.	Agriculture.	NF	2
		Turbidity levels expected to be slightly elevated due to clearing for farming.	Agriculture.		
		Oxygen and temperature expected to fluctuate due to variable flows.	Abstraction.	F	

D7.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
B	Stable	B		Consistent variability over time dependent on dam operations probably still impacting this site.	2

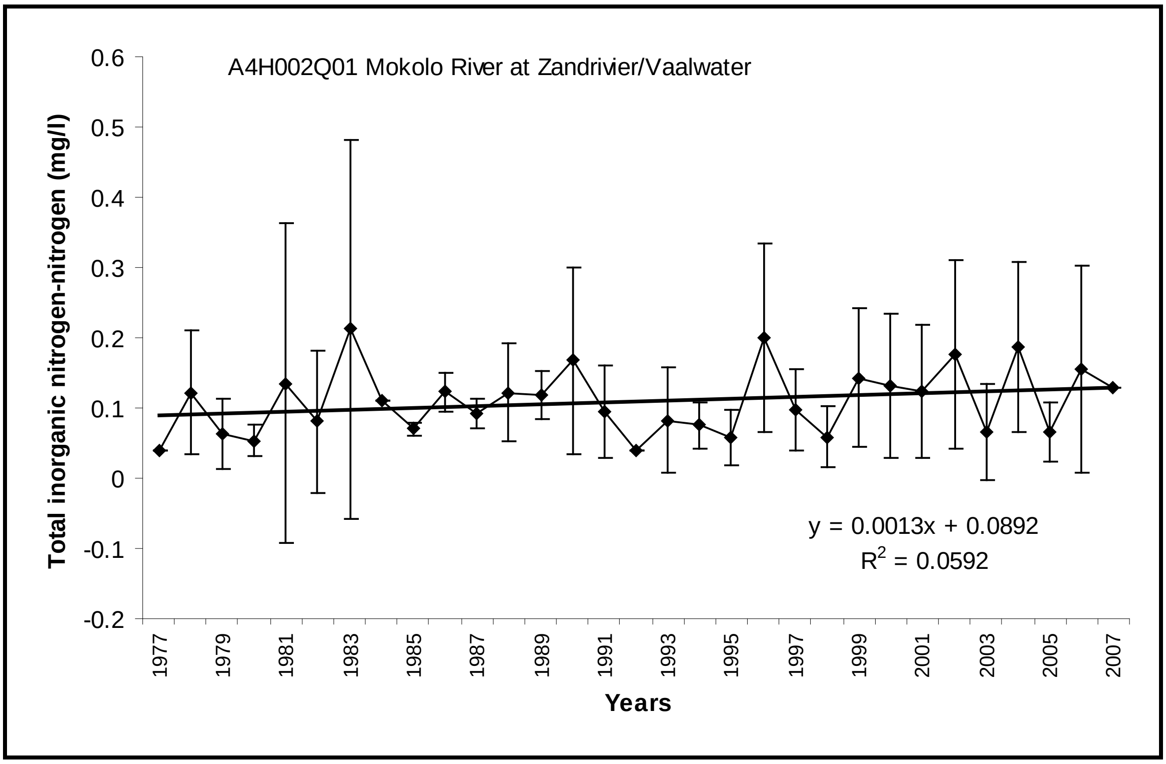
D7.5 REC: B

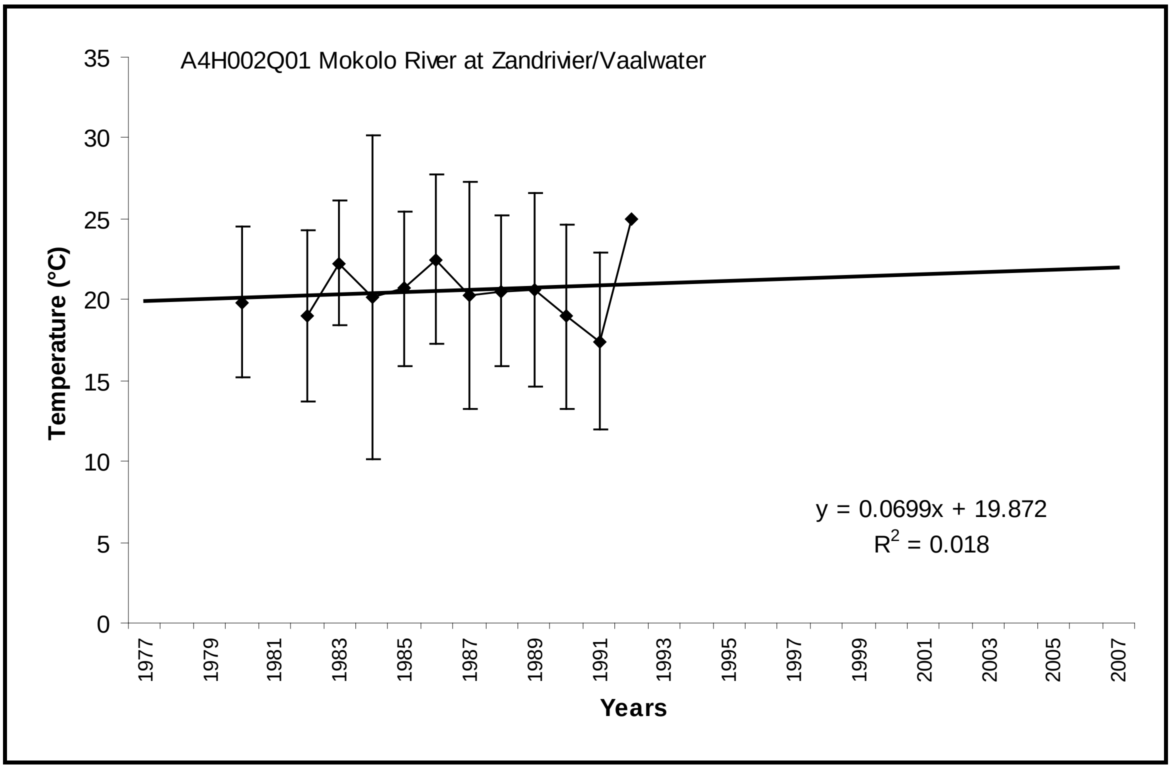
PES	REC	Comments	Conf
B	A/B	Increased flow will result in a decrease in the variability of water temperatures and a subsequent increase in the oxygen concentration.	3

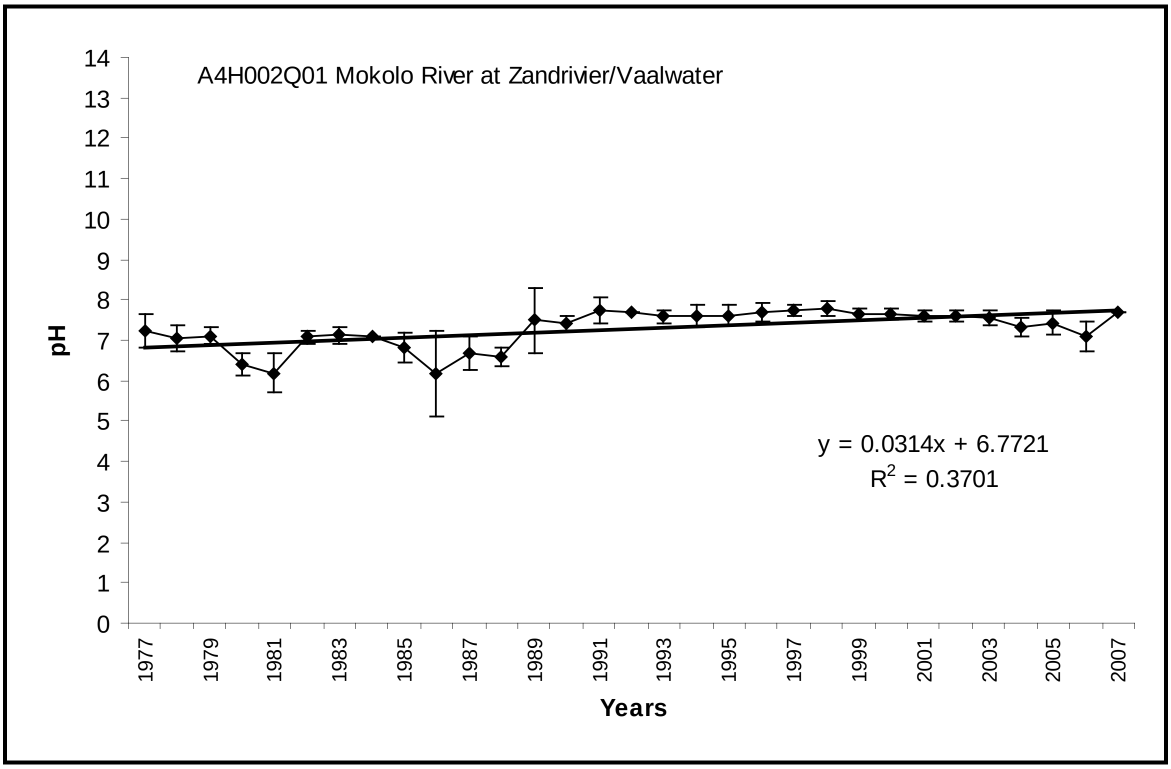
D7.6 AEC: C/D

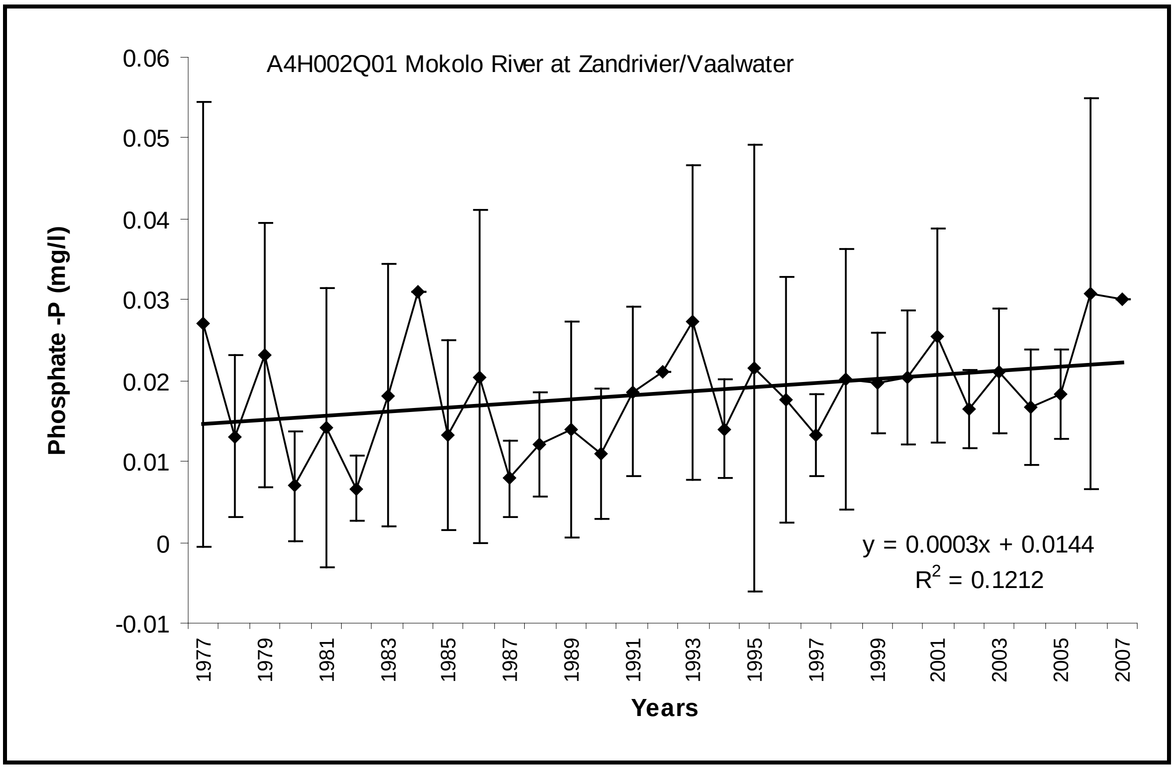
PES	AEC	Comments	Conf
B	B/C	Lower flows will result in stagnant pools where temperature will increase and oxygen concentrations will decrease. Concentration of any nutrients and toxicants is also likely to occur.	3

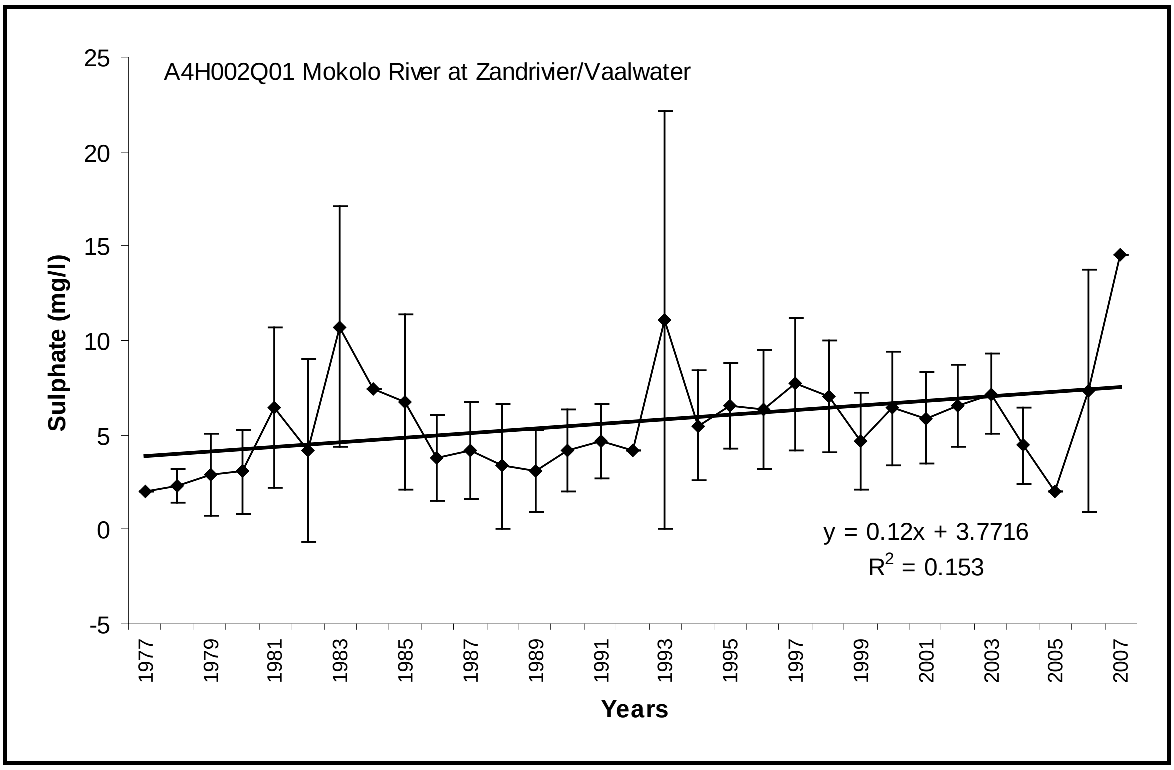
D8 MONITORING FREQUENCIES OF RELEVANT GUAGES

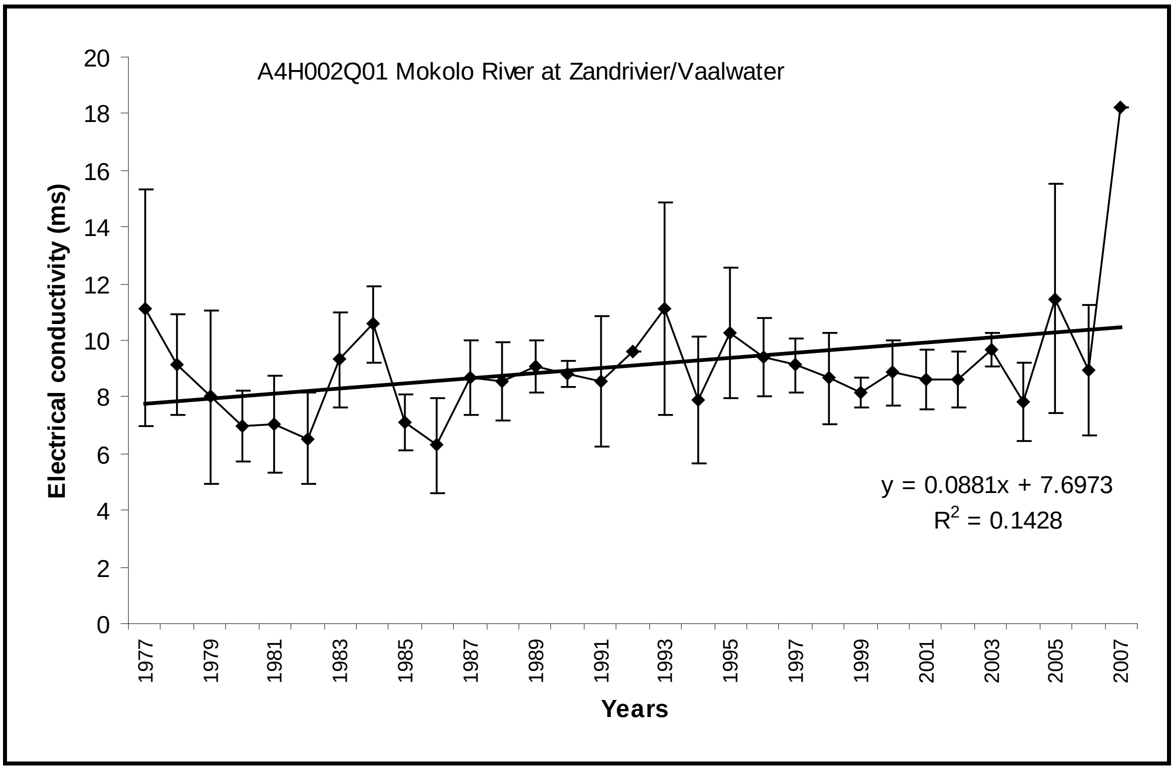


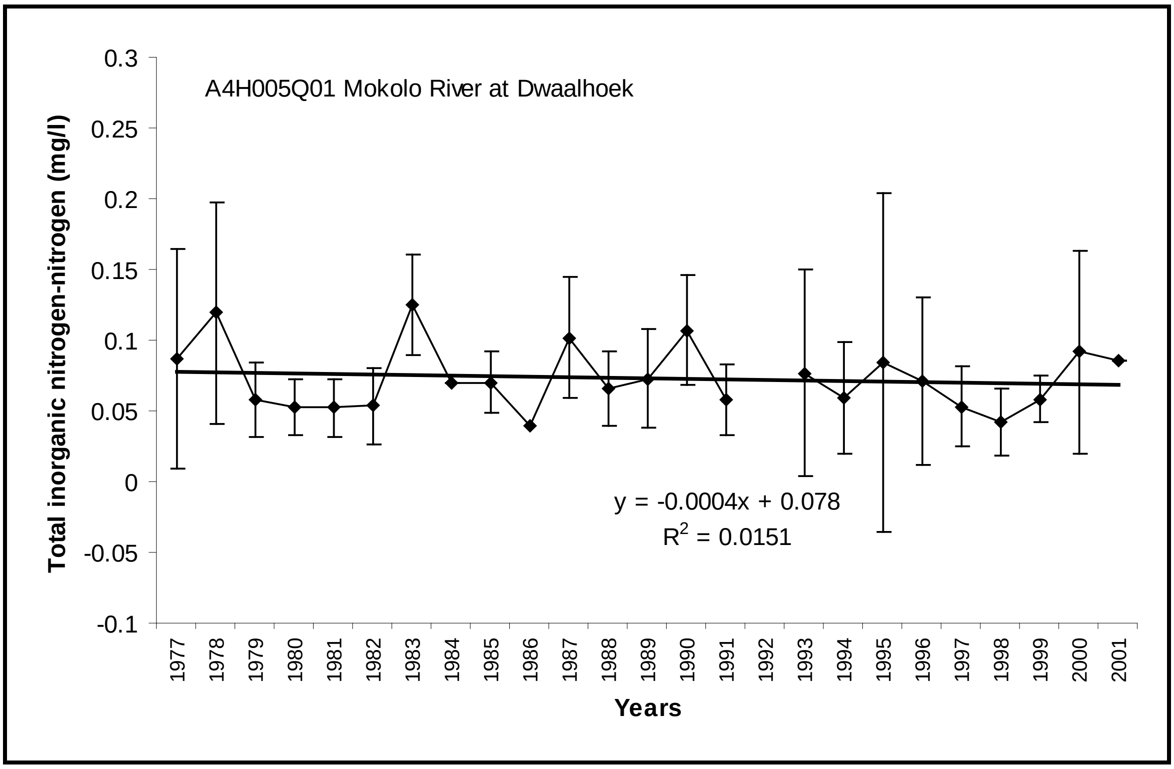


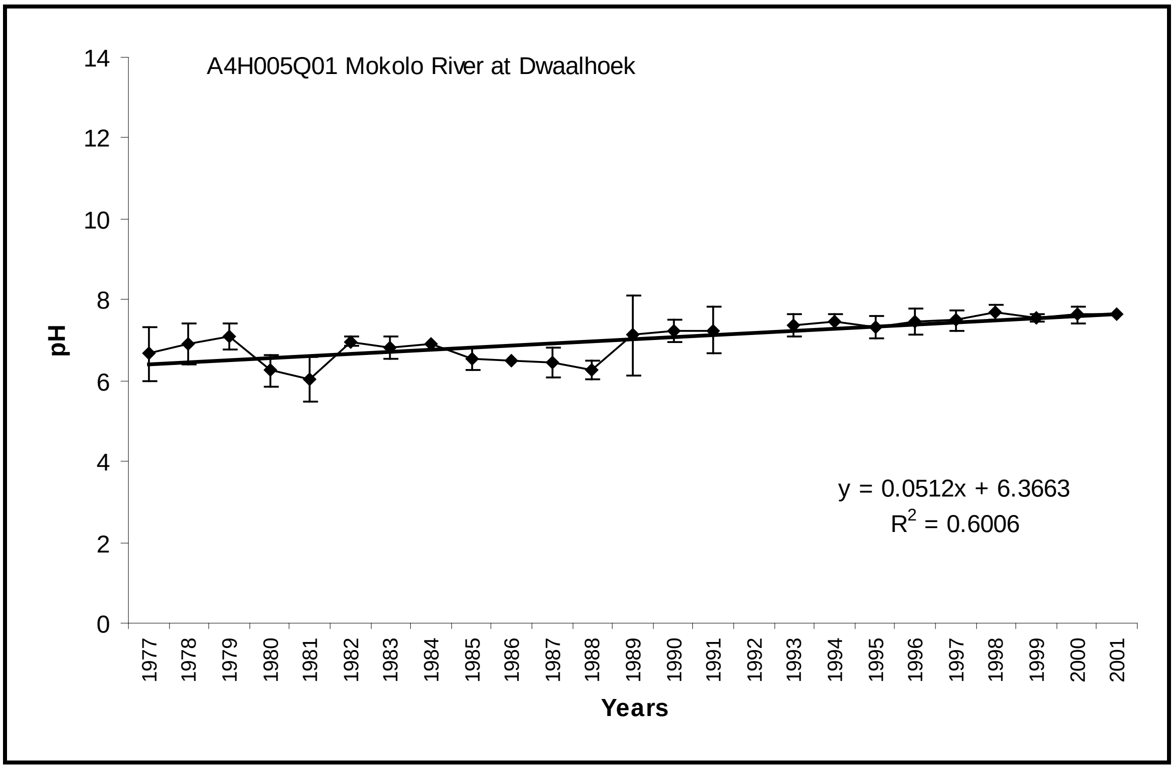

A4H002Q01 Mokolo River at Zandrivier/Vaalwater
pH
Years
y = 0.0314x + 6.7721
R^2 = 0.3701
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007

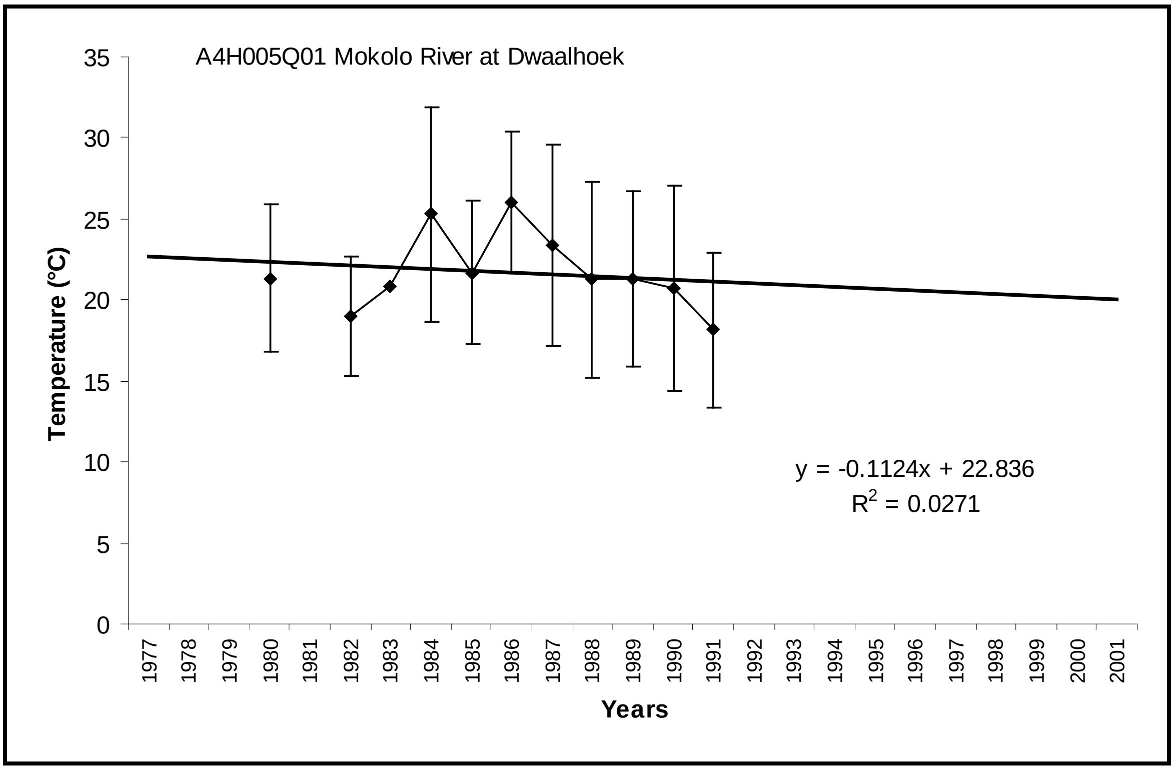

A4H002Q01 Mokolo River at Zandrivier/Vaalwater
Phosphate -P (mg/l)
Years
y = 0.0003x + 0.0144
R^2 = 0.1212
-0.01
0
0.01
0.02
0.03
0.04
0.05
0.06
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007

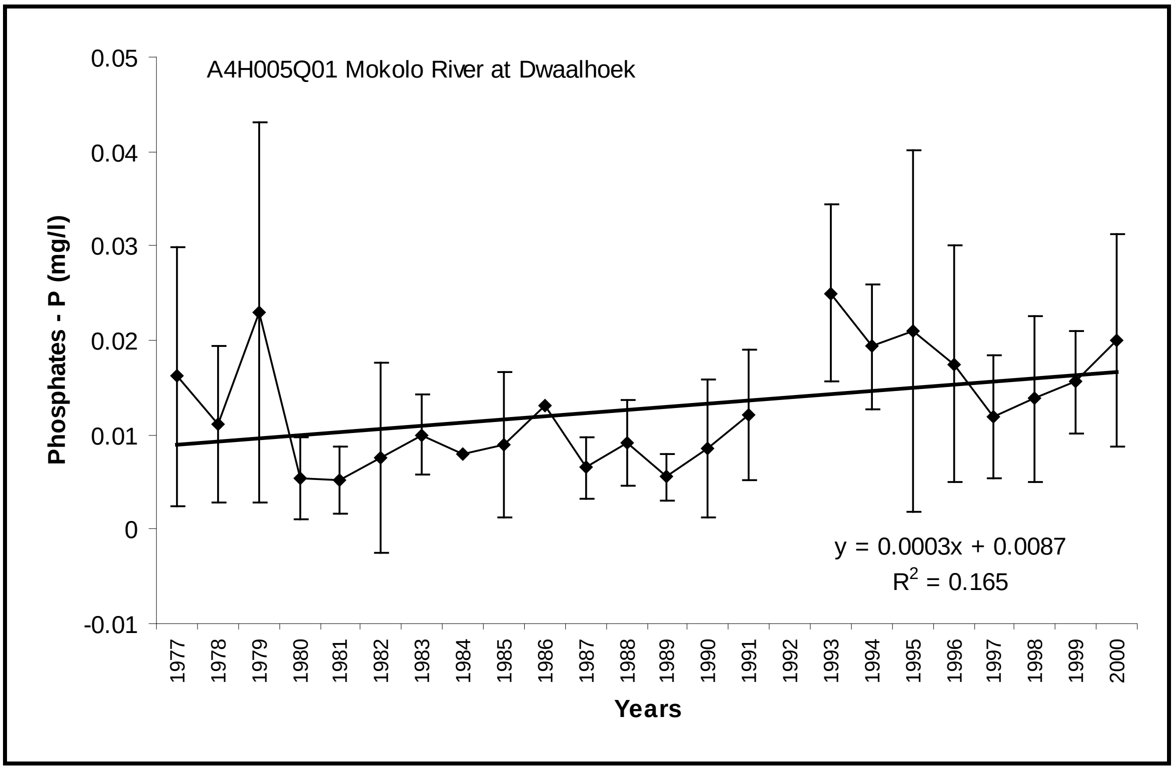

A4H002Q01 Mokolo River at Zandrivier/Vaalwater
Sulphate (mg/l)
Years
y = 0.12x + 3.7716
R2 = 0.153
25
20
15
10
5
0
-5
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007

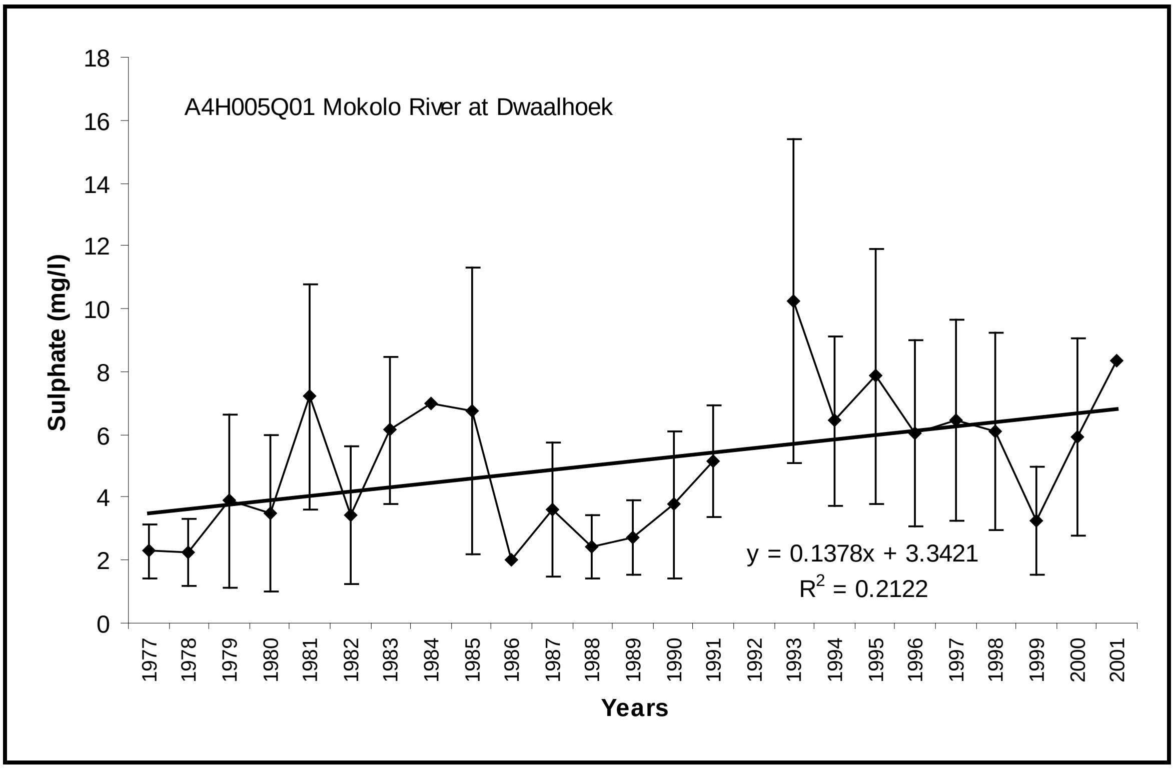

A4H002Q01 Mokolo River at Zandrivier/Vaalwater
Electrical conductivity (ms)
Years
y = 0.0881x + 7.6973
R2 = 0.1428
20
18
16
14
12
10
8
6
4
2
0
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007

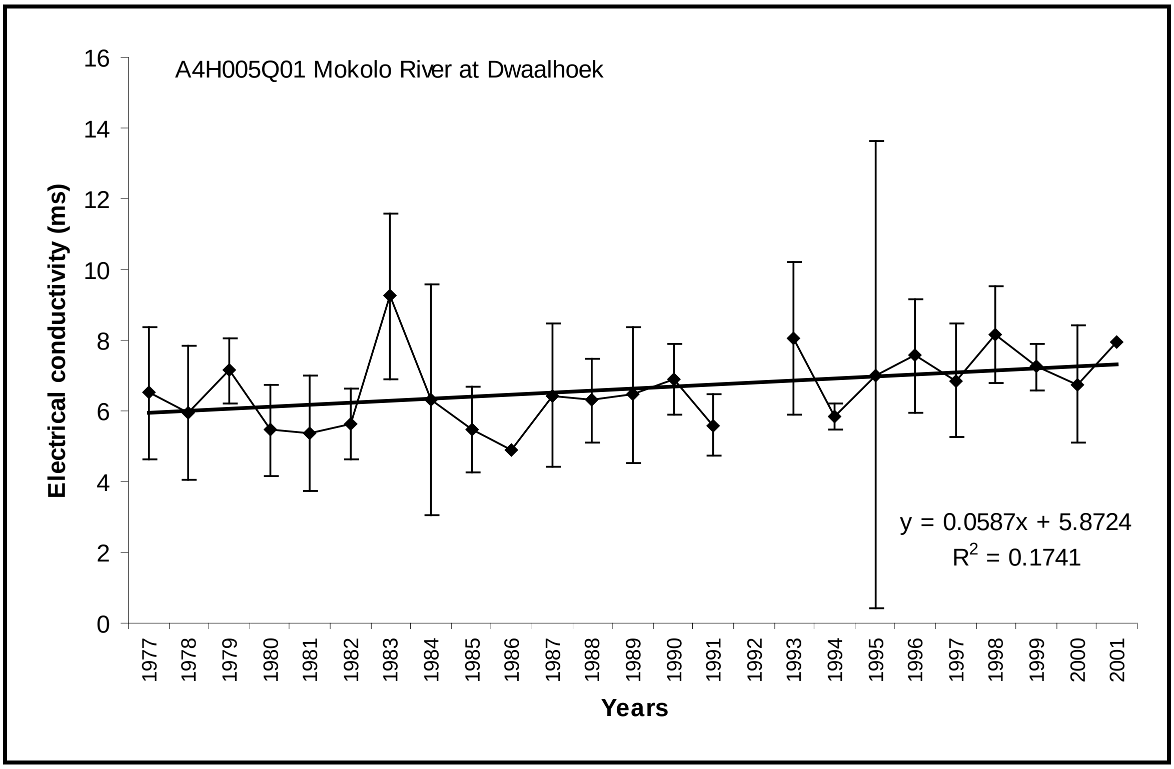

A4H005Q01 Mokolo River at Dwaalhoek
Total inorganic nitrogen-nitrogen (mg/l)
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
y = -0.0004x + 0.078
R2 = 0.0151
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
Years

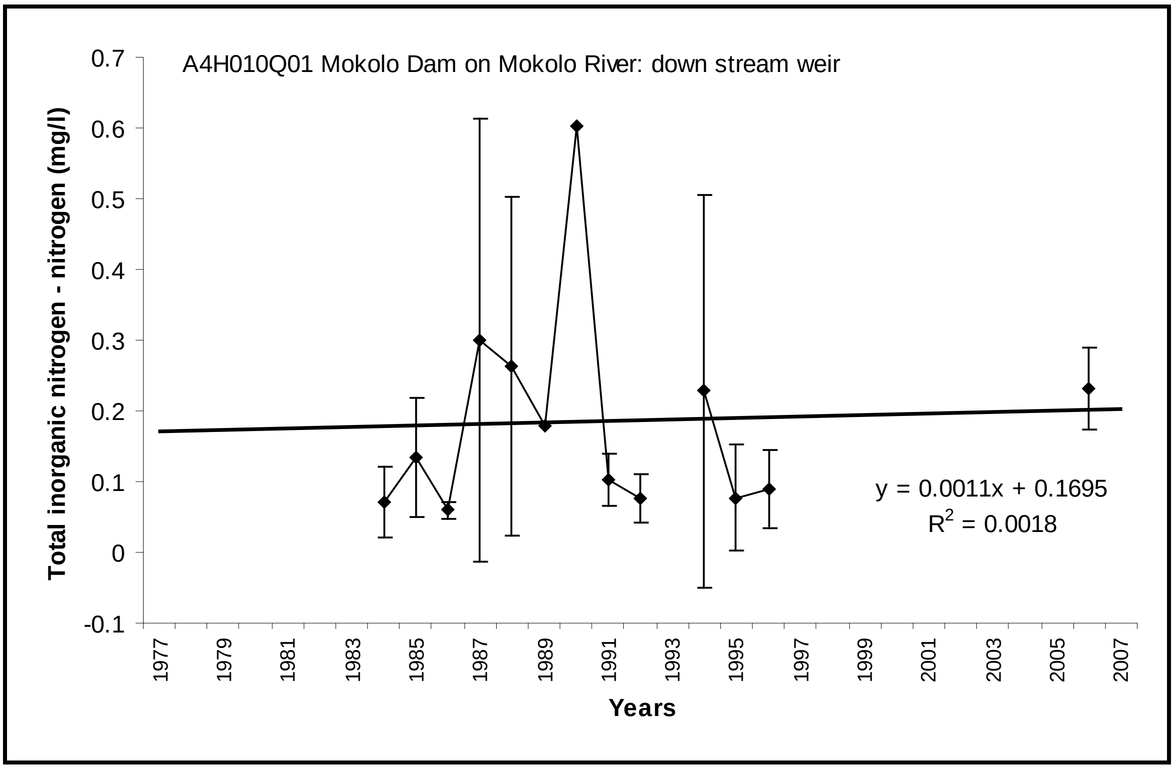

A4H005Q01 Mokolo River at Dwaalhoek
pH
14
12
10
8
6
4
2
0
y = 0.0512x + 6.3663
R2 = 0.6006
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
Years

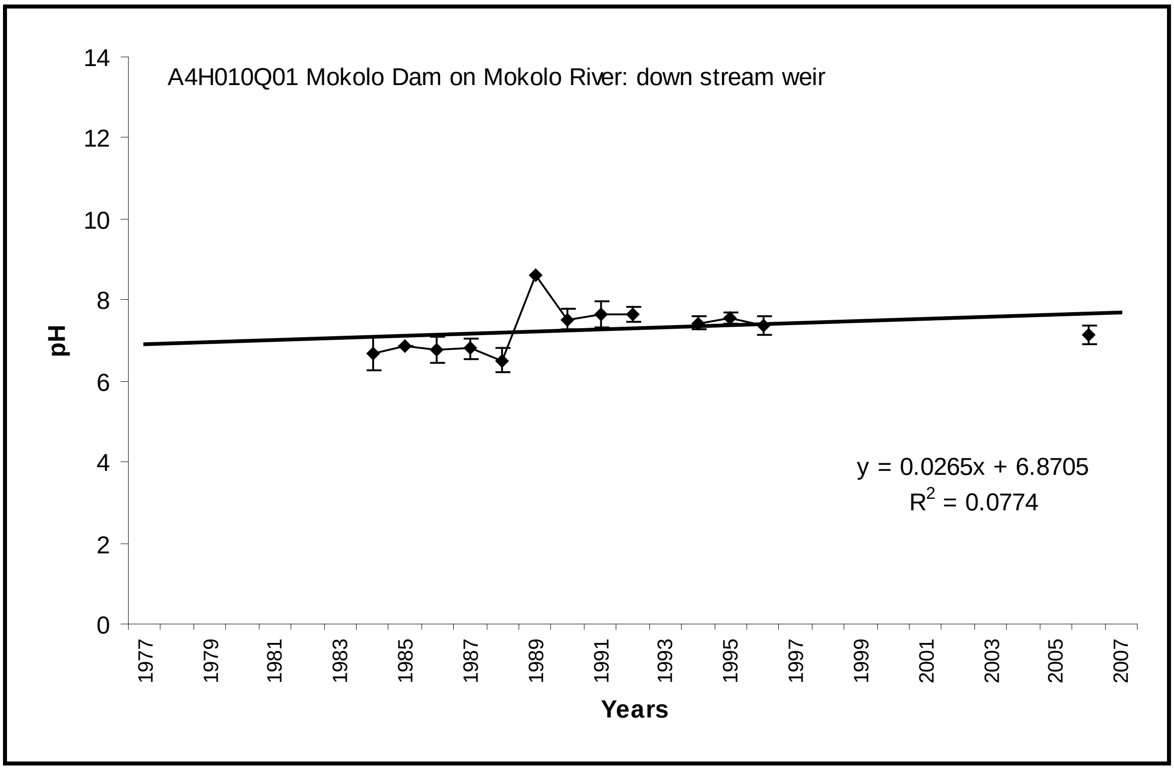

A4H005Q01 Mokolo River at Dwaalhoek
Temperature (°C)
Years
y = -0.1124x + 22.836
R2 = 0.0271
35
30
25
20
15
10
5
0
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

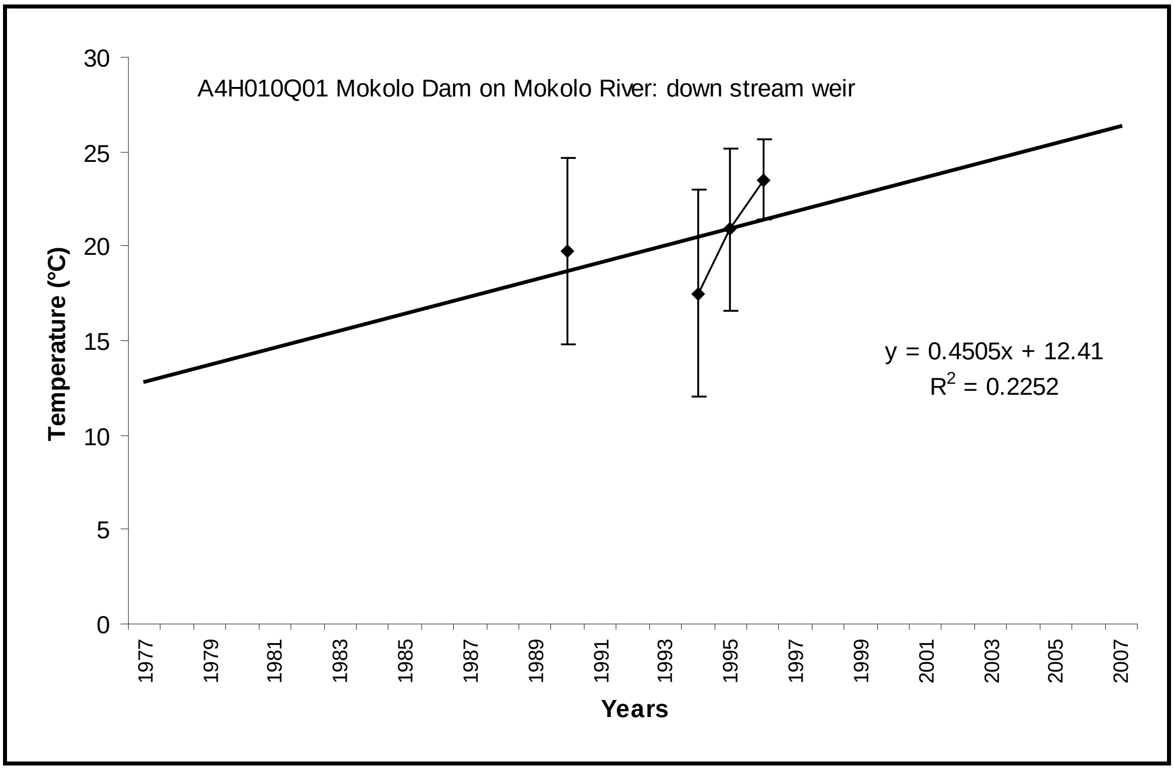

A4H005Q01 Mokolo River at Dwaalhoek
Phosphates - P (mg/l)
Years
y = 0.0003x + 0.0087
R2 = 0.165
0.05
0.04
0.03
0.02
0.01
0
-0.01
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

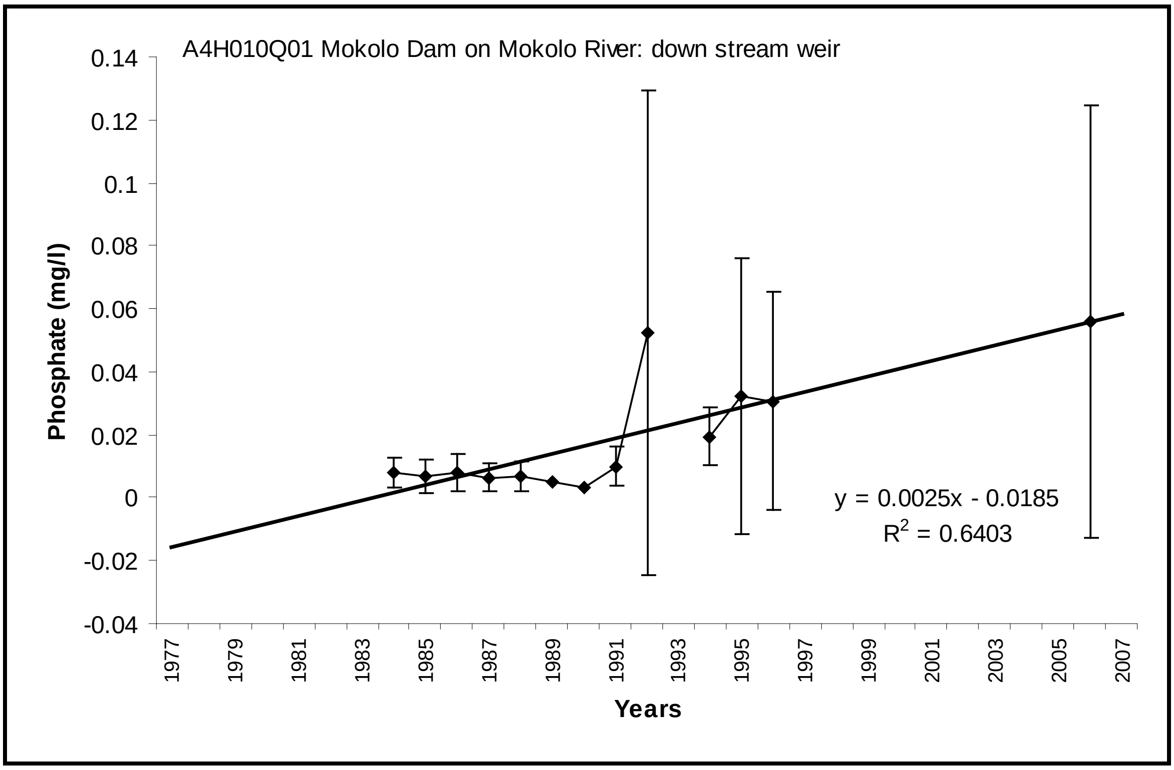

A4H005Q01 Mokolo River at Dwaalhoek
Sulphate (mg/l)
Years
y = 0.1378x + 3.3421
R2 = 0.2122

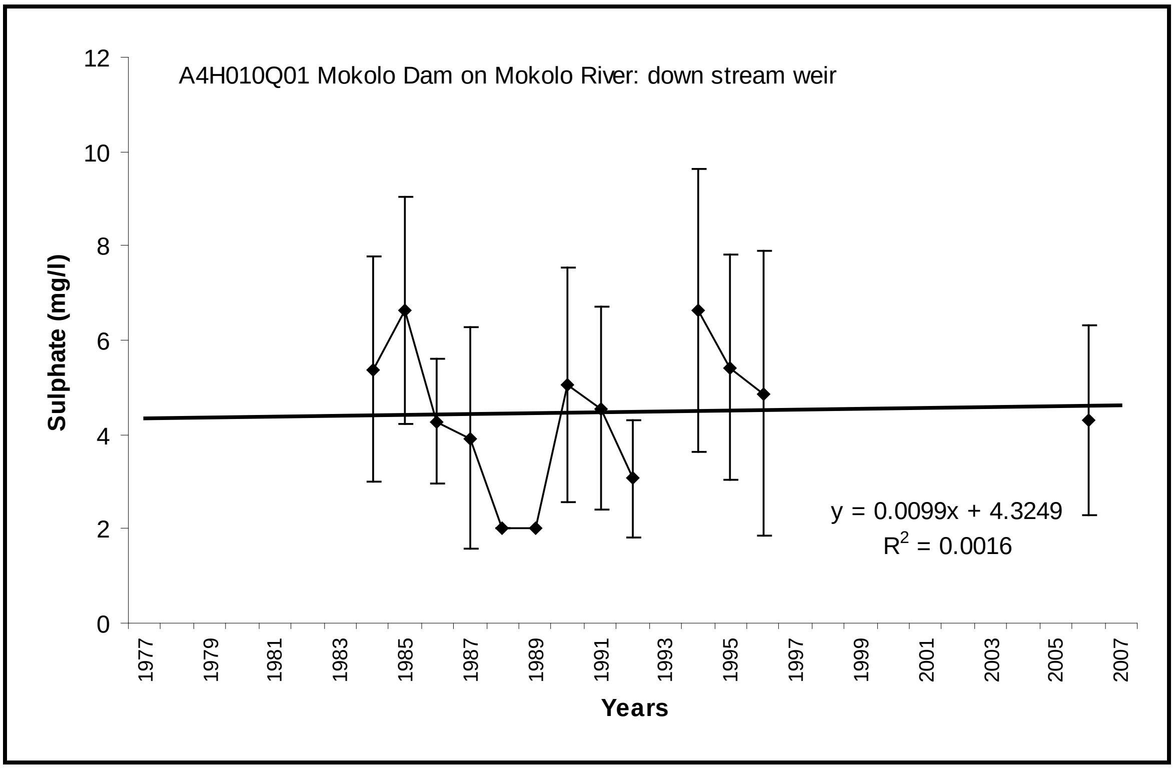

A4H005Q01 Mokolo River at Dwaalhoek
Electrical conductivity (ms)
Years
y = 0.0587x + 5.8724
R2 = 0.1741

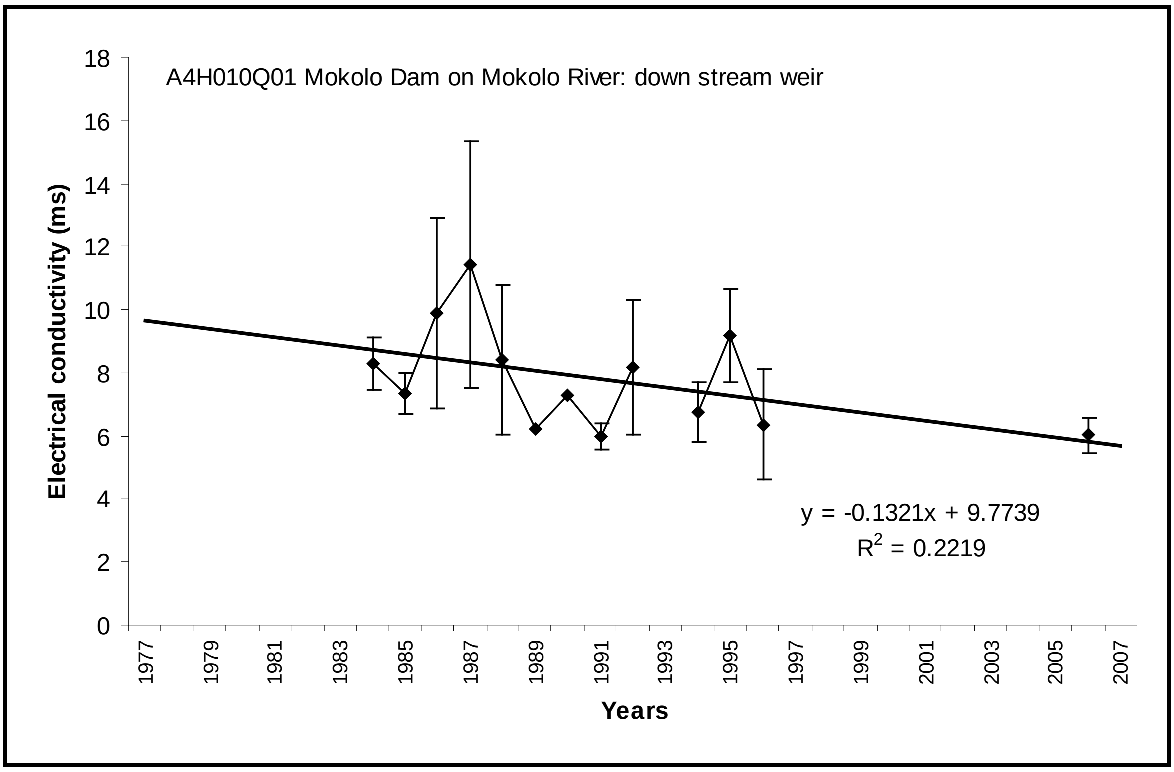

A4H010Q01 Mokolo Dam on Mokolo River: down stream weir
Total inorganic nitrogen - nitrogen (mg/l)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
Years
y = 0.0011x + 0.1695
R^2 = 0.0018

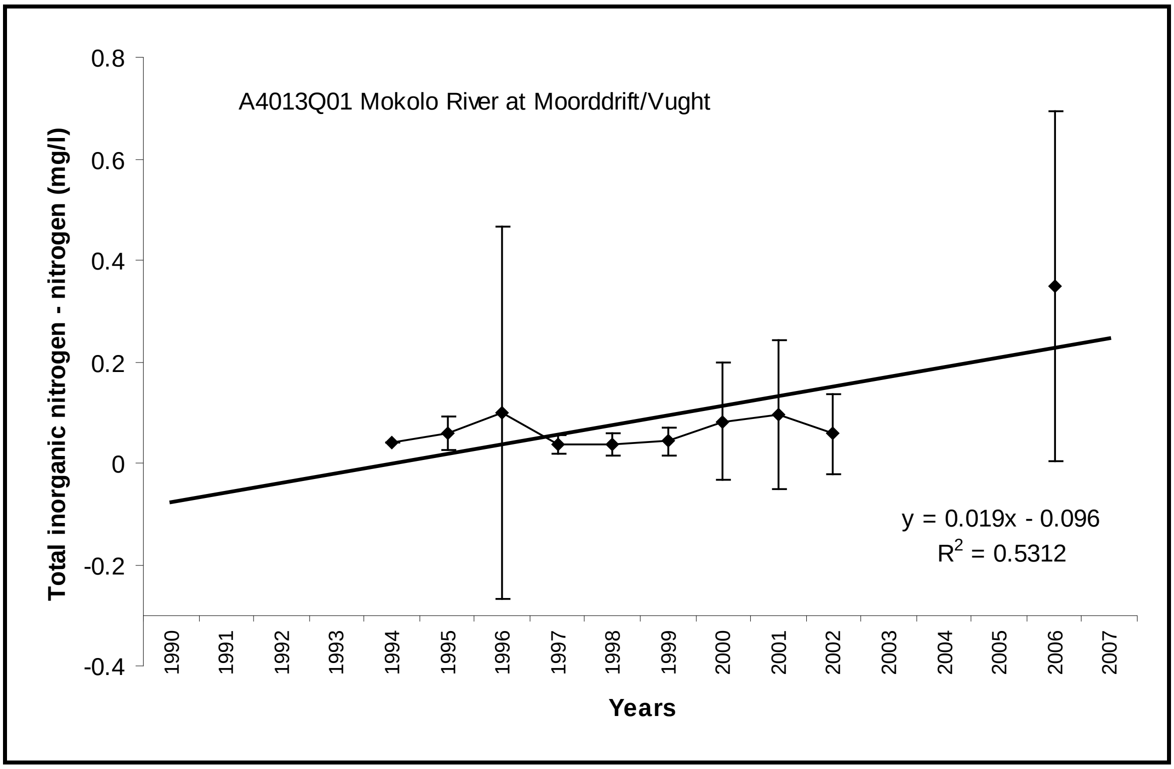

A4H010Q01 Mokolo Dam on Mokolo River: down stream weir
pH
14
12
10
8
6
4
2
0
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
Years
y = 0.0265x + 6.8705
R^2 = 0.0774

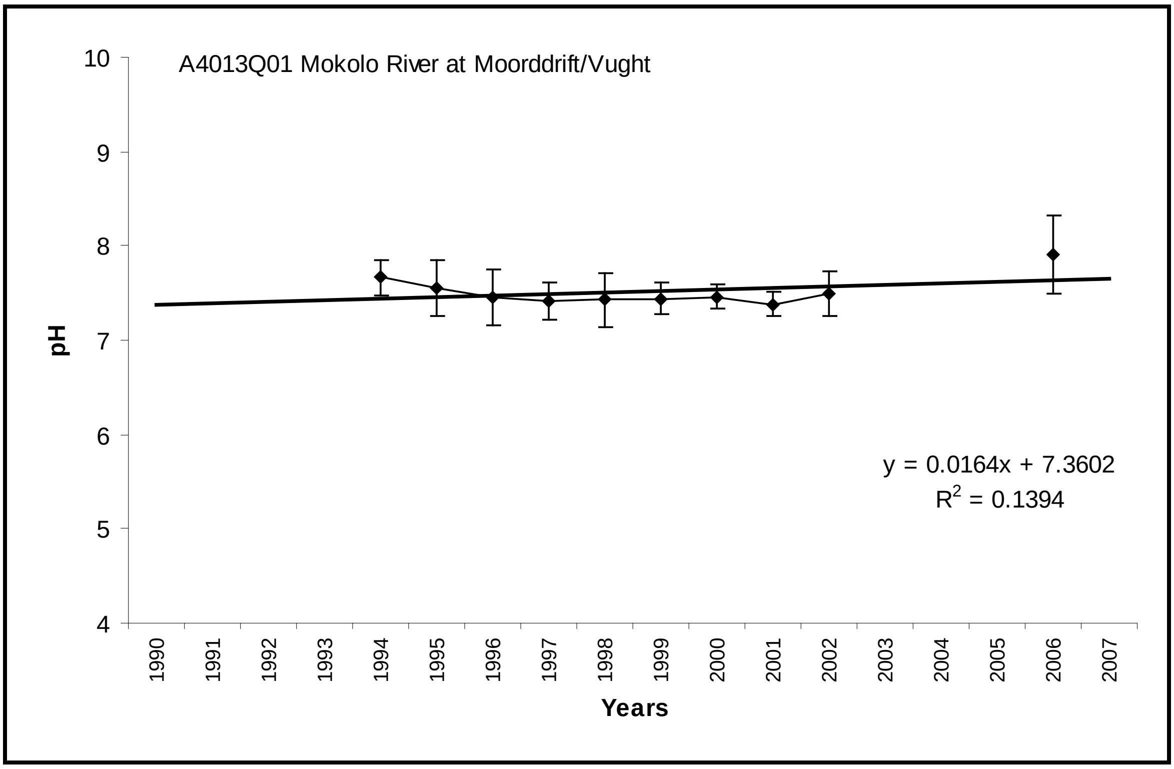

A4H010Q01 Mokolo Dam on Mokolo River: down stream weir
Temperature (°C)
Years
y = 0.4505x + 12.41
R2 = 0.2252
0
5
10
15
20
25
30
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007

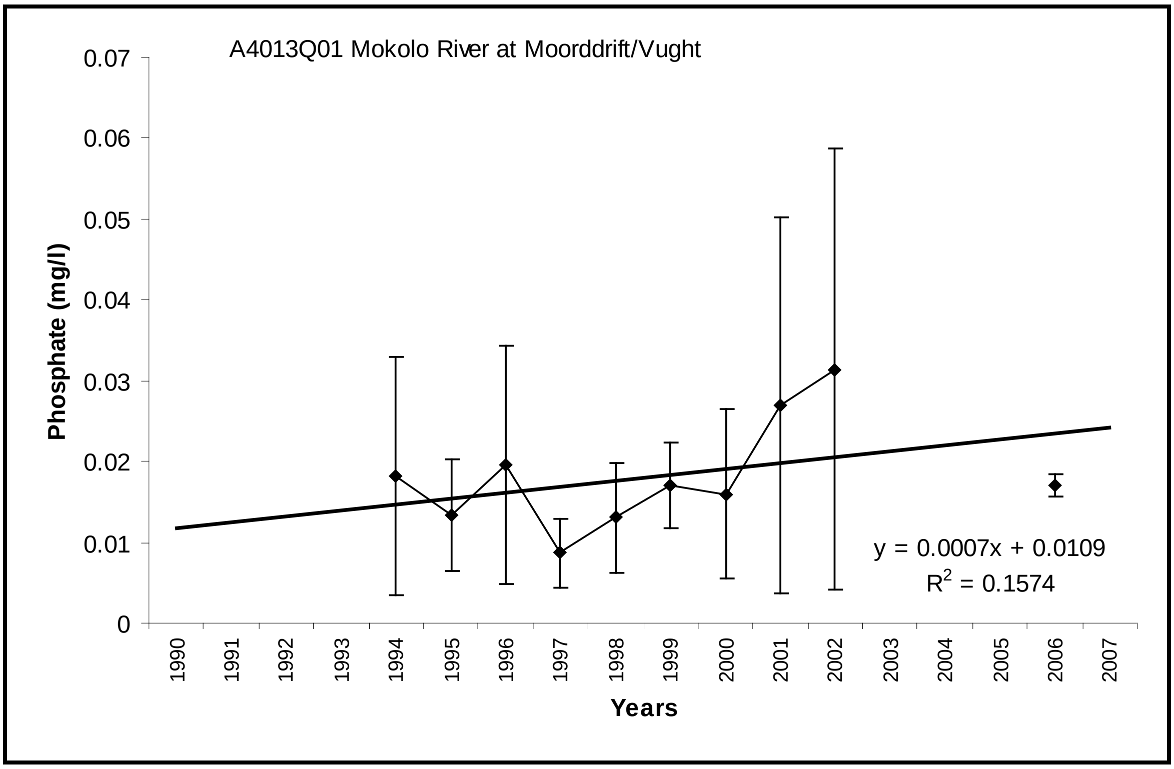

A4H010Q01 Mokolo Dam on Mokolo River: down stream weir
Phosphate (mg/l)
Years
y = 0.0025x - 0.0185
R2 = 0.6403
-0.04
-0.02
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007

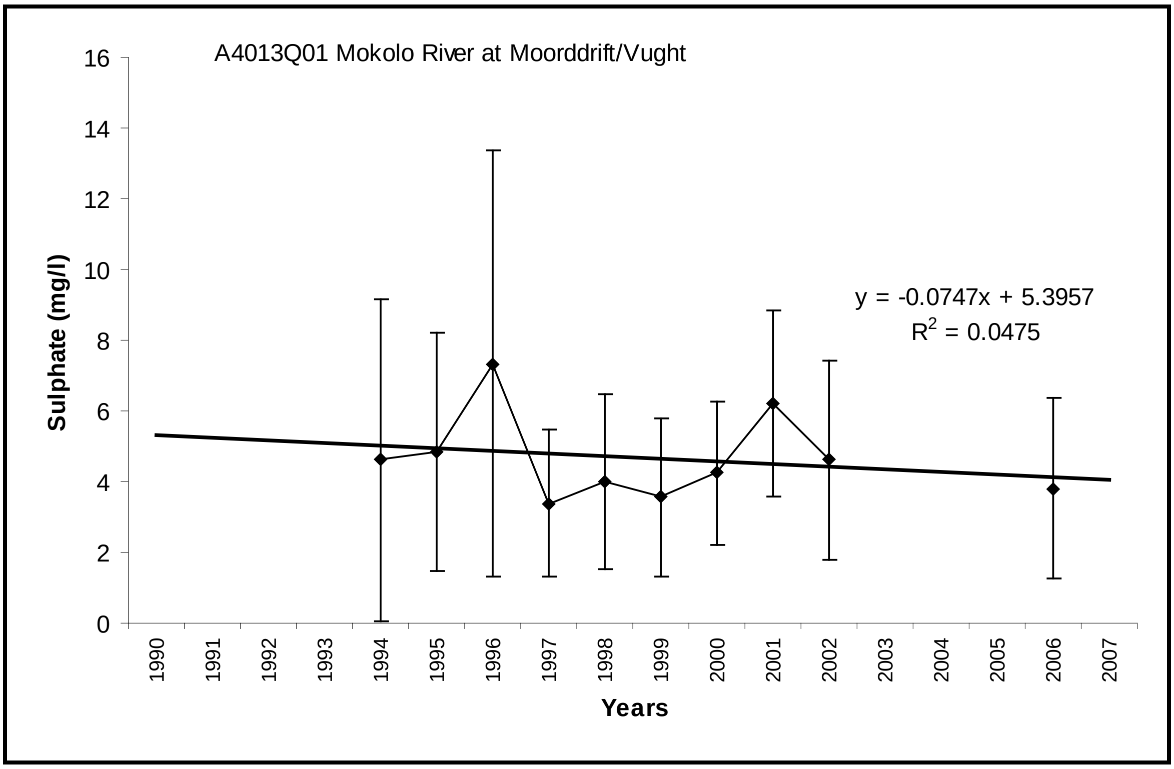

A4H010Q01 Mokolo Dam on Mokolo River: down stream weir
Sulphate (mg/l)
Years
y = 0.0099x + 4.3249
R^2 = 0.0016

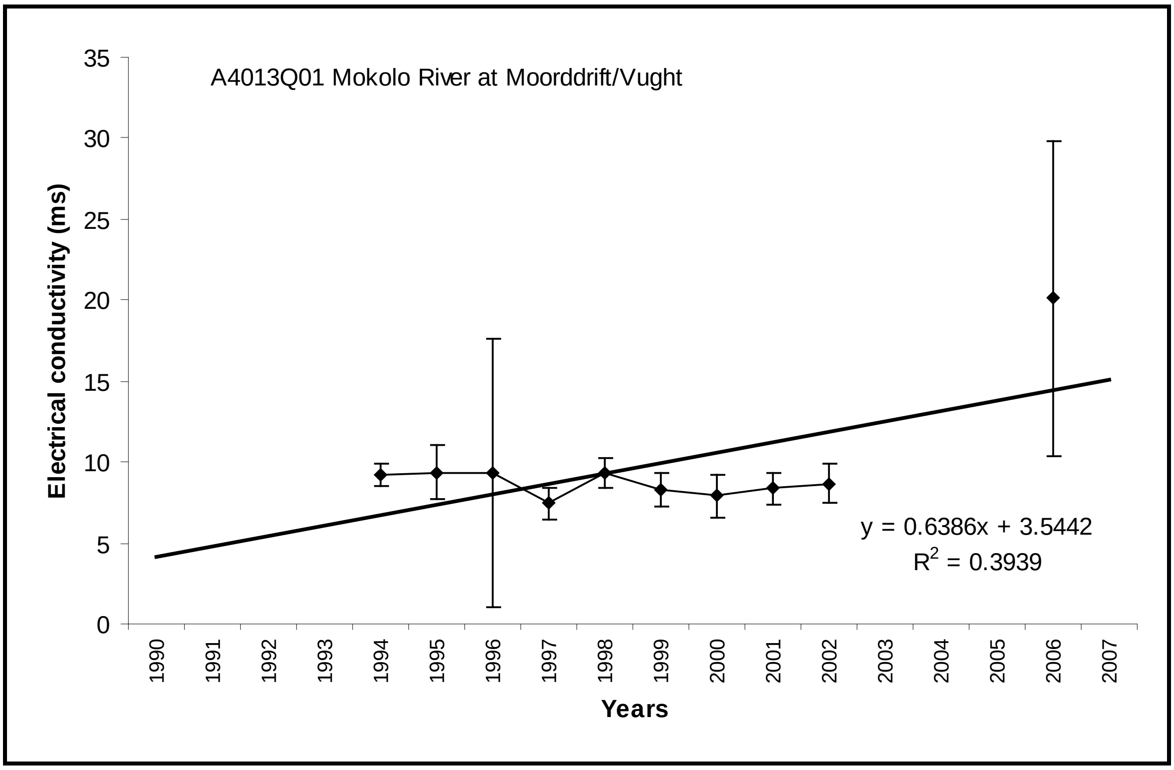

A4H010Q01 Mokolo Dam on Mokolo River: down stream weir
Electrical conductivity (ms)
Years
y = -0.1321x + 9.7739
R^2 = 0.2219

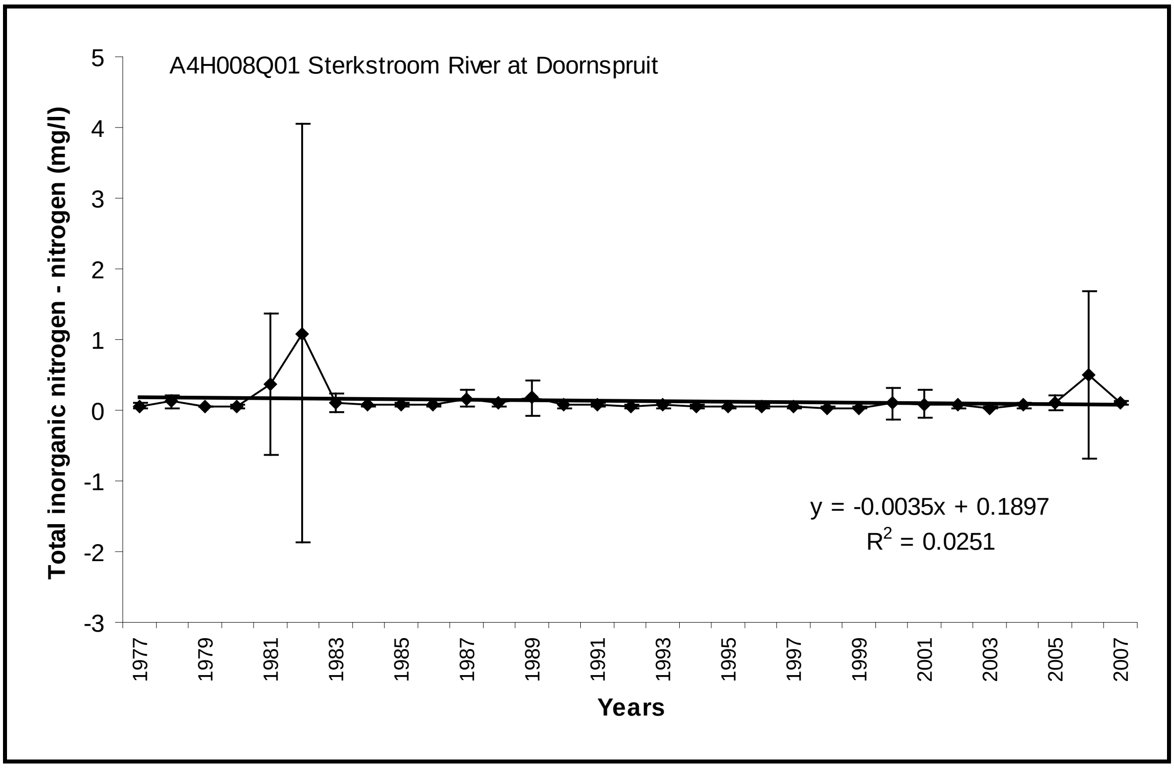

A4013Q01 Mokolo River at Moorddrift/Vught
Total inorganic nitrogen - nitrogen (mg/l)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Years
y = 0.019x - 0.096
R2 = 0.5312

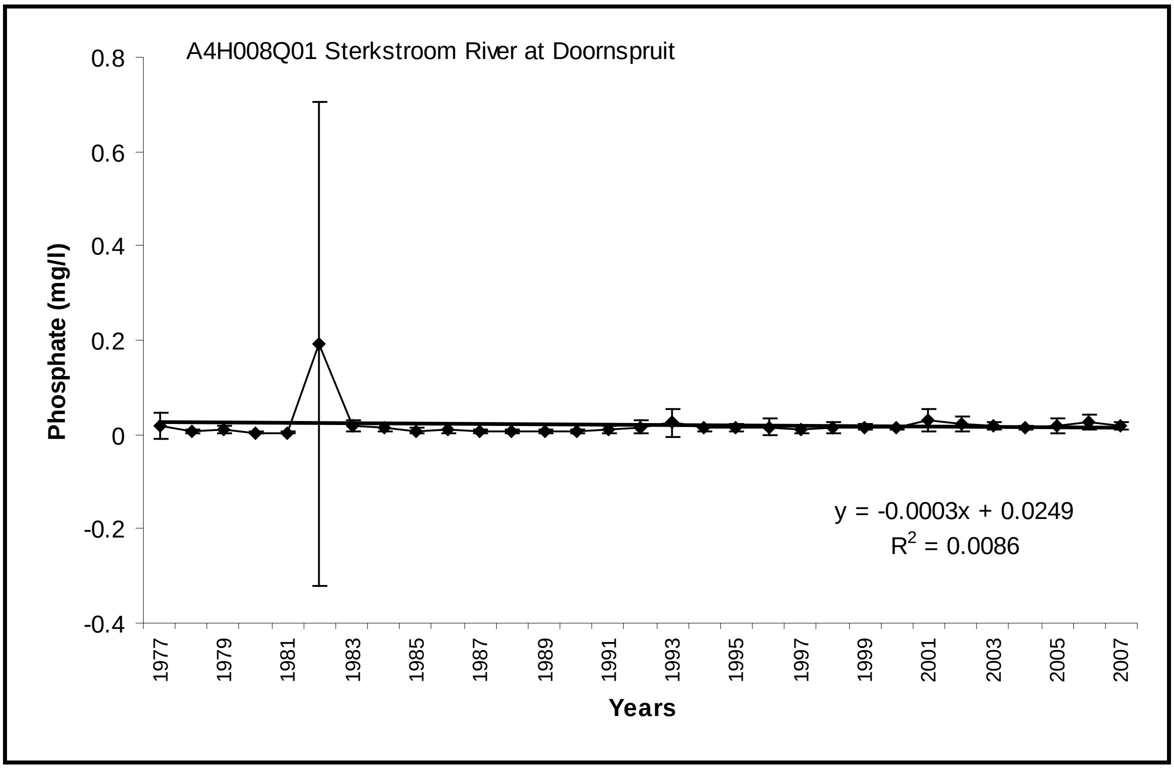

A4013Q01 Mokolo River at Moorddrift/Vught
pH
10
9
8
7
6
5
4
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Years
y = 0.0164x + 7.3602
R2 = 0.1394

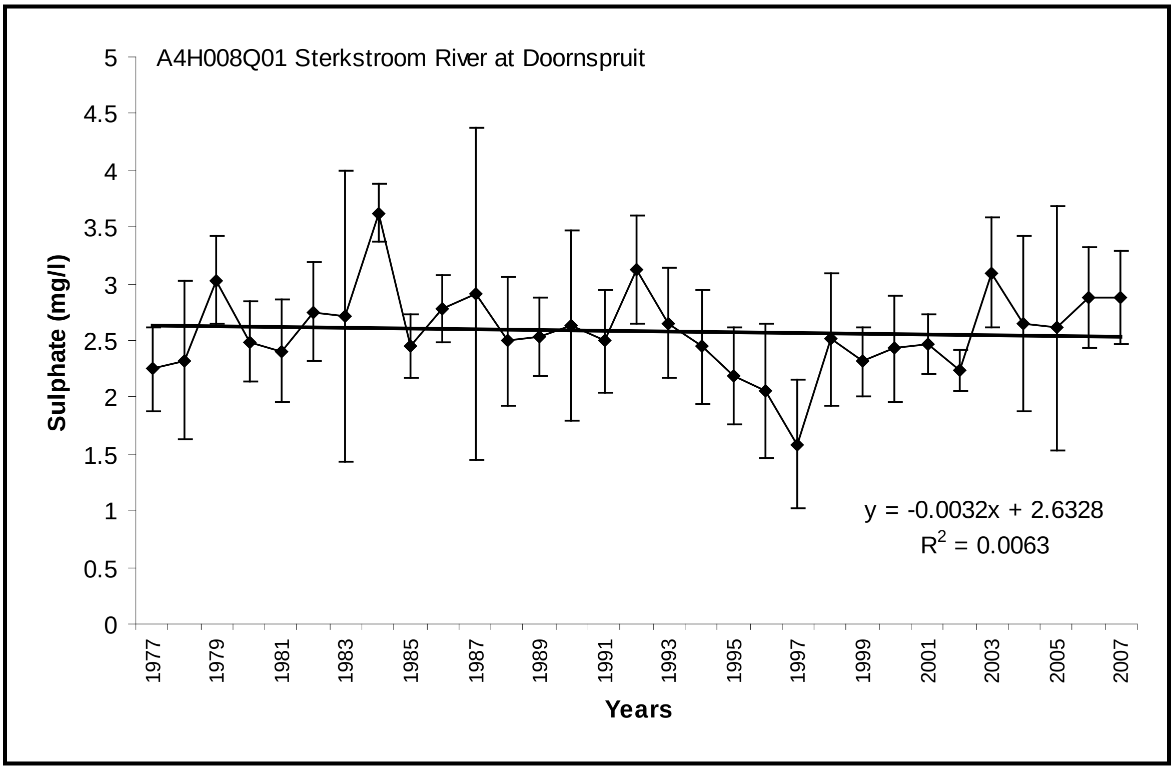

A4013Q01 Mokolo River at Moorddrift/Vught
Phosphate (mg/l)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Years
y = 0.0007x + 0.0109
R^2 = 0.1574

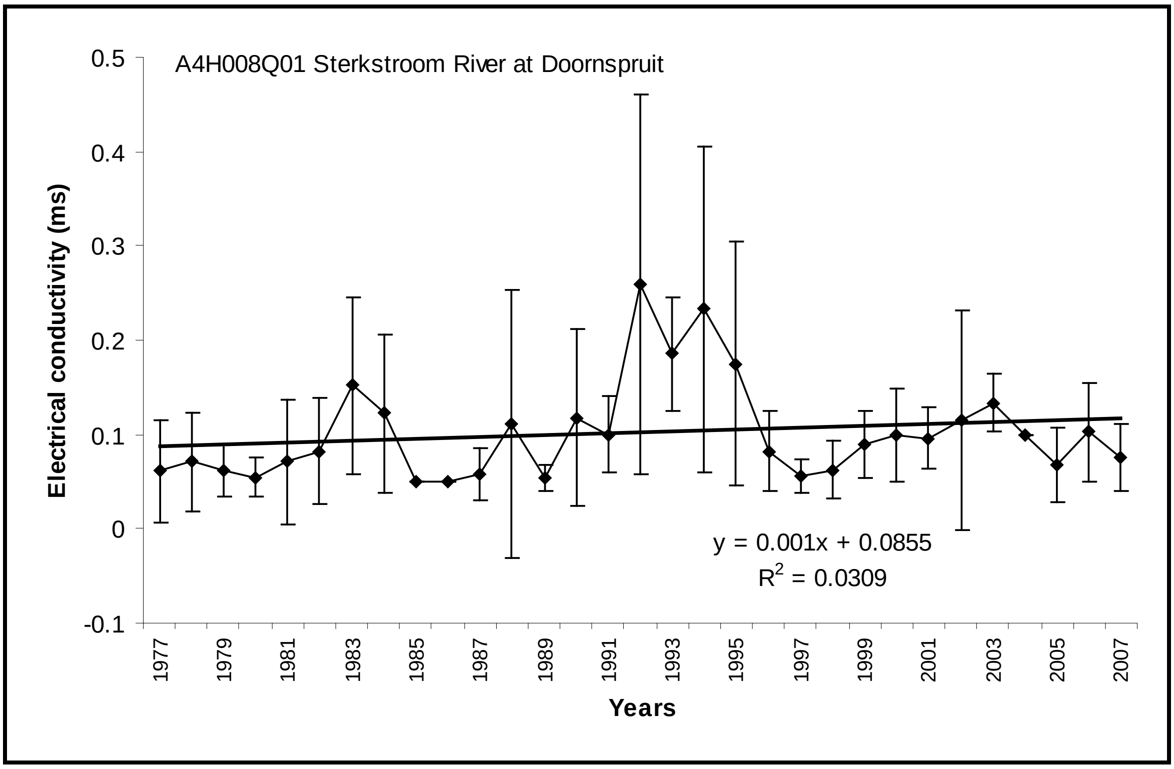

A4013Q01 Mokolo River at Moorddrift/Vught
Sulphate (mg/l)
16
14
12
10
8
6
4
2
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007
Years
y = -0.0747x + 5.3957
R^2 = 0.0475

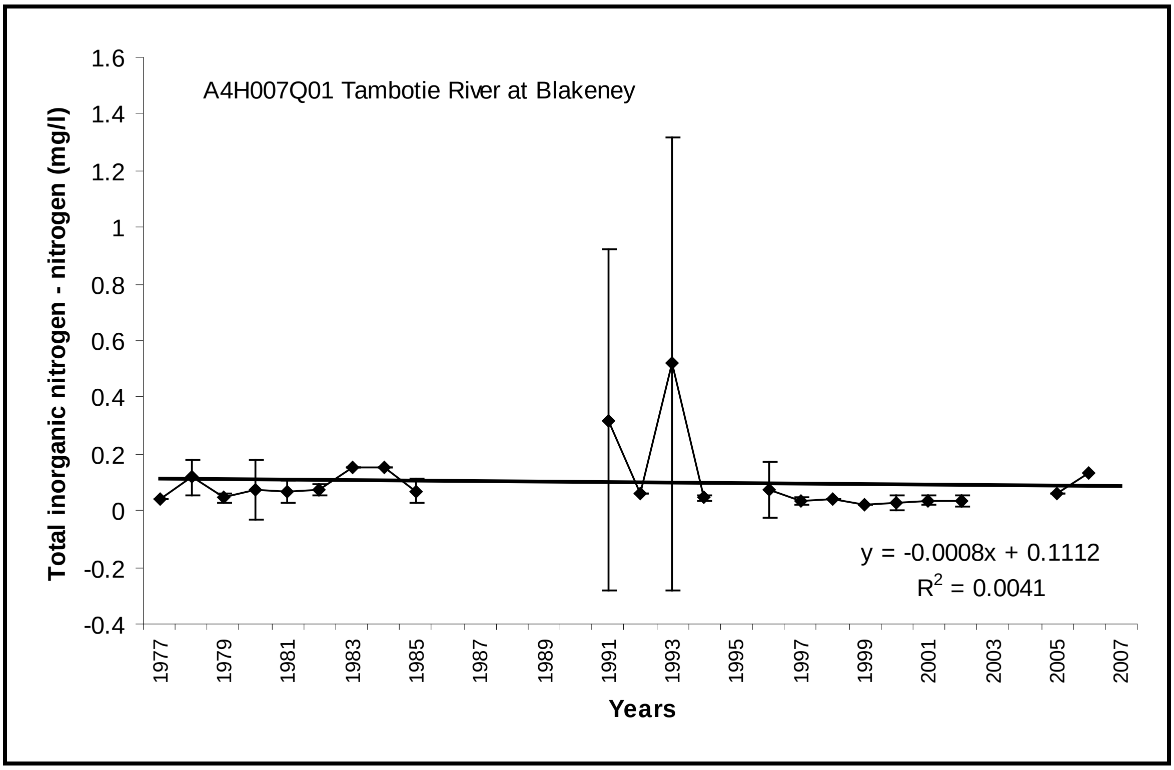

A4013Q01 Mokolo River at Moorddrift/Vught
Electrical conductivity (ms)
y = 0.6386x + 3.5442
R2 = 0.3939
Years
35
30
25
20
15
10
5
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007

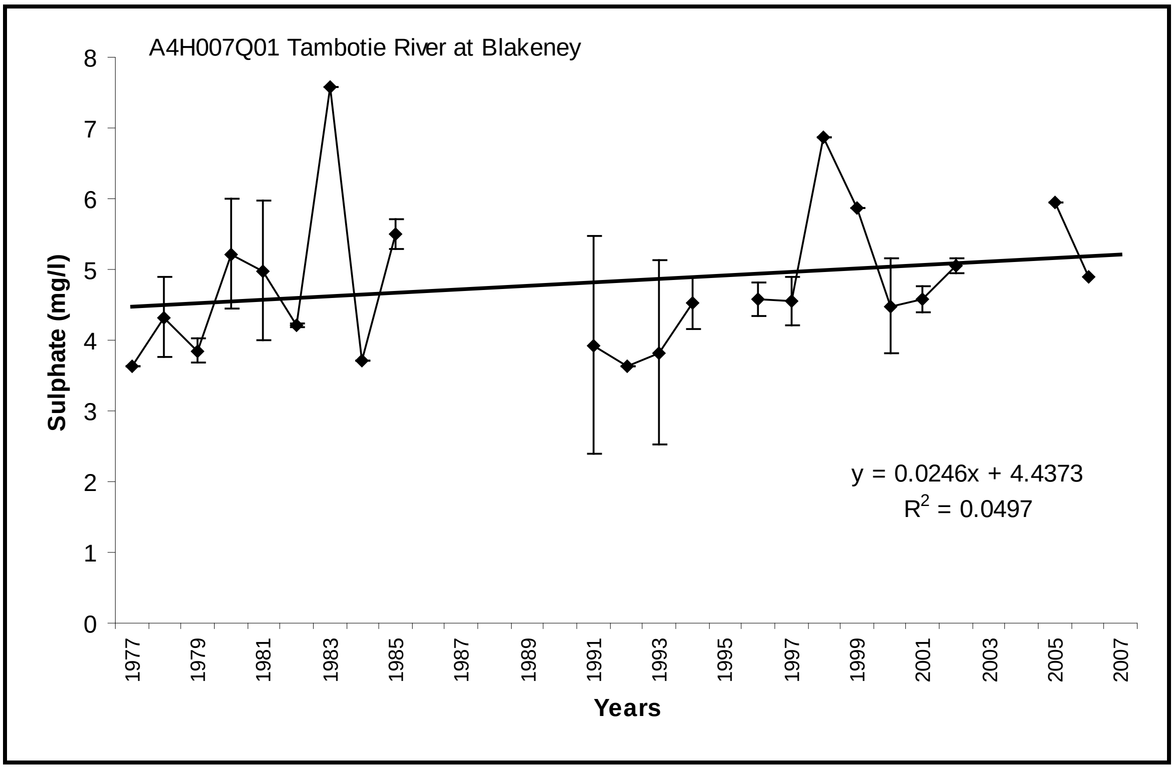

A4H008Q01 Sterkstroom River at Doornspruit
Total inorganic nitrogen - nitrogen (mg/l)
y = -0.0035x + 0.1897
R2 = 0.0251
Years
5
4
3
2
1
0
-1
-2
-3
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007

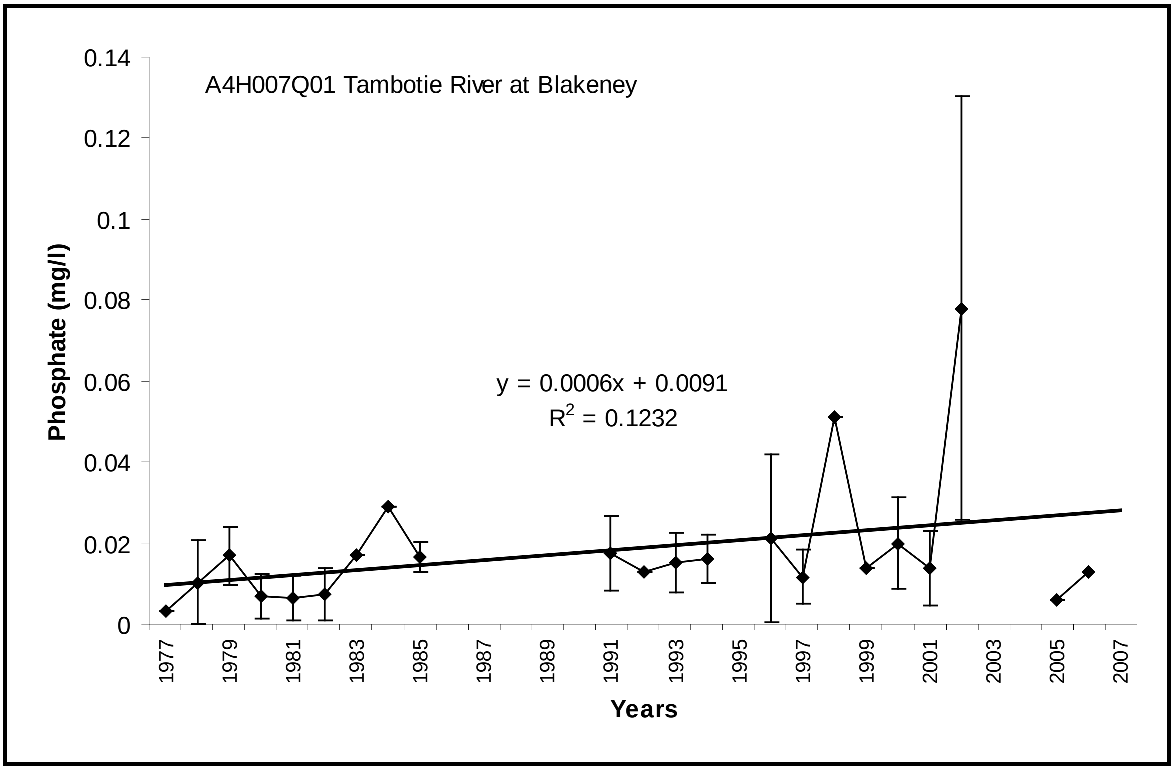

A4H008Q01 Sterkstroom River at Doornspruit
Phosphate (mg/l)
Years
y = -0.0003x + 0.0249
R^2 = 0.0086

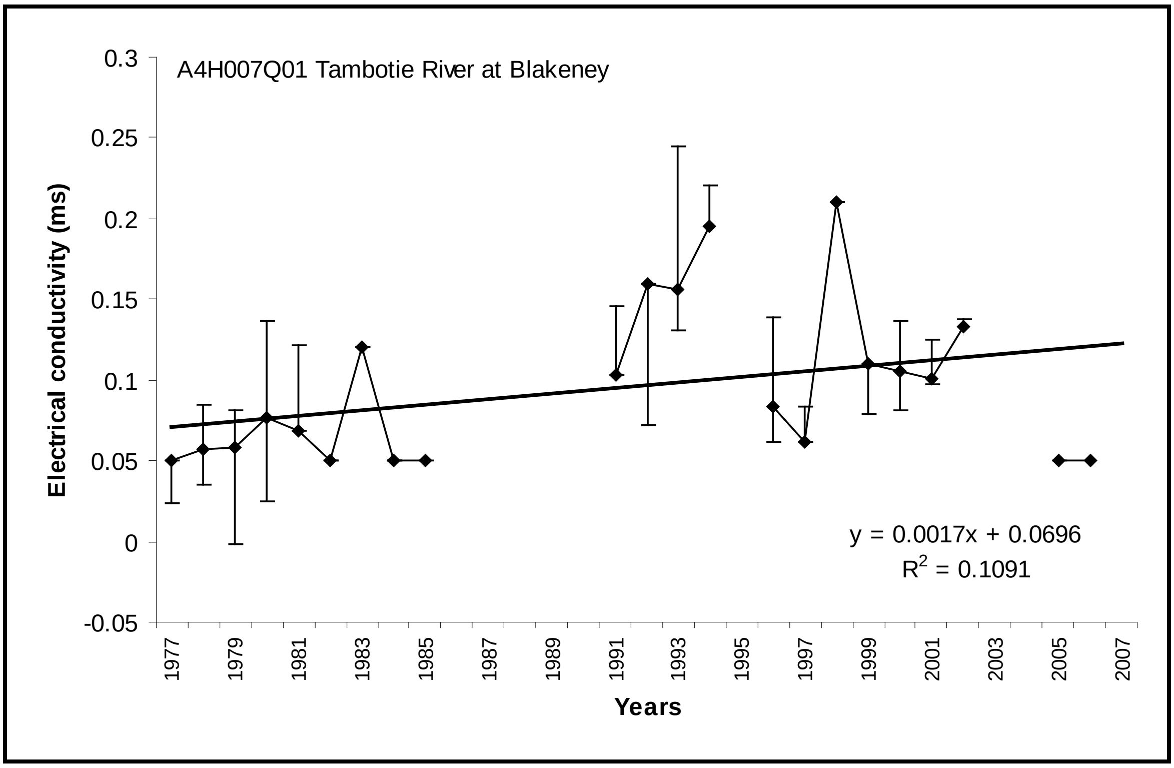

A4H008Q01 Sterkstroom River at Doornspruit
Sulphate (mg/l)
Years
y = -0.0032x + 2.6328
R^2 = 0.0063

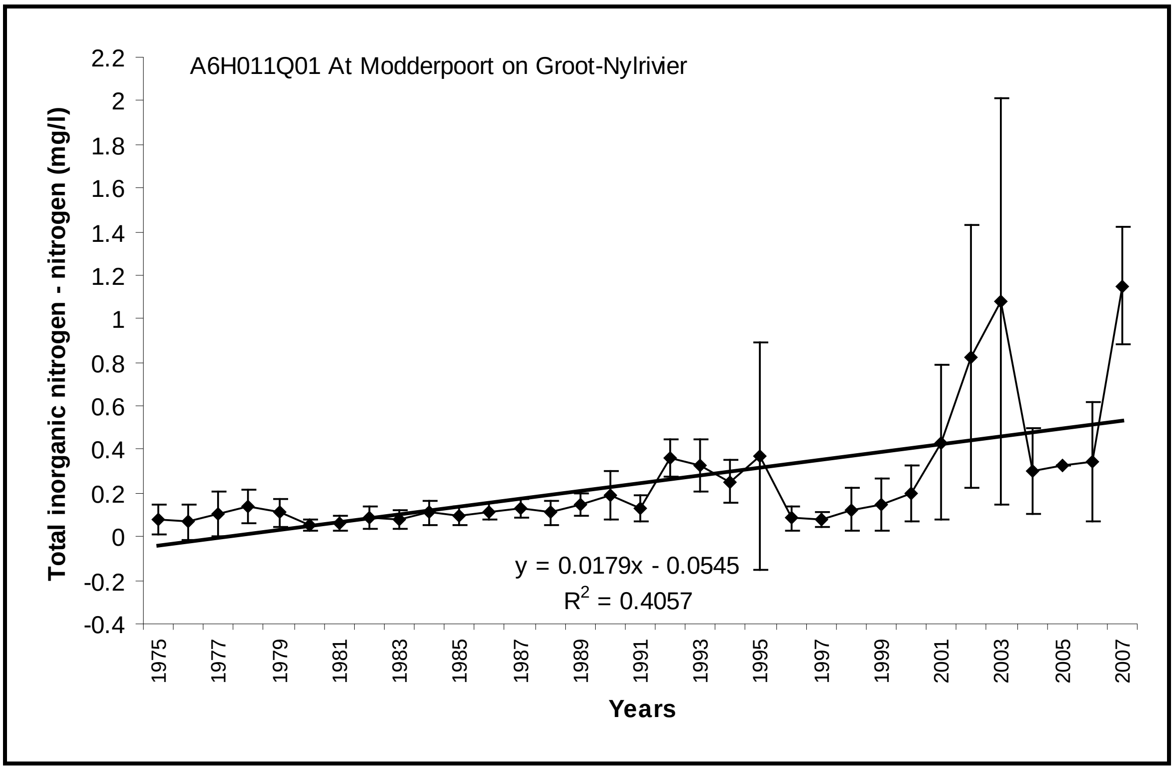

A4H008Q01 Sterkstroom River at Doornspruit
Electrical conductivity (ms)
Years
y = 0.001x + 0.0855
R2 = 0.0309

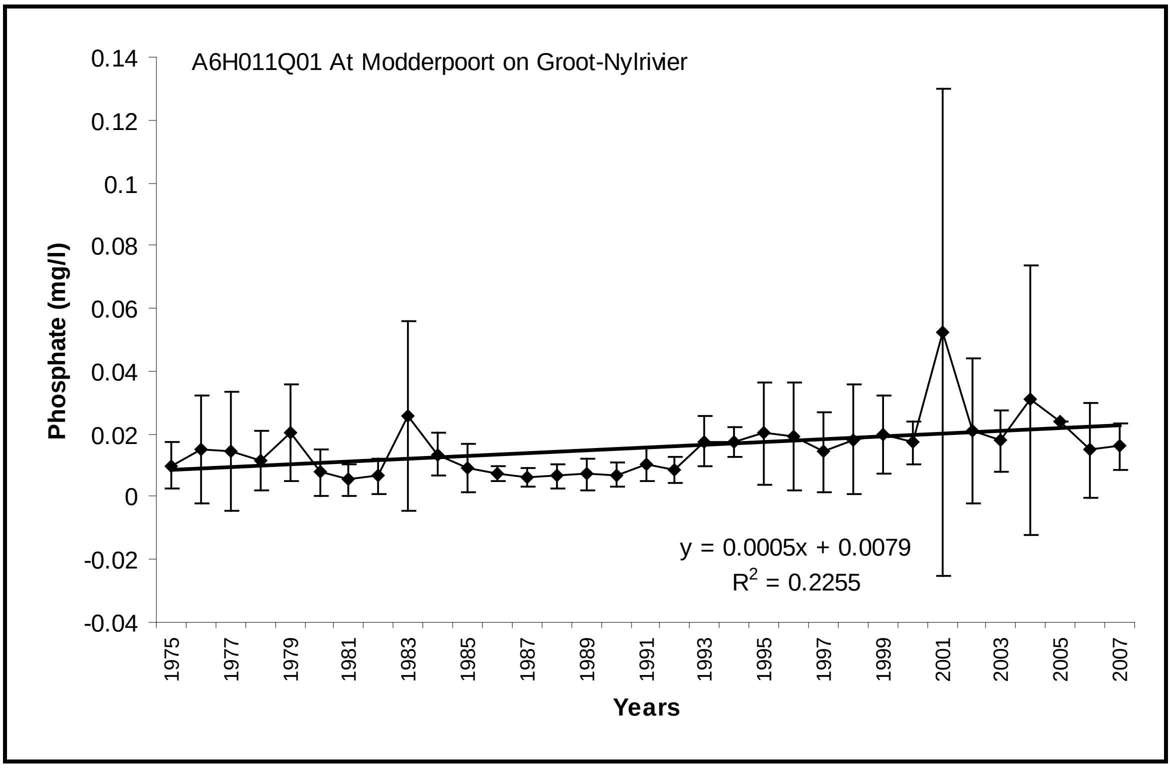

A4H007Q01 Tambotie River at Blakeney
Total inorganic nitrogen - nitrogen (mg/l)
Years
y = -0.0008x + 0.1112
R2 = 0.0041


A4H007Q01 Tambotie River at Blakeney
Sulphate (mg/l)
Years
y = 0.0246x + 4.4373
R2 = 0.0497
0
1
2
3
4
5
6
7
8
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007

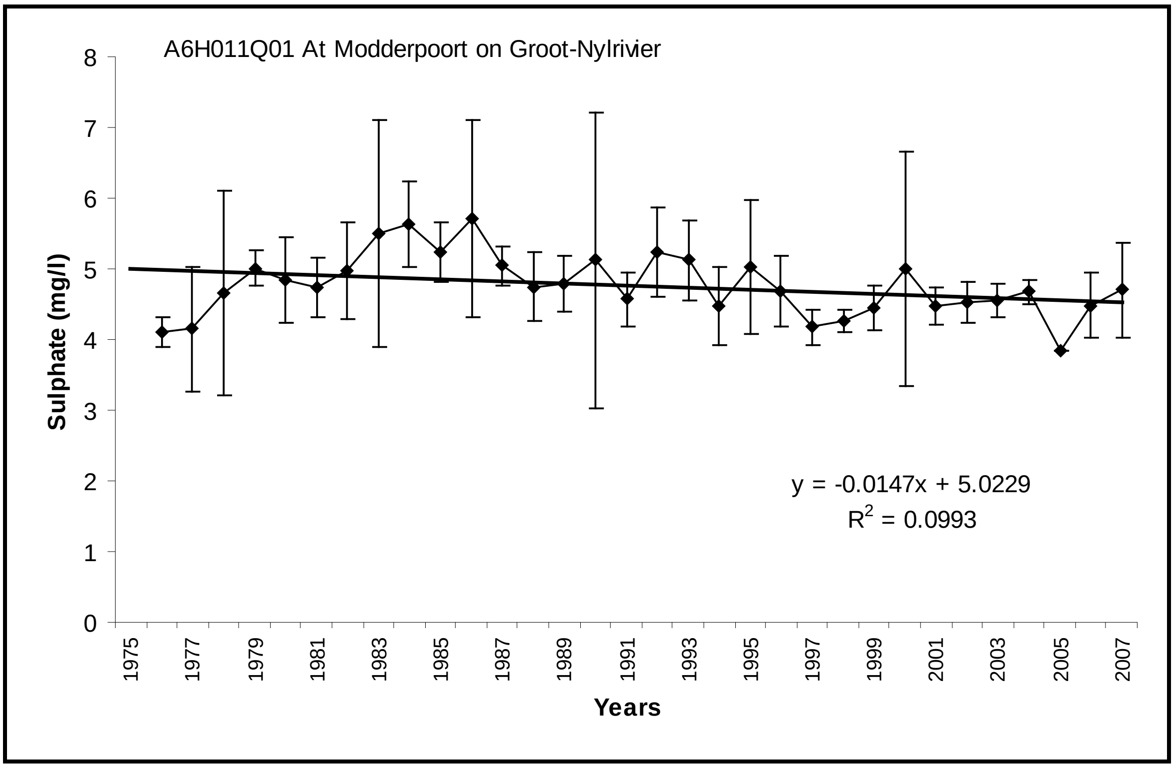

A4H007Q01 Tambotie River at Blakeney
Phosphate (mg/l)
Years
y = 0.0006x + 0.0091
R2 = 0.1232
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007


A4H007Q01 Tambotie River at Blakeney
Electrical conductivity (ms)
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
y = 0.0017x + 0.0696
R^2 = 0.1091
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
Years

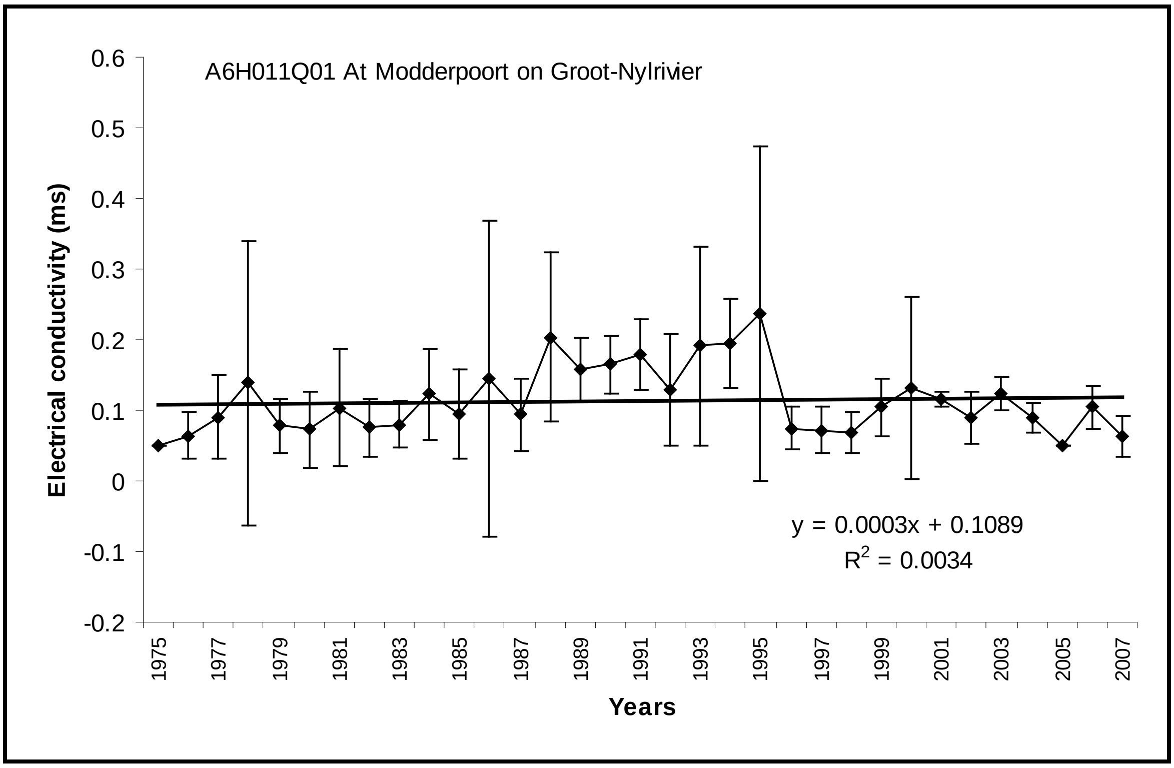

A6H011Q01 At Modderpoort on Groot-Nylrivier
Total inorganic nitrogen - nitrogen (mg/l)
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
y = 0.0179x - 0.0545
R^2 = 0.4057
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
Years

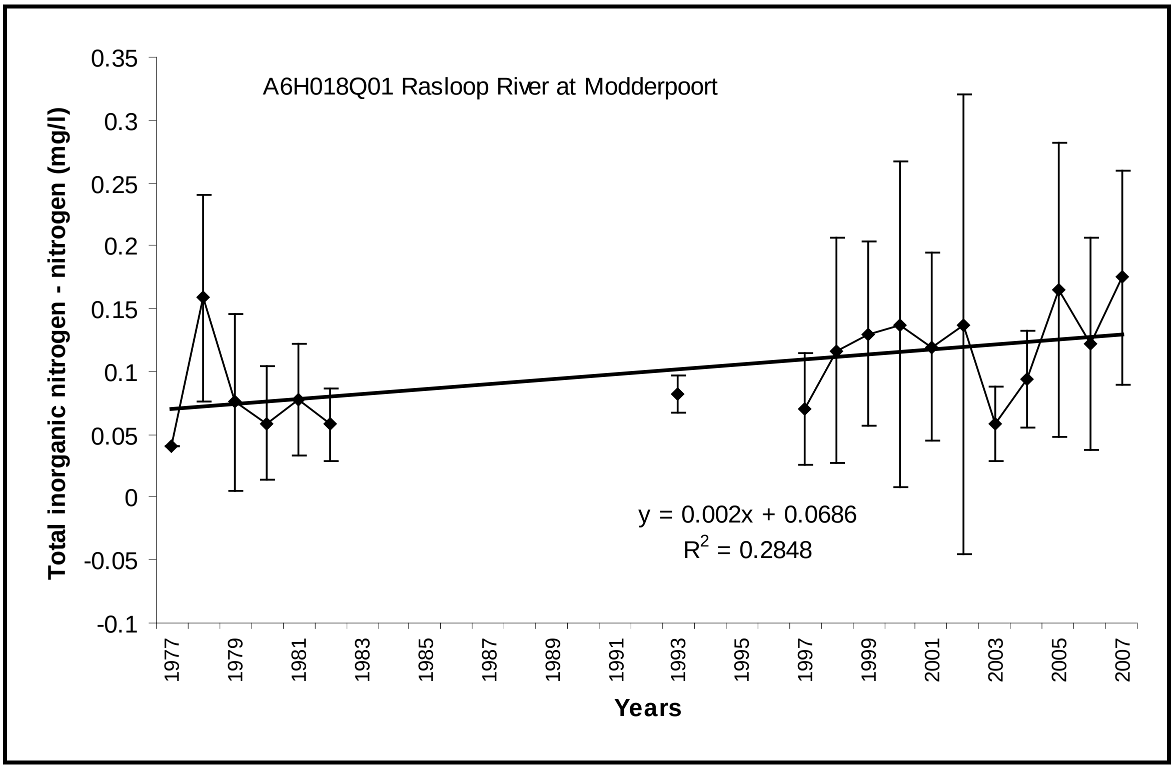


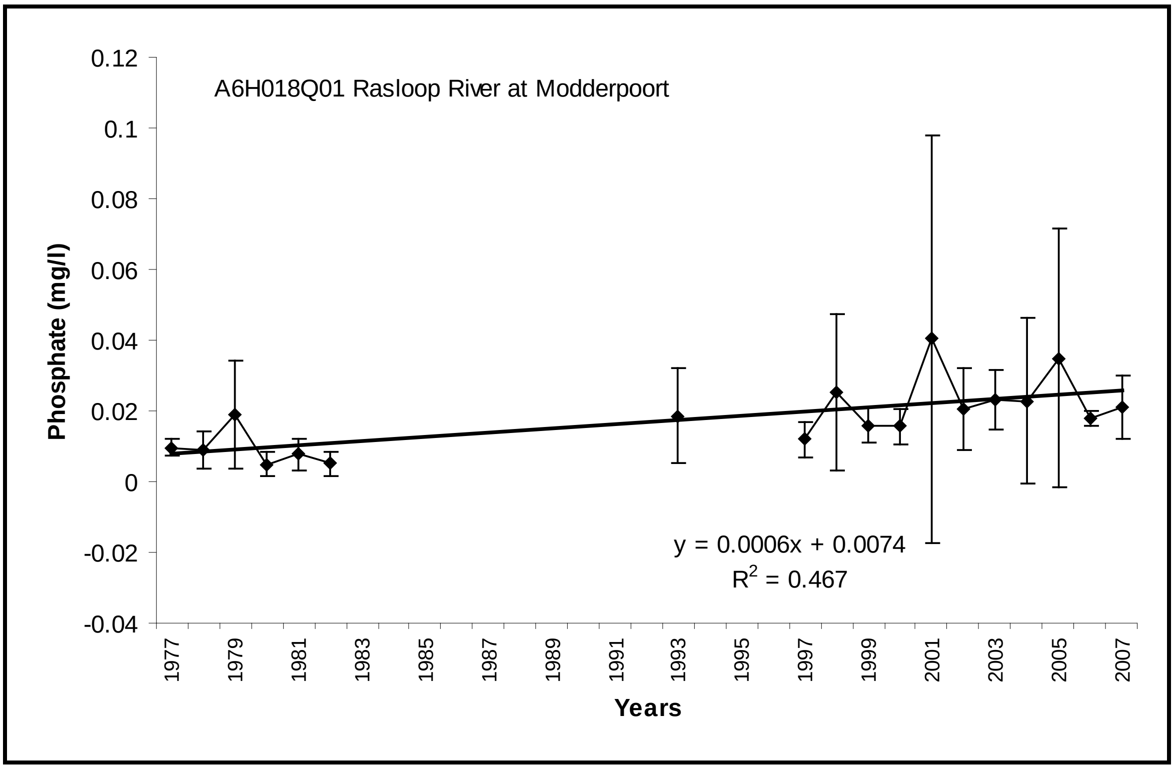
A6H011Q01 At Modderpoort on Groot-Nylrivier
Phosphate (mg/l)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
y = 0.0005x + 0.0079
R^2 = 0.2255
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
Years

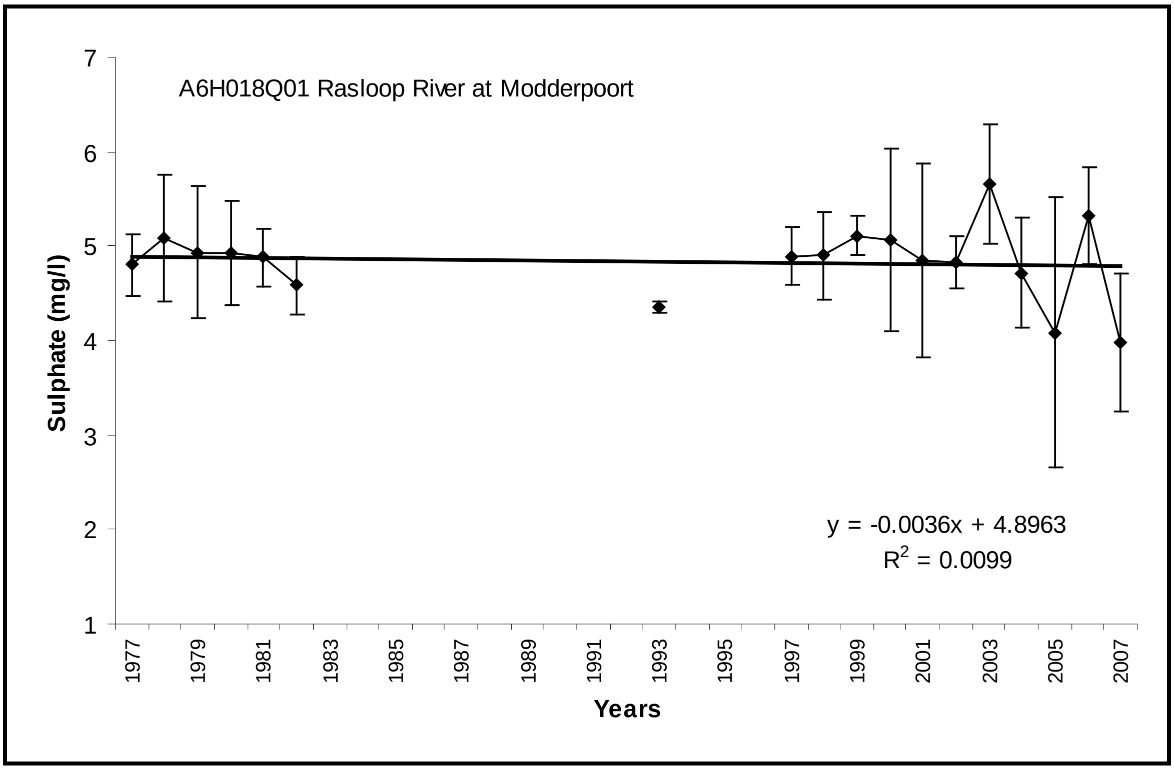


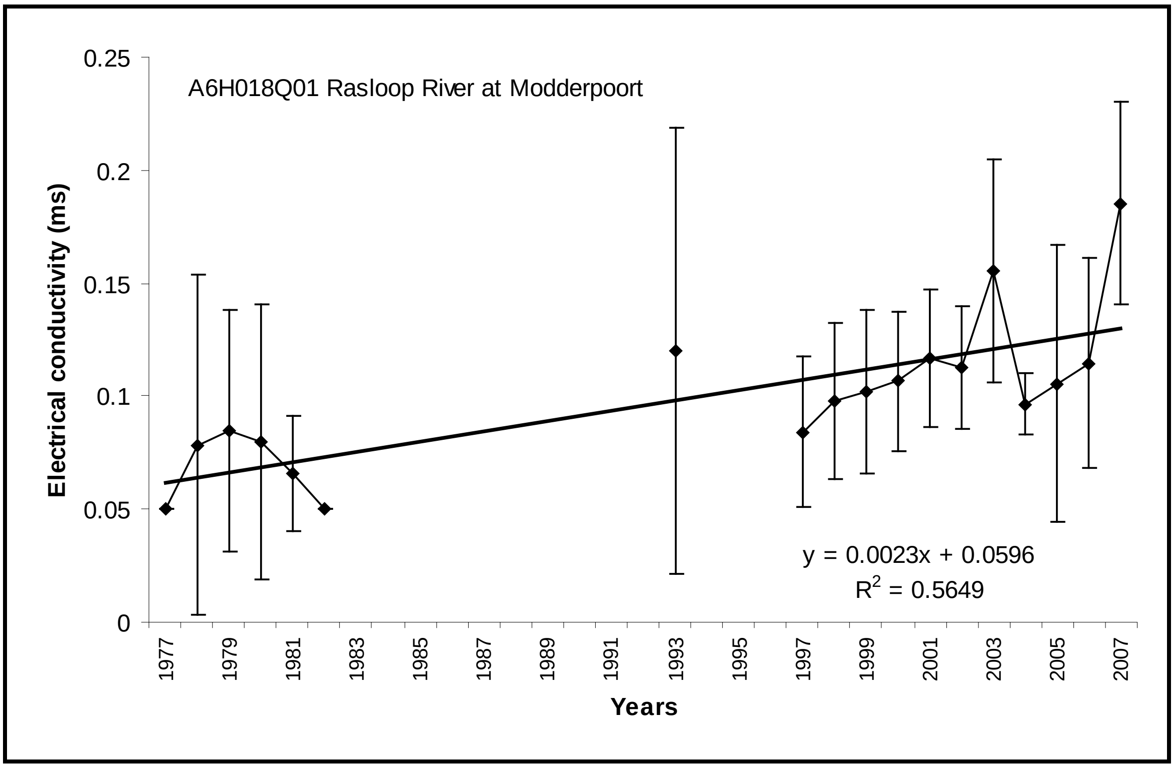
A6H011Q01 At Modderpoort on Groot-Nylrivier
Sulphate (mg/l)
8
7
6
5
4
3
2
1
0
y = -0.0147x + 5.0229
R^2 = 0.0993
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
Years


A6H011Q01 At Modderpoort on Groot-Nylrivier
Electrical conductivity (ms)
Years
y = 0.0003x + 0.1089
R2 = 0.0034


A6H018Q01 Rasloop River at Modderpoort
Total inorganic nitrogen - nitrogen (mg/l)
Years
y = 0.002x + 0.0686
R2 = 0.2848


A6H018Q01 Rasloop River at Modderpoort
Phosphate (mg/l)
Years
y = 0.0006x + 0.0074
R2 = 0.467


A6H018Q01 Rasloop River at Modderpoort
Sulphate (mg/l)
Years
y = -0.0036x + 4.8963
R2 = 0.0099


A6H018Q01 Rasloop River at Modderpoort
Electrical conductivity (ms)
0.25
0.2
0.15
0.1
0.05
0
y = 0.0023x + 0.0596
R2 = 0.5649
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
Years

D9 REFERENCES

Ashton, P.J., Love, D., Mahachi, H., and Dirks, P.H.G.M. 2001. *An Overview of the Impact of Mining and Mineral Processing Operations on Water Resources and Water Quality in the Zambezi, Limpopo and Olifants Catchments in Southern Africa.* Contract Report to the Mining, Minerals and Sustainable Development (SOUTHERN AFRICA) Project, by CSIREnvironmentek, Pretoria, South Africa and Geology Department, University of Zimbabwe, Harare, Zimbabwe. Report No. ENV-P-C 2001-042. xvi and 336 pp.

Department of Water Affairs and Forestry, South Africa (DWAF). 1996. *Water quality guidelines. Volume 7: Aquatic Ecosystems.* Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry, South Africa (DWAF). 2002. *Assessing water quality in Ecological Reserve determinations for rivers: Version 2, Draft 15.0, March 2002*. Department of Water Affairs and Forestry, Pretoria.

Department of Water Affairs and Forestry, South Africa (DWAF). 2004a. *Internal Strategic Perspective: Limpopo Water Management Area.* Prepared by Goba Moahloli Keeve Steyn (Pty) Ltd, in association with Tlou & Matji (Pty) Ltd and Golder Associates (Pty) Ltd. on behalf of the Directorate: National Water Resource Planning. Report No. P WMA 01/000/00/0304.

Department of Water Affairs and Forestry, South Africa (DWAF). 2004b. *Inclusion of electrical conductivity (EC) in water quality assessments within ecological Reserve determinations.* Report prepared for Department of Water Affairs and Forestry, Pretoria, South Africa

Department of Water Affairs and Forestry, South Africa (DWAF). 2008a. *Intermediate Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Limpopo Water Management Area, Mpumalanga. Mokolo River System: Resource Unit Delineation:* Prepared by Clean Stream Biological Services and Water for Africa, authored by Kotze PJ and Louw, MD. Report no. 26/8/3/10/14/006

Department of Water Affairs and Forestry, South Africa (DWAF). 2008b. *Methods for determining the Water Quality component of the Ecological Reserve.* Report prepared for Department of Water Affairs and Forestry, Pretoria, South Africa by Scherman Consulting

Kleynhans, C.J., Louw, M.D., Thirion, C., Rossouw, N. and Rowntree, K. 2005. *River Ecoclassification: Manual for Ecostatus Determination.* First draft for training purposes.

Midgley *et al*., 1999. Quoted in Chapter 4 of *Impacts of Mining and Minerals Processing on the Biophysical Environment in Southern Africa*. (Full reference could not be located).

Ninham Shand web-site: http://projects.shands.co.za/Hydro/hydro/WQReserve/main.htm.

Palmer, C.G., Muller, W.J. and Hughes, D.A. 2004. *Chapter 6: Water quality in the ecological Reserve. IN: SPATSIM, an integrating framework for ecological Reserve and implementation: incorporating water quality and quantity components for riv*ers. Hughes DA (Ed.) WRC Report No. 1160/1/04, Water Research Commission, Pretoria.

Pulles, W., Howie, D., Otto, D. and Easton, J. 1996. *A Manual on Mine Water Treatment and Management Practices in South Africa.* Appendix Volume 1: *Literature Reviews*. Water Research Commission Report No. 527/1/96.

River Health Programme (RHP). 2006. *State-of-Rivers Report: The Mokolo River.* Department of Environmental Affairs and Tourism, Pretoria. ISBN No. 978-0-620-38215-1.

Van Vuuren, L. 2006. *Economic boom strains water resource.* Prepared for the Water Wheel of December 2006.

APPENDIX E: DIATOM ANALYSIS AS AN ADDITIONAL PHYSICO-CHEMICAL RESPONS VARIABLE

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E1 BACKGROUND AND TERMINOLOGY

E1.1 BACKGROUND

Diatoms are of great ecological importance because of their role as primary producers, and form the base of the aquatic food web. They usually account for the highest number of species among the primary producers in aquatic systems (Leira, 2005). Diatoms are photosynthetic unicellular organisms and are found in almost all aquatic and semi-aquatic habitats.

Diatoms are a siliceous class (*Bacilariophyceae* of the phylum *Bacilariophyt*a) of algae. A remarkable aspect of diatoms is their silicon dioxide cell walls. The cell walls are perforated and ornamented with many holes, which are arranged in defined and unique patterns. Identification is based on the nature of these perforations as well as their orientation and densities.

Recent studies, as well as studies in progress, have identified diatoms as useful organisms to include in the suite of biomonitoring tools currently used in South Africa (Bate *et al*., 2002, De la Rey *et al*., 2004, Taylor, 2004) both for assessments of current water quality and for establishing historical conditions in rivers in South Africa (Taylor *et al*., 2005a).

Diatoms have been shown to be reliable indicators of specific water quality problems such as organic pollution, eutrophication, acidification and metal pollution (Rott 1991, Tilman *et al*., 1982, Dixit *et al*., 1992, Cattaneo *et al.,* 2004), as well as for general water quality (AFNOR, 2000). The reasons why diatoms are useful tools for biomonitoring are listed by Round (1993):

- Diatoms have a universal occurrence throughout all rivers;
- Field sampling is rapid and easy;
- Cell cycle is rapid and they react quickly to perturbation;
- Diatoms are relatively insensitive to physical features in the environment;
- Cell counting by microscopic techniques is rapid and accurate;
- Cell numbers per unit area of substratum are enormous, making random counts excellent assessments of diatoms;
- The ecological requirements of diatoms are in many cases better known than those of any other group of riverine organisms;
- Permanent records can be made from every sample;
- Diatoms do not have specific food requirements, specialised habitat niches, and are not governed to a major extent by stream flow.

The specific water quality tolerances of diatoms have been resolved into different diatom-based water quality indices, used around the world. In general, each diatom species used in the calculation of the index is assigned two values; the first value reflects the tolerance or affinity of the particular diatom species to a certain water quality (good or bad) while the second value indicates how strong (or weak) the relationship is. These values are then weighted by the abundance of the particular diatom species in the sample. The diatom index used in the present study is known as the Specific Pollution sensitivity Index (SPI; (Coste in CEMAGREF, 1982)), one of the most extensively tested indices in Europe.

Diatom-based water quality indices have recently been evaluated and implemented in South Africa (Taylor 2004, River Health Programme, 2005). De la Rey *et al*. (2004) and Taylor (2004) showed that diatom-based pollution indices may be good bio-indicators of water quality in aquatic ecosystems in South Africa by demonstrating a measurable relationship between water quality variables such as pH, electrical conductivity, phosphorus and nitrogen, and the structure of diatom communities as reflected by diatom index scores.

The close association between diatom community composition and water quality allows for inferences to be drawn about water quality.

E1.2 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)

E2 METHODS

E2.1 SAMPLING

Epilithon and Epiphyton were sampled as outlined Taylor *et al*., 2005b and Taylor *et al*., 2007a. These methods were designed and refined as part of the Diatom Assessment Protocol (DAP), a Water Research Commission (WRC) initiative. Taylor *et al.,* 2007a, have based the method manual on several key documents including Kelly *et al.* (1998), CEN (2003), DARES (2004) and Taylor *et al.,* 2005b. Diatom samples were taken at each site by scrubbing the substrate with a small brush and rinsing both the brush and the substrate with distilled water. Samples were taken from five or more cobbles (diameter > 64, ≤265 mm) at sites where cobbles were available and the flows allowed sampling. Epiphyton sampling was taken if the flows were too high to sample or epilithon was absent.

E2.2 ANALYSIS

Preparation of diatom slides followed the Hot HCl and $KMnO_4$ method as outlined in Taylor *et al.,* 2007a. Counts of diatom valves on slides were made using a Zeiss microscope with phase contrast optics (1000x). The aim of the data analysis was to count diatom valves to produce semi-quantitative data from which ecological conclusions can be drawn (Taylor *et al*., 2007a). Schoeman, (1973) and Battarbee (1986) concluded that a count of 400 valves per slide is satisfactory for the calculation of relative abundance of diatom species and this range is supported by Prygiel *et al.* (2002), according to Taylor *et al*. (2007a). Therefore a count of 400 valves per sample or more was counted and the nomenclature followed Krammer and Lange-Bertalot (1986-91). Diatom index values were calculated in the database programme OMNIDIA (Lecointe *et al.*, 1993) for epilithon and epiphyton data in order to generate index scores to general water quality variables.

E3 RESULTS

E3.1 SAMPLING SITES

Diatom samples taken during September 2007, January and March 2008 at the EWR sites as well as 4 water quality monitoring sites and were analysed as part of the Intermediate Reserve determination study for the Mokolo River system. The aim of the diatom study is to provide biological water quality information for conditions on the day of biological component sampling regarding the aquatic health and functioning of the River system, and providing additional input to the physico-chemical component of the study as a response variable.

Details of the sampling sites are given in Table E1.

Table E1 Sampling sites

EWR site number	EWR site name	River	Co-ordinates		RU	Quat	WQSU
			Latitude	Longitude			
EWR 1A	Vaalwater	Mokolo	24 17.362	28 05.544	MRU B	A42C	4
EWR 1B	Tobacco	Mokolo	24 10.697	27 58.661	MRU B	A42E	4
EWR 2	Ka'ingo	Mokolo	24 03.897	27 47.230	RAU B.1	A42F	4
EWR 3	Gorge	Mokolo	23 58.080	27 43.614	RAU C.1	A42G	5
EWR 4	Malalatau	Mokolo	23 46.272	27 45.315	RAU C.2	A42G	5
WQ Site 1	WQSU 3: Upper Mokolo River	Mokolo			MRU A		3
WQ Site 2	WQSU 6: Mokolo River below Lephalale	Mokolo			MRU E		6
WQ Site 3	WQSU 7: Dwars River	Dwars			MRU B		7
WQ Site 4	WQSU 8: Sterkstroom River	Sterkstroom			MRU B		8

E3.2 DIATOM ASSEMBLAGE

The diatom abundances of the different EWR sites and water quality sites are given in Table E2 and E3 respectively.

Table E2 Diatom species assemblage and abundances of samples for EWR 1 - 4

Species	EWR 1A		EWR 1B	EWR 2		EWR 3			EWR 4	
	Jan-08	Mar-08	Jan-08	Jan-08	Mar-08	Sep-07	Jan-08	Mar-08	Sep-07	Mar-08
	52	53	54	55	56	57	58	59	60	61
Adlafia bryophila (Petersen) Moser Lange-Bertalot & Metzeltin							1			1
Achnanthidium affine (Grun) Czarnecki		23			1				9	
Amphora copulata (Kutz) Schoeman & Archibald										1
Achnanthes crassa Hustedt	6		2						4	
Achnanthes catenata Bily & Marvan	1	12				2	4	17	4	
Achnanthidium sp.							10		22	
Achnanthidium eutrophilum (Lange-Bertalot) Lange-Bertalot		8							3	
Achnanthidium straubianum (Lange-Bertalot) Lange-Bertalot			2							
Achnanthes exigua Grunow in Cl. & Grun.									3	5
Asterionella formosa Hassall			1							
Achnanthes lanceolata (Breb.) Grun. ssp. frequentissima Lange-Bertalot										1
Achnanthes linearis (W.Sm.) Grunow							11			
Achnanthes minutissima Kutz. var. affinis (Grunow) Lange-Bertalot	9	4	2				12	2	4	
Achnanthes minutissima Kutzing	290	247	338	9	101	55	162	91	136	89
Achnanthes minutissima Kutzing var. macrocephala Hustedt	20	12	15		19	2	24	18	91	46
Achnanthes minutissima Kutzing var. saprophila Kobayasi et Mayama		1	1			5			5	
Achnanthes swazi Cholnoky		2								
Aulacoseira granulata (Ehr.) Simonsen				2			1			
Brachysira neoexilis Lange-Bertalot	2		2		65		1		4	9
Cymbella affinis Kutzing	1					4	1			
Cymbella aspera (Ehrenberg) H. Peragallo		1								
Caloneis bacillum (Grunow) Cleve					1					
Cyclostephanos dubius (Fricke) Round				1						
Craticula halophila (Grunow ex Van Heurck) Mann			1	1	1	2	1		5	
Cymbella helvetica Kutzing						1	1			
Cymbella kolbei Hustedt		2	1		9	1		1		4
Cyclotella meneghiniana Kutzing										1
Cymbella minuta Hilse ex Rabenhorst		2								1
Caloneis molaris (Grunow) Krammer									1	
Cocconeis placentula Ehrenberg									1	
Cyclotella pseudostelligera Hustedt							8	5		2
Craticula cuspidata (Kutzing) Mann										1
Craticula submolesta (Hust.) Lange-Bertalot										1
Cyclotella stelligera Cleve et Grun (in Van Heurck)				7			2	42	1	13
Diadesmis contenta (Grunow ex V. Heurck) Mann										1
Epithemia adnata (Kutzing) Brebisson									1	
Eunotia bilunaris (Ehr.) Mills					1					
Encyonopsis buedelii Krammer					2					
Encyonopsis cesatii (Rabenhorst) Krammer				1						
Eunotia incise Gregory			1							7
Encyonema silesiacum (Bleisch in Rabh.) D.G. Mann							8			
Eunotia minor (Kutzing) Grunow in Van Heurck	6	1	1	1	3		8		1	8
Encyonema mesianum (Cholnoky) D.G. Mann	1	5	6		21		1	12		63
Encyonema neogracile Krammer			5		1		4			
Eolimna minima (Grunow) Lange-Bertalot							1			

Species	EWR 1A		EWR 1B	EWR 2		EWR 3			EWR 4	
	Jan-08	Mar-08	Jan-08	Jan-08	Mar-08	Sep-07	Jan-08	Mar-08	Sep-07	Mar-08
	52	53	54	55	56	57	58	59	60	61
Eunotia pectinalis (Dyllwyn) Rabenhorst		3			3			1		
Encyonopsis raytonensis (Cholnoky) Krammer			2							
Eunotia rhomboidea Hustedt		3			3		1	2		23
Eunotia sp.										18
Fragilaria biceps (Kutzing) Lange-Bertalot		1	2		4		2	1	4	5
Fragilaria capucina Desmazieres var. capucina	1	3	1	230	12	23	10	21		
Fragilaria construens (Ehr.) Grunow								1		7
Fragilaria crotonensis Kitton								11		
Frustulia crassinervia (Breb.) Lange-Bertalot et Krammer					1					
Fragilaria capucina Desmazieres var. vaucheriae (Kutzing) Lange-Bertalot				1	1					
Fragilaria elliptica Schumann (Staurosira)	2		10				31	1	1	
Fragilaria leptostauron (Ehr.)			2	1			14			
Fragilaria nanana Lange-Bertalot				4	31			2	21	
Fragilaria pinnata Ehrenberg			2				5			2
Frustulia rostrata Hustedt										2
Frustulia saxonica Rabenhorst					2					
Fragilaria tenera (W.Smith) Lange-Bertalot					1			1		3
Fragilaria ulna (Nitzsch.) Lange-Bertalot			1	47					9	
Frustulia vulgaris (Thwaites) De Toni	1						1			
Gomphonema affine Kutzing			1	1	2					
Gomphonema angustatum (Kutzing) Rabenhorst	9	3	4		4			10	3	3
Gomphonema angustum Agardh								1		
Gomphonema clavatum Ehr.						4				
Gomphonema exilissimum(Grun.) Lange-Bertalot & Reichardt		1	1	4	1		2		3	
Gomphonema gracile Ehrenberg	1	2		46	1	2	22	3	24	2
Gomphonema hebridense Gregory					1					
Gomphonema insigne Gregory				10		1	3			
Gomphonema lagenula Kützing	19	14	2		40		4		4	5
Gomphonema species	12	17	10	27	28	17	12	8	13	3
Gomphonema parvulum (Kützing) Kützing	8	5	3	1	3		2			
Gomphonema parvulum var. parvulius Lange-Bertalot & Reichardt	4			2						
Gomphonema venusta Passy. Kociolek & Lowe						305		2		
Hantzschia amphioxys (Ehr.) Grunow in Cleve et Grunow 1880					1					
Navicula angusta Grunow					9					
Navicula iranensis Hustedt		4						1		5
Navicula arvensis Hustedt				1						
Navicula cryptocephala Kutzing		4	1		1		1		1	
Navicula cryptotenella Lange-Bertalot					5		4		1	
Nitzschia dissipata (Kutzing) Grunow var. dissipata	1									
Nitzschia filiformis (W.M.Smith) Van Heurck									1	
Nitzschia heufleriana Grunow										1
Navicula heimansioides Lange-Bertalot		8	2	1	9		20	115	5	4
Nitzschia gracilis Hantzsch										4
Nitzschia inconspicua Grunow					1					
Nitzschia irremissa Cholnoky										1
Nitzschia lancettula O.Muller			1							
Navicula molestiformis Hustedt						3				
Navicula notha Wallace	4	9	3		10		5	28	6	36
Navicula radiosa Kützing		2			1					

Species	EWR 1A		EWR 1B	EWR 2		EWR 3			EWR 4	
	Jan-08	Mar-08	Jan-08	Jan-08	Mar-08	Sep-07	Jan-08	Mar-08	Sep-07	Mar-08
	52	53	54	55	56	57	58	59	60	61
Navicula ranomafanensis (Manguin) Metzeltin & Lange-Bertalot		2		1			2	1		
Nitzschia recta Hantzsch in Rabenhorst		2								
Navicula rhynchocephala Kutzing							1			
Navicula rostellata Kutzing							3			
Nitzschia species	2	7			1		2		3	11
Pinnularia borealis Ehrenberg							1			
Placoneis clementis (Grun.) Cox									1	3
Pinnularia gibba Ehrenberg										1
Pinnularia subbrevistriata Krammer							1			
Pinnularia subcapitata Gregory										1
Surirella linearis W.M.Smith		1								
Seminavis strigosa (Hustedt) Danieledis & Economou-Amilli									5	
Surirella ovalis Brebisson							1			
Sellaphora pupula (Kutzing) Mereschkowksy				1						
Thalassiosira pseudonana Hasle et Heimdal								4		9
TOTAL COUNT	**400**	**411**	**426**	**400**	**401**	**427**	**411**	**402**	**400**	**403**

- Shaded blocks indicate dominant species per sample.

Table E3 Diatom species assemblage and abundances of samples for WQ Sites 1 - 4

Species	WQ 1	WQ 2	WQ 3	WQ 4
	Mar-08	Mar-08	Mar-08	Mar-08
	62	63	64	65
Aulacoseira ambigua (Grun.) Simonsen				2
Adlafia bryophila (Petersen) Moser Lange-Bertalot & Metzeltin	3	2	2	1
Achnanthidium affine (Grun) Czarnecki	13	2		
Achnanthes clevei Grunow var. clevei (=Karayevia)	2			
Amphora coffeaeformis (Agardh) Kutzing	2			
Achnanthes catenata Bily & Marvan	5	6		
Achnanthes exigua Grunow in Cl. & Grun.			1	
Achnanthes lanceolata ssp. rostrata (Oestrup) Lange-Bertalot	1			
Achnanthes lauenburgiana Hustedt	1			
Achnanthes minutissima Kutz. var. affinis (Grunow) Lange-Bertalot	5	4		1
Achnanthes minutissima Kutzing	143	105	45	13
Achnanthes minutissima Kutzing var. macrocephala Hustedt		15	8	13
Achnanthes minutissima Kutzing var. saprophila Kobayasi et Mayama	11	3		
Brachysira neoexilis Lange-Bertalot	1	56	1	2
Bacillaria paradoxa Gmelin			3	
Cymbella affinis Kutzing			2	
Cymbella aspera (Ehrenberg) H. Peragallo			1	
Caloneis bacillum (Grunow) Cleve	6		1	
Cymbella kolbei Hustedt		5		
Cyclotella meneghiniana Kutzing			3	
Cocconeis pediculus Ehrenberg	2			
Craticula submolesta (Hust.) Lange-Bertalot			2	
Cymbella subleptoceros Krammer			1	
Cyclotella stelligera Cleve et Grun (in Van Heurck)			8	1
Eunotia bilunaris (Ehr.) Mills			2	2
Eunotia flexuosa (Brebisson Kutzing		2	3	
Eunotia formica Ehrenberg			5	

Species	WQ 1	WQ 2	WQ 3	WQ 4
	Mar-08	Mar-08	Mar-08	Mar-08
	62	63	64	65
Eunotia incisa Gregory	2		9	16
Eunotia minor (Kutzing) Grunow in Van Heurck	13	3	12	8
Encyonema mesianum (Cholnoky) D.G. Mann		24	53	3
Encyonema neogracile Krammer			1	
Eunotia pectinalis (Kutz.) Rabenhorst var. undulata (Ralfs) Rabenhorst	9	1		
Encyonopsis raytonensis (Cholnoky) Krammer	1			
Eunotia rhomboidea Hustedt		4	5	13
Epithemia sorex Kutzing		1		
Eunotia sp.			8	21
Fragilaria biceps (Kutzing) Lange-Bertalot	1	3	9	1
Fragilaria capucina Desmazieres var. capucina		3	1	119
Fragilaria construens (Ehr.) Grunow			3	
Fragilaria crotonensis Kitton				1
Frustulia crassinervia (Breb.) Lange-Bertalot et Krammer	9			
Fragilaria elliptica Schumann (Staurosira)			1	
Fragilaria nanana Lange-Bertalot		34		123
Fragilaria pinnata Ehrenberg			3	1
Frustulia rostrata Hustedt	2		6	1
Fragilaria tenera (W.Smith) Lange-Bertalot		7	6	3
Fragilaria ulna (Nitzsch.) Lange-Bertalot	2			
Fragilaria vaucheriae (Kutzing)		4		
Frustulia vulgaris (Thwaites) De Toni	3			1
Gomphonema affine Kutzing	1	1	1	
Gomphonema angustatum (Kutzing) Rabenhorst		4	10	
Gomphonema angustum Agardh			1	
Geissleria decussis(Ostrup) Lange-Bertalot & Metzeltin			1	
Gomphonema exilissimum (Grun.) Lange-Bertalot & Reichardt	11	6		2
Gomphonema gracile Ehrenberg	5		5	4
Gomphonema lagenula Kützing	7	50	23	1
Gomphoneis olivacea (Hornemann) Dawson ex Ross & Sims	6			
Gomphonema species	57	12	9	3
Gomphonema parvulum (Kützing) Kützing	24		2	1
Gomphonema parvulum var. parvulius Lange-Bertalot & Reichardt	3		1	
Gomphonema pseudoaugur Lange-Bertalot	4	1		
Gomphonema subtile Ehr.		5		2
Gomphonema venusta Passy. Kociolek & Lowe	1	1		
Gyrosigma acuminatum (Kutzing) Rabenhorst	6			
Mayamaea atomus (Kutzing) Lange-Bertalot	2		4	
Melosira varians Agardh			1	
Navicula angusta Grunow		9		
Navicula accomoda Hustedt			2	
Navicula iranensis Hustedt			5	
Navicula cryptocephala Kutzing	1			
Navicula cryptotenella Lange-Bertalot		3		
Nitzschia dissipata (Kutzing) Grunow var. media (Hantzsch.) Grunow	3			
Neidium productum (W.M.Smith)Cleve		1		
Nitzschia hantzschiana Rabenhorst			2	
Navicula heimansioides Lange-Bertalot	3	12	17	48
Nitzschia gracilis Hantzsch	1		7	
Nitzschia irremissa Cholnoky			13	
Nitzschia liebetruthii Rabenhorst	5			

Species	WQ 1	WQ 2	WQ 3	WQ 4
	Mar-08	Mar-08	Mar-08	Mar-08
	62	63	64	65
Nitzschia linearis(Agardh) W.M. Smith var. subtilis (Grunow) Hustedt			7	
Navicula molestiformis Hustedt	2		2	
Navicula notha Wallace		11	51	5
Nitzschia paleacea (Grunow) Grunow in van Heurck	1			
Navicula pseudolanceolata Lange-Bertalot	3			
Navicula radiosa Kützing			1	
Nitzschia recta Hantzsch in Rabenhorst	2		1	
Navicula schroeteri Meister var. symmetrica (Patrick) Lange-Bertalot	1			
Navicula veneta Kutzing			2	
Navicula viridula (Kutz.) Ehr.	1			
Nitzschia species	12			1
Placoneis clementis (Grun.) Cox			1	
Pinnularia divergens W.M.Sm.			2	
Pinnularia gibba Ehrenberg			1	
Pinnularia subcapitata Gregory			1	
Placoneis undulata (Oestrup) Lange-Bertalot			6	
Sellaphora pupula (Kutzing) Mereschkowksy	1		2	
Sellaphora seminulum (Grunow) D.G. Mann			1	
Stauroneis thermicola (Petersen) Lund	1			
Tabellaria flocculosa (Roth) Kutzing				1
Thalassiosira pseudonana Hasle et Heimdal			13	2
TOTAL COUNT	**401**	**400**	**400**	**416**

- Shaded blocks indicate dominant species per sample.

E3.3 DIATOM BASED WATER QUALITY SCORES

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 is given in Table E4 and the SPI for the samples in Table E5.

Table E4 Adjusted class limit boundaries for the SPI index applied in this study

SPI score	Class	Ecological Category
>17.3	HIGH QUALITY	A
16.8 – 17.2		A/B
13.3 – 16.7	GOOD QUALITY	B
12.9 – 13.2		B/C
9.2 – 12.8	MODERATE QUALITY	C
8.9 – 9.1		C/D
5.3 – 8.8	POOR QUALITY	D
4.8 – 5.2		D/E
< 4.8	BAD QUALITY	E

Table E5 SPI scores for the different samples

EWR site	Site name	River	No species	Specific Pollution sensitivity Index (SPI)	Category	Class

September 2007						
EWR 3	Gorge	Mokolo	15	16.6	B	Good quality
EWR 4	Malalatau	Mokolo	34	17.8	A	High quality
January 2008						
EWR 1A	Vaalwater	Mokolo	21	17.3	A/B	Good quality
EWR 1B	Tobacco	Mokolo	31	18.8	A	High quality
EWR 2	Ka'ingo	Mokolo	23	16.	B	Good quality
EWR 3	Gorge	Mokolo	44	17.4	A	High quality
March 2008						
EWR 1A	Vaalwater	Mokolo	32	16.8	A/B	Good quality
EWR 2	Ka'ingo	Mokolo	38	16.1	B	Good quality
EWR 3	Gorge	Mokolo	28	18.4	A	High quality
EWR 4	Malalatau	Mokolo	40	17.4	A	High quality
WQ Site 1		Mokolo	49	14.8	B	Good quality
WQ Site 2		Mokolo	33	15.9	B	Good quality
WQ Site 3		Dwars	61	15.5	B	Good quality
WQ Site 4		Sterkstroom	32	18.8	A	High quality

E3.4 EWR 1A: VAALWATER

Land-use is farming (agricultural and extensive game-farming), with urban settlements and associated activities present, i.e. Vaalwater town. The STW is a maturation ponding system, with no chemical treatment. The Dwars River and Sterkstroom systems enter the Mokolo River in this WQSU (DWAF, 2008). The site is below Vaalwater town, so some toxicant load is expected.

Sample: 16 January 2008

Site	Dominant species	Species contribution to sample (%)
EWR 1A	*Acnanthidium minutissima*	73
	Achnanthes minutissima var. macrocephala	5
	Gomphonema lagenula	5

A. *minutissima* was the dominant species in this sample and favours well oxygenated clean fresh water (Taylor *et al.*, 2007b). *A minutissima* is an indicator of natural/anthropogenic disturbances and indicates the presence of diffuse pollutants (Ács *et al.*, 2004). According to Barbour *et al.*, 1999, *A. minutissimum* indicates moderate levels of disturbance at this site with 73% dominance. *A. minutissima var. macrocephala* indicates oligo- to mesotrophic calcareous conditions (Taylor *et al.*, 2007b).

The SPI indicates good water quality (17.3) at this site and the diatom based ecological classification indicates continuously high oxygenated circumneutral water. The present diatom water quality is an A/B category. The presence of pollution tolerant species, although in very small numbers, indicates that upstream anthropogenic activities (agriculture) may be impacting slightly on this EWR site and may be the source of slightly elevated concentrations of organically bound nitrogen (ammonia). This is supported by the presence of *Gomphonema parvulum*, *G. gracile* and *Cymbella affinis* (Taylor *et al.*, 2007b).

Sample: 28 March 2008

Site	Dominant species	Species contribution to

		sample (%)
EWR 1A	*Achnanthidium minutissima*	60
	Achnanthidium affine	6

As with the January 2008 sample *A. minutissima* was dominant although the dominance was 60%, and indicates moderate anthropogenic disturbance levels (Barbour *et al.*, 1999, Ács *et al.*, 2004). *A. affine* prefers well oxygenated, calcareous, alkaline waters.

The SPI indicates good water quality (16.8) at this site and the diatom based ecological classification indicates continuously high oxygenated circumneutral water (Taylor *et al.*, 2007b). The present diatom water quality is an A/B category although this assessment is slightly lower than the January 2008 sample. There is an increased number of pollution tolerant species (e.g. *G. parvulum, A. minutissima var. saprophila, A. eutrophilum and N. cryptocephala*) (Taylor *et al.*, 2007b) although still in small numbers and a decline in species sensitive to pollution. The species composition indicates that although the flows were high agricultural runoff and urban activities (site is downstream of Vaalwater) is increasing nutrient loading and pollution in general at this site. The overall impact is moderate as slightly elevated organically bound nitrogen is present.

Trend:

Short and long term: The trend for this site is stable. The flow during both samples was high and this has had a definite dilution effect on the water quality. The community composition indicates that there were critical levels of pollution present (*G. parvulum*, and *N. cryptocephala*). It is expected that with a reduction in flow the current condition of the biological water quality will deteriorate to a B category (SPI score 13 – 17). Nutrient loading (N and P) are causes of concern for this reach. As the reach experiences periods of no flow (presence of *Eunotia* spp.) it is expected that oxygen and temperature will have an impact on this reach. Due to Vaalwater upstream of the site, toxicants may be a problem in this reach especially, ammonia.

Confidence: Moderate, as only 2 samples were taken and both these samples were under high flow conditions. The diatom results reflect a dilution effect of possible water quality related impacts.

Overall site category: B

A summary of the diatom results are given in Table E6.

Table E6 Summary of the generic diatom based ecological classification for all the samples taken at EWR 1A

EWR 1A	January 2008	March 2008
pH	Circumneutral	Circumneutral
Salinity	Fresh brackish (Cond <139 mS/m)	Fresh brackish (Cond <139 mS/m)
Organic nitrogen	Slightly elevated concentrations of organically bound nitrogen	Slightly elevated concentrations of organically bound nitrogen
Oxygen levels	Continuously high (~100% saturation)	Continuously high (~100% saturation)
Pollution levels	Moderately polluted	Moderately polluted
Trophic status	Oligo - Eutrophic	Oligo - Eutrophic
SPI score	17.3	16.8
Class	Good quality	Good quality
Category	**A/B**	**A/B**

E3.5 EWR 1B: TOBACCO

EWR 1B lies within MRU Mokolo B and WQSU 4. Land cover is the same as discussed under EWR 1A.

Sample: 17 January 2008

Site	Dominant Species	Species contribution to sample (%)
EWR 1B	*Achnanthidium minutissima*	79

As with EWR 1A, *A. minutissima* was dominant although the dominance was 79%, and indicates severe anthropogenic disturbance levels (Barbour *et al.*, 1999, Ács *et al.*, 2004). Due to high flows experienced during January 2008 there were no other dominant species. The diatom community indicates that the river was very slow flowing and may have stopped flowing at a stage (presence of *Eunotia* species, and *Achnanthes crassa*) (Taylor *et al.*, 2007b). There is evidence that at low flow conditions the pollution levels are very high to critical (Presence of *G. parvulum* and *N. cryptocephala*) (Taylor *et al.*, 2007b) and that organic enrichment due to agricultural runoff is impacting this site.

The SPI indicates high water quality (18.8) at this site and the diatom based ecological classification indicates continually high oxygenated circumneutral water. The present diatom water quality is in an A category. The score is high due to the very high flows, and this score reflects a dilution effect of water quality related impacts. The site is moderately polluted due to nutrient loading from agricultural activities in the area.

Trend:

Short term: The trend for this site is negative. The current score of the diatom community is not a true reflection of the impacts on the site due to the dilution effect of the high flows. The community composition indicates that there were very high levels of pollution present (*G. parvulum* and *N. cryptotenella*) (Taylor *et al.*, 2007b). It is expected that with a reduction in flow the current condition of the biological water quality will deteriorate to a B category (SPI score 13 – 17).

Long term: The long term trend is stable. It is expected that with a reduction in flow the current condition of the biological water quality will deteriorate to a B category (SPI score 13 – 17). Nutrient loading (N and P) are causes of concern for this reach. As the reach experiences periods of no flow (presence of *Eunotia* spp) it is expected that oxygen and temperature will have an impact on this reach. Toxicants may be a problem in this reach especially, ammonia.

Confidence: Low, as only 1 sample was taken, during high flow conditions. The diatom results reflect a dilution effect of possible water quality related impacts.

Overall site category: A/B

A summary of the diatom results are given in Table E7.

Table E7 Summary of the generic diatom based ecological classification for all the samples taken at EWR 1B

EWR 1B	January 2008
pH	Circumneutral
Salinity	Fresh brackish (Cond <139 mS/m)
Organic nitrogen	Slightly elevated concentrations of organically bound nitrogen
Oxygen levels	Continuously high (~100% saturation)
Pollution levels	Moderately polluted
Trophic status	Oligo - Eutrophic
SPI score	18.8
Class	High quality
Category	**A**

E3.6 WQ SITE 1

WQ site one is situated in MRU A and WQSU 3. Land-use in the area is extensively agricultural, with vegetable and fruit farming dominating. Pole-treating activities (CCA-wax) are also found upstream of Vaalwater town (DWAF, 2008). The site is downstream of Alma and the Sand River confluence in the Mokolo.

Sample: 25 March 2008

Site	Dominant Species	Species contribution to sample (%)
WQ 1	*Achnanthes minutissima*	36
	Gomphonema species	14
	Gomphonema parvulum	6

WQ Site 1 was dominated by *A. minutissima* which favours clean well oxygenated waters and indicates minor anthropogenic impacts (Barbour *et al.*, 1999, Ács *et al.*, 2004). *Gomphonema* spp. has a wide ecological range while *G. parvulum* is tolerant of extremely polluted conditions (Taylor *et al.*, 2007b). The presence of *Eunotia* spp. and *F. crassinervia* is an indication that there were very low flows or zero flow conditions (Taylor *et al.*, 2007b).

The SPI index indicates good water quality (14.8), and the diatom based ecological classification indicates continuous oxygen saturation and circumneutral water. The diatom water quality is in a B category. Variables of concern are salinity and nutrients (presence of *Amphora coffeaeformis* (sodium based salinity), *Gyrosigma acuminatum*, *Gomphonema parvulum* and *N. cryptocephala*) (Taylor *et al.*, 2007b). As the diatom community indicates very low flow to zero flow conditions temperature and oxygen could impact on the biota.

Trend:
Short term and long term: The trend for this site is stable. The community indicates that the periods of zero flow do occur at this site (presence of *Eunotia* spp.) and therefore temperature and oxygen may be variables of concern. There is evidence of organic enrichment at this site and therefore nutrients and toxicants (ammonia) are also variables of concern especially during low flows.

Confidence: Low, as one sample was taken during high flows.

Overall site category: B

A summary of the diatom results are given in Table E8.

Table E8 Summary of the generic diatom based ecological classification for all the samples taken at WQ Site 1

WQ Site 1	March 2008
pH	Circumneutral
Salinity	Fresh brackish (Cond <139 mS/m)
Organic nitrogen	Slightly elevated concentrations of organically bound nitrogen
Oxygen levels	Continuously high (~100% saturation)
Pollution levels	Moderately polluted
Trophic status	Oligo - Eutrophic
SPI score	14.8
Class	Good quality
Category	**B**

E3.7 WQ SITE 2

The site falls within MRU E and WQSU 6. This area contains extensive game farms, irrigation of crops, and urban and industrial activities such as brick-making and the Groot Geluk coal mine and Matimba power station. Medupi power station is currently under construction. Sand-mining takes place in the lower sections of the Mokolo River in the Limpopo flood-plain area. The Tambotie and Sandspruit tributaries enter the Mokolo River in this WQSU (DWAF, 2008).

Sample: 27 March 2008

Site	Dominant Species	Species contribution to sample (%)
WQ 2	*Achnanthes minutissima*	26
	Brachysira neoexilis	14
	Gomphonema lagenula	13
	Fragilaria nanana	9
	Encyonema mesianum	6

WQ Site 2 was dominated by *A. minutissima* which favours clean well oxygenated waters and indicates minor anthropogenic impacts (Barbour *et al.*, 1999, Ács *et al.*, 2004). *B. neoexilis* is generally found in clean oligo- to mesotrophic waters, while *F. nanana* is found in the plankton of oligotrophic lakes. *E. mesianum* favours weakly acidic waters (Taylor *et al.*, 2007b).

The SPI index indicates good water quality (15.9), and the diatom based ecological classification indicates continuous oxygen saturation and circumneutral water. The diatom water quality is in a B. The diatom assemblage generally indicated that this site was minimally impacted by nutrient loading.

Trend:
Short term and long term: The trend for this site is stable. It is evident that the water quality at this site is overall of good quality. As there is evidence that zero flow conditions occur at this site (presence of Eunotia *spp.)* increased water temperature and low oxygen levels may impact on this site. This is substantiated by the presence of *E. sorex*.

Confidence: Low as one sample was taken during high flows.

Overall site category: B

A summary of the diatom results are given in Table E9.

Table E9 Summary of the generic diatom based ecological classification for all the samples taken at WQ Site 2

WQ Site 2	March 2008
pH	Circumneutral
Salinity	Fresh brackish (Cond <139 mS/m)
Organic nitrogen	Very little concentrations of organically bound nitrogen
Oxygen levels	Continuously high (~100% saturation)
Pollution levels	Moderately polluted
Trophic status	Oligo - Eutrophic
SPI score	15.9
Class	Good quality
Category	**B**

Overall reach category: B
It seems the tributaries entering the Mokolo in this reach are of good – high quality. The biological water quality at EWR 1A and B is of high quality although all samples were taken at high flows.

E3.8 EWR 2: KA'INGO

EWR 2 lies within MRU B and WQSU 4. Land cover and use is the same as for EWR 1A and B. (DWAF, 2008).

Sample: 14 January 2008

Site	Dominant Species	Species contribution to sample (%)
EWR 2	*Fragilaria capucina var. capucina*	57
	Fragilaria ulna	12
	Gomphonema gracile	12
	Gomphonema spp.	7

F. capucina var. capucina was the dominant species in this sample and favours circumneutral, oligo- to mesotrophic waters with moderate electrolyte content. *F. ulna* is often found in meso- to eutrophic, alkaline waters. *G. gracile* favours electrolyte rich conditions, but is not tolerant to more than moderate pollution levels (Taylor *et al.*, 2007b).

The SPI indicates good water quality (16.0), and the diatom based ecological classification indicates continuous oxygen saturation and circumneutral conditions. Overall the diatom water quality was in a B category at the time of sampling, but it is evident that agricultural activities upstream of the site are impacting the diatom community. The community composition indicates that there was very high levels of pollution present (*G. parvulum* and *S. pupula*) (Taylor *et al.*, 2007b) at lower flows and that the high SPI score is due to the dilution effect.

Sample: 27 March 2008

Site	Dominant Species	Species contribution to sample (%)
EWR 2	*Achnanthidium minutissima*	25
	Brachysira neoexilis	16
	Gomphonema lagenula	10
	Fragilaria nanana	8
	Gomphonema species	7
	Encyonema mesianum	5
	Achnanthes minutissima var. macrocephala	5

All the dominant species indicate a preference for either oligotrophic or oligo- to mesotrophic conditions (Taylor *et al.*, 2007b). There is once again indications that the river stopped flowing or that flow was very low (presence of *Eunotia* spp. and *F. crassinervia*).

The SPI indicates good water quality (16.1), and the diatom based ecological classification indicates continuous oxygen saturation and circumneutral conditions. Overall the diatom water quality was in a B category at the time of sampling, but it is evident that agricultural activities upstream of the site are impacting the diatom community. The community composition indicates that there was very high levels of pollution present (*G. parvulum* and *N. cryptocephala*).

Trend:

Short term: The trend for this site is slightly negative as the high flows have had a dilution effect on water quality related issues.

Long term: The long term trend is stable. Scores indicate nutrient loading, ionic concentrations (presence of *Craticula halophila*) and moderate organic pollution are causes of concern at this site. As there is an indication of very low flow periods to zero flow at times, temperature and oxygen may also be variables of concern.

Confidence: Moderate, as only 2 samples were taken and both these samples were under high flow conditions. The diatom results reflect a dilution effect of possible water quality related impacts.

Overall site category: B

A summary of the diatom results are given in Table E10.

Table E10 Summary of the generic diatom based ecological classification for all the samples taken at EWR 2

EWR 2	January 2008	March 2008
pH	Circumneutral	Circumneutral
Salinity	Fresh brackish (Cond <139 mS/m)	Fresh brackish (Cond <139 mS/m)
Organic nitrogen	Slightly elevated concentrations of organically bound nitrogen	Slightly elevated concentrations of organically bound nitrogen
Oxygen levels	Continuously high (~100% saturation)	Continuously high (~100% saturation)
Pollution levels	Moderately polluted	Moderately polluted
Trophic status	Mesotrophic	Oligo - Eutrophic
SPI score	16.	16.1
Class	Good quality	Good quality
Category	**B**	**B**

E3.9 WQ SITE 4

WQ Site 4 is on the Sterkstroom which enters the Mokolo below EWR 1B. Land-use is primarily game-farming and largely lies within protected areas of private nature reserves (DWAF, 2008).

Sample: 27 March 2008

Site	Dominant Species	Species contribution to sample (%)
WQ 4	*Fragilaria nanana*	30
	Fragilaria capucina var. *capucina*	29
	Navicula heimansiodes	12
	Eunotia sp.	5

The sample was dominated by *F. nanana* which usually occurs on the plankton of oligotrophic lakes. *F. capucina var. capucina* and *N. heimansioides* favours circumneutral, oligo- to mesotrophic waters with a poor to moderate electrolyte content. The presence of *Eunotia* spp. indicates good water quality but that very low flow or zero flows were present before the high flows experienced during sampling (Taylor *et al.*, 2007b).

The SPI index indicates high water quality (18.8), and the diatom based ecological classification indicates continual oxygen saturation and neutral water. The diatom water quality is in an A category. Overall the biological water quality at this site is very good under the high flow conditions. The diatom community does not reflect serious pollution related impacts and temperature and oxygen may be variables of concern under low flow conditions.

Trend:

Short and long term: The trend for this site is stable. There is no indication that there are serious point source pollution problems at this site.

Confidence: Low as only one sample was taken during high flows.

Overall site category: A

A summary of the diatom results are given in Table D11.

Table E11 Summary of the generic diatom based ecological classification for all the samples taken at WQ Site 4

WQ Site 4	March 2008
pH	Circumneutral
Salinity	Fresh brackish (Cond <139 mS/m)
Organic nitrogen	Very little concentrations of organically bound nitrogen
Oxygen levels	Continuously high (~100% saturation)
Pollution levels	Slightly polluted
Trophic status	Oligo - Mesotrophic
SPI score	18.8
Class	High quality
Category	**A**

Overall reach category: B

The samples taken at EWR 2 during January and March 2008 indicated that the biological water quality was in a B category. The Sterkstroom sample indicates that the biological water quality at high flows is of high quality.

E3.10 EWR 3: GORGE

EWR 3 lies within MRU C and WQSU 5. This site lies within a gorge area downstream of Mokolo Dam and there are minimal anthropogenic activities (game farms).

Sample: 11 September 2007
FLOW: 0.009m^3/s

Site	Dominant Species	Species contribution to sample (%)
EWR 3	*Gomphonema venusta*	71
	Achnanthes minutissima	12
	Fragilaria capucina var. capucina	5

G. venusta is common in the northern parts of the country and occurs in circumneutral to weakly acidic waters that are oligo- to mesotrophic and have low to moderate electrolyte content (Taylor *et al.*, 2007b). The presence of *A. minutissima* indicates low levels of anthropogenic impacts with a dominance of 12% (Barbour *et al.*, 1999, Ács *et al.*, 2004). *F. capucina var. capucina* also prefers circumneutral, oligo- to mesotrophic waters with moderate electrolyte content (Taylor *et al.*, 2007b).

The SPI index indicates good water quality (16.6), and the diatom based ecological classification indicates continuous oxygen saturation and circumneutral water. The biological water quality was assessed as a B category. The diatom community shows that there is very little nutrient loading and that the level of organic enrichment present may be due to stagnant/humic conditions. There is however evidence of elevated electrolyte content due to the presence of *G. clavatum* and *C. halophila* (Taylor *et al.*, 2007b). Temperature and Oxygen are variables of concern due to zero flows experienced at times.

Sample: 16 January 2008

Site	Dominant Species	Species contribution to sample (%)
EWR 3	*Achnanthes minutissima*	39
	Fragilaria elliptica	8
	Achnanthes minutissima var. macrocephala	6
	Gomphonema gracile	5
	Navicula heimansioides	5

During the January 2008 sampling, the flows were very high. The presence of *A. minutissima* indicates minor levels of anthropogenic impacts with a dominance of 39% (Barbour *et al.*, 1999, Ács *et al.*, 2004). This species favours well oxygenated clean fresh water (Taylor *et al.*, 2007b). *A. minutissima var. macrocephala* favours calcareous, oligo- to mesotrophic conditions while *G. gracile* favours electrolyte rich conditions, but is not tolerant to more than moderate pollution levels (Taylor *et al.*, 2007b). *N. heimansioides* indicates oligotrophic conditions (Taylor *et al.*, 2007b).

The SPI index indicates high water quality (17.4), and the diatom based ecological classification indicates continuous oxygen saturation and circumneutral water. The biological water quality was assessed as an A category. The diatom community shows that critical levels of pollution were present (presence of *N. cryptocephala*, *N. rostellata* and *E. minima*) (Taylor *et al.*, 2007b). This could be due to leakage from a pipe from the dam (bottom water) or sewage could source as there is small development in the area.

Sample: 27 March 2008

Site	Dominant Species	Species contribution to sample (%)
EWR 3	*Navicula heimansioides*	29
	Achnanthes minutissima	23
	Cyclotella stelligera	10
	Navicula notha	7
	Fragilaria capucina var. *capucina*	5

The dominants, *N. heimansioides* and *N. notha* have a preference for acidic to neutral oligotrophic waters with low electrolyte content (Taylor *et al.*, 2007b). *A minutissima* indicates low levels of anthropogenic impacts with a dominance of 23% (Barbour *et al.*, 1999, Ács *et al.*, 2004). *F. capucina var. capucina* also prefers circumneutral, oligo- to mesotrophic waters with moderate electrolyte content (Taylor *et al.*, 2007b).

The SPI index indicates high water quality (18.4), and the diatom based ecological classification indicates continuous oxygen saturation and circumneutral water. The biological water quality was assessed as an A category. The diatom community shows that no critical levels of pollution were present.

Trend:

Short term and long term: The trend for this site is stable. It seems that the general water quality of the Mokolo Dam is good. The major concern regarding the water quality at this site is that during no flow periods, temperature and oxygen are variables of concern. There are slight elevated concentrations of organically bound nitrogen (ammonia) and during the dry season these concentrations may become an issue.

Confidence: Moderate to good, as 3 samples were taken at various flow conditions.

Overall reach category: B

A summary of the diatom results are given in Table D12.

Table E12 Summary of the generic diatom based ecological classification for all the samples taken at EWR 3

EWR 3	September 2007	January 2008	March 2008
pH	Circumneutral	Circumneutral	Circumneutral
Salinity	Fresh brackish (Cond <139 mS/m)	Fresh brackish (Cond <139 mS/m)	Fresh brackish (Cond <139 mS/m)
Organic nitrogen	Slightly elevated concentrations of organically bound nitrogen	Slightly elevated concentrations of organically bound nitrogen	Slightly elevated concentrations of organically bound nitrogen
Oxygen levels	Continuously high (~100% saturation)	Continuously high (~100% saturation)	Continuously high (~100% saturation)
Pollution levels	Moderately polluted	Moderately polluted	Moderately polluted
Trophic status	Oligo - Eutrophic	Oligo - Eutrophic	Oligo - Eutrophic
SPI score	16.6	17.4	18.4
Class	Good quality	High quality	High quality
Category	**B**	**A**	**A**

E3.11 EWR 4: MALALATAU

EWR 4 is situated within MRU C and WQSU 5. Land cover is dominated by agriculture and some sand mining in the area (DWAF, 2008).

Sample: 10 September 2007
FLOW: 0.095m^3/s

Site	Dominant Species	Species contribution to sample (%)
EWR 4	*Achnanthes minutissima*	34
	Achnanthes minutissima var. macrocephala	23
	Gomphonema gracile	6
	Achnanthidium sp.	6
	Fragilaria nanana	5

Samples were taken from *Phragmites* due to the absence of epilithon and the main channel was stagnant forming isolated pools at places. *A minutissima* indicates minor levels of anthropogenic impacts with a dominance of 34% (Barbour *et al.*, 1999, Ács *et al.*, 2004). *A. minutissima var. macrocephala* favours calcareous, oligo- to mesotrophic conditions while *G. gracile* favours electrolyte rich conditions, but is not tolerant to more than moderate pollution levels (Taylor *et al.*, 2007b). *F. nanana* occurs in the plankton of oligotrophic lakes (Taylor *et al.*, 2007b).

The SPI index indicates high water quality (17.8), and the diatom based ecological classification indicates continuous oxygen saturation and circumneutral water. The diatom water quality is in an A category. Although the diatom community indicates continuous oxygen saturation it is expected that this condition will not prevail for long as the presence of *E. adnata* and *A. exigua* indicate elevated temperature and therefore this condition will impact on oxygen levels. There are no major concerns regarding nutrient loading although farming activities in the area are impacting slightly on the site in this regard. Salinity is a concern at this site due to the presence of *C. halophila* and *Seminavis strigosa*.

Sample: 27 March 2008

Site	Dominant Species	Species contribution to sample (%)
EWR 4	*Achnanthes minutissima*	22
	Encyonema mesianum	16
	Achnanthes minutissima var. macrocephala	11
	Navicula notha	9
	Eunotia rhomboidea	6

During the January 2008 sampling, the flows were markedly higher. As with the September sample *A. minutissima* was dominant and indicates no anthropogenic impacts (Barbour *et al.*, 1999, Ács *et al.*, 2004). *E. rhomboidea* and *N. notha* both indicate oligotrophic conditions with electrolyte poor content (Taylor *et al.*, 2007b). *E. mesianum* prefers slightly acidic conditions while *A. minutissima var. macrocephala* favours oligo- to mesotrophic conditions and calcareous waters (Taylor *et al.*, 2007b).

The SPI index indicates high water quality (17.4), and the diatom based ecological classification indicates continuous oxygen saturation and circumneutral water. The biological water quality was assessed as an A category. There are no major concerns regarding nutrient loading although farming activities in the area are impacting slightly on the site.

Trend:

Short term and long term: The trend for this site is stable. Impacts on the site are minimal and the biological water quality as indicated by the diatoms remained the same during high and low flows. Variables of concern in this reach are temperature, oxygen and salinity.

Confidence: Moderate, as 2 samples were taken at this site at different flows.

Overall reach category: A/B

A summary of the diatom results are given in Table E13.

Table E13 Summary of the generic diatom based ecological classification for all the samples taken at EWR 4

EWR 4	September 2007	March 2008
pH	Circumneutral	Circumneutral
Salinity	Fresh brackish (Cond <139 mS/m)	Fresh brackish (Cond <139 mS/m)
Organic nitrogen	Slightly elevated concentrations of organically bound nitrogen	Slightly elevated concentrations of organically bound nitrogen
Oxygen levels	Continuously high (~100% saturation)	Continuously high (~100% saturation)

Pollution levels	Moderately polluted	Moderately polluted
Trophic status	Oligo - Eutrophic	Oligo - Eutrophic
SPI score	17.8	17.4
Class	High quality	High quality
Category	**A**	**A**

E3.12 WQ SITE 3

This site is located in the Dwars River, in WQSU 7. Land-use appears to be primarily cattle farming, with disused irrigation equipment in evidence.

Sample: 27 March 2008

Site	Dominant Species	Species contribution to sample (%)
WQ 3	*Encyonema mesianum*	13
	Navicula notha	13
	Achnanthes minutissima	11
	Gomphonema lagenula	5

The sample was dominated by *N. notha* which indicates oligotrophic conditions with electrolyte poor content and *E. mesianum* which prefers slightly acidic conditions (Taylor *et al.*, 2007b). *A. minutissima* favours clean well oxygenated waters and indicates minor anthropogenic impacts (Barbour *et al.*, 1999, Ács *et al.*, 2004) at this site.

The SPI index indicates moderate water quality (15.5), and the diatom based ecological classification indicates continual oxygen saturation and alkaline water. The diatom water quality is in a B category. This score is however not a true reflection of the prevailing conditions. The flows were very high during sampling and the score rather reflects a dilution effect of water quality related problems. There is evidence of sewage at this site (presence of *Mayamaea atomus*, *Navicula accomoda*, *N. molestiformis* and *N. veneta*).

Trend:
Short term: The trend for this site is negative. The high flows are causing a dilution effect, and as there is evidence of zero flow conditions (presence of *Eunotia* spp.), the organic pollution will have a negative effect and impact greatly on the biota at this site. The water quality may under low flow conditions fall rapidly to a C category.

Long term: The trend for this site is stable. The intermittent high flows are flushing the site clean; however the organic pollution at this site is a concern. Under low flow conditions variables of concern are oxygen, temperature, salinity input and nutrient loading.

Confidence: Low to moderate as only one sample was taken during high flows. The diatom community however did indicate point source pollution.

Overall site and reach category: C

A summary of the diatom results are given in Table E14.

Table E14 Summary of the generic diatom based ecological classification for all the samples taken at WQ Site 3

WQ Site 3	March 2008
pH	Alkaline
Salinity	Fresh brackish (Cond <139 mS/m)
Organic nitrogen	Very little concentrations of organically bound nitrogen
Oxygen levels	Continuously high (~100% saturation)
Pollution levels	Slightly polluted
Trophic status	Oligo - Mesotrophic
SPI score	15.5
Class	Good quality
Category	**B**

E4 REFERENCES

Ács, E., Szabó, Tóth, B. and Kiss K.T. 2004. Investigation of Benthic Algal communities, especially diatoms of some Hungarian streams in connection with reference conditions of the Water Framework Directives. *Acta Botanica Hungarica 46 (3–4), pp. 255–277, 2004.*

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

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

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

Bate, G.C., Adams, J.B. and van Der Molen, J.S. 2002. Diatoms as indicators of water quality in South African river systems. WRC Report No 814/1/02. Water Research Commission. Pretoria.

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.

CEMAGREF (1982) Etude des methodes biologiques quantitatives d'appreciation de la qualite des eaux. Rapport Division Qualité des Eaux Lyon - Agence Financiere de Bassin Rhône-Méditerranée- Corse. Pierre-Benite.

Cholnoky, B.J. 1968. Die Ökologie der Diatomeen in Binnengewässern. J Cramer, Lehre.

Comité Européen de Normalisation (CEN) (2003). Water quality – Guidance standard for the routine sampling and pre-treatment of benthic diatoms from rivers. European Standard. EN 13946:2003.
Diatoms for Assessing River Ecological Status (DARES) (2004). Sampling protocol. Version 1. http://craticula.ncl.ac.uk/dares/methods.htm

De la Rey, P.A., Taylor, J.C., Laas, A., Van Rensburg, L. and 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.

Dixit, S.S., Smol, J.P., Kingston, J.C. and Charles, D.F. 1992. Diatoms: Powerful indicators of environmental change. *Environmental Science and Technology* **26**: 23–33.

Department of Water Affairs and Forestry (DWAF), 2007. Resource Directed Measures: Reserve Determination studies for selected surface water, groundwater, estuaries and wetlands in the Outeniqua (Knysna and Swartvlei) catchment. Delineation Report. Prepared by Coastal and Environmental Services. Report no. RDM/ K40K50/00/ CON/0207

Department of Water Affairs and Forestry, South Africa (DWAF). 2008. Intermediate Reserve Determination Study for Selected Water Resources (Rivers, Groundwater and Wetlands) in the Limpopo Water Management Area, Mpumalanga. Mokolo River System: Resource Unit Delineation: Prepared by Clean Stream Biological Services and Water for Africa, authored by Kotze PJ and Louw, MD. Report no. 26/8/3/10/14/006.

Fore, L.S., 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.*

Kelly, M.G., Cazaubon, A., Coring, E., Dell'uomo, A., Ector, L., Goldsmith, B., Guasch, H., Hürlimann, J., Jarlman, A., Kawecka, B., Kwandrans, J., Laugaste, R., Lindstrøm, E.A., Leitao, M., Marvan, P., Padisak, J., Pipp, E., Prygiel, J., Rott, E., Sabater, S., Van Dam, H., and Vizinet, J. 1998. Recommendations for the routine sampling of diatoms for water quality assessments in Europe. *Journal of Applied Phycology* **10**: 215-224.

Kelly, M.G., Adams, C., Graves, A.C., Jamieson, J., Krokowski, J., Lycett, E.B., Murray-Bligh, J., Pritchard, S., and Wilkins, C. 2001. The Trophic Diatom Index: A User's Manual. Revised edition. R&D 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.

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

Prygiel, J., Carpentier, P., Almeida, S., Coste, M., Druart, J.C., Ector, L., Guillard, D., Honoré, M.A., Iserentant, R., Ledeganck, P., Lalanne-Cassou, C., Lesnaik, C., Mercier, I., Moncout, P., Nazart, M., Nouchet, N., Peres, F., Peeters, V., Rimet, F., Rumeau, A., Sabater, S., Straub, F., Torrisi, M., Tudesque, L., Van der Vijver, B., Vidal, H., Vizinet, J and Zydek, N. 2002. Determination of the biological diatom index (IBD NF T 90-354): results of an inter-comparison exercise. *Journal of Applied Phycology* **14**: 27-39.

River Health Programme (2005). State-of-Rivers Report: Monitoring and Managing the Ecological State of Rivers in the Crocodile (West) Marico Water Management Area. Department of Environmental Affairs and Tourism, Pretoria.

Rott, E. 1991. Methodological aspects and perspectives in the use of periphyton for monitoring and protecting rivers. In: Whitton, B.A., Rott, E. & Friedrich, G. editors. Use of Algae for Monitoring Rivers. E. Rott, Institüt für Botanik, Univ. Innsbruk. pp 9-16.

Round, F.E. 1993. A Review and Methods for the Use of Epilithic Diatoms for Detecting and Monitoring Changes in River Water Quality. Methods for the examination of water and associated materials. HMSO Publications, London.

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

Taylor, .J.C. 2004. The Application of Diatom-Based Pollution Indices in The Vaal Catchment. Unpublished M.Sc. thesis, North-West University, Potchefstroom Campus, Potchefstroom.

Taylor, J.C., Harding, W.R., Archibald, C.G.M. and van Rensburg, L. 2005a. Diatoms as indicators of water quality in the Jukskei-Crocodile River system in 1956 and 1957, a re-analysis of diatom count data generated by BJ Cholnoky. *Water SA* **31(2)**: 327-346.

Taylor, J.C., De la Rey, P.A. and Van Rensburg, L. 2005b. Recommendations for the collection, preparation and enumeration of diatoms from riverine habitats for water quality monitoring in South Africa. *African Journal of Aquatic Science,* **30(1)**: 65–75.

Taylor, J.C., Harding, W.R. and Archibald, C.G.M. 2007a. A methods manual for the collection, preparation and analysis of diatom samples. Water Research Commission Report TT281/07. Water Research Commission. Pretoria.

Taylor, J.C., Harding, W.R. and Archibald, C.G.M. 2007. An illustrated guide to some common diatom species from South Africa. Water Research Commission Report TT282/07. Water Research Commission. Pretoria.

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

APPENDIX F: FISH SPECIALIST REPORT

Dr P Kotze, Clean Stream Biological Services

Fish Species Abbreviations:

AURA	AMPHILIUS URANOSCOPUS (PFEFFER, 1889)
BBIF	BARBUS BIFRENATUS FOWLER, 1935
BBRI	BARBUS BREVIPINNIS JUBB, 1966
BMAR	LABEOBARBUS MAREQUENSIS SMITH, 1841
BPAU	BARBUS PALUDINOSUS PETERS, 1852
BTRI	BARBUS TRIMACULATUS PETERS, 1852
BUNI	BARBUS UNITAENIATUS GÜNTHER, 1866
BVIV	BARBUS VIVIPARUS WEBER, 1897
CFLA	CHETIA FLAVIVENTRIS TREWAVAS, 1961
CGAR	CLARIAS GARIEPINUS (BURCHELL, 1822)
CPRE	CHILOGLANIS PRETORIAE VAN DER HORST, 1931
LCON	LABEO CONGORO PETERS, 1852
LCYL	LABEO CYLINDRICUS PETERS, 1852
LMOL	LABEO MOLYBDINUS DU PLESSIS, 1963
LROS	LABEO ROSAE STEINDACHNER, 1894 (LABEO ALTEVILIS)
LRUD	LABEO RUDDI BOULENGER, 1907
MACU	MICRALESTES ACUTIDENS (PETERS, 1852)
MMAC	MARCUSENIUS MACROLEPIDOTUS (PETERS, 1852)
OMOS	OREOCHROMIS MOSSAMBICUS (PETERS, 1852)
PCAT	PETROCEPHALUS WESSELSI KRAMER & VAN DER BANK, 2000
PPHI	PSEUDOCRENILABRUS PHILANDER (WEBER, 1897)
SINT	SCHILBE INTERMEDIUS RÜPPELL, 1832
SZAM	SYNODONTIS ZAMBEZENSIS PETERS, 1852
TREN	TILAPIA RENDALLI (BOULENGER, 1896)
TSPA	TILAPIA SPARRMANII SMITH, 1840

F1 EWR 1A: VAALWATER

F1.1 DATA AVAILABILITY

Data availability	Conf
Single site visits and fish sampling during April 2008. Mokolo Biomonitoring Reports (Angliss *et al*., 2003; Angliss, 2003). Limpopo Environmental Affairs Fish Distribution Data Base. Updated June 2007. Rivers Database (2007): Database on fish distribution in South African Rivers. Atlas of Southern African Freshwater fishes (Scott *et al*., 2006). SAIAB Data base (2006). Reference Fish Frequency of Occurrence Report (Kleynhans *et al.,* 2007).	4

F1.2 REFERENCE CONDITIONS

Reference conditions broadly refer to "expectations on the state of aquatic biological communities in the absence of human disturbance and pollution". In the context of this report, it refers specifically to the fish species present in a particular river reach and their frequency of occurrence under reference habitat conditions (Kleynhans *et al.,* 2007).

EWR 1A falls within the lower foothills geomorphic zone and EcoRegion 6.02, Natural resource unit (NRU) C, Management Resource Unit (MRU) B and Water Quality Sub Unit (WQSU) 4. Reference conditions set should be valid for the reach of the Mokolo River from the start of EcoRegion 6.02 to the Sterkstroom confluence. Reference conditions set for site A4MOKO-VAAL (Kleynhans *et al.,* 2007), (exact site) was used as reference conditions for the Mokolo River reach incorporating site EWR 1A.

There is presently some uncertainty about the previous identification of *Barbus brevipinus* (BBRI) in the Mokolo River System. The Barbus species in the Mokolo River have some resemblance with BBRI (type locality: Sabie River, Mpumalanga) but differ to some extent with regards to appearance and possibly also preferences and intolerances to changes in the environment. This species is currently referred to as *Barbus sp. "Waterberg"* until its taxonomy is verified. For the purpose of this Fish Response Assessment Index (FRAI) application, this species is however still referred to as BBRI and the preferences and tolerance ratings of this species were used in the calculations. There are no records available of MBRE in the reach of the Mokolo River, although its habitat preference and availability, and natural distribution range suggest that this species may be included in the reference condition for this section of the Mokolo River.

Spp abbreviation	Scientific names: Reference species	Reference FROC CATEGORY A	Overall confidence in Reference condition
AJOH	APLOCHEILICHTHYS JOHNSTONI (GÜNTHER, 1893)	2	4
ALAB	ANGUILLA BENGALENSIS LABIATA PETERS, 1852	1	
AMOS	ANGUILLA MOSSAMBICA PETERS 1852	1	
AURA	AMPHILIUS URANOSCOPUS (PFEFFER, 1889)	2	
BBIF	BARBUS BIFRENATUS FOWLER, 1935	4	
BBRI	BARBUS BREVIPINNIS JUBB, 1966	4	
BMAR	LABEOBARBUS MAREQUENSIS SMITH, 1841	5	
BPAU	BARBUS PALUDINOSUS PETERS, 1852	5	
BTRI	BARBUS TRIMACULATUS PETERS, 1852	5	
BUNI	BARBUS UNITAENIATUS GÜNTHER, 1866	4	
BVIV	BARBUS VIVIPARUS WEBER, 1897	3	

Spp abbreviation	Scientific names: Reference species	Reference FROC CATEGORY A	Overall confidence in Reference condition
CFLA	CHETIA FLAVIVENTRIS TREWAVAS, 1961	3	
CGAR	CLARIAS GARIEPINUS (BURCHELL, 1822)	5	
CPRE	CHILOGLANIS PRETORIAE VAN DER HORST, 1931	5	
LCYL	LABEO CYLINDRICUS PETERS, 1852	3	
LMOL	LABEO MOLYBDINUS DU PLESSIS, 1963	5	
MACU	MICRALESTES ACUTIDENS (PETERS, 1852)	3	
MMAC	MARCUSENIUS MACROLEPIDOTUS (PETERS, 1852)	2	
OMOS	OREOCHROMIS MOSSAMBICUS (PETERS, 1852)	5	
PCAT	PETROCEPHALUS WESSELSI KRAMER & VAN DER BANK, 2000	2	
PPHI	PSEUDOCRENILABRUS PHILANDER (WEBER, 1897)	5	
TREN	TILAPIA RENDALLI (BOULENGER, 1896)	2	
TSPA	TILAPIA SPARRMANII SMITH, 1840	5	
FROC ratings: 0 = absent 1 = present at very few sites (<10%) 2 = present at few sites (>10 - 25%)	3 = present at about >25 - 50 % of sites 4 = present at most sites (>50 - 75%) 5 = present at almost all sites (>75%)		

F1.3 PRESENT ECOLOGICAL STATE

F1.3.1 Site suitability

Site suitability in terms of assessment index	Two small rheophilic species expected (AURA and CPRE). Their optimal habitat requirements (Fast Deep (FD) and Fast Shallow (FS) with substrate) are abundant at site. Six large and 11 small semi-rheophilic species are expected. Their required habitat is also well represented at the site. Four limnophilic species are expected, and their habitat requirements are also met at the site. Localised impacts on the riparian zone may alter overhanging vegetation habitats. Habitat requirements (flow-depth categories and cover) of all species are expected in this RU is represented at site. Site is estimated to have less Slow Deep (SD) and more FS than the rest of the RU.		
	EWR suitability = 3.5 Site FRAI suitability = 4.0	**Confidence**	4

The PES was calculated for the reach of the Mokolo River stretching from the start of EcoRegion 6.02 to the Dwars River confluence, within which site EWR 1A is situated.

PES description	Most of the expected fish species are still present within this RU although the FROC of some species have been reduced from reference conditions. The only species expected to be absent from this section are the two eel species (AMOS and ALAB). There are no records available of the two expected eel species, AMOS and ALAB previously sampled in this section of the Mokolo River. A very large (1.3 m) adult ALAB was sampled in 2002 by Mr. M. Angliss in the Sand River tributary of Mokolo (@A4Sand-Louba), upstream of the EWR site. Although this record gives a faint hope of eels still occurring in the upper Mokolo River, there is a strong possibility that this specimen may have migrated upstream before the construction of Mokolo Dam (1980). Female eels can stay in freshwater systems for ± 20years (Skelton, 2002). Although the ramp at Mokolo Dam seems to be passable (based on visual observations), present results indicate otherwise with a strong possibility that eels have been eradicated from the upper Mokolo River System as a result of this (Mokolo Dam) and other downstream migration barriers as well as the flow modification in the Limpopo River. It is estimated that the decreased flows resulted in altered habitats and may be responsible for decreased FROC of species such as BBRI, BMAR, CPRE, LMOL and MACU. Loss in substrate quality due to benthic algal growth and some siltation may have contributed to decreased FROC of species with high preference for substrate as cover (BMAR, CPRE, and LMOL). Loss of overhang (due to riparian activities, grazing and agriculture) may be responsible for decreased FROC of species such as BBRI, BTRI, BUNI, BVIV, PCAT and TREN. Slight deterioration in water quality can also be responsible for decreased FROC of species such as BBRI, CPRE, LMOL and MACU. The presence of alien predator MSAL also contributes to the reduced FROC of some species (especially small species).

	C	Confidence	3

F1.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
		Loss of habitat (decreased fast shallow (FS) and fast deep (FD) diversity as a result of flow modification (especially during winter).	Irrigation and small farm dams.		
		Presence of migration barriers reduces migration success (breeding, feeding and dispersal) of some species.	Mokolo Dam and other dams as well as weirs. Farm dams in tributaries reduce refuge areas.		
		Decreased overhanging vegetation as cover for fish.	Increased bank erosion related to agricultural, livestock and game farming activities.		
		Increased sedimentation result in deterioration of substrate as habitat (clogging interstitial spaces, loss of important spawning habitats, etc.).	Bank erosion and agriculture contribute to increased sedimentation (clearing of natural vegetation).		
		Decreased substrate quality related to increased benthic growth.	Increased nutrients from point and diffuse sources (Alma and Vaalwater WWTW, agriculture).		
		Decreased water quality affect species with requirement for high water quality.	Toxicants from agricultural areas.		
		Decreased species diversity and abundance (especially small species) as result of presence of alien predator (MSAL).	Presence of alien predatory species (MSAL) naturally spreading and introduced for recreation/angling.		

F1.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C	Negative	C	Long term	Increasing pressure due to the presence of alien predator MSAL may result in further deterioration in long term, although it is estimated that it should remain within the same category.	3

F1.5 REC: B

PES	REC	Comments	Conf
		Improved flows (no zero flows) and improved freshets and moderate floods will result in improved substrate quality (flushing of algae and sediment, improved interstitial spaces), which should be reflected by improved FROC and abundance of species with a preference for substrates (AURA, BMAR, CPRE, LMOL, and LCYL). Improved flows will improve overall conditions for the rheophilic species (AURA and CPRE). Improved flows will also result in improved flowing marginal habitats and improved water quality (higher dilution), which should result in improved FROC/abundance of species such as BBRI, and MACU.	3

F1.6 AEC: D

PES	AEC	Comments	Conf
		Deterioration in flows (more frequent and longer lasting zero flows) will have a serious impact on the FROC of rheophilic species (AURA, CPRE), which in a worst case scenarios may be lost from the reach. Decreased flows, freshettes and moderate floods will result in further deterioration in substrate quality, which will be reflected by a decreased FROC and abundance of species with preference for substrate (AURA, CPRE, BMAR, LCYL, and LMOL). Deteriorated flowing conditions will lead to an overall decrease in marginal flowing habitat for fish affecting species such as BBIF and BVIV. Further deterioration in water quality may also lead to decreased FROC of intolerant species (BBRI, AURA, and CPRE).	2

F2 EWR 1B: TOBACCO

F2.1 DATA AVAILABILITY

Data availability	Conf
Single site visits and fish sampling during April 2008. Mokolo Biomonitoring Reports (Angliss *et al*., 2003; Angliss, 2003). Limpopo Environmental Affairs Fish Distribution Data Base. Updated June 2007. Rivers Database (2007): Database on fish distribution in South African Rivers. Atlas of Southern African Freshwater fishes (Scott et al., 2006). SAIAB Data base (2006). Reference Fish Frequency of Occurrence Report (Kleynhans *et al.,* 2007).	4

F2.2 REFERENCE CONDITIONS

EWR 1B (Tobacco) falls within the lower foothills geomorphic zone, EcoRegion 6.02, NRU C, MRU B and WQSU 4. Reference conditions set should be valid for the reach of the Mokolo River from the start of EcoRegion 6.02 to the Sterkstroom confluence. Reference conditions as set for site A4MOKO-VAAL (Kleynhans *et al.,* 2007), were used as a starting point for setting reference conditions for the reach incorporating site EWR 1B. The following changes were made:

- MACU was added to the expected list as this species was sampled at site EWR1b during April 2008.
- AURA was excluded from the expected species list for this reach of the Mokolo River. It is expected that this species occurs in the upper reaches (higher altitudes) of the Mokolo River and its tributaries of EcoRegions 6.01, 7.02 and 7.03. The transitional phase for this species is estimated to be the upper reaches of the Mokolo River at the start of EcoRegion 6.01 (hence the inclusion of this species in the EWR1A reach).
- Expected FROC of BBRI was reduced, as there is no record of this species occurring in the Mokolo River from this point downstream. Records indicate it is more associated with the tributaries.

Spp abbreviation	Scientific names: Reference species	Reference FROC CATEGORY A	Overall confidence in Reference condition
AJOH	APLOCHEILICHTHYS JOHNSTONI (GÜNTHER, 1893)	2	3
ALAB	ANGUILLA BENGALENSIS LABIATA PETERS, 1852	1	
AMOS	ANGUILLA MOSSAMBICA PETERS 1852	1	
AURA	AMPHILIUS URANOSCOPUS (PFEFFER, 1889)	2	
BBIF	BARBUS BIFRENATUS FOWLER, 1935	4	
BBRI	BARBUS BREVIPINNIS JUBB, 1966	2	
BMAR	LABEOBARBUS MAREQUENSIS SMITH, 1841	5	
BPAU	BARBUS PALUDINOSUS PETERS, 1852	5	
BTRI	BARBUS TRIMACULATUS PETERS, 1852	5	
BUNI	BARBUS UNITAENIATUS GÜNTHER, 1866	4	
BVIV	BARBUS VIVIPARUS WEBER, 1897	3	
CFLA	CHETIA FLAVIVENTRIS TREWAVAS, 1961	3	
CGAR	CLARIAS GARIEPINUS (BURCHELL, 1822)	5	
CPRE	CHILOGLANIS PRETORIAE VAN DER HORST, 1931	5	
LCYL	LABEO CYLINDRICUS PETERS, 1852	3	
LMOL	LABEO MOLYBDINUS DU PLESSIS, 1963	5	
MACU	MICRALESTES ACUTIDENS (PETERS, 1852)	3	
MBRE	MESOBOLA BREVIANALIS (BOULENGER, 1908)	3	
MMAC	MARCUSENIUS MACROLEPIDOTUS (PETERS, 1852)	2	

Spp abbreviation	Scientific names: Reference species	Reference FROC CATEGORY A	Overall confidence in Reference condition
OMOS	OREOCHROMIS MOSSAMBICUS (PETERS, 1852)	5	
PCAT	PETROCEPHALUS WESSELSI KRAMER & VAN DER BANK, 2000	2	
PPHI	PSEUDOCRENILABRUS PHILANDER (WEBER, 1897)	5	
TREN	TILAPIA RENDALLI (BOULENGER, 1896)	2	
TSPA	TILAPIA SPARRMANII SMITH, 1840	5	
FROC ratings: 0 = absent 1 = present at very few sites (<10%) 2 = present at few sites (>10 - 25%)	3 = present at about >25 - 50 % of sites 4 = present at most sites (>50 - 75%) 5 = present at almost all sites (>75%)		

F2.3 PRESENT ECOLOGICAL STATE

F2.3.1 Site suitability

Site suitability in terms of assessment index	One small rheophilic species is expected (CPRE). Its optimal habitat requirements (FS and FD with substrate) are abundant at the site. Six large and 11 small semi-rheophilic species are expected. Their required habitat is also well represented at the site. Four limnophilic species are expected, and their habitat requirements are also met at the site. A small weir downstream of the site may have an affect on the natural fish assemblage at the site. Habitat requirements (flow-depth categories and cover) of all species expected in RU are represented at site. The site is estimated to have less Slow Deep (SD) and slightly more of the other flow-depth classes than the rest of the RU, but in general is representative of the entire RU.		
	EWR suitability = 3.5 Site FRAI suitability = 4.0	**Confidence**	4

The PES was calculated for the reach of the Mokolo River stretching from the Dwars River confluence to Sterkstroom confluence, within which site EWR 1B is situated.

PES description	Most of the expected fish species are still present within this RU although the FROC of some species have been reduced from reference conditions. The only species expected to be absent from this section are the two eel species (AMOS and ALAB). There are no records available of the two expected eel species, AMOS and ALAB recently sampled in this section of the Mokolo River. A very large (1.3 m) adult ALAB was sampled in 2002 by Mr. M. Angliss in the Sand River tributary of Mokolo (@A4Sand-Louba), upstream of the EWR site. Although this record gives a faint hope of eels still occurring in the upper Mokolo River, there is a strong possibility that this specimen may have migrated upstream before the construction of Mokolo Dam (1980). Female eels can stay in freshwater systems for ± 20 years (Skelton, 2002). Although the ramp at Mokolo Dam seems to be passable (based on visual observations), present results indicate otherwise with a strong possibility that eels have been eradicated from the upper Mokolo River System as a result of this (Mokolo Dam) and other downstream migration barriers as well as the flow modification in the Limpopo River. It is estimated that the decreased flows resulted in altered habitats and may be responsible for decreased FROC of species such as BBRI, BMAR, CPRE, LMOL and LCYL. Loss in substrate quality due to benthic algal growth and some siltation may have contributed to decreased FROC of species with high preference for substrate as cover (BMAR, CPRE, LMOL and LCYL). Loss of overhang (due to riparian activities, grazing and agriculture) may be responsible for decreased FROC of species such as BBIF, BBRI, BPAU, BTRI, BUNI, and BVIV. Slight deterioration in water quality can also be responsible for decreased FROC of species such as BBRI, CPRE, LMOL and LCYL. The presence of alien predator MSAL also contributes to the reduced FROC of some species (especially small species).		
	C (73%)	**Confidence**	3

F2.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf

PES	Conf	Causes	Sources	F/NF	Conf
		Loss of habitat (decreases FS and FD) diversity as a result of flow modification (especially during winter).	Irrigation and small farm dams.		
		Presence of migration barriers reduces migration success (breeding, feeding and dispersal) of some species.	Mokolo Dam and other dams as well as weirs. Farm dams in tributaries reduce refuge areas.		
		Decreased overhanging vegetation as cover for fish.	Increased bank erosion related to agricultural, livestock and game farming activities.		
		Increased sedimentation result in deterioration of substrate as habitat (clogging interstitial spaces, loss of important spawning habitats, etc.).	Bank erosion and agriculture contribute to increased sedimentation (clearing of natural vegetation).		
		Decreased substrate quality related to increased benthic growth.	Increased nutrients from point and diffuse sources (Vaalwater WWTW, and agriculture).		
		Decreased water quality affect species with requirement for high water quality.	Toxicants from agricultural areas.		
		Decreased species diversity and abundance (especially small species).	Presence of alien predatory species (MSAL) naturally spreading and introduced for recreation / angling.		

F2.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C	Negative	C		Increasing pressure due to the presence of alien predator MSAL may result in further deterioration over the long term, although it is estimated that it should remain within the same category.	3

F2.5 REC: B

PES	REC	Comments	Conf
C	B	Improved flows (no zero flows) and improved freshettes and moderate floods will result in improved substrate quality (flushing of algae and sediment, improved interstitial spaces), which should be reflected by improved FROC and abundance of species with a preference for substrates (BMAR, CPRE, LMOL, LCYL). Improved flows will improve overall conditions for the rheophilic species (CPRE). Overall improved conditions (habitat, flow and water quality) should be reflected in increased FROC and abundance of most species.	3

F2.6 AEC: NATIVE ECS TO SERVE AS THE RANGE OF EWR SCENARIOS

PES	AEC	Comments	Conf
C	D	Deterioration in flows (more frequent and longer lasting zero flows) will have a serious impact on the FROC of rheophilic species (CPRE), which in worst case scenarios may be lost from the reach. Decreased flows, freshettes and moderate floods will result in further deterioration in substrate quality, which will be reflected by a decreased FROC and abundance of species with preference for substrate (CPRE, BMAR, LCYL, and LMOL). Deteriorated flowing conditions will lead to an overall decrease in marginal flowing habitat for fish affecting species such as BBIF and BVIV. Further deterioration in water quality may also lead to decreased FROC of intolerant species (BBRI, CPRE). Increased temperature as a result of decreased water levels and lower flows may impact on species such as TSPA. Tolerant species, such as CGAR, may also be impacted as a result of decreased habitats and food availability. An overall deterioration in conditions (flow, habitat and water quality) may reduce the FROC of most species (including MMAC, PCAT, TREN, and MACU).	2.5

F3 EWR 2: KA'INGO

F3.1 DATA AVAILABILITY

Data availability	Conf
Single site visits and fish sampling during April 2008. Mokolo Biomonitoring Reports (Angliss *et al*., 2003; Angliss, 2003). Limpopo Environmental Affairs Fish Distribution Data Base. Updated June 2007. Rivers Database (2007): Database on fish distribution in South African Rivers. Atlas of Southern African Freshwater fishes (Scott et al., 2006). SAIAB Data base (2006). Reference Fish Frequency of Occurrence Report (Kleynhans *et al.,* 2007).	4

F3.2 REFERENCE CONDITIONS

EWR 2 falls within the lower foothills geomorphic zone and EcoRegion 6.02, NRU D, MRU B, Resource Assessment Unit (RAU) B.1 and WQSU 4. Reference conditions set for EWR 2 should be valid for the reach of the Mokolo River from the Sterkstroom confluence to the inflow into the Mokolo Dam. Reference conditions set for site A4MOKO-ABDAM (Kleynhans *et al.,* 2007), were used as a starting point for setting reference conditions for the reach incorporating site EWR 2. The following alteration was made:

- The two eel species (ALAB and AMOS) were included in the expected list, although they were indicated as "code 3" species in Kleynhans *et al.,* 2007. It is estimated that these species would have occurred in this reach naturally.
- BBRI, indicated as a "code 3" species in Kleynhans *et al.,* 2007 was excluded from the expected fish species list. There is no record of this species occurring in this section of the Mokolo River (1988 to 2008) and all available records indicate that it is more likely associated with the tributaries.
- Two more "code 3" species, namely BPAU and BUNI were excluded from the reach, as there is no record available of these species being present at any of five sites sampled within this reach between 1988 and 2008.
- AURA was excluded from the expected species list for this reach of the Mokolo River. It is expected that this species occurs in the upper reaches (higher altitudes) of the Mokolo River and its tributaries of EcoRegions 6.01, 7.02 and 7.03. The transitional phase for this species is estimated to be the upper reaches of the Mokolo River at the start of EcoRegion 6.01 (hence the inclusion of this species in EWR 1A reach).
- BVIV and BPAU are present both up and downstream of this reach and may occur here from time to time when migrating through. They have however not been sampled and may be as a result of poor marginal cover in this bedrock dominated section.

Spp abbreviation	Scientific names: Reference species	Reference FROC CATEGORY A	Overall confidence in Reference condition
AJOH	APLOCHEILICHTHYS JOHNSTONI (GÜNTHER, 1893)	3	4
ALAB	ANGUILLA BENGALENSIS LABIATA PETERS, 1852	1	
AMOS	ANGUILLA MOSSAMBICA PETERS 1852	1	
BBIF	BARBUS BIFRENATUS FOWLER, 1935	5	
BMAR	LABEOBARBUS MAREQUENSIS SMITH, 1841	5	
BTRI	BARBUS TRIMACULATUS PETERS, 1852	3	
CFLA	CHETIA FLAVIVENTRIS TREWAVAS, 1961	3	
CGAR	CLARIAS GARIEPINUS (BURCHELL, 1822)	2	

Spp abbreviation	Scientific names: Reference species	Reference FROC CATEGORY A	Overall confidence in Reference condition
CPRE	CHILOGLANIS PRETORIAE VAN DER HORST, 1931	5	
LCYL	LABEO CYLINDRICUS PETERS, 1852	4	
LMOL	LABEO MOLYBDINUS DU PLESSIS, 1963	4	
MACU	MICRALESTES ACUTIDENS (PETERS, 1852)	4	
MBRE	MESOBOLA BREVIANALIS (BOULENGER, 1908)	4	
MMAC	MARCUSENIUS MACROLEPIDOTUS (PETERS, 1852)	1	
OMOS	OREOCHROMIS MOSSAMBICUS (PETERS, 1852)	3	
PCAT	PETROCEPHALUS WESSELSI KRAMER & VAN DER BANK, 2000	1	
PPHI	PSEUDOCRENILABRUS PHILANDER (WEBER, 1897)	4	
SINT	SCHILBE INTERMEDIUS RÜPPELL, 1832	2	
SZAM	SYNODONTIS ZAMBEZENSIS PETERS, 1852	1	
TREN	TILAPIA RENDALLI (BOULENGER, 1896)	3	
TSPA	TILAPIA SPARRMANII SMITH, 1840	5	
FROC ratings: 0 = absent 1 = present at very few sites (<10%) 2 = present at few sites (>10 - 25%)	3 = present at about >25 - 50 % of sites 4 = present at most sites (>50 - 75%) 5 = present at almost all sites (>75%)		

F3.3 PRESENT ECOLOGICAL STATE

F3.3.1 Site suitability

Site suitability in terms of assessment index	One small rheophilic species is expected (CPRE). Its optimal habitat requirements (FS and FD with substrate) are very well represented at site. Eight large and 7 small semi-rheophilic species are expected. Their required habitat is also relatively well represented at the site. Four limnophilic species expected, and their habitat requirements are also met at the site. Instream and riparian habitats in close to natural state. Habitat requirements (flow-depth categories and cover) of all species expected in the RU are represented at site. Site is estimated to have slightly less SD than the rest of the RU, but is very representative of entire MRU B.1.		
	EWR suitability = 3.5 Site FRAI suitability = 3.5	**Confidence**	3.5

The PES was calculated for the reach of the Mokolo River stretching from the Sterkstroom confluence to the inflow into the Mokolo Dam, within which site EWR 2 is situated.

PES description	Most of the expected fish species are still present within this RU although the FROC of some species have been reduced from reference conditions. The only species expected to have been lost from this section are the two eel species (AMOS and ALAB). There are no records available of the two expected eel species, AMOS and ALAB previously sampled in this section of the Mokolo River. Although the ramp at Mokolo Dam seems to be passable (based on visual observations), present results indicate otherwise with a strong possibility that eels have been eradicated from the upper Mokolo River System as a result of this (Mokolo Dam) and other downstream migration barriers as well as the flow modification in the Limpopo River. It is estimated that the decreased flows resulted in altered habitats (decrease in fast habitats) and may be responsible for decreased FROC of species such as BMAR, CPRE, LMOL and LCYL. Loss in substrate quality due to benthic algal growth and some siltation may have further contributed to decreased FROC of these species (having a high preference for substrate as cover). Loss of overhang and undercut banks (due to decreased water level, riparian activities, grazing and agriculture) may be responsible for decreased FROC of species such as BBIF, BTRI, MMAC and TREN. Slight deterioration in water quality can also be responsible for further decreased FROC of species such as CPRE, LMOL, LCYL and MMAC. Although the alien species MSAL and CCAR are abundant in the Mokolo Dam, there are no definite records of them in the river itself (Angliss, 2002). It is however thought that they will move into the river from time to time and also have an impact on the indigenous fish species.		
	C (65.1%)	**Confidence**	3

F3.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
		Loss of habitat (decreased FS and FD) diversity as a result of flow modification (especially during winter).	Irrigation and small farm dams.		
		Presence of migration barriers reduces migration success (breeding, feeding and dispersal) of some species.	Mokolo Dam and other dams as well as weirs. Farm dams in tributaries reduce refuge areas.		
		Decreased overhanging vegetation and undercut banks as cover for fish.	Increased bank erosion related to agricultural, livestock and game farming activities.		
		Deterioration of substrate as habitat (clogging interstitial spaces, loss of important spawning habitats, etc) due to increased sedimentation.	Bank erosion and agriculture clearing of natural vegetation.		
		Decreased substrate quality related to increased benthic growth.	Increased nutrients from point and diffuse sources (Vaalwater WWTW, agriculture).		
		Decreased water quality affect species with requirement for high water quality.	Effluents from agricultural areas (pesticides).		
		Decreased species diversity and abundance (especially small species).	Presence of alien predatory species (MSAL) naturally spreading and introduced for recreation / angling.		

F3.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C	Negative	C	Long term	Increasing pressure due to the presence of alien predator MSAL may result in further deterioration over the long term, although it is estimated that it should remain within the same category.	3

F3.5 REC: B

PES	REC	Comments	Conf
C	B	This scenario will result in improved substrate quality (flushing of algae and sediment, improved interstitial spaces), which should be reflected by improved FROC and abundance of species with a preference for substrates (BMAR, CPRE, LMOL, and LCYL). Improved flows (decreased zero flows) will improve overall conditions for the rheophilic species (CPRE). Overall improved conditions (habitat, flow and water quality) should be reflected in increased FROC and abundance of other species such as MBRE and MMAC.	3

F3.6 AEC: C/D

PES	AEC	Comments	Conf
C	D	Deterioration in flows (more frequent and longer lasting zero flows) will have a serious impact on the FROC of rheophilic species CPRE, which in worse case scenarios may be lost from the reach. Decreased flows, freshettes and moderate floods will result in further deterioration in substrate quality, which will be reflected by a decreased FROC and abundance of species with preference for substrate (CPRE, BMAR, LCYL, and LMOL). Deteriorated flowing conditions will lead to an overall decrease in marginal flowing habitat for fish, affecting species such as BBIF and possibly MACU. Further deterioration in water quality may also lead to decreased FROC of intolerant species (CPRE).	2.5

F4 EWR 3: GORGE

F4.1 DATA AVAILABILITY

Data availability	Conf
Single site visits and fish sampling during September 2007. Mokolo Biomonitoring Reports (Angliss *et al*., 2003; Angliss, 2003). Limpopo Environmental Affairs Fish Distribution Data Base. Updated June 2007. Rivers Database (2007): Database on fish distribution in South African Rivers. Atlas of Southern African Freshwater fishes (Scott et al., 2006). SAIAB Data base (2006). Reference Fish Frequency of Occurrence Report (Kleynhans *et al.,* 2007).	4

F4.2 REFERENCE CONDITIONS

EWR 3 falls within the upper foothills geomorphic zone and EcoRegion 6.01, NRU D, MRU C, RAU C.1 and WQSU 5. Reference conditions set should be valid for the reach of the Mokolo River within RAU C.1 (outflow of Mokolo Dam to just upstream of confluence with Poer se loop). The closest available site with reference conditions set by Kleynhans *et al.,* 2007 is site A4MOKO-BEDAM. This site lies 32 km downstream of the EWR site, outside the assessment reach, 40 m lower in altitude, and importantly downstream of the gorge area. The information for this site was therefore used as a starting point for setting reference conditions for the reach incorporating EWR 3, with the following alteration made:

- Two eel species (ALAB, and AMOS) were included in the expected list (listed as “code 3” species in Kleynhans *et al.,* 2007). It is estimated that these species would have occurred in this reach naturally, as their habitat requirements are met, and they would have moved through this area to reach the upper reaches of the river.
- Another eel species namely AMAR was added to the expected species list. This species was sampled at Wildebeesfontein (very close to EWR 3) by CJ Kleynhans in 1988 (Rivers database, 2007).
- BANN (code 3 spp) was included in the expected lists as it was previously sampled at A4MOGO-WWORK by M. Angliss in 2002 (Angliss, 2002).
- BRAD and LCON were added to the expected lists as they were previously sampled at Wildebeesfontein (very close to EWR 3) by CJ Kleynhans in 1988 (Rivers database, 2007).
- LRUD was excluded from expected list as its optimal habitat is not well represented and records available of this species in the gorge.

Spp abbreviation	Scientific names: Reference species	Reference FROC CATEGORY A	Overall confidence in Reference condition
AJOH	APLOCHEILICHTHYS JOHNSTONI (GÜNTHER, 1893)	3	4
ALAB	ANGUILLA BENGALENSIS LABIATA PETERS, 1852	1	
AMAR	ANGUILLA MARMORATA QUOY & GAIMARD 1824	1	
AMOS	ANGUILLA MOSSAMBICA PETERS 1852	1	
BANN	BARBUS ANNECTENS GILCHRIST & THOMPSON, 1917	1	
BBIF	BARBUS BIFRENATUS FOWLER, 1935	4	
BMAR	LABEOBARBUS MAREQUENSIS SMITH, 1841	4	
BPAU	BARBUS PALUDINOSUS PETERS, 1852	4	
BRAD	BARBUS RADIATUS PETERS, 1853	1	
BTRI	BARBUS TRIMACULATUS PETERS, 1852	4	

Spp abbreviation	Scientific names: Reference species	Reference FROC CATEGORY A	Overall confidence in Reference condition
BUNI	BARBUS UNITAENIATUS GÜNTHER, 1866	3	
CFLA	CHETIA FLAVIVENTRIS TREWAVAS, 1961	3	
CGAR	CLARIAS GARIEPINUS (BURCHELL, 1822)	2	
CPAR	CHILOGLANIS PARATUS CRASS, 1960	3	
CPRE	CHILOGLANIS PRETORIAE VAN DER HORST, 1931	4	
LCON	LABEO CONGORO PETERS, 1852	1	
LCYL	LABEO CYLINDRICUS PETERS, 1852	3	
LMOL	LABEO MOLYBDINUS DU PLESSIS, 1963	5	
MACU	MICRALESTES ACUTIDENS (PETERS, 1852)	4	
MBRE	MESOBOLA BREVIANALIS (BOULENGER, 1908)	3	
MMAC	MARCUSENIUS MACROLEPIDOTUS (PETERS, 1852)	1	
OMOS	OREOCHROMIS MOSSAMBICUS (PETERS, 1852)	3	
PCAT	PETROCEPHALUS WESSELSI KRAMER & VAN DER BANK, 2000	1	
PPHI	PSEUDOCRENILABRUS PHILANDER (WEBER, 1897)	4	
SINT	SCHILBE INTERMEDIUS RÜPPELL, 1832	2	
TREN	TILAPIA RENDALLI (BOULENGER, 1896)	4	
TSPA	TILAPIA SPARRMANII SMITH, 1840	3	

FROC ratings:
0 = absent
1 = present at very few sites (<10%)
2 = present at few sites (>10 - 25%)
3 = present at about >25 - 50 % of sites
4 = present at most sites (>50 - 75%)
5 = present at almost all sites (>75%)

F4.3 PRESENT ECOLOGICAL STATE

F4.3.1 Site suitability

Site suitability in terms of assessment index	One small rheophilic species expected (CPRE). Its optimal habitat requirement (FS and FD with substrate) is very well represented at site. Ten large and 10 small semi-rheophilic species are expected. Their required habitat is also relatively well represented at the site. Four limnophilic species are expected, and their habitat requirements are also met at site. Instream and riparian habitats in close to natural state. Habitat requirements (flow-depth categories and cover) of all species expected in the RU are represented at the site. Site estimated to have slightly less SD habitat than the rest of the RU, but is representative of entire MRU C.1.		
	EWR suitability = 4.5 Site FRAI suitability = 3.5	**Confidence**	4

The PES was calculated for the reach of the Mokolo River within RAU C.1 (outflow of Mokolo Dam to just upstream of confluence with Poer se loop), within which site EWR 3 is situated.

PES description	Most of the expected fish species are still present within this RU although the FROC of some species have been reduced from reference conditions. The only species expected to have been lost from this section are the three eel species (AMOS, AMAR and ALAB), probably as a result of downstream migration barriers and fragmentation. It is estimated that the decreased base flows resulted in altered habitats (loss of fast habitats) and may be responsible for decreased FROC of species such as BMAR, CPAR, CPRE, LCON and MACU). Loss in substrate quality (some siltation as result of loss in natural floods) may have further contributed to decreased FROC of BMAR, CPAR, CPRE and LCON (having a high preference for substrate as cover). Loss of overhang and undercut banks (due to decreased water level/altered hydrological regime) may have contributed to the decreased FROC of species such as BBIF, BPAU, BRAD, BUNI, TRI, MACU and TREN. Altered water quality as a result of Mokolo Dam releases may also have contributed to further decreased FROC of species such as CPRE, CPAR and MACU. Although the alien species MSAL and CCAR are abundant in the Mokolo Dam, there are no records of them in the river section in the gorge, and it is thought that they do not occur here presently.		
	C (65.8%)	**Confidence**	3

F4.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
		Loss of habitat (decreased FS and FD) diversity as a result of flow modification (especially during winter).	Mokolo Dam, upstream Irrigation and small farm dams.		
		Deterioration of substrate as habitat (clogging interstitial spaces, loss of important spawning habitats, etc) due to increased sedimentation.	Decreased floods or natural freshettes.		
		Presence of migration barriers reduces migration success (breeding, feeding and dispersal) of some species.	Mokolo Dam (upstream) and other dams as well as weirs. Farm dams in tributaries reduce refuge areas.		
		Decreased overhanging vegetation and undercut banks as cover for fish.	Altered flows (fluctuating water levels and generally lower flows).		

F4.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C	Stable	C		The fish in this reach have been exposed to the present impacts (Mokolo Dam since 1980) over a long period and have adapted to the current conditions.	3

F4.5 REC: B

PES	REC	Comments	Conf
C	B	Improved flows (reduced zero flows) would improve conditions for the rheophilic species CPRE as well as various semi-rheophilic species (CPAR, BMAR, MACU, and TREN), which should be reflected in improved FROC and abundance of these species in this reach. Improved flows (closer to natural regime) may even result in the improvement of downstream conditions to the extent that some of the eel species may return to this section of the Mokolo River (low confidence assumption). Improved freshettes and moderate floods will result in improved substrate quality (flushing of algae and sediment, improved interstitial spaces), which should be reflected by improved FROC and abundance of species with a preference for substrates (BMAR, CPRE, and CPAR). Overall improved conditions (habitat, flow and water quality) would result in decreased stress and should be reflected by increased FROC and abundance of other species resulting in an overall improved fish assemblage in this reach..	3

F4.6 AEC: C/D

PES	AEC	Comments	Conf
C	D	Deterioration in flows will have a serious impact on the FROC of the rheophilic species CPRE, which will most probably be lost from the reach. Decreased flows, freshettes and moderate floods will result in further deterioration in substrate quality (increased embeddedness of substrates in sediment and algal growth) which will be reflected by a decreased FROC and abundance of species with preference for substrate (CPRE, CPAR, LCYL, and LMOL). Loss of overhanging vegetation (marginal zone) will have a negative impact on the FROC of species with a preference for overhanging vegetation (AJOH, BTRI, CFLA, MMAC, PCAT, PPHI, and TSPA).	3

F5 EWR 4: MALALATAU

F5.1 DATA AVAILABILITY

Data availability	Conf
Single site visits and fish sampling during September 2007. Mokolo Biomonitoring Reports (Angliss *et al*., 2003; Angliss, 2003). Limpopo Environmental Affairs Fish Distribution Data Base. Updated June 2007. Rivers Database (2007): Database on fish distribution in South African Rivers. Atlas of Southern African Freshwater fishes (Scott et al., 2006). SAIAB Data base (2006). Reference Fish Frequency of Occurrence Report (Kleynhans *et al.,* 2007).	4

F5.2 REFERENCE CONDITIONS

EWR 4 falls within the lowland geomorphic zone and EcoRegion 6.01, NRU D, MRU C, RAU C.2 and WQSU 5. Reference conditions are valid for the reach of the Mokolo River within RAU C.2 (Mokolo River from confluence with Poer se loop to confluence with Rietspruit/end of EcoRegion 6.01). The closest available site with reference conditions set by Kleynhans *et al.,* 2007 is site A4MOKO-BEDAM. This site lies 6 km upstream of the EWR site, within RAU C.2, approximately 9 m higher in altitude within the same geomorphic zone. The information for this site was therefore used for setting reference conditions for the reach incorporating EWR 4, with the following alteration made:

- Three eel species (ALAB, AMOS and AMAR) were included in the expected list. It is estimated that these species may have frequented this reach under natural conditions (as a migration route and utilising slow-deep habitats).
- Two code 3 species, BMAR and BUNI were included as some of their habitat requirements are met in this reach and because of their presence up- and downstream of this reach.
- BVIV, LCON and LROS were added to the expected list as they were sampled or observed during the 2007 survey.
- Due to the low abundance of stones as substrate, the FROC of species with preference for this habitat was reduced (BMAR, CPAR, CPRE, LMOL).

Spp abbreviation	Scientific names: Reference species	Reference FROC CATEGORY A	Overall confidence in Reference condition
AJOH	APLOCHEILICHTHYS JOHNSTONI (GÜNTHER, 1893)	3	3
ALAB	ANGUILLA BENGALENSIS LABIATA PETERS, 1852	1	
AMAR	ANGUILLA MARMORATA QUOY & GAIMARD 1824	1	
AMOS	ANGUILLA MOSSAMBICA PETERS 1852	1	
BBIF	BARBUS BIFRENATUS FOWLER, 1935	4	
BMAR	LABEOBARBUS MAREQUENSIS SMITH, 1841	2	
BPAU	BARBUS PALUDINOSUS PETERS, 1852	4	
BTRI	BARBUS TRIMACULATUS PETERS, 1852	4	
BUNI	BARBUS UNITAENIATUS GÜNTHER, 1866	2	
BVIV	BARBUS VIVIPARUS WEBER, 1897	2	
CFLA	CHETIA FLAVIVENTRIS TREWAVAS, 1961	3	
CGAR	CLARIAS GARIEPINUS (BURCHELL, 1822)	2	
CPAR	CHILOGLANIS PARATUS CRASS, 1960	2	
CPRE	CHILOGLANIS PRETORIAE VAN DER HORST, 1931	1	
LCON	LABEO CONGORO PETERS, 1852	1	

Spp abbreviation	Scientific names: Reference species	Reference FROC CATEGORY A	Overall confidence in Reference condition
LCYL	LABEO CYLINDRICUS PETERS, 1852	3	
LMOL	LABEO MOLYBDINUS DU PLESSIS, 1963	3	
LROS	LABEO ROSAE STEINDACHNER, 1894 (LABEO ALTEVILIS)	1	
LRUD	LABEO RUDDI BOULENGER, 1907	1	
MACU	MICRALESTES ACUTIDENS (PETERS, 1852)	4	
MBRE	MESOBOLA BREVIANALIS (BOULENGER, 1908)	3	
MMAC	MARCUSENIUS MACROLEPIDOTUS (PETERS, 1852)	1	
OMOS	OREOCHROMIS MOSSAMBICUS (PETERS, 1852)	3	
PCAT	PETROCEPHALUS WESSELSI KRAMER & VAN DER BANK, 2000	1	
PPHI	PSEUDOCRENILABRUS PHILANDER (WEBER, 1897)	4	
SINT	SCHILBE INTERMEDIUS RÜPPELL, 1832	2	
TREN	TILAPIA RENDALLI (BOULENGER, 1896)	4	
TSPA	TILAPIA SPARRMANII SMITH, 1840	3	
FROC ratings: 0 = absent 1 = present at very few sites (<10%) 2 = present at few sites (>10 - 25%)	3 = present at about >25 - 50 % of sites 4 = present at most sites (>50 - 75%) 5 = present at almost all sites (>75%)		

F5.3 PRESENT ECOLOGICAL STATE

F5.3.1 Site suitability

Site suitability in terms of assessment index	One small rheophilic species expected (CPRE). Its optimal habitat requirement (FS and FD with substrate) is not well represent at site. Thirteen large and 10 small semi-rheophilic species are expected. Their required habitat is relatively well represented at the site. Four limnophilic species are expected, and their habitat requirements are also met at the site. Habitat requirements (flow-depth categories and cover) of most species expected in the RU are represented at site. Site estimated to be very well representative of habitats in MRU C.2.		
	EWR suitability = 2.5 Site FRAI suitability = 4.0	**Confidence**	3

The PES was calculated for the reach of the Mokolo River within RAU C.2 (Mokolo River from confluence with Poer se loop to confluence with Rietspruit/end of EcoRegion 6.01), within which site EWR 4 is situated.

PES description	Most of the expected fish species are still present within this RU although the FROC of some species have been reduced from reference conditions. Species expected to have been lost from this section are the three eel species (AMOS, AMAR and ALAB), probably as a result of downstream migration barriers and fragmentation and the rheophilic species CPRE, probably as a result of the occurrence of zero flows. It is estimated that the decreased base flows resulted in loss of fast habitats and may be responsible for decreased FROC of species such as BMAR, CPAR, LCON, LCYL, LCON and MACU). Loss of stones as substrate quality (siltation as result of loss in natural floods as well as decreased amount related to decreased flow and zero flows) may have further contributed to decreased FROC of BMAR, CPAR, CPRE and LCON (having a high preference for substrate as cover). Loss of overhang and undercut banks (due to decreased water level/altered hydrological regime and agricultural activities, bank erosion) may have contributed to the decreased FROC of species such as BPAU, BUNI, TRI, MACU and TREN. Slightly altered water quality as a result of Mokolo Dam releases and decreased flows/zero flows may also have contributed to further decreased FROC of species such as CPRE, CPAR, LCYL, LMOL and MACU. Although the alien species MSAL and CCAR are abundant in the Mokolo Dam, there are no records of them in the lower Mokolo river section and it is thought that they do not occur here presently.		
	PES = C (62.2%)	**Confidence**	3

F5.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
		Loss of habitat (decreased FS and FD) diversity as a result of flow modification (especially during winter).	Mokolo Dam, upstream irrigation and small farm dams.		
		Increased sedimentation result in deterioration of substrate as habitat (clogging interstitial spaces, loss of important spawning habitats, etc.).	Decreased floods or natural freshettes.		
		Presence of migration barriers reduces migration success (breeding, feeding and dispersal) of some species.	Mokolo Dam (upstream) and other dams as well as weirs. Also farm dams in tributaries reduce refuge areas.		
		Decreased overhanging vegetation and undercut banks as cover for fish.	Altered flows (fluctuating water levels and generally lower flows, agriculture, erosion).		

F5.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C	Stable	C		The fish in this reach have been exposed to the present impacts (Mokolo Dam since 1980) over a long period and have adapted to the current conditions.	3

F5.5 REC: B

PES	REC	Comments	Conf
C	B	Improved flows (less zero flows, better base flows) will improve conditions for most species, especially the expected rheophilic species (CPRE) and most semi-rheophilic species (BMAR, BPAU, BUNI, CPAR, LCYL, LMOL, MBRE, MACU, and TREN). Improved flows (closer to natural regime) may even result in improvement of downstream conditions to the extent that some of the eel species (AMOS, AMAR and ALAB) may return to this section of the Mokolo River (low confidence assumption). Overall improved conditions (habitat, flow and water quality) would result in reduced stress and should be reflected by increased FROC and abundance of some species resulting in an overall improved fish assemblage in this reach.	2

F5.6 AEC: C/D

PES	AEC	Comments	Conf
C	D	Deterioration in flows (more frequent and longer lasting zero flows) will have a major impact on the FROC of most species (especially semi-rheophilic species) through the loss of habitat (fast habitats, depth in pools, reduced inundated vegetation and overhanging vegetation) and reduced water quality (increased temperature and decreased oxygen). The above mentioned impacts will result in decreased FROC and abundance of species such as BBIF, BTRI, BVIV, CPAR, LCYL, LMOL, MACU, MMAC, PCAT and TSPA. The reduced FROC of TSPA is associated with increased water temperatures.	3

F6 REFERENCES

Angliss, M.K., Fouche, P.J., Fouche, P.S.O., Rodgers, S.S.M., Netshiungane E. and du Preez, L. 2003. A. biomonitoring survey of the Mogol (Mokolo) River Catchment in the Limpopo Province. Internal report of Limpopo Environmental Affairs.

Angliss, M.K. 2003. A biomonitoring survey of the Mogol (Mokolo) River Catchment in the Limpopo Province. Site Inventory Report. Internal report of Limpopo Environmental Affairs.

Kleynhans, C.J. 2003. National Aquatic Ecosystem Biomonitoring Programme: Report on a National Workshop on the use of Fish in Aquatic System Health Assessment. NAEBP Report Series No. 16. Institute for Water Quality Studies, DWAF, Pretoria. South Africa.

Kleynhans, C.J., Louw, M.D., Moolman, J. 2007. 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.

Limpopo Environmental Affairs Fish Distribution Data Base. Updated June 2007.

Rivers Database 2007. Database on fish distribution in South African Rivers.

Scott, L.E.P., Skelton, P.H., Booth, A.J., 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.

Skelton, P.H. 2001. A complete guide to freshwater fishes of Southern Africa. Struik Publishers (Pty) Ltd., Cape Town, South Africa. 395pp.

APPENDIX G: MACROINVERTEBRATE SPECIALIST REPORT

C Thirion, D: RQS, DWAF
Dr AC Uys, Laughing Waters

G1 EWR 1A: VAALWATER

G1.1 DATA AVAILABILITY

Data availability	Conf
The following data were available: Macroinvertebrate data and analysis from a single sampling trip to the site on 16 June 2008. Macroinvertebrate data from the Rivers Database for the following sites: A4MOKO-MOKOL, A4MOKO-STERK, A4MOKO-STERK, A4MOKO-VAALW, A4MOKO-WITFO). Preliminary maps and information on the catchment as supplied by Delana Louw, Water for Africa. Specialist assessments for this study: Hydrological assessment (HAI) by Prof Denis Hughes. IHI assessment by Delana Louw. Diatom Assessment by Shael Koekemoer. Geomorphological Assessment Index by Mark Rountree. Vegetation Assessment Index by James McKenzie. A Level 1 Ecosystem Classification System for South Africa, Lesotho and Swaziland. Department of Water Affairs and Forestry, Pretoria, 2005. A Level 2 Ecosystem Classification System for South Africa, Lesotho and Swaziland. Department of Water Affairs and Forestry, Pretoria, 2007. Dallas (2007): SASS5 Data Interpretation Guidelines River Health Programme: State of the Rivers Report for the Mokolo River. A catchment in the Limpopo Province. August 2006.	2

G1.2 REFERENCE CONDITIONS

Reference conditions	Conf
National River Health Programme sites occurring in the same Level II EcoRegion and geomorphological zone were used to determine reference conditions for EWR1A. The total reference conditions comprise the cumulative data set from these sites, the sample site as well as taxa derived to have been there under reference conditions. An indication of reference abundance and frequency of occurrence of these taxa were also estimated based on expert judgement. The reference total SASS 5 score is 200 with more than 28 taxa and an ASPT of 7.	3

RHP Ref Site	River	Latitude	Longitude	EcoRegion	Gm Zone	Alt	Quat	SASS	ASPT
A4MOKO-MOKOL	Mokolo	-24.05798	27.79485	6.02	Lowland river	933	A42F	172	6.2
A4MOKO-STERK	Mokolo	-24.1861	27.9547	6.02	Lowland river	1048	A42E	149	6.5
A4MOKO-VAALW	Mokolo	-24.2894	28.0924	6.02	Lowland river	1147	A42C	182	6.5
A4MOKO-WITFO	Mokolo	-24.1137	27.80235	6.02	Lowland river	952	A42F	182	6.5

G1.3 PRESENT ECOLOGICAL STATE

G1.3.1 Site suitability

Throughout the report, suitability in this context is specific to invertebrates, and is gauged in relation to a similar site in the same EcoRegion, geomorphic zone and altitude, in its natural state.

Site suitability in terms of assessment index	The site is situated near Vaalwater and shows signs of being impacted by water quality. The site has a variety of different biotopes available providing potential habitat for a diversity of macroinvertebrates. Only a limited amount of mud is available, but mud is a poor habitat for invertebrates. Due to the location of the site there is considerable local disturbance such as people and cattle crossing the river that have a negative impact on the macroinvertebrate assemblage at the site.		
	3	**Confidence**	4

PES	TOTAL SASS SCORE	NO OF TAXA	ASPT
	127	26	5.3
PES description	The macroinvertebrates at this site is currently in a C condition, mainly as a result of water quality deterioration as indicated by the Macro Invertebrate Assessment Index (MIRAI) metrics (water quality – 59%, and connectivity and seasonality - 59.7%). Although many of the more sensitive macroinvertebrate families still occur at the site, their abundances and frequency of occurrence have decreased. A good example is the stonefly family Perlidae that should occur in B abundance (70%) of the time was only found once and as a single individual. The present macroinvertebrate assemblage consists of a variety of invertebrates including: Oligochaeta, Potamonautidae, Hydracarina, >2spp Baetidae, Caenidae, Leptophlebiidae, Coenagrionidae, Libellulidae, Corixidae, Gerridae, Naucoridae, Veliidae, >2spp Hydropsychidae, Hydroptilidae, Leptoceridae, Dytiscidae, Elmidae, Gyrinidae, Chironomidae, Simuliidae, Tabanidae, Ancylidae, Physidae and Planorbinae. The SASS score of 127 and ASPT of 5.3 relates to a C category according to Dallas (2007) interpretation guidelines. The MIRAI score of 62.3% also relates to a C category.		
	C	Confidence	2

G1.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
		Decreased low flows.	Abstraction.	F	
		Increased nutrients.	Agriculture.	NF	
		Decreased water quality.	Runoff from Vaalwater.	NF	

G1.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C	Negative	D	5 years	The invertebrates are still adjusting to the flow and water quality.	2

G1.5 REC: B/C

PES	REC	Comments	Conf
C	B/C	No zero flow periods and the return of freshettes and some moderate floods will result in more scour to remove some algae and fines between the cobbles. This will result in better cobble habitat. The decrease in *Phragmites* and *Typha* will result in more grasses in the marginal zone improving the vegetation habitat for the invertebrates. The invertebrates will respond to the improved habitat by the return of some of the more sensitive taxa and an improvement in the abundance and frequency of occurrence of the more sensitive taxa. This will result in the invertebrates improving to a B/C category with a SASS5 score of about 180 and an ASPT of around 6.5	3

G1.6 AEC: D

PES	AEC	Comments	Conf
C	D	Increased zero flows and longer periods of very low flows could result in a deterioration of the water quality. Increased nutrient concentrations linked to higher temperatures will result in increased algal growth, and therefore decreased quantity and quality of habitat. Although the *Myriophyllum* will also increase the increased filamentous algae will decrease the quality of the habitat. *Phragmites* and *Typha* will increase and replace some of the more suitable grasses. This will result in a deterioration of the taxa preferring vegetation habitat (lower number of taxa, lower frequencies and abundances). There will be more sediment in the system and the cobbles will become more embedded resulting in a loss of the more sensitive cobble dwelling invertebrates and a decreased abundance and frequency of occurrence of other cobble dwelling invertebrates. These conditions will result in the invertebrates deteriorating to a D EC with a SASS5 score around 100 and an ASPT of around 5.	2.5

G2 EWR 1B: TOBACCO

G2.1 DATA AVAILABILITY

Data availability	Conf
Macroinvertebrate data and analysis from a two sampling trips to the site on 17 January 2008 and 16 June 2008. Macroinvertebrate data from the Rivers Database for the following sites: A4MOKO-MOKOL, A4MOKO-STERK, A4MOKO-STERK, A4MOKO-VAALW, A4MOKO-WITFO). Preliminary maps and information on the catchment as supplied by Delana Louw, Water for Africa. Specialist assessments for this study: Hydrological assessment (HAI) by Prof Denis Hughes. IHI assessment by Delana Louw. Diatom Assessment by Shael Koekemoer. Geomorphological Assessment Index by Mark Rountree. Vegetation Assessment Index by James McKenzie. A Level 1 Ecosystem Classification System for South Africa, Lesotho and Swaziland. Department of Water Affairs and Forestry, Pretoria, 2005. A Level 2 Ecosystem Classification System for South Africa, Lesotho and Swaziland. Department of Water Affairs and Forestry, Pretoria, 2007. Dallas (2007): SASS5 Data Interpretation Guidelines River Health Programme: State of the Rivers Report for the Mokolo River. A catchment in the Limpopo Province. August 2006.	3

G2.2 REFERENCE CONDITIONS

Reference conditions	Conf
National River Health Programme sites occurring in the same Level II EcoRegion and geomorphological zone were used to determine reference conditions for EWR1B. The total reference conditions comprise the cumulative data set from these sites, the sample site as well as taxa derived to have been there under reference conditions. An indication of reference abundance and frequency of occurrence of these taxa were also estimated based on expert judgement. The reference total SASS 5 score 200 with more than 28 taxa and an ASPT of 7.	3

RHP Ref Site	River	Latitude	Longitude	EcoRegion	Gm Zone	Alt	Quat	SASS	ASPT
A4MOKO-MOKOL	Mokolo	-24.05798	27.79485	6.02	Lowland river	933	A42F	172	6.2
A4MOKO-STERK	Mokolo	-24.1861	27.9547	6.02	Lowland river	1048	A42E	149	6.5
A4MOKO-VAALW	Mokolo	-24.2894	28.0924	6.02	Lowland river	1147	A42C	182	6.5
A4MOKO-WITFO	Mokolo	-24.1137	27.80235	6.02	Lowland river	952	A42F	182	6.5

G2.3 PRESENT ECOLOGICAL STATE

G2.3.1 Site suitability

Throughout the report, suitability in this context is specific to invertebrates, and is gauged in relation to a similar site in the same EcoRegion, geomorphic zone and altitude, in its natural state.

Site suitability in terms of assessment index	The site has a variety of different biotopes available providing potential habitat for a diversity of macroinvertebrates. There are sufficient stones available at low flows, although they are quite large and difficult to move. The .habitat in the side channels (only activated by freshes) is better than the habitat in the main channel. Only limited vegetation is inundated during low flow conditions.		
	3	**Confidence**	3

PES	TOTAL SASS SCORE	NO OF TAXA	ASPT
	130 188	24 31	5.3 6.1
PES description	The current EC is mainly as a result of a slight deterioration in water quality as indicated by the MIRAI metric water quality - 78.6%). Most of the more sensitive macroinvertebrate families still occur at the site but at reduced abundances and frequency of occurrence. In addition the highly sensitive stonefly family Perlidae and moderately sensitive Aeshnid dragonfly and Philopotamid caddisfly were absent at the site. These three taxa all prefer cobble habitat and faster velocities. The increased nutrient concentrations also affect the cobble habitat by decreasing the quantity and quality of available habitat as a result of excessive algal growth. The present macroinvertebrate assemblage consists of a variety of invertebrates including: Annelidae, Flatworms, Crustaceans, Ephemeroptera (>2spp Baetidae, Caenidae, Leptophlebiidae, Machodorythidae, Tricorythidae), Damselflies (Coenagrionidae, Chlorocyphidae, Synlestidae), Dragonflies (Gomphidae, Libellulidae) a variety of Hemipterans (Belostomatidae, Corixidae, Gerridae, Hydrometridae, Naucoridae, Veliidae),Caddisflies (>2spp Hydropsychidae, Hydroptilidae, Leptoceridae), Beetles (Dytiscidae, Elmidae, Gyrinidae, Haliplidae, Hydrophilidae) Dipterans (Chironomidae, Simuliidae, Tabanidae),Molluscs (Ancylidae, Physidae, Planorbinae and Corbiculidae)w/. The SASS score of 188 and ASPT of 6.1 relates to an A category, and the SASS score of 130 and an ASPT of 5.4 equates to a C category according to Dallas (2007) interpretation guidelines. There is however, a shortage of data for this EcoRegion and according to the Mokolo SoR report, the invertebrates in this EcoRegion are impacted. The MIRAI score of 81.7% relates to a B/C category.		
	B/C	Confidence	3

G2.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
B/C	3	Decreased low flows and increased zero flows.	Abstraction for agriculture.	F	
		Increased nutrient concentrations.	Runoff from agriculture.		

G2.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
B/C	Stable	B/C		The macroinvertebrate assemblage has already adapted to the changes in the system.	3

G2.5 REC: B

PES	REC	Comments	Conf
B/C	A/B	The cessation of zero flows and the return of freshettes and some moderate floods will result in more scour to remove some algae and fines between the cobbles. This will result in better cobble habitat. The decrease in *Phragmites* and *Typha* will result in more grasses in the marginal zone improving the vegetation habitat for the invertebrates. The invertebrates will respond to the improved habitat by the return of some of the more sensitive taxa and an improvement in the abundance and frequency of occurrence of the more sensitive taxa. This will result in the invertebrates improving to an A/B category with a SASS score of about 190 and an ASPT of around 6.4	2.5

G2.6 AEC: C/D

PES	AEC	Comments	Conf
B/C	C/D	Increased zero flows and longer periods of very low flows could result in a deterioration of the water quality. Increased nutrient concentrations linked to higher temperatures will result in increased algal growth, and therefore decreased quantity and quality of habitat. Although the *Myriophyllum* will also increase the increased filamentous algae will decrease the quality of the habitat. *Phragmites* and *Typha* will increase and replace	3

PES	AEC	Comments	Conf
		some of the more suitable grasses. This will result in a deterioration of the taxa preferring vegetation habitat (lower number of taxa, lower frequencies and abundances). There will be more sediment in the system and the cobbles will become more embedded resulting in a loss of the more sensitive cobble dwelling invertebrates and a decreased in the abundance and frequency of occurrence of other cobble dwelling invertebrates. These conditions will result in the invertebrates deteriorating to a C/D category with the SASS5 score around 100 and an ASPT of around 5.5.	

G3 EWR 2: MOKOLO RIVER

G3.1 DATA AVAILABILITY

Data availability	Conf
Macroinvertebrate data and analysis from 2 sampling trips to the site on 16 January 2008 and 7 March 2008. Macroinvertebrate data from the Rivers Database for the following sites: A4MOKO-MOKOL, A4MOKO-STERK, A4MOKO-STERK, A4MOKO-VAALW, A4MOKO-WITFO). Preliminary maps and information on the catchment as supplied by Delana Louw, Water for Africa. Specialist assessments for this study: Hydrological assessment (HAI) by Prof Denis Hughes. IHI assessment by Delana Louw. Diatom Assessment by Shael Koekemoer. Geomorphological Assessment Index by Mark Rountree. Vegetation Assessment Index by James McKenzie. A Level 1 Ecosystem Classification System for South Africa, Lesotho and Swaziland. Department of Water Affairs and Forestry, Pretoria, 2005. A Level 2 Ecosystem Classification System for South Africa, Lesotho and Swaziland. Department of Water Affairs and Forestry, Pretoria, 2007. Dallas (2007): SASS5 Data Interpretation Guidelines River Health Programme: State of the Rivers Report for the Mokolo River. A catchment in the Limpopo Province. August 2006.	3

G3.2 REFERENCE CONDITIONS

Reference conditions	Conf
National River Health Programme sites occurring in the same Level II EcoRegion and geomorphological zone were used to determine reference conditions for EWR1B. The total reference conditions comprise the cumulative data set from these sites, the sample site as well as taxa derived to have been there under reference conditions. An indication of reference abundance and frequency of occurrence of these taxa were also estimated based on expert judgement. The reference total SASS 5 score is 200 with more than 28 taxa and an ASPT of 7.	3

RHP Ref Site	River	Latitude	Longitude	EcoRegion	Gm Zone	Alt	Quat	SASS	ASPT
A4MOKO-MOKOL	Mokolo	-24.05798	27.79485	6.02	Lowland river	933	A42F	172	6.2
A4MOKO-STERK	Mokolo	-24.1861	27.9547	6.02	Lowland river	1048	A42E	149	6.5
A4MOKO-VAALW	Mokolo	-24.2894	28.0924	6.02	Lowland river	1147	A42C	182	6.5
A4MOKO-WITFO	Mokolo	-24.1137	27.80235	6.02	Lowland river	952	A42F	182	6.5

G3.3 PRESENT ECOLOGICAL STATE

G3.3.1 Site suitability

Site suitability in terms of assessment index	The site has a variety of different biotopes available providing potential habitat for a diversity of macroinvertebrates. There are limited cobbles available at low flows, with the bedrock being the dominant habitat. The .habitat in the side channels (only activated by freshes) is better than the habitat in the main channel. Only limited vegetation is inundated during low flow conditions. At lower flows most of the sand is in current.		
	3	**Confidence**	3

PES	**TOTAL SASS SCORE**	**NO OF TAXA**	**ASPT**
	82 **123**	**16** **18**	**5.3** **6.8**
PES description	The EC is mainly as a result of impaired flow conditions and corresponding decrease in habitat as indicated by the MIRAI metrics (flow - 74.2% and habitat - 75.6%). This is also clearly evident from the large number of flow sensitive cobble-dwelling taxa that were absent at this site (Libellulidae, Philopotamidae, Elmidae, Tricorythidae etc.). The present macroinvertebrate assemblage consists of a variety of invertebrates including Annelida, Crustaceans, Plecoptera, Ephemeroptera (>2spp Baetidae, Caenidae, Heptageniidae, Leptophlebiidae, Machadorythidae, Oligoneuridae), Damselflies (Coenagrionidae,), Dragonflies (Gomphidae,) Hemipterans (Corixidae, Gerridae, Veliidae), Caddisflies (2spp Hydropsychidae, Hydroptilidae, Leptoceridae), Beetles (Dytiscidae) Dipterans (Chironomidae, Simuliidae, Molluscs (Ancylidae, and Sphaeriidae). The SASS score of 82 and ASPT of 5.1 relates to an E/F category, and the SASS score of 123 and an ASPT of 6.8 equates to a B category according to H Dallas' SASS interpretation guidelines. The average SASS score of 103 and ASPT of 6.05 equates to a category D according to Dallas (2007). Because the river only started flowing a few weeks before the first sampling trip, the invertebrates were still colonising the river and as such the results from the second trip was used to derive the PES. There is however, a shortage of data for this EcoRegion and according to the Mokolo SoR report, the invertebrates in this EcoRegion are impacted. The MIRAI score of 76.7% relates to a C category.		
	C	**Confidence**	3

G3.3.2 PES causes and sources

PES	**Conf**	**Causes**	**Sources**	**F/NF**	**Conf**
B/C	3	Decreased low flows and increased zero flows.	Abstraction for agriculture.	F	
		Increased nutrient concentrations.	Runoff from agriculture.		

G3.4 PES TREND

PES	**Trend**	**Trend PES**	**Time**	**Reasons**	**Conf**
C	Stable	C		The macroinvertebrate assemblage has already adapted to the changes in the system.	3

G3.5 REC: B

PES	**REC**	**Comments**	**Conf**
C	B	The change in vegetation from reeds and *Miscanthus* to other larger leafed species (e.g. *Ludwigia* and *Persecaria* spp.) will result in improved habitat. The main improvement will be seen in increased diversity and numbers of Hemiptera, Odonata, Gastropoda and Tricoptera. This will result in the improvement of the EC, with a SASS score of about 170 and an ASPT of about 6.5.	3

G3.6 AEC: C/D

PES	**AEC**	**Comments**	**Conf**
C	D	Increased sedimentation and algal growth will decrease the amount and quality of available cobble habitat. There will poorer vegetation habitat available as the reeds in the marginal zone will increase. The diversity of cobble dwelling invertebrates preferring fast flows will decrease resulting in a D EC with a SASS score of about 80 and an ASPT of about 5.	3

G4 EWR 3: GORGE

G4.1 DATA AVAILABILITY

Data availability	Conf
Macroinvertebrate data and analysis from a single sampling trip to the site on 11TH September 2007 (two sets of samples). Macroinvertebrate data from the River Health Program 'Rivers Client' for sites AMOKO_GROEN and AMOKO_VAALW (see Reference Sites). Personal communications and assistance with data from Christa Thirion (DWAF: RQS). Preliminary maps and information on the catchment as supplied by Delana Louw, Water for Africa. Specialist assessments for this study: Hydrological assessment by Prof Denis Hughes. IHI assessment by Delana Louw. Diatom Assessment by Shael Koekemoer. Geomorphological Assessment Index by Mark Rountree. Vegetation Assessment Index by James McKenzie. A Level 1 Ecosystem Classification System for South Africa, Lesotho and Swaziland. Department of Water Affairs and Forestry, Pretoria, 2005. A Level 2 Ecosystem Classification System for South Africa, Lesotho and Swaziland. Department of Water Affairs and Forestry, Pretoria, 2007. Dallas (2007): SASS5 Data Interpretation Guidelines River Health Programme: State of the Rivers Report for the Mokolo River. A catchment in the Limpopo Province. August 2006.	3

G4.2 REFERENCE CONDITIONS

Reference conditions	Conf
River Health Programme sites were used to determine a reference condition. The site information and reference site information which confirm the criteria used are presented below. Two National River Health Programme reference sites were used for EWR4: AMOKO WITFO. Data from this site and the sample site have been used to formulate a total reference condition. In consultation, the reference total SASS 5 score for EWR3 has been set in the vicinity of 150+ with >25 taxa and an ASPT of 6+. Dallas (2007) sets the A category for this EcoRegion at 155 with an ASPT between 6 and 7.	*2.5*

RHP Ref Site	River	Latitude	Longitude	EcoRegion	Gm Zone	Alt	Quat	SASS	ASPT
AMOKO-GROEN	MOKOLO	-24.32148	28.11745	6.01	Upper foothill		A42C	137	6.2
AMOKO-VAALW	MOKOLO	-24.28937	28.092400	6.02	Upper Foothill		A42C	182	6.5

G4.3 PRESENT ECOLOGICAL STATE

G4.3.1 Site suitability

Site suitability in terms of assessment index	The site is immediately downstream of the dam in a gorge section. Habitat suitability is reasonably high, with dominant bedrock and cobble substrate and a riffle-run-pool morphology. However the significant alteration in hydrology is likely to have had effects on habitat, particularly from a geomorphological point of view (loss of sediments due to dam). Greater vegetation abundance would be anticipated under natural conditions. For the site under present conditions, suitability is moderate.		
	3	**Confidence**	2.5

PES (Scores averaged over 2 samples)	**TOTAL SASS SCORE**	**NO OF TAXA**	**ASPT**
	140	26	5.4
PES description	The macroinvertebrate fauna collected was largely resilient as demonstrated by the low ASPT. The only sensitive elements of the fauna were Baetidae (>2spp), Leptophlebiidae, Perlidae, and Heptageniidae. The only sensitive flow-dependent taxa scoring >12 were Heptageniidae – a greater number of these taxa would be anticipated at a site of this nature in the unimpacted state. According to Dallas (2007, under review) a SASS5 score of 155 represents an A category for a river in this EcoRegion; however this site at a score of 140 achieves a MIRAI EC		

	of a C. This is attributed largely to the extensive change to hydrology (base flows, zero flows and floods) and the resultant effects on hydraulic habitat availability and diversity, and to the deterioration in water quality.		
	C (76.2%)	**Confidence**	2.5

G4.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
C	2.5	Significantly altered hydrology (low flows, zero flows and floods).	Upstream Mokolo Dam.		
		Loss of seasonal cues due to unseasonal releases.	Mokolo Dam.		
		Loss of connectivity.	Mokolo dam.		

G4.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C	Negative	C/D	5 years	Present impacts (alteration of moderate and low flows on the ecosystem and the loss of seasonal cues) are causing a negative trend on macroinvertebrates. During summer this is particularly an issue and the loss of the higher scoring, more sensitive invertebrates will result in further deterioration in community diversity.	2.5

G4.5 REC: B

PES	REC	Comments	Conf
C	B	Improved base flow and flood delivery results in an increase in rheophilic taxa and invertebrates with a preference for marginal vegetation. Cobble areas will be activated as flow areas over a greater area and for a longer period of time, with a result that taxa with a preference for fast flows and cobbles will increase in number and abundance. Seasonality is closer to natural. The deviation from reference for all these factors is reduced.	2

G4.6 AEC: C/D

PES	AEC	Comments	Conf
C	D	Extensive loss of habitat (marginal vegetation, fast flow over coarse sediments) and deterioration of remaining habitat, plus the loss of seasonal cues would result in a severe loss of taxa. The community will comprise only the most resilient taxa, scoring <8 in the SASS5 method.	2

G5 EWR 4: MALALATAU

G5.1 DATA AVAILABILITY

Data availability	Conf
Macroinvertebrate data and analysis from a single sampling trip to the site on 2007 (two sets of samples); Macroinvertebrate data from the River Health Program 'Rivers Client' for site A4MOKO-WITFO (see Reference Sites). Preliminary maps and information on the catchment as supplied by Delana Louw, Water for Africa; Personal communications and assistance with data from Christa Thirion (DWAF: RQS) and Colleen Todd (DWAF:RQS). Specialist assessments for this study: Hydrological assessment by Prof Denis Hughes. IHI assessment by Delana Louw. Diatom Assessment by Shael Koekemoer. Geomorphological Assessment Index by Mark Rountree. Vegetation Assessment Index by James McKenzie. A Level 1 Ecosystem Classification System for South Africa, Lesotho and Swaziland. Department of Water Affairs and Forestry, Pretoria, 2005. A Level 2 Ecosystem Classification System for South Africa, Lesotho and Swaziland. Department of Water Affairs and Forestry, Pretoria, 2007. Dallas (2007): SASS5 Data Interpretation Guidelines.	2.5

G5.2 REFERENCE CONDITIONS

Reference conditions	Conf
The River Health Programme sites were used to determine a reference condition. The site information and reference site information which confirm the criteria used are presented below. Two National River Health Programme reference sites were used for EWR4: AMOKO WITFO. Data from this site and the sample site have been used to formulate a total reference condition. In consultation, the reference total SASS 5 score for EWR3 has been set in the vicinity of 150+ with >25 taxa and an ASPT of 6+. Dallas (2007) sets the A category for this EcoRegion at 155 with an ASPT between 6 and 7.	2.5

RHP Ref Site	River	Latitude	Longitude	EcoRegion	Gm Zone	Alt	Quat	SASS	ASPT
A4 MOKO MOKO	Mokolo	-24.05798	27.29485	6.02	Lowland		A42F	101	5.9
A4 MOKO WITFO	Mokolo	-24.1137	27.29485	6.02	Lowland		A42F	152	6.1

G5.3 PRESENT ECOLOGICAL STATE

G5.3.1 Site suitability

Site suitability in terms of assessment index	The site is some distance downstream of the Mokolo Dam and is a typical lowland sand-bed system. As a result of the dam, it has significantly altered hydrology. This is the major change in the system. As a result there has been significant reed encroachment into the main sand-bed channel. This is likely to continue over time. The site suitability is low because of the low habitat diversity; however this is to a large extent natural in this section of the river. Increased flow (which would be the case under natural conditions) and naturalised vegetation would increase the suitability.		
	2.5	**Confidence**	3

PES (Scores averaged over 2 samples)	**TOTAL SASS SCORE**	**NO OF TAXA**	**ASPT**
	126	26	4.8
PES description	The macroinvertebrate community collected at EWR 4 was largely resilient in nature and typical of a lowland alluvial system. No high-scoring invertebrates were collected. The highest scoring invertebrates were Baetidae (>2 species). The majority of taxa were collected in submerged aquatic vegetation, scarce inundated riparian vegetation, and in shallow runs in the coarse		

	sandy substrate. According to the Dallas (2007) banding (still under review), the scores at this site place it in a B category. The MIRAI however places this site in a C category.		
	C (71.7%)	**Confidence**	2.5

G5.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
C	2.5	Significant alterations to low flows and floods.	Abstraction (irrigation).		
		Increased salts, nutrients and toxics; decreased water clarity.	Irrigation return flows; other land-use practices and Mokolo Dam.		
		Increased sediment loading (related to erosion of banks as a result of clearing of crops e.g. sugarcane).	Land-use.		

G5.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C	Stable	C		The community at this site appears to have adjusted to the hydrological conditions at the site.	2.5

G5.5 REC: B

PES	REC	Comments	Conf
C	B	Increased flow and flood delivery will result in an increase in availability of habitat due to the exposure of gravels and the increased inundation of marginal vegetation. The result (over time) will be an increase in diversity and abundance of invertebrates favouring these habitats. The augmentation of base flows and the return to seasonal flows will favour an increase in overall sensitivity of the community. Rheophilic invertebrates will increase in diversity and abundance.	2.5

G5.6 AEC: C/D

PES	AEC	Comments	Conf
C	D	This scenario will impact on the available marginal vegetation and water quality, negatively affecting the diversity of the few higher-scoring taxa with a preference for vegetation (e.g. Atyidae, and Baetidae). These conditions will also prevent colonisation by taxa with a preference for moderate to fast flow velocities and marginal/aquatic vegetation.	2.5

G6 REFERENCES

Dallas, H. 2007. River Health Programme: SASS5 Data Interpretation Guidelines. Document prepared for Institute for Natural Resources, and Department of Water Affairs and Forestry.

Kleynhans, C.J., Thirion, C. and Moolman, J. 2005. A Level I River Ecoregion classification System for South Africa, Lesotho and Swaziland. Report No. N/0000/00/REQ0104. Resource Quality Services, Department of Water Affairs and Forestry, Pretoria, South Africa.

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

River Health Programme (RHP). 2006. State-of-Rivers Report. The Mokolo River System. Department of Environmental Affairs and Tourism Pretoria.

APPENDIX H: RIPARIAN VEGETATION

J Mackenzie, BioRiver

H1 EWR 1A: VAALWATER

H1.1 DATA AVAILABILITY

Data availability	Conf
Satellite images (Google earth) of the respective reach and aerial photos (1949, 1956, 1965, 1984, 2005). Hydraulic cross-section (profile) at the site together with surveyed key vegetation points for setting flows. Hydrology specialist report. EcoRegion class and associated information. Geomorphic zone classification and Geomorphology Assessment Index (GAI). IHI segments / impacts. Biomes of South Africa: Savanna (Rutherford & Westfall, 1986); Savanna (bushveld) (van Wyk & van Wyk, 1997) Savanna (Mucina & Rutherford, 2006). Bioregions of South Africa: Central Bushveld (SVIcb 7) (Mucina & Rutherford, 2006). Vegetation Type: Undifferentiated bushveld and woodland (van Wyk & van Wyk, 1997). Vegetation Units: Central Sandy Bushveld (SVcb 12), (Mucina & Rutherford, 2006). State of the Rivers Report (Mokolo River). NBI herbarium records. Coates-Palgrave (Trees of Southern Africa). Gibbs Russel *et.al.* (1991) Grasses of Southern Africa. Memoirs of the botanical Survey of South Africa Field Data (March 2008).	4.5

H1.2 REFERENCE CONDITIONS

Marginal zone

The woody component has reduced from reference with a reduction in *Gomphostigma virgatum* and absence of *Combretum erythrophyllum*. Some 10% invasion by woody (*Eucalyptus* and *Sesbania punicea*) and non-woody aliens and reduced recruitment of *C. erythrophyllum*. There has been a probable reduction in frequency of activation of distributaries on left hand bank floodplain. Under reference condition 10 - 20% cover of *C. erythrophyllum* (mostly juveniles and sub-adults) is expected, as well as an absence of aliens.

Lower zone

Under reference conditions an increase in woody cover from 10% to at least 20% (*C. erythrophyllum*) is expected as well as increase in recruitment of *C. erythrophyllum* and the absence of aliens. Probable reduction in frequency of flooding of the Lower zone.

Upper zone

Under reference conditions increase in woody cover from current 30% to approximately 70% (comprising mostly of terrestrial woodland species) expected as well as an increase in recruitment of *C. erythrophyllum* and the absence of aliens. A far higher diversity of indigenous herbaceous species expected, as the non-woody layer is currently completely dominated by *Cynodon dactylon* and ruderal weeds. A probable reduction in frequency of flooding of the Upper zone.

Confidence: **4**

H1.3 PRESENT ECOLOGICAL STATE

H1.3.1 Site suitability

Site Suitability for the Assessment of Environmental Flows		
Habitat availability	**Rate**	**Motivation where applicable**
Presence / absence of the marginal zone.	1	Marginal zone mostly present and intact.
Proportion of marginal zone that is able to be sampled.	0	80 - 100% marginal zone was sampled.
	1	
Channel morphology		
Channel bank stabilization.	0	80 - 100% bank not undercut or eroding.
Channel manipulation.	1	Channel largely unmanipulated.
Profile distance too long to effectively conduct Vegetation Response Assessment Index (VEGRAI).	1	Entire profile was sampled.
	1	
Vegetation		
Occurrence of obligate, marginal zone riparian species.	1	More than sufficient obligate riparian species in marginal zone.
Occurrence of obligate, non-marginal zone riparian species.	3	Lower and upper zone obligates were present, but not abundant.
Occurrence of species that are (regional) indicators of the riparian zone, or wetness.		Obligates present, so unrated.
Recent fire/s at site.	0	No recent fires at site.
Exotic species at the site.	3	40 - 60% exotics in upper zone.
Left and right-hand banks have riparian vegetation in similar condition.	0	Banks similar.
Able to obtain sufficient survey points of indicator species for flow requirements.	1	Sufficient points for channel to set flows.
Plant species easily identifiable i.e. leaves or flowers present at time of site visit.	0	All key species identifiable.
	3	
Hydraulic control		
Unnatural up/downstream control affecting site.	1	Site affected by upstream weir.
	1	
Overall Site Suitability Rating.	**1.5**	**Site moderately suitable.**
Confidence	**4.5**	
Suitability rating:		
0 - Suite highly suitable	1 - Site suitable	2 - Site moderately suitable
3 - Site unsuitable	4 - Site extremely unsuitable	5 - Site not to be used

PES description	The marginal zone was flooded at the time of the site visit and the following description is based on observations made by wading in relatively clear water. Vegetation structure, cover, abundance and species composition are moderately altered. The zone is dominated by hygrophytic grasses with a significant component of *Phragmites*. The woody component is reduced from reference with a reduction in *G. virgatum* and absence of *C. erythrophyllum*. There is some (10%) invasion by woody (*Eucalyptus* and *S. punicea)* and non-woody aliens and reduced recruitment of *C. erythrophyllum*. Impacts included woody vegetation removal, probable reduced flows (water abstraction), alien invasion and settlement and extensive cultivation of upper zone and catchment. Lower zone: Vegetation type, structure, cover, abundance and composition is somewhat altered by heavy grazing, tree cutting (*C. erythrophyllum* heavily targeted), invasion by *Eucalyptus* and alien weeds and probable reduced water quantity and quality. The upper zone and adjacent catchment is extensively settled and mostly cultivated. Alien woody cover (*Eucalyptus* and *S.*

	punicea) has recently been reduced by clearing of large *Eucalyptus* trees. The zone is currently dominated by hygrophytic grasses and sedges and to lesser extent forbs. Upper zone: There has been a serious to extreme change in vegetation type, structure, cover, abundance and composition to what is expected. This degradation is the result of tree cutting (*C. erythrophyllum* heavily targeted), heavy grazing, cultivation of the upper zone, invasion by *Eucalyptus* and alien ruderal weeds and probable reduced water quantity and quality. The adjacent catchment is extensively settled, cleared of indigenous woodland and mostly cultivated.		
	C/D	**Confidence**	3.5

H1.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
C/D	3.5	Loss of cover and species composition changes.	Vegetation removal and exotic species invasion.		
		Reduced cover.	Soil erosion around exotic *Eucalyptus.*		
		Change in cover and extent of marginal zone.	Reduced flows.		

H1.3.3 Profile

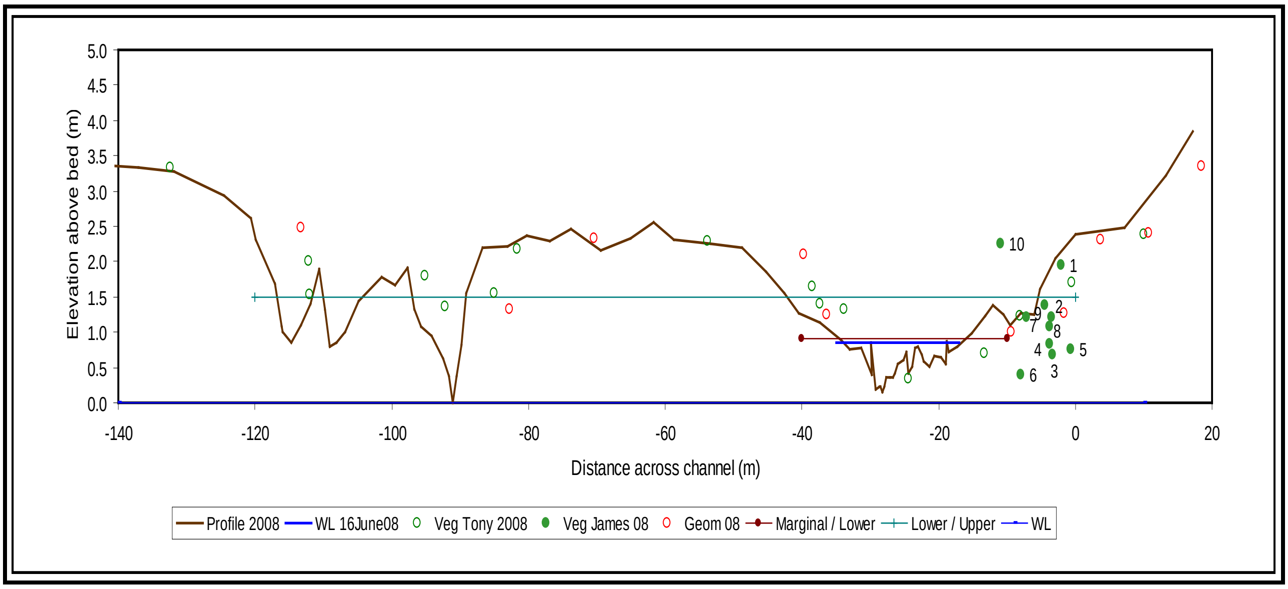

Figure H1 Riparian vegetation survey points used to assess low and high flow requirements

Key:

1	*Combretum erythrophyllum* (lower limit)	2	*Cyperus dives* (upper limit)
3	*Cyperus dives* (lower limit)	4	*Gomphostigma virgatum* (lower limit)
5	*Phragmites mauritianus* (lower limit)	6	*Phragmites mauritianus* (lower limit)
7	*Phragmites mauritianus* (upper limit)	8	*Cyperus dives* (lower limit)
9	*Cyperus dives* (upper limit)	10	*Combretum erythrophyllum* (lower limit)

H1.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
C/D	Negative	D	5 years	Many exotics at this site are invasive and will increase over time if left un checked.	3

H1.5 REC: B

PES	REC	Comments	Conf
C/D	B/C	By improving flows only a C (72.2%) will be achieved. To attain a B/C EC, removal of exotics and reduced vegetation removal must also take place, especially on the upper zone. Improved flows will reduce *Phragmites* and *Typha* cover in the marginal and lower zones, and improve woody species composition (*Gomphostigma)* will increase in the marginal zone, while *C. erythrophyllum* will reduce in the marginal zone, but increase in lower zone. .	2.3

H1.6 AEC: D

PES	AEC	Comments	Conf
C/D	D	Reducing base flows and high flows and increasing zero flow periods is likely to lead to a significant increase in cover and abundance of *Phragmites* and a reduction of species diversity in the non-woody layer of the marginal and lower zones. Increased sedimentation, zero flow periods and *Phragmites* cover is likely to lead to a severe reduction in cover and abundance of the only significant species in the marginal zone, namely *Gomphostigma virgatum*.	2

H2 EWR 1B: TOBACCO

H2.1 DATA AVAILABILITY

Data availability	Conf
Satellite images (Google earth) of the respective reach and aerial photos (1956, 1965, 1984, 2005). Hydraulic cross-section (profile) at the site together with surveyed key vegetation points for setting flows. Hydrology specialist report. EcoRegion class and associated information. Geomorphic Zone classification and GAI. IHI segments / impacts. Biomes of South Africa: Savanna (Rutherford & Westfall, 1986); Savanna (bushveld) (van Wyk & van Wyk, 1997) Savanna (Mucina & Rutherford, 2006). Bioregions of South Africa: Central Bushveld (SVIcb 7) (Mucina & Rutherford, 2006). Vegetation Type: Undifferentiated bushveld and woodland (van Wyk & van Wyk, 1997). Vegetation Units: Central Sandy Bushveld (SVcb 12), (Mucina & Rutherford, 2006). State of the Rivers Report (Mokolo River). NBI herbarium records. Coates-Palgrave (Trees of Southern Africa). Gibbs Russel *et.al.* (1991) Grasses of Southern Africa. Memoirs of the botanical Survey of South Africa Field Data (March 2008).	4.5

H2.2 REFERENCE CONDITIONS

Marginal zone

Patchy mosaic of open exposed bedrock, grass and herbaceous areas and reedbeds where alluvial deposit occurred.

Lower zone

Patchy mosaic of open exposed bedrock, grass and herbaceous areas, and reedbeds or woody species where alluvial deposit occurred. Zone is variable, but with Savanna components showing through.

Upper zone

Typical Savanna vegetation structure, dominated by woody species, but with a significant grassed understorey.

Confidence: 4

H2.3 PRESENT ECOLOGICAL STATE

H2.3.1 Site suitability

Site Suitability for the Assessment of Environmental Flows		
Habitat availability	**Rate**	**Motivation where applicable**
Presence / absence of the marginal zone.	0	Marginal completely present.
Proportion of marginal zone that is able to be sampled.	0	Entire marginal zone was sampled, although some submerged.
	0	
Channel morphology		
Channel bank stabilization.	0	Less than 20% undercutting, and stabilized by vegetation.
Channel manipulation.	0	No channel manipulation observed at site.
Profile distance too long to effectively conduct	2	Only RHB and mid-channel features sampled.

Site Suitability for the Assessment of Environmental Flows		
Habitat availability	**Rate**	**Motivation where applicable**
VEGRAI.		
	2	
Vegetation		
Occurrence of obligate, marginal zone riparian species.	1	More than sufficient obligate riparian species in marginal zone: *Miscanthus, Phragmites, and Cliffortia*.
Occurrence of obligate, non-marginal zone riparian species.	2	Sufficient obligate riparian species in non-marginal zone.
Occurrence of species that are (regional) indicators of the riparian zone, or wetness.		Obligates present, so unrated.
Recent fire/s at site.	0	No recent fires at site.
Exotic species at the site.	1	10 - 15% exotic species at the site.
Left and right-hand banks have riparian vegetation in similar condition.	0	Banks similar.
Able to obtain sufficient survey points of indicator species for flow requirements.	1	Sufficient, but not on left bank (LB)
Plant species easily identifiable i.e. leaves or flowers present at time of site visit.	0	All key species identifiable.
	2	
Hydraulic control		
Unnatural up/downstream control affecting site.	0	Not observed in immediate vicinity.
	0	
Overall Site Suitability Rating.	1.0[1]	**Site suitable.**
Confidence	5	

Suitability rating:

0 - Suite highly suitable	1 - Site suitable	2 - Site moderately suitable
3 - Site unsuitable	4 - Site extremely unsuitable	5 - Site not to be used

PES description	Marginal zone: The zone is cobble and boulder dominated with exposed bedrock dominated by non-woody riparian vegetation, mainly *Phragmites mauritianus*, *Schoenoplectus corymbosus* and *Persecaria* species. This zone was mostly inundated at the time of the site visit. Lower zone: The zone is cobble and boulder dominated with alluvial point bar and backwater depressions dominated by *P. mauritianus* and *Miscanthus junceus*, with a small woody component of *C. erythrophyllum* and the alien *S. punicea* Upper zone: Dominated by woody vegetation with typical woodland vegetation structure. The zone is mostly consolidated alluvia dominated by *C. erythrophyllum*, *Acacia karoo* and *Panicum maximum*.		
	B/C	**Confidence**	2.7

H2.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
B/C	2.7	Changes to species composition and loss of indigenous plant cover.	Invasion by exotic species.		
		High *Miscanthus* cover in marginal zone suggests reduced flows and flooding disturbance. Terrestrialisation by *A. karoo* suggests reduced floods and reed encroachment suggests reduced base flows.	Flow reductions.		

H2.3.3 Profile

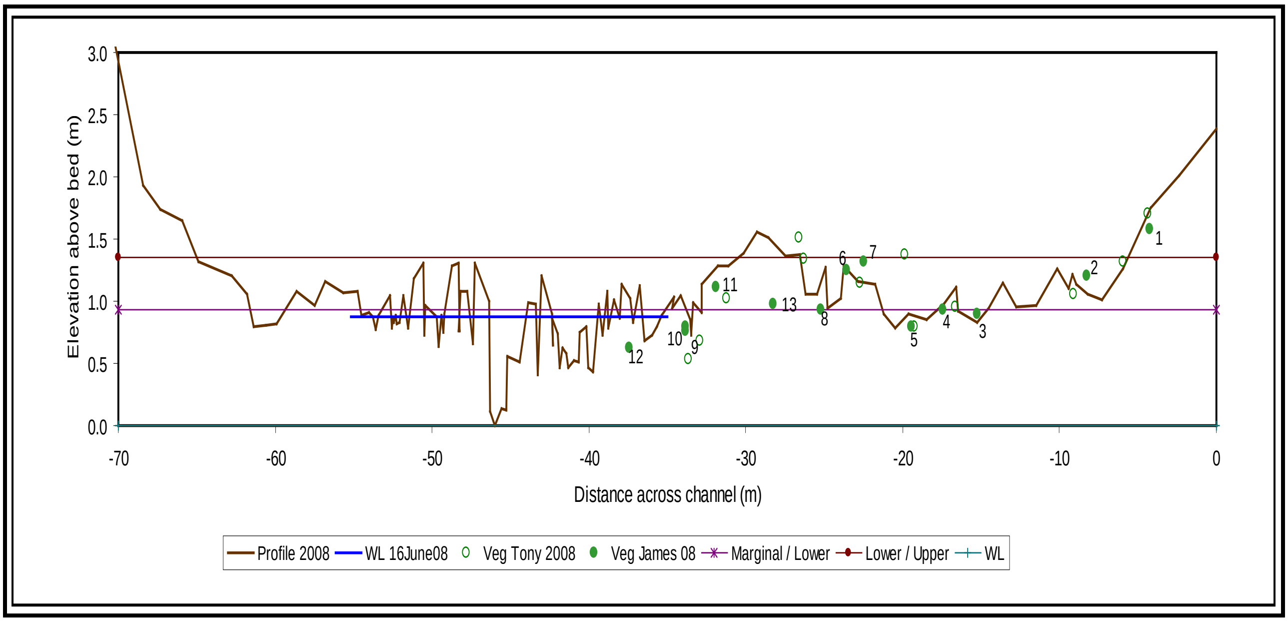

Figure H2 Riparian vegetation survey points used to assess low and high flow requirements

Key:

1	*Terminalia sericea* (general tree line) (lower limit)	2	*Miscanthus* at backwater (upper limit)
3	*Miscanthus* at backwater (lower limit)	4	*Gomphostigma* at backwater (lower limit)
5	*Schoenoplectus* and *Persecaria* at backwater (lower limit)		
6	*Combretum erythrophyllum* (upper limit)	7	*Miscanthus junceus* (upper limit)
8	*Persecaria* and *Miscanthus* (lower limit)	9	*Gomphostigma* and *Persecaria* (lower limit)
10	Schoenoplectus (lower limit)	11	Schoenoplectus (upper limit)
12	*Phragmites mauritianus*, *Schoenoplectus* and *Persecaria* (lower limit)		
13	*Phragmites mauritianus* (upper limit)		

H2.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
B/C	Negative	C/D	10 years	Increase in invasive species.	3

H2.5 REC: B

PES	REC	Comments	Conf
B/C	B	Increased baseflows and small floods will improve species composition in the marginal zone (replacement of *Miscanthus* with large-leaved hydrophytes). Terrestrialisation of lower zone will also be reduced.	2.4

H2.6 AEC: C/D

PES	AEC	Comments	Conf
BC	CD	Reduce dry season base flows and moderate floods even more. This will result in reduced cover and recruitment of woodies, especially Combretum erythrophyllum as reeds expand and exclude most other non-woody species.	2.6

H3 EWR 2: KA'INGO

H3.1 DATA AVAILABILITY

Data availability	Conf
Satellite images (Google earth) of the respective reach and aerial photos (1956, 1965, 2005). Hydraulic cross-section (profile) at the site together with surveyed key vegetation points for setting flows. Hydrology specialist report. EcoRegion class and associated information. Geomorphic zone classification and GAI. IHI segments / impacts. Biomes of South Africa: Savanna (Rutherford & Westfall, 1986); Savanna (bushveld) (van Wyk & van Wyk, 1997) Savanna (Mucina & Rutherford, 2006). Bioregions of South Africa: Central Bushveld (SVIcb 7) (Mucina & Rutherford, 2006). Vegetation Type: Undifferentiated bushveld and woodland (van Wyk & van Wyk, 1997). Vegetation Units: Central Sandy Bushveld (SVcb 12), (Mucina & Rutherford, 2006). State of the Rivers Report (Mokolo River). NBI herbarium records. Coates-Palgrave (Trees of Southern Africa). Gibbs Russel *et.al.* (1991) Grasses of Southern Africa. Memoirs of the botanical Survey of South Africa No.58. NBI Pretoria. Field Data (March 2008).	4.5

H3.2 REFERENCE CONDITIONS

Marginal zone

The zone is dominated by non-woody species (*Phragmites* and riparian grasses) with some woodies (*Syzigium intermedium* and *S. mucronata*) present. The vegetation is considered to be largely unaltered by anthropogenic impacts, and invasion (less than 10% cover) by herbaceous alien species is the only discernable alteration from reference state.

Lower zone

Mixed woody and non-woody species are dominant. The lower zone vegetation is considered to be largely unaltered by anthropogenic impacts, and invasion (less than 10% cover) by herbaceous alien species is the only discernable alteration from reference state. The area is subjected to healthy grazing levels by game.

Upper zone

The zone is woody dominated with characteristic Savanna herbaceous layer. The vegetation is considered to be largely unaltered by anthropogenic impacts, and invasion (less than 10% cover) by herbaceous alien species is the only discernable alteration from reference state. The area is subjected to healthy grazing levels by game.

Confidence: 4

H3.3 PRESENT ECOLOGICAL STATE

H3.3.1 Site suitability

Site Suitability for the Assessment of Environmental Flows		
Habitat availability	**Rate**	**Motivation where applicable**
Presence / absence of the marginal zone.	1	Marginal zone mostly present and intact.
Proportion of marginal zone that is able to be sampled.	0	80 - 100% marginal zone was ample, although inundated.
	1	
Channel morphology		
Channel bank stabilization.	0	80 - 100%% bank not undercut or eroding.
Channel manipulation.	1	Channel largely unmanipulated.
Profile distance too long to effectively conduct VEGRAI.	2	60 - 80% of profile was sampled.
	2	
Vegetation		
Occurrence of obligate, marginal zone riparian species.	1	More than sufficient obligate riparian species in marginal zone.
Occurrence of obligate, non-marginal zone riparian species.	2	Lower and upper zone obligates were present, but not abundant.
Occurrence of species that are (regional) indicators of the riparian zone, or wetness.		Obligates present, so unrated.
Recent fire/s at site.	0	No recent fires at site.
Exotic species at the site.	2	Up to 20 - 40% exotics.
Left and right-hand banks have riparian vegetation in similar condition.	0	Banks similar.
Able to obtain sufficient survey points of indicator species for flow requirements.	0	Sufficient points for channel to set flows.
Plant species easily identifiable i.e. leaves or flowers present at time of site visit.	0	All key species identifiable.
	2	
Hydraulic control		
Unnatural up/downstream control affecting site.	0	Not observed at site.
	0	
Overall Site Suitability Rating.	1.3	**Site suitable.**
Confidence	4.5	
Suitability rating: 0 - Suite highly suitable 3 - Site unsuitable	1 - Site suitable 4 - Site extremely unsuitable	2 - Site moderately suitable 5 - Site not to be used

PES description	The middle and lower zone was flooded at the time of the site visit and the following description is based on observations made by wading in relatively clear water at the time of the site visit. Marginal zone: Vegetation structure, cover, abundance and species composition is close to what is expected. The zone is dominated by hygrophytic grasses such as *Ischaemum fasiculatum, Eragrostis inamoena* and *Phragmites*. The only significant woody species is *S. intermedium* which displays a healthy population structure. Lower zone: Substrates are unconsolidated alluvial sands with 70% alluvial boulder cover. Vegetation structure, cover, abundance and species composition is close to what is expected. Dominant trees and shrubs are *S. intermedium* and *Nuxia oppositifolia* though various other woody species are present. *Phragmites* and *Aristida cf. transvaalensis* is common to dominant in the herbaceous layer. Upper zone: This zone is steep and rocky and dominated by terrestrial species with facultative riparian species (e.g. *Peltophorum* and *Terminalia*) present, and obligate riparian species are absent. The substrate comprises transported (hillwash), non-hydric soils with high rock cover.

	Vegetation structure, cover, abundance and species composition is close to what is expected.		
	A/B	**Confidence**	3.2

H3.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
A/B	3.3	Change in species composition and population structure.	Exotic species invasion (small impact).		

H3.3.3 Profile

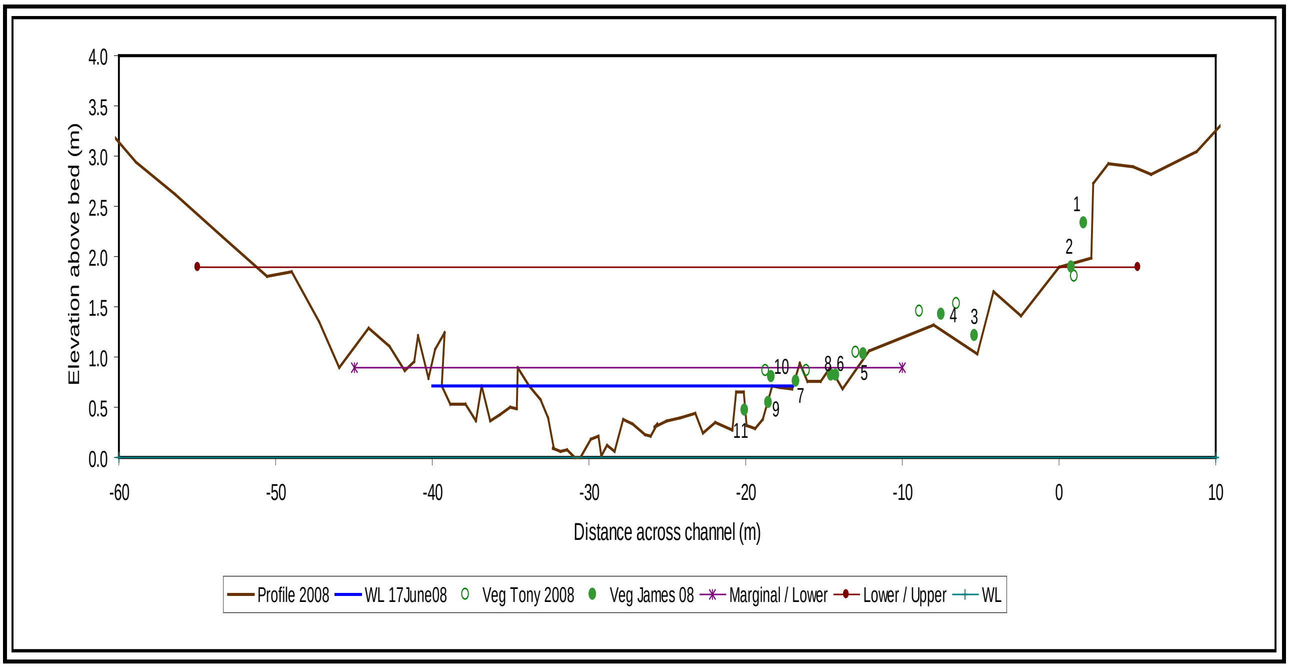

Figure H3 Riparian vegetation survey points used to assess low and high flow requirements

Key:

1	*Terminalia sericea* seep (lower limit)	2	*Aristida* (upper limit)
3	*Aristida* (lower limit)	4	*Syzigium intermedium* (upper limit)
5	*Syzigium intermedium* recruitment	6	*Syzigium intermedium* (upper limit)
7	*Syzigium intermedium* (lower limit)	8	*Phragmites mauritianus* (upper limit)
9	*Phragmites mauritianus* (lower limit)	10	*Syzigium intermedium* (lower limit)
11	*Phragmites mauritianus* (lower limit).		

H3.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
A/B	Stable	A/B		Response to reduced flows has stabilized. Low proportion of exotics and no aggressive invaders.	4

H3.5 REC: B

PES	REC	Comments	Conf
A/B	A/B	Maintain the current EC. The species composition will change. Reeds and *Miscanthus* will decrease in the marginal zone and will be replaced by other marginal plants (better marginal habitat than reeds).	N/A

H3.6 AEC: C/D

PES	AEC	Comments	Conf
A/B	B/C	Flow changes will result in a lower EC. Increased open rocky areas with an increase in terrestrial grasses, and slight increase in reeds will occur where sediment accumulates. Overall a reduction in flows will result in the terrestrialisation of the marginal and lower zones.	2

H4 EWR 3: GORGE

H4.1 DATA AVAILABILITY

Data availability	Conf
Satellite images (Google earth) of the respective reach and aerial photos (1969, 1980, 1990, 2005). Hydraulic cross-section (profile) at the site together with surveyed key vegetation points for setting flows. Hydrology specialist report. EcoRegion class and associated information. Geomorphic Zone classification and GAI. IHI segments / impacts. Biomes of South Africa: Savanna (Rutherford & Westfall, 1986); Savanna (bushveld) (van Wyk & van Wyk, 1997) Savanna (Mucina & Rutherford, 2006). Bioregions of South Africa: Central Bushveld (SVIcb 7) (Mucina & Rutherford, 2006). Vegetation Type: Undifferentiated bushveld and woodland (van Wyk & van Wyk, 1997). Vegetation Units: Waterberg Mountain Bushveld (SVcb 17), (Mucina & Rutherford, 2006). State of the Rivers Report (Mokolo River). NBI herbarium records. Coates-Palgrave (Trees of Southern Africa). Gibbs Russel *et.al.* (1991) Grasses of Southern Africa. Memoirs of the botanical Survey of South Africa No.58. NBI Pretoria. Field Data (March 2008).	4.5

H4.2 REFERENCE CONDITIONS

Marginal zone

Patchy mosaic of open exposed bedrock, grass and herbaceous areas and reedbeds where alluvial deposit do occur is expected.

Lower zone

Patchy mosaic of open exposed bedrock, grass and herbaceous areas, and reedbeds or woody species where alluvial deposits occur is expected. Vegetation is variable, but with Savanna components showing through.

Upper zone

Typical Savanna vegetation structure, dominated by woody species, but with a significant grassed understorey.

Confidence: 4

H4.3 PRESENT ECOLOGICAL STATE

H4.3.1 Site suitability

Site Suitability for the Assessment of Environmental Flows		
Habitat availability	**Rate**	**Motivation where applicable**
Presence / absence of the marginal zone.	1	Marginal zone mostly present and intact.
Proportion of marginal zone that is able to be sampled.	0	80 - 100% marginal zone was sampled, although inundated.
	1	
Channel morphology		
Channel bank stabilization.	0	80 -.100% bank not undercut or eroding.
Channel manipulation.	1	Channel largely unmanipulated.

Site Suitability for the Assessment of Environmental Flows		
Habitat availability	**Rate**	**Motivation where applicable**
Profile distance too long to effectively conduct VEGRAI.	2	60 - 80% of profile was sampled.
	2	
Vegetation		
Occurrence of obligate, marginal zone riparian species.	1	More than sufficient obligate riparian species in marginal zone.
Occurrence of obligate, non-marginal zone riparian species.	2	Lower and upper zone obligates were present, but not abundant.
Occurrence of species that are (regional) indicators of the riparian zone, or wetness.		Obligates present, so unrated.
Recent fire/s at site.	0	No recent fires at site.
Exotic species at the site.	1	Less than 10% exotics throughout.
Left and right-hand banks have riparian vegetation in similar condition.	1	Banks similar, but with floodplain on RHB.
Able to obtain sufficient survey points of indicator species for flow requirements.	0	Sufficient points for channel to set flows.
Plant species easily identifiable i.e. leaves or flowers present at time of site visit.	0	All key species identifiable.
	2	
Hydraulic control		
Unnatural up/downstream control affecting site.	0	Not observed at site.
	0	
Overall Site Suitability Rating.	**1.3**	**Site suitable.**
Confidence	**4**	
Suitability rating: 0 - Suite highly suitable 3 - Site unsuitable	1 - Site suitable 4 - Site extremely unsuitable	2 - Site moderately suitable 5 - Site not to be used

PES description	Marginal zone: Dominated by a mixture of open sandy alluvia and reed beds (*Phragmites*) in an alluvial braided channel with backwater pools. *Cyperus* and *Persecaria* spp. are common. Lower zone: Predominantly alluvial and undulating. The macro-channel floor is predominantly unconsolidated with a mix of open sands, reeds (*Phragmites*) and woody species (*Syzigium* and *Nuxia* spp. mainly) Upper zone: Dominated by trees and shrubs with an understorey characteristic of Savanna vegetation.		
	B	**Confidence**	3.4

H4.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
B	3.4	Changes in species composition and reduced habitat for indigenous riparian species.	Exotic species invasion.		
		Increase in reed cover and extent. Less open sand.	Reduced base flows and moderate floods.		

H4.3.3 Profile

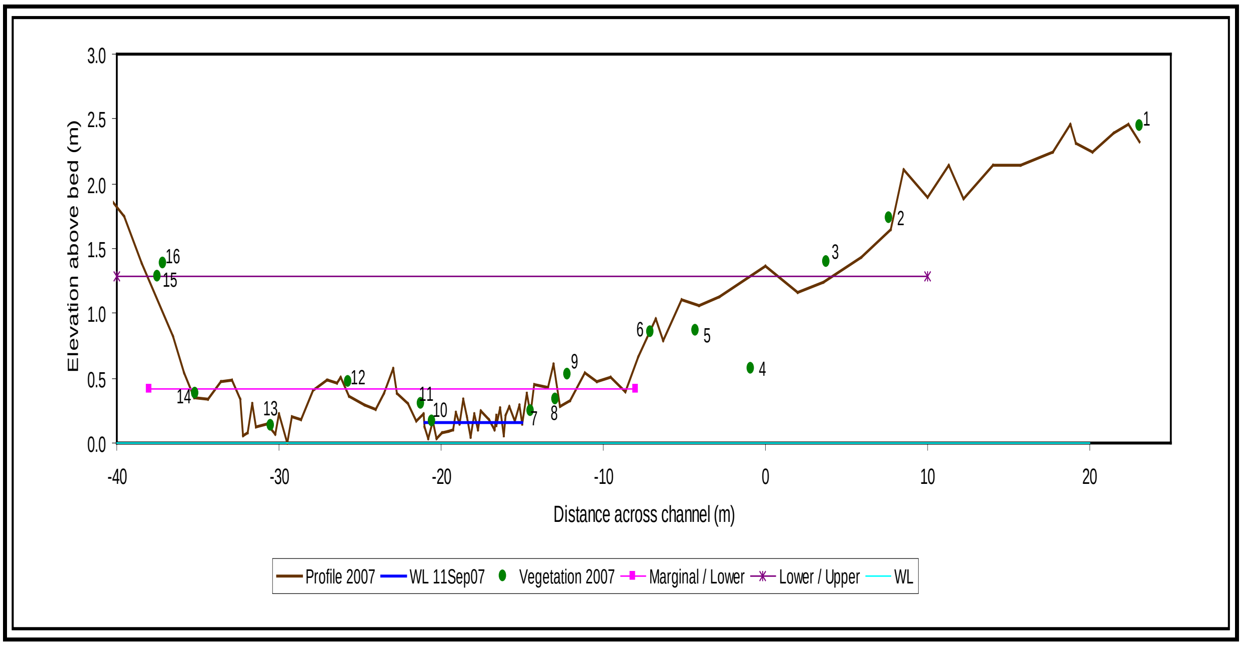

Figure H4 Riparian vegetation survey points used to assess low and high flow requirements

Key:

1	*Terminalia sericea* (lower limit)	2	*Bequaertiodendron magalismontanum* (lower limit)
3	*Syzigium* (upper limit)	4	*Ishaemum* (upper limit)
5	*Syzigium* (recruits) (upper limit)	6	*Phragmites mauritianus* and *Ishaemum* (upper limit)
7	*Ishaemum* (lower limit)	8	*Phragmites mauritianus* (lower limit)
9	*Cyperus dendatus*	10	*Phragmites mauritianus* (lower limit)
11	*Syzigium* (recruits) (lower limit)	12	*Syzigium* (recruits) and *Cyperus denudatus*
13	*Ishaemum and Syzigium* recruits (lower limit)		
14	*Phragmites mauritianus* (lower limit)	15	*Syzigium* (upper limit)
16	*Nuxia oppositifolia* (upper limit)		

H4.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
B	Stable	B		Response to reduced flows has stabilized. The exotic vegetation proportion is low and unlikely to cause a negative trend.	3

H4.5 REC: B

PES	REC	Comments	Conf
B	B	Maintenance of the current EC.	N/A

H4.6 AEC: C/D

PES	AEC	Comments	Conf
B	C	With reduced floods the woody recruitment is likely to increase on the marginal zone, but it is assumed that the reduction is not to the point where existing individuals die i.e. existing riparian woody individuals are likely to survive on the lower zone. Similarly, reeds are unlikely to expand resulting in the marginal zone being comprised of more exposed bedrock.	2.5

H5 EWR 4: MALALATAU

H5.1 DATA AVAILABILITY

Data availability	Conf
Satellite images (Google earth) of the respective reach and aerial photos (1949, 1969, 1980, 1990, 2005). Hydraulic cross-section (profile) at the site together with surveyed key vegetation points for setting flows. Hydrology specialist report. EcoRegion class and associated information. Geomorphic Zone classification and GAI. IHI segments / impacts. Biomes of South Africa: Savanna (Rutherford & Westfall, 1986); Savanna (bushveld) (van Wyk & van Wyk, 1997) Savanna (Mucina & Rutherford, 2006). Bioregions of South Africa: Central Bushveld (SVIcb 7) (Mucina & Rutherford, 2006). Vegetation Type: Undifferentiated bushveld and woodland (van Wyk & van Wyk, 1997). Vegetation Units: Waterberg Mountain Bushveld (SVcb 17), (Mucina & Rutherford, 2006). State of the Rivers Report (Mokolo River). NBI herbarium records. Coates-Palgrave (Trees of Southern Africa). Gibbs Russel *et al.* (1991) Grasses of Southern Africa. Memoirs of the botanical Survey of South Africa No.58. NBI Pretoria. Field Data (March 2008).	4.5

H5.2 REFERENCE CONDITIONS

Marginal zone

EWR 4 falls on the transition between Waterberg Mountain Bushveld and Limpopo Sweet Bushveld. The zone is dominated by non-woody species (*Phragmites* mainly) and open unconsolidated sediments, with a minor woody component (*Syzigium* spp.).

Lower zone

A patchy mosaic of open alluvia, reedbeds and woody vegetation is expected.

Upper zone

Savanna type woody dominated vegetation is expected.

Confidence: 4

H5.3 PRESENT ECOLOGICAL STATE

H5.3.1 Site suitability

Site Suitability for the Assessment of Environmental Flows		
Habitat availability	**Rate**	**Motivation where applicable**
Presence / absence of the marginal zone.	1	Marginal zone mostly present and intact.
Proportion of marginal zone that is able to be sampled.	0	80 - 100% marginal zone was sampled, although inundated.
	1	
Channel morphology		
Channel bank stabilization.	0	80 - 100%% bank not undercut or eroding.
Channel manipulation.	1	Channel largely unmanipulated.
Profile distance too long to effectively conduct VEGRAI.	1	Entire profile sampled.
	1	

Site Suitability for the Assessment of Environmental Flows		
Habitat availability	**Rate**	**Motivation where applicable**
Vegetation		
Occurrence of obligate, marginal zone riparian species.	1	More than sufficient obligate riparian species in marginal zone.
Occurrence of obligate, non-marginal zone riparian species.	2	Lower and upper zone obligates were present, but not abundant.
Occurrence of species that are (regional) indicators of the riparian zone, or wetness.		Obligates present, so unrated.
Recent fire/s at site.	0	No recent fires at site.
Exotic species at the site.	1	Less than 10% exotics throughout.
Left and right-hand banks have riparian vegetation in similar condition.	1	Banks similar.
Able to obtain sufficient survey points of indicator species for flow requirements.	0	Sufficient points for channel to set flows.
Plant species easily identifiable i.e. leaves or flowers present at time of site visit.	0	All key species identifiable.
	2	
Hydraulic control		
Unnatural up/downstream control affecting site.	4	Large upstream dam.
	4	
Overall Site Suitability Rating.	2.0	**Site moderately suitable.**
Confidence	4	
Suitability rating: 0 - Suite highly suitable 3 - Site unsuitable	1 - Site suitable 4 - Site extremely unsuitable	2 - Site moderately suitable 5 - Site not to be used

PES description	Marginal zone: Dominated by a mixture of open sandy alluvia and reed beds (*Phragmites*) in an alluvial braided channel with backwater pools. *Cyperus* and *Persecaria* species are common. Lower zone: Predominantly alluvial and undulating. The macro-channel floor is predominantly unconsolidated with a mix of open sands, reeds (*Phragmites*) and woody species (*Syzigium* and *Nuxia* species mainly). Upper zone: Dominated by trees and shrubs with an understorey characteristic of Savanna vegetation.		
	B	**Confidence**	3.4

H5.3.2 PES causes and sources

PES	Conf	Causes	Sources	F/NF	Conf
B/C	3.4	Changes in species composition and reduced habitat for indigenous riparian species.	Exotic species invasion.		
		Increase in reed cover and extent and less open sand due to reduced base flows and moderate floods.	Mokolo Dam.		

H5.3.3 Profile

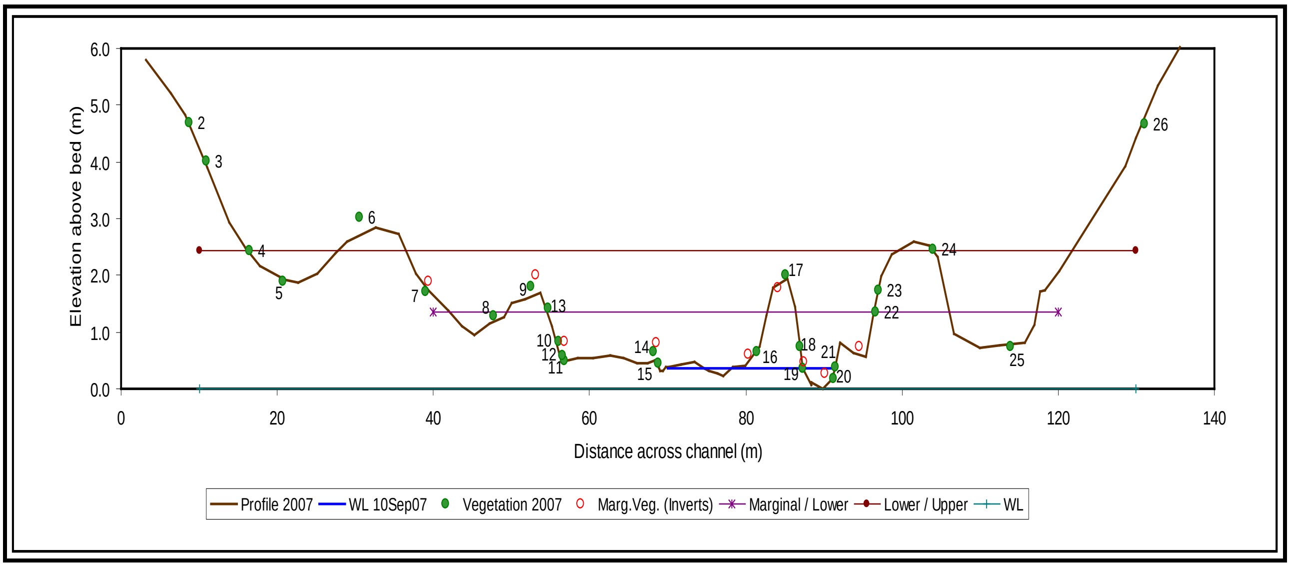

Figure H5 Riparian vegetation survey points used to assess low and high flow requirements

Key:

1	*Xanthocercis zambesiaca* (lower limit)	2	*Spirostachys africana* (lower limit)
3	*Phragmites mauritianus* (upper limit)	4	*Syzigium intermedium* (upper limit)
5	*Syzigium intermedium* (recruits) (back channel)		
6	*Eragrostis curvula* (upper limit)	7	*Phragmites mauritianus* (upper limit)
9	*Syzigium intermedium* (upper limit)	10	*Cyperus* (upper limit)
11	*Phragmites mauri*tianus/*Cyperus*/*Ludwigia* (lower limit)		
12	*Ludwigia* (upper limit)	13	Maximum limit soil moisture
14	*Cyperus* (upper limit)	15	*Cyperus* (lower limit)
16	*Cyperus*/*Phragmites mauritianus* respectively (upper limit/lower limit respectively)		
17	*Phragmites mauritianus*/*Syzigium intermedium* respectively (upper limit/lower limit respectively)		
18	*Persecaria* (upper limit)	19	*Cyperus* (lower limit)
20	*Ludwigia* (lower limit)	21	*Phragmites mauritianus* (lower limit)
22	*Phragmites mauritianus* (upper limit)	23	*Syzigium intermedium* (lower limit)
24	*Syzigium inter*medium (upper limit)	25	Level of backwater pool
26	*Xanthocercis zambesiaca* (lower limit)		

H5.4 PES TREND

PES	Trend	Trend PES	Time	Reasons	Conf
B	Stable	B		Response to reduced flows has stabilized.	3

H5.5 REC: B

PES	REC	Comments	Conf
B	A/B	If flow level exceeds addition incision then reed cover and density will increase (improve). Species composition will also improve as other grasses are less water stressed and become more abundant/vigorous.	2

H5.6 AEC: C/D

PES	AEC	Comments	Conf
B	C	Reduce dry season base flows and moderate floods. Increase periods of zero flow (increase capacity of Mokolo Dam). There will be an increase in open sand in the marginal zone, with reduced reed cover and density. Reeds are not likely to expand and grow towards receding water levels since existing alluvial bars are steep-sided and further incision is likely to occur i.e. bars even steeper with increased water stress for reeds. There will also be reduced recruitment and establishment of woody species which will alter the population structure. Existing larger specimens are likely to survive in the short term. Over the long term, woody cover is likely to reduce as recruitment reduction affects population over time and therefore woody cover and abundance will reduce.	2

H6 REFERENCES

Coates Palgrave, K. and Drummond, R. B. 1983. *Trees of Southern Africa*, C. Struik Publishing, Cape Town, South Africa.

Gibbs Russell, G. E., Watson, L., Koekemoer, M., Smook, L., Barker, N. P., Anderson, H. M., and Dallwitz, M. J. 1990. 'Grasses of Southern Africa', *Memoirs of the Botanical Survey of South Africa*, No. 58.

Mucina, L. and Rutherford, M.C. (eds). 2006. The Vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. National Biodiversity Institute, Pretoria.

Rutherford, M.C. and Westfall, R.H. 1986. Biomes of southern Africa – an objective categorization. Memoirs of the Botanical Survey of South Africa **54**: 1-98.

Van Wyk, B. and Van Wyk, P. 1997. *Field Guide to Trees of Southern Africa*, C. Struik Publishing, Cape Town, South Africa.