PROJECT NAME	:	PRE-FEASIBILITY STUDY INTO MEASURES TO IMPROVE THE MANAGEMENT OF THE LOWER ORANGE RIVER AND TO PROVIDE FOR FUTURE DEVELOPMENTS ALONG THE BORDER BETWEEN NAMIBIA AND SOUTH AFRICA
REPORT TITLE	:	Specialist Report on the Environmental Flow Requirements - Riverine
AUTHOR	:	CA Brown Contributions by: C Benade, C Brown, C Boucher, W Harding, J Hattingh, D Louw, M Luger, M Mare, R Palmer
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DATE	:	February 2005

Submitted on behalf of the Project Team by Lower Orange River Consultants:

	09/03/05	…………………………	…………
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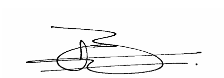
Task Leader		Study Leader	



…	09/03/05
CA BROWN	(Date)
Author	

PERMANENT WATER COMMISSION

Approved for the Planning Committee of the Permanent Water Commission:

..………………………………	………………...	……………………………………………	
P Heyns (NAM)	(Date)	**PH van Niekerk** (RSA)	(Date)

LIST OF REPORTS

TITLE	REPORT NUMBER		
	DWAF RSA	DWA Namibia	LORC (NS)
Main Report	PB D000/00/4703	400/8/1/P-13	3749/97331
Synopsis	PB D000/00/4703	400/8/1/P-13	3749/97331
Legal, Institutional, Water Sharing, Cost Sharing, Management and Dam Operation	PB D000/00/4603	400/8/1/P-10	3692/97331
Specialist Report on the Environmental Flow Requirements - Riverine	**PB D000/00/4503**	**400/8/1/P-07**	**3519/97331**
Specialist Report on the Determination of the Preliminary Ecological Reserve on a Rapid Level for Orange River Estuary	PB D000/00/4503	400/8/1/P-08	3663/97331
Water Requirements	PB D000/00/4202	400/8/1/P-02	3486/97331
Hydrology, Water Quality and Systems Analysis (Volume A)	PB D000/00/4303	400/8/1/P04	3736/97331
Hydrology, Water Quality and Systems Analysis (Volume B)	PB D000/00/4303	400/8/1/P-03	3485/97331
Water Conservation and Demand Management	PB D000/00/4903	400/8/1/P-12	3487/97331
Dam Development Options and Economic Analysis – Volume 1	PB D000/00/4403	400/8/1/P-05	3484/97331
Dam Development Options and Economic Analysis – Volume 2 (Appendices)	PB D000/00/4403	400/8/1/P-05	3484/97331
Environmental Assessment of the Proposed Dam Sites on the Orange River	PB D000/00/4503	400/8/1/P-06	3873/97331
Vioolsdrift/Noordoewer Joint Irrigation Scheme: Assessment of Viability	PB D000/00/4803	400/8/1/P-11	3525/97331
Public Consultation	PB D000/00/4503	400/8/1/P-09	3869/97331
Inception Report	PB D000/00/4102	400/8/1/P-01	3365/97331

EXECUTIVE SUMMARY

Background

The Lower Orange River Management Study (LORMS) January 2002 Progress Report for Task 2.1C: Social/Environmental Demands provided the outcome of the comparison between the 1996 estimates for the instream flow requirements for the Orange River (DWAF PD000/00/6197) and those obtained from the Desktop Model using the latest hydrology. If the Ecological Flow Requirements (EFR) had to be supplied from which Vanderkloof Dam (the last major structure on the Orange River mainstem), then implementing the EFR would be problematic. Using the river as a conduit for irrigation water creates ecological problems related to unnaturally high and stable flows in the river. Using the environmental flow estimates of either the Orange River Replanning Study (ORRS) or the Desktop for planning purposes in LORMS may not be appropriate or feasible, and it was recommended that the relationship between the current flow regime in the river and the EFR recommended by the Desktop Model be examined, and that where appropriate, recommended flows be revised.

Specialist Disciplines and Team Members

Team Leaders:	*Mike Luger (Ninham Shand)*
	Cate Brown (Southern Waters)
Hydrology:	*Manie Maré (WRP)*
Geomorphology:	*Johan Hattingh (Private Consultant)*
Water Quality:	*Bill Harding (Southern Waters)*
Vegetation:	*Charlie Boucher (University of Stellenbosch)*
Macroinvertebrates:	*Rob Palmer (Afridev)*
Fish:	*Ben Benade (Eco-Impack)*
Process:	*Delana Louw (IWR Source to Sea)*
Assistants:	*Rodney February (Southern Waters) and Milicent Solomons (Ninham Shand).*

Study Area

The study focussed on the river reach of the Orange River between Augrabies and Onseepkans, however, where appropriate, specialists also contextualised their information within the wider LORMS study area (i.e., from the confluence of the Vaal to the mouth of the Orange River).

Assumptions and Results of Hydrological Modelling

The Desktop D Category EFR was modelled as a separate, consumptive user. However, all the water travelling down the river would affect the functioning of the ecosystem.

System delays, e.g., the time taken for water to travel down the Orange River from Vanderkloof Dam to Upington were not incorporated into the modelling results. The effect of these delays would be to retard the onset of seasons, and thus dampen seasonal variation in the Lower Orange River (LOR).

The development scenarios shown in ***Table E.1*** *were provided for consideration.*

Table E.1: Development Scenarios Provided for Consideration

Scenario Description	***Scenario No.****	***Flow in MCM[1] at Given Site***	
		Augrabies	***River Mouth***
Natural flow		*10,587.30*	*10,833.01*
Current system with 2005 demands	*1-M*	*4,382.12*	*4,423.46*
Vanderkloof lower level storage	*1-P*	*4,254.89*	*4,296.43*
Vioolsdrift reregulating dam	*1-Q*	*4,268.94*	*4,082.10*
Large Vioolsdrift	*1-R*	*4,231.92*	*3,369.92*

Note: All the development scenarios included the 2005 development level demands and the EFR from the ORRS.

The naturalised modelled data set was used as input to the Desktop Model, and EFR results were generated for Category C and D for the Lower Orange River. Observed

[1] Million Cubic Meters

hydrological data from various locations in and around the study reach were also used in Task 8.3.

A summary comparison of the various flow regimes is given in ***Table E.2****. Key mismatches between Present Day flow patterns and Category C and D flow regimes recommended by the Desktop Model are:*

- *Volume of Desktop D EFR considerably less than present (2000) at Zeekoebaart-Upington;*
- *Lower winter flows recommended in Desktop D EFR;*
- *Seasonal distribution dampened relative to natural (i.e., less variation between the seasons), but retained in Desktop D EFR, has more variation than present day flow pattern.*

Table E.2: Summary Comparison ofFflow Regimes

Scenario Description	Scenario No.*	Increased Dry Season Flows[2]	Stop-Flow Conditions	Intra-Annual Flood Events[2]		Variability	
				Normal/Wet Years	Drought Years	Year-on-Year	Short-term
Natural flow	Natural	No	Yes	Yes	Yes	Very high	Very high
1991-2000 Observed	Present Day	Yes, particular in autumn	No	Reduced	No	Dampened	Much reduced
2005 (2005)	1-M	No	No	No	No	Very low	Cannot determine
Vanderkloof lower level storage	1-P	No	No	No	No	Very low	
Vioolsdrift reregulating dam	1-Q	No	No	No	No	Very low	
Large Vioolsdrift	1-R	No	No	No	No	Very low	
Hydropower release incl.	Hydro	Yes, in particular autumn	No	No	No	Very low	
Category D Desktop	D-Desk	No	No	Reduced	Yes	Low-moderate	Reduced[3]
Category C Desktop	C-Desk	No	No	Reduced	Yes	Low-moderate	Reduced

[2] Relative to the natural situation

[3] The Desktop Model only provides a flood volume and we have assumed that this related to a single flood. This could in effect be a volume that related to several smaller floods each with relatively short durations.

Mismatches between predicted development flow patterns and Category C and D flow regimes recommended by the Desktop Model:

- *Seasonal distribution maintained in 2005, Vanderkloof low-level storage (1-P) and Vioolsdrift re-regulating (1-R) dam scenarios.*
- *Low winter flows implemented in 2005, 1-P, 1-R and 1-Q Vioolsdrift storage dam.*

Summer flows exceed Desktop – but well in line with naturalised and observed (1932-1940) –delayed onset of high flows with 1-Q.

Present Ecological Status (PES) of the Orange River between Augrabies and Onseepkans, the trajectory of change in condition and flow-related reasons for river condition deviating from natural

Table E.3 *is a summary of the Present Ecological Status (PES) for each of the disciplines considered for the river in the environmental flow tasks. In general, the ecological condition of the river is deemed to be on a negative trajectory, with all disciplines expecting a one-category deterioration in condition in the next twenty years. River systems function as an integrated whole, and changes made in one part of a system will inevitably lead to changes in another part, and so it is unsurprising that the disciplines predict similar trends.*

Table E.3: Summary of the Present Ecological Status (PES) for each of the disciplines considered, their predicted trajectory of change for 20 years and an indication of whether these changes documented/expected are related to changes in the flow regime of the Orange River. Colour codes are provided in the key

Discipline	PES	Trajectory	20-year prediction	Flow-related	Non flow-related
Water quality	B/C - Category	Negative	C/D - Category	No	Yes
Geomorphology	C- Category	Negative	D - Category	Largely	Channel manipulation - levees
Algae	D - Category	Negative	E/F - Category	Partly - not flushed	Partly - imported from u/s
Vegetation	D - Category	Negative	E - Category	Some	Predominately
Macroinvertebrates	D - Category	Negative	D/E-Category	Some	Predominately
Fish	D - Category	Negative	D/E-Category	Partly	WQ also
Overall	D - Category	Negative	D/E-Category	ONLY PARTLY	Predominately

Category	A	B	C	D	E/F
Colour used	green	blue	purple	yellow	red

The most important aspects of the flow regime for maintaining or improving the current ecological condition are reinstating the winter lowflows (i.e., reducing current flows) and the November freshet. The flow-related contribution factors identified were:

- *unseasonal winter releases;*
- *lack of very low flow periods;*
- *lack of the November freshet;*
- *reduction in water volume;*
- *reduction in wet and dry season inter-annual floods; and*
- *lack of flow variability.*

Ecological Flow (EF) Regime Provided to LORMS Modellers for Use in Planning Models

The following process for providing an EF regime to LORMS modellers was agreed on and adopted:

1. *The Desktop D Category EFR estimates were split into their lowflow and highflow components.*
2. *The lowflow requirements ONLY to be used as a demand file for the yield modelling from Vanderkloof Dam.*
3. *The monthly flow duration curves for the resultant flow regime (using the lowflow ONLY demand file) at Augrabies were compared with the (total) Desktop D Category EFR estimations for Augrabies.*
4. *For months where the (total) Desktop D Category EFR estimates exceeded the actual flows at Augrabies obtained with the lowflow ONLY demand file, the difference was considered to be a flood. The volume of water equating to the required flood was then added into the lowflow ONLY demand file where required.*
5. *The resultant demand file comprised the lowflows ONLY for the Desktop D, plus selected 'top-up' flood volumes.*
6. *This demand files is NOT the EFR, and the term "Top-up" D Demand File was coined to describe the resultant demand file.*
7. *Use of this file instead of the Desktop D demand file significantly improved system yield.*
8. *The EFR was considered to be the actual current day flows in the river at Augrabies, and the "Top-up" D Demand File merely part of the operating rules for achieving those flows.*

*The "Top-up" D Demand File itself is provided in **Appendix 6**.*

Ecological Consequences of the Flow Regime Provided to LORMS Modellers for Use in Planning Models

Essentially the implementation of the "Top-up" D Demand File provides a slightly more varied flow regime than would be achieved with the lowflows ONLY option, but has the advantage of not affecting the yield as negatively as the Desktop D reported in the LORMS January 2002 Progress Report.

The resultant flow regime at Augrabies, if the "Top-up" D Demand File is run in conjunction with other planning scenarios, should maintain the current gradual C to C/D Category trajectory. The extent to which the negative trajectory can be halted will depend on the degree of variability that can be managed in the system, as well as issues other than flow, and cannot be assessed in this task. This variability will include:

- *reinstatement of year-on-year variability;*
- *provision of intra-annual floods; and*
- *capping of winter releases.*

The recommended category for a Comprehensive Reserve Determination would most likely be a C-Category.

Limitations of the Study

Most of the data available for analysis in Task 8.3 were monthly data. Furthermore, no reliable gauge records were available with which monthly data could be disaggregated into daily flow sequences. This limited the analyses in the following ways:

1. *Daily and monthly variability could not be adequately explored.*
2. *The number frequency and volumes of flood events within a month versus lowflows cannot be determined.*
3. *Short-term distributional clashes between modelled scenarios and EFRs cannot be determined.*
4. *No hydraulic investigations were undertaken, and volumetric considerations could not be linked to velocity, wetted area or depth in the river channel itself.*

[Previous hydraulic measurements undertaken by the Orange River Environmental Task Group, where found to be insufficiently accurate.]

In addition, the PES and trajectory assessments provided by the specialists were based on available information and on observations made during a short field trip.

Recommendations for Future Work to Determine the EFR for the LOR

It was the consensus of the all of the people involved in Task 8.3 that a ***Comprehensive Reserve/EFR Determination on the lower Orange River*** *should be undertaken as a matter of priority.*

Furthermore, the study team stressed the importance of controlling mechanical manipulation of the river bed, banks and floodplain, as these factors are major contributors towards the decline in the condition of the riverine ecosystem and, together with the manipulation of the flow regime, will eventually lead to its complete collapse.

Particular attention should be given to maintaining the few remaining and relatively undisturbed anastamosed sections, such as upstream of Onseepkans. These areas are considered to be ecologically very important.

The periodic emptying of the existing Boegoeberg Dam for maintenance, which releases pulses of sediment-laden water, has detrimental downstream impacts, and should be managed to minimise the impact (i.e., sediments should be flushed more frequently during high-flow periods, and not during winter, when possible).

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ABBREVIATIONS

a^{1}	:	per annum
ASPT	:	Average Score per Taxon
Ca	:	Calcium
Chla	:	Chlorophyll-a
DSV	:	Deep Storage Volume
DWAF	:	Department of Water Affairs and Forestry (RSA)
EF	:	Ecological Flow
EFR	:	Ecological Flow Requirement
EIS	:	Ecological Importance and Sensitivity
EISC	:	Ecological Importance and Sensitivity Class
ERC	:	Ecological Reference Condition
HRT	:	Hydraulic Retention Time
IFR	:	Instream Flow Requirement
K	:	Potassium
LHWP	:	Lesotho Highlands Water Project
LOR	:	Lower Orange River
LORMS	:	Lower Orange River Management Study
MAR	:	Mean Annual Runoff
MCM	:	Million Cubic Meter
Mg	:	Magnesium
mS	:	milliSiemens
m.o.l.	:	minimum operating level
Na	:	Potassium
NH-N	:	Ammonium-nitrogen
NH_3	:	Ammonia
Nmar	:	natural Mean Annual Runoff
NOx	:	Nitrate-nitrogen
NP	:	National Park
ORE	:	Orange River Expedition
ORRS	:	Orange River Replanning Study
P	:	Phosphorus / Orthophosphate
PD	:	Present Day
PES	:	Present Ecological Status
pH	:	Concentration of Hydrogen Ions
RSA	:	Republic of South Africa
SASS4	:	South African Scoring System (Version 4)
Sd	:	Standard Deviation

ss	**:**	Suspended Solids
TDS	**:**	Total Dissolved Solids
ToR	**:**	Terms of Reference
TSS	**:**	Total Suspended Solids

PREAMBLE

Task 8.3 should not be considered an Environmental Flows Determination. The output of Task 8.3 was required for Planning Purposes and the scope of work for the Task in no way approached that required for an Environmental Flow Determination. Furthermore, the demand files provided to the Lower Orange River Replanning Study (LORMS) modellers at the end of the Task do no constitute the Environmental Flow Requirements (EFR) for the Lower Orange River (LOR), and the term "Top-up" D Demand File was coined to describe the resultant demand file.

The EFR was considered to be the actual flows in the river at Augrabies, and the "Top-up" D Demand File merely part of the operating rules for achieving those flows.

1. INTRODUCTION

The Lower Orange River Management Study (LORMS) January 2002 Progress Report for Task 2.1C: Social/Environmental Demands provided the outcome of the comparison between the 1996 estimates for the instream flow requirements for the Orange River (DWAF PD000/00/6197) and those obtained from the Desktop Model using the latest hydrology. In summary:

- There was a large discrepancy between the 1996 Orange River Replanning Study (ORRS) riverine flow requirements (2.27% Mean Annual Runoff [MAR]) and the Desktop estimate (13.23 and 16.84% for Category D and C respectively at Augrabies).
- The distributions of flows recommended by the Desktop for a C or D Category significantly reduce estimates of yield for users.

Furthermore, initial indications are that if the Ecological Flow Requirements (EFRs) had to be supplied from Vanderkloof Dam (the last major structure on the Orange River mainstem), then implementing the EFRs would be problematic. Also using the river as a conduit for irrigation, water creates ecological problems related to unnaturally high and stable flows in the river. Thus, using the environmental flow estimates of either the ORRS or the Desktop for planning purposes in LORMS may not be feasible, and it was recommended that the relationship between the current flow regime in the river and the EFRs recommended by the Desktop Model be examined, and that where appropriate changes be made to the recommended flows.

The question arises as to whether the current flow distributions are damaging the riverine ecosystem, i.e., *is the present condition of the system on a negative trajectory as a result of flow changes in the system*. If the condition of the river is not declining under present circumstances, then the relevance of implementing the recommended EFRs must be questioned.

Alternatively, if the condition of the river is declining it is important to determine which aspects of the flow regime (if any) are causing this. Once this is known, then it will be possible to determine a sensible way forward.

It is accepted that, for the most part, information on the condition of the river, its trajectory of change and the possible reasons for this, is not readily available, and such assessments would need to be based on the expert opinion of river scientists familiar with the Orange River. It was therefore recommended that a specialist team be assembled *to assess the options available for ascertaining the EFRs for the Lower Orange River (LOR).*

1.1 Specialist Disciplines/Team Members

Team Leaders:	Mike Luger (Ninham Shand)
	Cate Brown (Southern Waters)
Hydrology:	Manie Maré (WRP)
Geomorphology:	Johan Hattingh (Private Consultant)
Water Quality:	Bill Harding (Southern Waters)
Vegetation:	Charlie Boucher (University of Stellenbosch)
Macroinvertebrates:	Rob Palmer (Afridev)
Fish:	Ben Benade (Eko-Impak)
Process:	Delana Louw (IWR Source to Sea)
Assistants:	Rodney February (Southern Waters) and Milicent Solomons (Ninham Shand)

1.2 Terms of Reference (ToR)

The ToR for this additional task entailed the following tasks:

Task 1 Review assumptions and results of hydrological modelling.

Task 2 Identify temporal and volumetric mismatches between Present Day flow patterns and Category C and D flow regimes recommended by the Desktop Model.

Task 3 Identify temporal and volumetric mismatches between predicted Development flow patterns and Category C and D flow regimes recommended by the Desktop Model.

Task 4

a. Describe the Ecological Reference Conditions (ERC) for a representative reach of the Orange River between Augrabies and Onseepkans.

b. Determine the Present Ecological Status (PES) of the Orange River between Augrabies and Onseepkans.

Task 5 Determine the trajectory of change in condition, if any, for a representative reach of the Orange River between Augrabies and Onseepkans.

Task 6 Identify, where possible, reasons for river condition deviating from natural. If these are flow-related, identify which aspects of the flow regime are ecologically problematic.

Task 7 Review and comment on the ecological appropriateness of the flow regimes recommended by the Desktop Model for Category C and D and provide information on likely ecological consequences.

This Task (Task 7) was changed during the course of the study to: "provide the LORMS hydrological modellers with an Environmental Flow (EF) regime for use in planning models".

Task 8 Evaluate flow patterns linked with up to four future development scenarios, provided by Ninham Shand, for a representative reach of the Orange River between Augrabies and Onseepkans, and provide information on the likely ecological consequences of each.

This Task (Task 8) was changed during the course of the study to: "provide ecological consequences for the EF regime provided to the LORMS hydrological modelers for use in planning models".

Task 9 Make recommendations for future work to determine the Ecological Flow (EF) requirements for the LOR.

1.2.1 Activities

The activities envisaged can be summarised as follows:

Field visit (29 and 30 April 2003): Specialists undertook a 2-day field visit to the LOR, concentrating their efforts between Augrabies and Onseepkans.

Reporting: Including a hydrological assessment (Tasks 1-3), and an assessment of Reference Conditions and Present Ecological Status for their discipline (Tasks 4-6).

Cape Town Workshop (26 and 27 May 2003): A 2-day workshop, involving specialists, and limited observers *to address Tasks 7-9.*

Final Reporting: Final Report on the Additional Environmental Flow Tasks.

1.2.2 Key Questions

For each ecosystem component:

1. Is the present condition of the system on a negative trajectory?
2. If so, is this as a result of flow changes in the system?
3. Which aspects of the flow regime (if any) are causing a decline in condition?
4. Which aspects of the flow regime (if any) have caused a decline in condition in the past?
5. Which aspects of the flow regime are most important for maintaining condition?
6. Which kind of flow changes would represent a threat to the system?

1.3 Study Area and Study Reach

The study area for the LORMS extends from the confluence of the Vaal to the mouth of the Orange River, with the focus on the area west of the 20^{o} latitude.

Table 1-1: Individual Team Members' Contributions towards the Completion of the Proposed Tasks. Contribution towards a Task is indicated by a "Yes"

	Brown	Luger	Mare	Louw	Hattingh	Harding	Boucher	Palmer	Benade
	Coordination and Compilation		Hydrology	Facilitation	Geomorphology	Water Quality	Botany	Invertebrates	Fish
Task 1: Assumptions and results of modelling	Yes		Yes						
Task 2: Mismatches between Desktop and PD	Yes		Yes						
Task 3: Mismatches between Desktop and development scenarios	Yes		Yes						
Task 4a: Describe the Ecological Reference Conditions					Yes	Yes	Yes	Yes	Yes
Task 4b: Determine the Present Ecological Status					Yes	Yes	Yes	Yes	Yes
Task 5: Determine the trajectory of change in condition.					Yes	Yes	Yes	Yes	Yes
Task 6: Identify, reasons for river condition deviating from natural.					Yes	Yes	Yes	Yes	Yes
Task 7: Review and comment on	Yes			Yes	Yes	Yes	Yes	Yes	Yes

	Brown	**Luger**	**Mare**	**Louw**	**Hattingh**	**Harding**	**Boucher**	**Palmer**	**Benade**
	Coordination and Compilation		Hydrology	Facilitation	Geomorphology	Water Quality	Botany	Invertebrates	Fish
the ecological appropriateness of the flow regimes recommended by the Desktop Model for Category C and D.									
Task 8: Evaluate flow patterns linked with up to four future development scenarios	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes
Task 9: Make recommendations for future work to determine the EFR for the lower Orange River	Yes			Yes					

to the Orange River Mouth. For the purposes of this assessment, to avoid unnecessary logistic complications and financial implications, most deliberations were focussed on the study reach between Augrabies and Onseepkans, however, specialists also contextualised their information within the wider study area.

1.3.1 Reasons for Focusing on the River Reach between Augrabies to Onseepkans

The reasons for focusing on the river reach between Augrabies to Onseepkans are:

- modelled hydrological data were already available for Augrabies;
- reasonably good observed records are available for the reaches of the river near Upington, and because of the low runoff downstream of Upington the patterns distinguished from these records could be extrapolated downstream;
- the reach is relatively accessible;
- the DWAF Upington officials were willing to assist with field investigations in this reach, which proved invaluable;
- the river downstream of Augrabies is less developed and less impacted that the reaches near and (some distance) upstream of Upington;
- in particular, a short section of river between Raap en Skraap and Onseepkans is relatively undisturbed but for manipulations of the flow regime, which provided the team with a good indication of the effect of flow changes already in place;
- the parts of river between Upington and Onseepkans are characterised by a wide braided channel, which was deemed to be more sensitive to flow changes than the single channel form which dominates downstream of Vioolsdrift; and
- the study reach overlapped with the focus area of LORMS, viz. west of the 20^{o} latitude to Vioolsdrift.

The hydrological data used are for Augrabies.

1.3.2 Summary of Land-use along Side the Orange River: Douglas to Vioolsdrift

The following is a summary of information obtained from the 1:250 000 topographical maps for the Orange River. The information is intended only to provide specialists with an indication of the extent of agricultural activities alongside different reaches of the Orange River. Most of the cultivation, certainly in the area between Groblershoop and Onseepkans, is vineyards (see also **Appendix 1**).

Douglas to Pieska:	From the town Douglas on the Vaal River to the town Prieska on the Orange River *c.* 60% of both sides of the riverbanks are under cultivation.
Prieska to Groblershoop:	From Prieska to Groblershoop on the Orange River *c.* 50% of both banks of the river are under cultivation.
Groblershoop to Augrabies:	Both banks of the Orange River are heavily cultivated estimated at between 80 and 90%.
Augrabies National Park:	The conservation area of the Augrabies National Park (NP) on the northern bank of the Orange River is about 45 km in length while the southern portion is about 15 km. These distances are measured as a straight line rather than along the length of the river. About 25 km beyond the town of Augrabies there is a 25 km section along the southern bank of the river that is under cultivation.
Augrabies NP to Vioolsdrift:	Pockets of cultivated land, which represents between 5 and 10% of land-use for this section of the Orange River (*c.* 350 km). The rest of the land is classified as vacant land.

1.4 Itinerary for Field Visit

1.4.1 Day 1: 29 April 2003

AM Specialist Team, plus Ms Bettie Conradie and Mr Willie Coetzee meet at Upington Airport.
View river at Onseepkans.
PM View river at Raap-en-Skraap.
View LORMS video of the LOR.
Overnight in Augrabies NP.

1.4.2 Day 2: 30 April 2003

AM View river at Augrabies.
View river at de Neus.
PM View river at Muggie Falls.
View river from Tierberg.
View at Kanon Eiland.
Return home.

1.5 Layout of this Report

The layout of the report is as follows:

Section 1 Provides a brief background to Task 8.3, the ToR and specialists involved in the assessments for different disciplines. This Section also includes an explanation of the reasons for the selection of the target river reach.

Section 2 Summarises the trends apparent in, and conflicts between, the various hydrological data that were made available for the study and were assessed during the study. These included the simulated monthly naturalised and present-day records for Augrabies, the outcome of five development scenarios, the environmental flows recommended by the Desktop Method and observed data from Zeekoebaart.

Section 3: Reviews the chemical status of the LOR, based on existing data and available scientific and management literature.

Section 4: Reviews the status riparian vegetation on the LOR, based on existing data and available scientific and management literature.

Section 5: Reviews the status of the fish communities in the LOR, based on existing data and available scientific and management literature.

Section 6: Provides an indication of the biophysical characteristics (*viz*. water quality, geomorphology, riparian and instream vegetation, macroinvertebrates and fish) of the Orange River that would be expected in the absence of anthropogenic influences. This constitutes on hypothetical natural or reference condition. Similarly, the hypothetical biophysical characteristics of the Orange River that would be expected if the river were in a Category B, C, D or E ecological condition, are also described.

Section 7: Provides each specialist's individual assessment of the present ecological status (PES) LOR along with their assessment of the reasons for the PES and an indication of the trajectory of change in condition for their discipline.

Section 8: Summarises the most pertinent information in Sections 2, 6 and 7.

Section 9: Describes the process adopted at the workshop and highlights some of the key discussions that took place during the workshop. This included Habitat Integrity assessments, where the PES statements given in Section 7 were crosschecked by doing the assessments from a slightly different approach in a group situation.

Section 10: Describes the outputs of the workshop, including the recommended "Top-up" D demand file that was recommended for use in the hydrological modelling required for LORMS.

Section 11: Recommendations for future work.

Section 12: References.

The Appendices provide text copies of pertinent data and background information and are cross-referenced in the text, where appropriate.

1.6 Acknowledgements

The assistance and data received from Mr Willie Coetzee and Ms Bettie Conradie of the Department of Water Affairs and Forestry (DWAF) Upington Office is gratefully acknowledged. The comments and inputs from Dr Chris Brown of the Namibian Nature Foundation and Mr Frikkie Becker of Alexander and Becker, Namibia at the workshop are also gratefully acknowledged.

2. HYDROLOGICAL SUMMARY ASSESSMENT (AUGRABIES)

This Section addresses Tasks 2 and 3. It does this by systematically identifying the temporal and volumetric mismatches between modelled data for various scenarios and crosschecking against observed records from the catchment.

Most of the assessments presented in this Section focus on Augrabies. The exception to this is the observed data, which were collected at Zeekoebaart near Upington.

2.1 Development Scenario Data Provided for Task 8.3

Table 2-1 gives a summary of the volumetric changes associated with the hydrological scenarios supplied for consideration in Task 8.3.

Table 2-1: Summary for the Final Flows at Augrabies and the River Mouth for the Scenarios under Consideration

Scenario Description	Scenario No.*	Flow in MCM[4] at Given Site	
		Augrabies	River Mouth
Natural flow		10,587.30	10,833.01
Current system with 2005 demands	1-M	4,382.12	4,423.46
Vanderkloof lower level storage	1-P	4,254.89	4,296.43
Vioolsdrift reregulating dam	1-Q	4,268.94	4,082.10
Large Vioolsdrift	1-R	4,231.92	3,369.92

Note: All the development scenarios included the 2005 development level demands and the EFR from the ORRS.

2.1.1 *Naturalised Data*

All the demands imposed on the Orange River System have been removed from the record (1932-1987). (**Appendix 2**).

[4] Million Cubic Meters

2.1.2 Scenario No. 1-M: 2005

Purpose

To determine surplus yield available at 2005-development level and to serve as the reference system yield. This yield will be used to compare with the yield from the other scenarios to determine the increase or decrease in yield.

Description

All the demands imposed on the Orange River System will be at 2005-development levels (**Appendix 2**), *viz.*:

- Phase 1 of the Lesotho Highlands Water Project (LHWP) and urban/industrial demands at 2005 development level.
- Updated/final existing irrigation demands based on scheduled areas and quota. Effect of return flows included in the model.
- Gariep and Vanderkloof Dams are not supported by any upstream dam, including Katse and Mohale Dams in Lesotho.
- Vaal River System will be modelled separately with 2005-development level spills used as inflow to the Orange River System, just upstream of the confluence of the Vaal and Riet Rivers. For the Vaal System Analysis, it is assumed that pumping from the Tugela River will continue until Sterkfontein Dam is full.
- Transfer from LHWP to Vaal = 804 MCM a^{-1} for the full Phase 1 as based on the most recent hydrology that was accepted by both the Republic of South Africa (RSA) and Lesotho. The given transfer of 804 MCM a^{-1} is based on the 1-in-100 year long-term stochastic firm yield.
- Transfer to the Eastern Cape through the Orange/Fish tunnel based on the updated LORMS demands (627 MCM a^{-1}, urban and irrigation)
- Orange/Riet transfer demands modelled in detail as part of the system.

- Orange/Douglas transfer, all demands modelled in detail as part of the system.
- Transfer from the Caledon to Modder from Welbedacht Dam, as well as the Novo transfer from Knellpoort Dam, will be in place and modelled in detail with all the demands in place as part of the system. Current existing operating rule used. This is, however, not necessarily the optimum operating rule.
- Compensation flow from Gariep Dam 16 $m^3 s^{-1}$.
- Hydropower generated in accordance with downstream demands only (no additional releases for hydropower purposes will therefore be made).
- Minimum operating level (m.o.l.) for Gariep at 1 231.63 m. (This is equal to the m.o.l. for Orange/Fish tunnel outlet. DSV = 637.25 MCM and live storage = 4 705.68 MCM).
- M.o.l. for Vanderkloof Dam at 1 147.78 m. (This is equal to the m.o.l. for releases into Vanderkloof canals. DSV = 1 014.38 MCM and live storage = 2 172.69 MCM).
- Lower Orange hydrology and spills from the Vaal will not be used to support any of the demands in the Orange River as these flows are currently not taken into account when water is released from Vanderkloof Dam.
- Fish River (Namibia) inflows will not contribute to any of the demands in the LOR.
- Operational losses will be included as a demand.
- River evaporation losses will be included along the river and abstracted as a demand at the previously defined river reaches.
- Include ORRS' environmental demands, river mouth and Instream Flow Requirements (IFRs).
- The 2045 Updated/verified sediment levels will be used in dams.

2.1.3 Scenario No. 1-p: Vanderkloof Lower Level Storage

Description

As for 2005 Scenario 1-M, but with the following additions:

- Lower level storage in Vanderkloof Dam will be utilized and the additional yield abstracted at Vanderkloof Dam (the additional yield will therefore not be released directly into the river to support users downstream).

2.1.4 Scenario No. 1-q: Vioolsdrift Re-regulating Dam

Description

As for Reference Scenario 1-p, but with the following additions:

- Include a re-regulating dam at Vioolsdrift. The saving in operational losses will be used to support possible future irrigation requirements in the LOR.

2.1.5 Scenario No. 1-r: Large Vioolsdrift

Description

As Scenario 1-p, but with the following changes:

- Include a large storage dam at Vioolsdrift. The saving in operational losses and additional yield will be used to support possible future irrigation requirements in the LOR.

2.1.6 Scenario No. HYRD: Hydropower

In Scenarios 1-m, 1-p, 1-q and 1-r, hydropower is only generated by means of the normal releases from Gariep and Vanderkloof Dams to satisfy all the downstream requirements and during times when the dams are spilling. Currently there are, however, three different releases or types of releases that are used to generate hydropower at Gariep and Vanderkloof Dams.

1. The normal releases to satisfy all the downstream requirements, including river losses and 1996 IFR, are released through the turbines to generate hydropower.

2. The surplus in the system available each year as determined in May every year can be released from the dams through the turbines any time during the year as required by Eskom. These releases occur most of the time during the winter months.
3. Based on storage control curves determined for Gariep and Vanderkloof Dams, water can be released at maximum flow through the turbines when the storage in the dam is above a specific level in a month. The purpose of this is to reduce spills from the dams to the minimum during periods of high inflow and to route most of the spills through the turbines. This should not conflict with EFRs as these high flows will be in phase with natural high flow periods.

Release Type 1 is already included in the scenarios analysed, and to a large extent, also the Type 3 releases. The only difference between the current method of Type 3 releases and Type 1 releases is that, in practise, the 'spill' is released through the turbines slightly before the actual spills would occur.

Type 2 releases are expected to reduce over time because the surplus in the system is decreasing each year as result of the growing system demand. For the purpose of this study, the typical hydropower releases from surplus water, which occurred two or three years ago, were added to the reference scenario flow sequences. By doing this, a typical full hydropower release scenario, as occurred in the past, was created.

Note: Type 2 releases are most likely to conflict with EFRs.

2.2 Desktop EFR Data

2.2.1 Description of the Desktop Method

The Desktop method provides a low-confidence estimate of the quantity component of the South African Ecological Reserve (DWAF 1999) for rivers and was developed in response to the need for a number of quick estimates where the application of the more detailed Intermediate or Comprehensive Reserve determinations are not considered appropriate. Such situations could arise when the degree of water resource development in a catchment is relatively small and no serious clashes between the EFRs and water users are expected, or when a rapid method of pinpointing likely problem areas in a catchment is required in advance of selecting sites to carry out more intensive, higher confidence estimates. The method is based on a generic regionalisation of past EFR assessments in South Africa. As such, it is recognised that there may be site specific ecological, or channel morphology considerations that might mean that the Desktop method will generate under- or over-estimates of the EFRs.

The method consists of four main steps:

- The use of a relationship between a hydrological index of flow variability (based on a combination of a monthly coefficient of variability of flow and an estimate of the proportion of total flow occurring as baseflow) and the annual EFR requirements for maintenance lowflows, maintenance high flows and drought lowflows (all expressed in % MAR). There are separate relationships defined for each Ecological Category of the river. The hydrological index is calculated from a monthly time series of flow that is selected to represent the reference conditions (frequently taken as the natural flow regime), and the default time series used are those provided with the reports on the Surface Water Resources of South Africa 1990 (Midgley, *et al*. 1994) for 1946 quaternary catchments in South Africa, Lesotho and Swaziland. These time series have also recently been updated to take account of improved methods of naturalising flow records in catchments where afforestation has had a major influence on flow regimes for quite some time (this update was carried out as part of the National Water Balance Model Project and has not been fully documented yet).

- The use of regionalised seasonal distributions of baseflow contribution to divide the annual totals into seasonal distributions of EFRs for the three components (maintenance high and lowflows and drought lowflows).
- The use of regionalised percentage assurance curves to specify the frequency of occurrence relationships of the defined maintenance and drought requirements for each month. These curves, or tables, are similar to flow duration curves, in that they specify the percentage of time that defined flows should be equalled or exceeded in the flow regime required to satisfy the EFR. The basic elements of their shapes are:

  - The percentage of time that drought flows should be experienced.
  - The percentage of time that maintenance flows should be equalled or exceeded.
  - The extent to which flows (in terms of low and high flows) should exceed the defined maintenance flows at relatively low assurances.

The final stage of the process is to generate a representative time series of monthly flow volumes using the time series of reference flows (WR90 by default) to provide the climatic cues to determine when to select required flows within the range between drought and the maximum. The actual process, within the computer program, steps through the monthly reference flows, identifies the percentage point on the reference flow calendar month duration curve and then selects a environmental flow that has the same percentage assurance value. For example, a very low flow in the reference time series will have a high percentage exceedence value and therefore a requirement at, or close to a drought flow, would be selected. A higher flow, on the other hand, is equalled or exceeded far less frequently and therefore, a flow with a much lower assurance (close to the maximum required flow) would be selected from the assurance curves.

The final result is a time series of requirements that integrates the different required flows (lows and high, maintenance and droughts) for all the months and which can be used for further analysis as necessary.

2.2.2 Desktop Data Used in Task 8.3

The naturalised modelled data set described in **Section 2.1** was used as input to the Desktop Model, and EFR results were generated for Categories C and D for the LOR. Although both sets of data were available, given the large discrepancies between Category D and the development scenarios provided (**Section 2.1**) and the outcome of the PES assessments (**Section 7**), deliberations tended to focus on the Category D outputs, and detailed comparisons are thus only provided between Category D (**Appendix 2**), the other scenarios and observed data.

2.3 Observed Data

The following observed data were used in this assessment:

- Official DWAF observed records for D7H008 (Zeekoebaart-Upington) and D8H003 (Vioolsdrift).
- Daily gauge levels 1997-2003 at Upington (D7H005), Neusberg and Kakamas (D7H003), obtained from the DWAF Office in Upington.

These data were used to:

- Cross-check against modelled data for any obvious anomalies; and
- Disaggregate monthly-modelled data to allow for flood analysis and comparison with observed data.

2.4 Trends Evident from Observed Data - Monthly

2.4.1 Procedure Adopted

The observed data from D7H008 (Zeekoebaart-Upington) were converted to monthly data, divided into *c.* 10-year periods and analysed for:

- MAR and Seasonal distribution; and
- Seasonal index.

Seven periods were used: 1932-1940; 1941-1950; 1951-1960; 1961-1970; 1971-1980; 1981-1990; and 1991-2000.

Note: Flood analysis cannot be performed on 10-year data sets, and so the floods were determined using the full-observed record (see **Section 2.3**).

2.4.2 Results

There has been a gradual decline in the MAR of the river over the period of record (**Figure 2-1**). The seasonal distribution of flows (monthly averages) for each ten-year period is provided in **Table 2-2** and **Figure 2-2**.

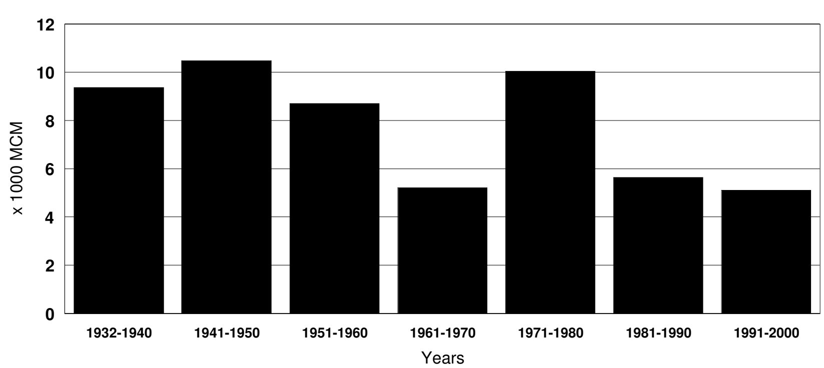

Figure 2-1: MAR for 10-Year Periods of the Observed Records from D7H008

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Table 2-2: Seasonal Distribution of Flows (Monthly Averages) for Each 10-Year Period.

Month	1932-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-1990	1991-2000
	Monthly Averages (MCM)						
Oct	298	500	807	158	374	423	182
Nov	1191	1031	910	461	577	464	293
Dec	1325	1263	1143	561	632	490	406
Jan	1575	1133	784	605	848	459	552
Feb	2005	1240	1419	1206	1940	912	763
Mar	1025	1946	1032	609	2081	801	761
Apr	734	1144	923	808	1198	580	708
May	504	850	722	297	760	337	431
Jun	300	423	359	212	465	284	459
Jul	107	327	194	113	423	299	230
Aug	130	164	118	93	408	292	144
Sep	182	465	300	97	349	312	191
MAR	9376	10486	8711	5220	10055	5653	5120

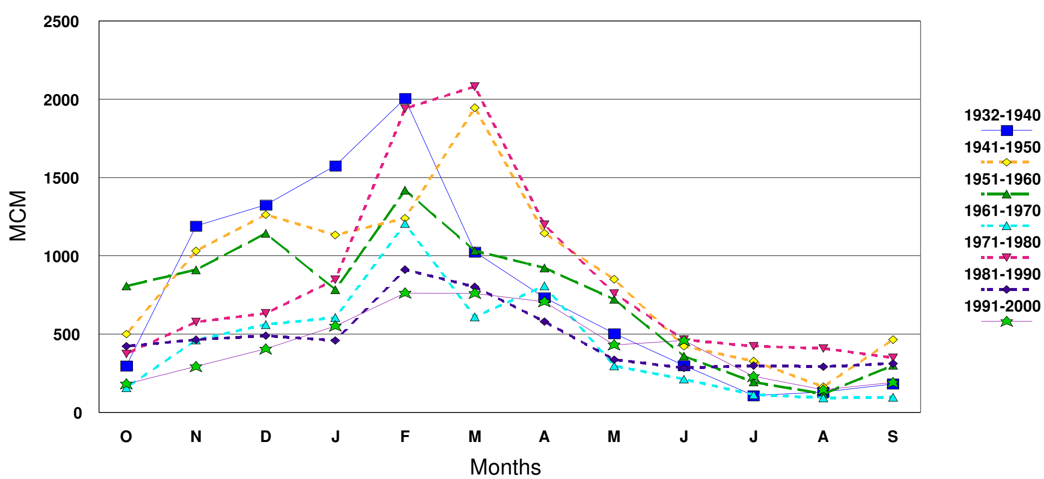

Figure 2-2: Seasonal Distribution of Flows (Monthly Averages) for Each 10-Year Period

Trends

- Marked decrease in summer flows (primarily November to March);
- Reduction in seasonal differentiation; and
- Increase in summer flows (primarily July and August).

2.5 Trends Evident from Observed Data - Daily

The most marked trend that is evident from the daily flow records is the loss of variability. The daily flow records were presented and discussed at the Workshop.

2.6 Flood Analysis: Inter-annual Floods

Performing an annual maximum series assessment on the data provided for this Task yielded the data presented in **Table 2-3**. The monthly naturalised and 2005 data sets were disaggregated using observed data from D7H008.

Table 2-3: Results of Annual Maximum Series Assessment on the Naturalised, 2005 and Observed Data Provided for this Task.

Data Set Used	Daily Peak Discharge in MCM			
	1:2	1:5	1:10	1:20
Natural (modelled data)	2832	5369	6667	9349
2005 (modelled data)	434	1380	2070	3422
Observed data[5]	1871	3299	4130	4973

Trends

- Marked decrease in magnitude of inter-annual floods – due to flood attenuation in the system and especially Gariep and Vanderkloof Dams.

[5] These data are from D7H008 for 1932 – 2000. This means that analyses of the full data set, such as is required for flood analysis, are confused by the trend of increasing abstraction over the period.

2.7 Comparison between Observed and Desktop Category D

Figure 2-3 is a comparison of the seasonal distribution of flows (monthly averages) for each ten-year period and for the Desktop D EFR estimate. Please note that the observed flow releases include the effect of the lag time for releases from Vanderkloof to Zeekoebaart, while the simulated flows exclude the effect of the lag time. (The observed record period 1996 to 2000 will provide a better comparison with the simulated values.)

Observations

- Volume of Desktop D EFR considerably less than present (2000) at Zeekoebaart-Upington;
- Low winter flows recommended in Desktop D EFR; and
- Seasonal distribution dampened, but retained in Desktop D EFR.

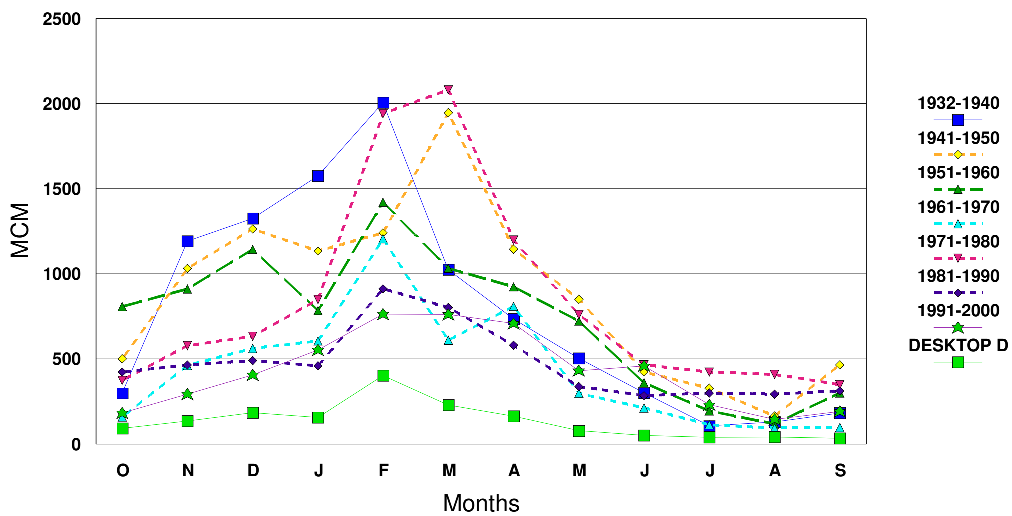

Figure 2-3: Seasonal Distribution of Flows (Monthly Averages) for Each 10-Year Period and for the Desktop D EFR Estimate

2.8 Comparison between Observed, Desktop Category D and Scenarios 1-P, 1-Q and 1-R

Figure 2-4 is a comparison of the seasonal distribution of flows (monthly averages) for 1991-2000 (observed data), modelled naturalised, 2005 and 1-P Scenarios, and for the Desktop D EFR estimate. Please note that the observed flow releases include the effect of the lag time for releases from Vanerkloof to Zeekoebaart while the simulated flows exclude the effect of the lag time.

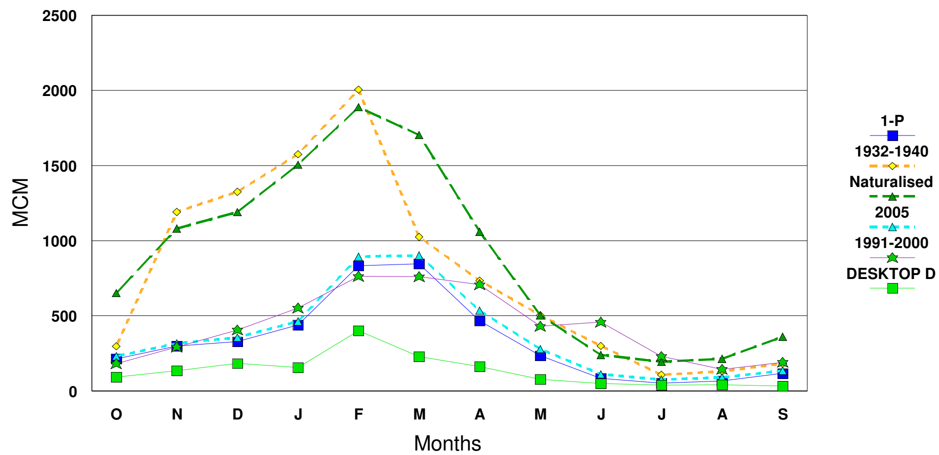

Figure 2-4: Seasonal Distribution of Flows (Monthly Averages) for 1991-2000 (Observed Data), Modelled Naturalised, 2005 and 1-P Scenarios, and for the Desktop D EFR Estimate

Figure 2-5 is a comparison of the seasonal distribution of flows (monthly averages) for 1991-2000 (observed data), modelled naturalised, 2005 and 1-P Scenarios, and for the Desktop D EFR estimate. Two scenarios show a markedly different distribution to natural:

- Scenario 1-Q, which has a delayed onset to the winter season; and
- Hydro, which has disproportionately high flows during the dry season.

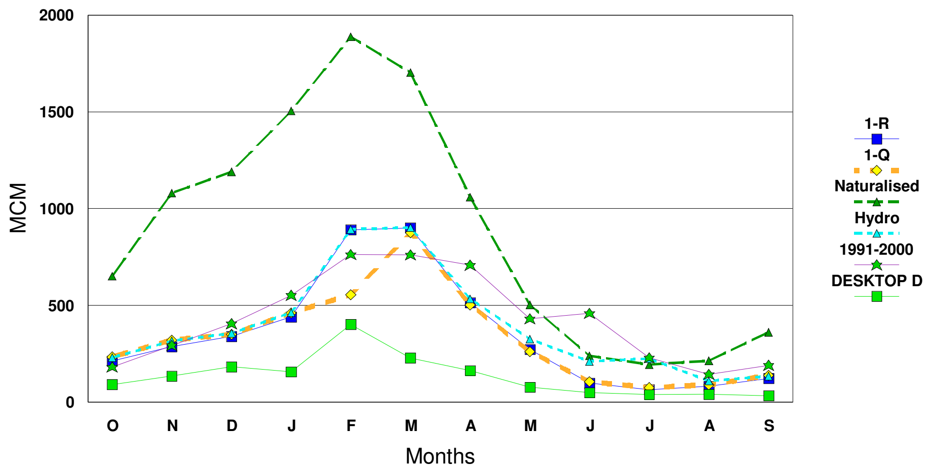

Figure 2-5: Seasonal Distribution of Flows (Monthly Averages) for 1991-2000 (Observed Data), Modelled Naturalised, 1-Q, 1-R and Hydro Scenarios, and for the Desktop D EFR Estimate

Observations

- Seasonal distribution maintained in 2005, 1-P and 1-R.
- Low winter flows implemented in 2005, 1-P, 1-Q and 1-R.
- Summer flows exceed Desktop – but well in line with naturalised and observed (1932-1940) –delayed onset of high flows with 1-Q.

Question: What are the ecological implications of a delayed wet season?

Question: From an ecological perspective, how long should the very low period go on?

2.9 More Detailed Comparison between Modelled Data: Natural, 2005 and Desktop Category D

2.9.1 *Differences in Annual Flows*

Natural MAR:	*c.* 10587.30 MCM.
2005 MAR:	*c.* 4 382.12 MCM (40% nMAR).
Category D Desktop MAR:	*c.* 1604.74 MCM (15% nMAR; 37% pMAR).

Note: Flows at the mouth of the Orange River are *naturally* lower than at Augrabies, as evaporation exceeds inflow in the lower river.

2.9.2 *VolumetricMismatches*

Mean 2005 Higher than Desktop D:	November-June.
Mean 2005 roughly equal Desktop D:	July to October.

2.9.3 *Year-on-Year Variability*

Referring to **Figures 2.6-2.12**, the following general observations pertain.

October:	2005 more constant. No mid-range floods? Desktop varies above and below 2005.
November:	2005 more constant. No mid-range floods? Desktop varies above and below 2005.
December:	2005 more constant. No mid-range floods? Desktop varies above and below 2005.
January:	2005 more constant. No mid-range floods? Desktop generally higher than 2005.
February:	2005 more constant. No mid-range floods? Desktop generally higher than 2005.
March:	Fairly comparable. No mid-range floods?
April:	2005 more constant. No mid-range floods? Desktop varies above and below 2005.

May :	2005 more constant. No mid-range floods? Desktop lower than 2005.
June:	2005 more constant. No mid-range floods? Desktop lower than 2005.
July:	2005 more constant. No mid-range floods? Desktop lower than 2005.
August:	2005 more constant. Desktop lower than 2005.
September:	2005 very steady baseflow. Desktop lower than 2005.

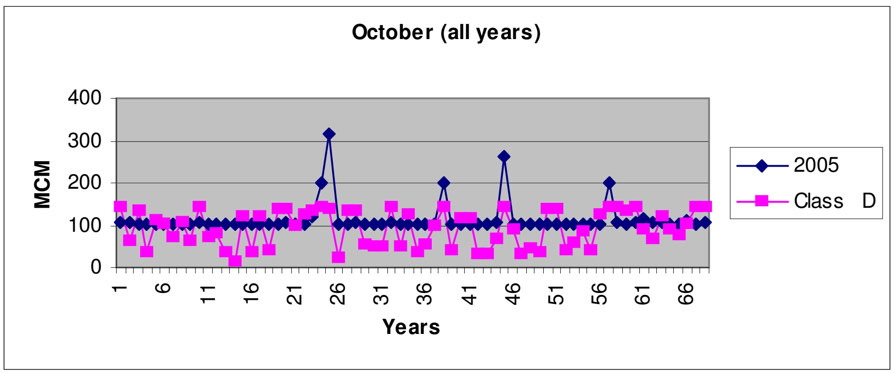

Figure 2-6: Year-on-Year Monthly Volomes for October: 2005 and Class D. Upper Range Capped at 200 MCM to Increase Resolution in the Lower Range

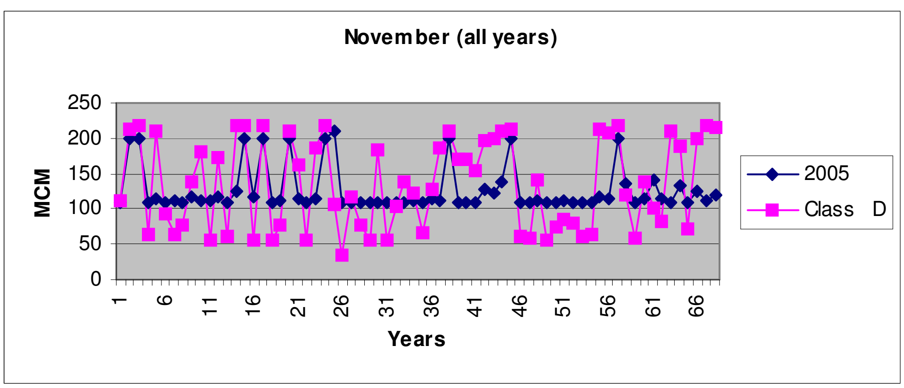

Figure 2-7: Year-on-Year Monthly Volumes for November: 2005 and Class D. Upper Range of Capped at 200 MCM to Increase Resolution in the Lower Range

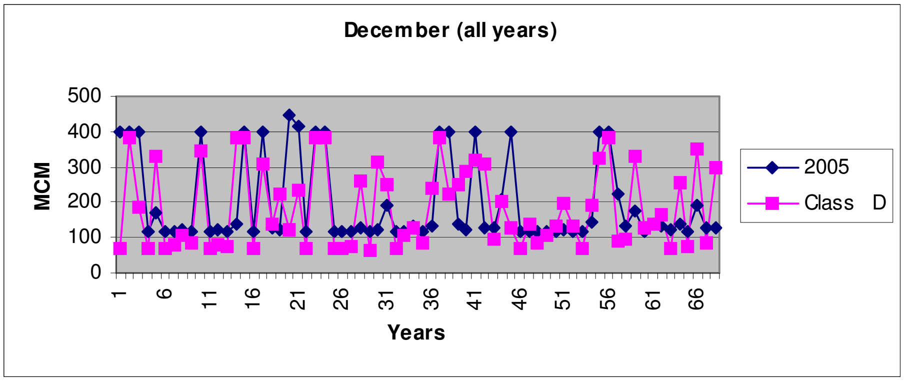

Figure 2-8: Year-on-Year Montly Volumes for December: 2005 and Class D. Upper Range of Capped at 400 MCM to Increase Resolution in the Lower Range

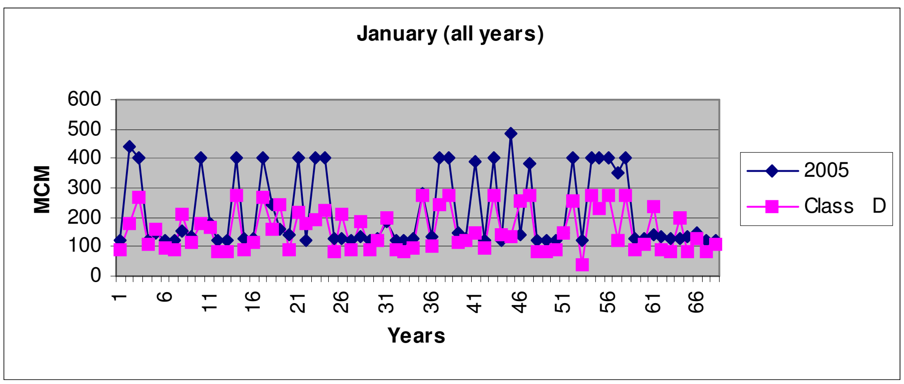

Figure 2-9: Year-on-Year Monthly Volumes for January: 2005 and Class D. Upper Range of Capped at 400 MCM to Increase Resolution in the Lower Range

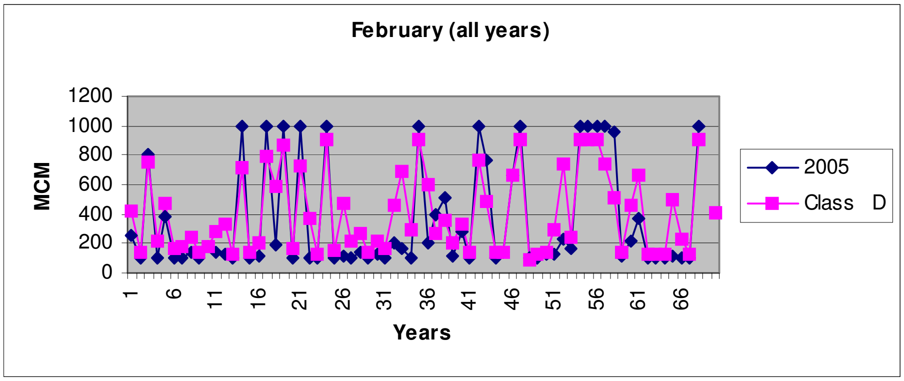

Figure 2-10: Year-on-Year Monthly Volumes for February: 2005 and Class D. Upper Range of Capped at 1000 MCM to Increase Resolution in the Lower Range

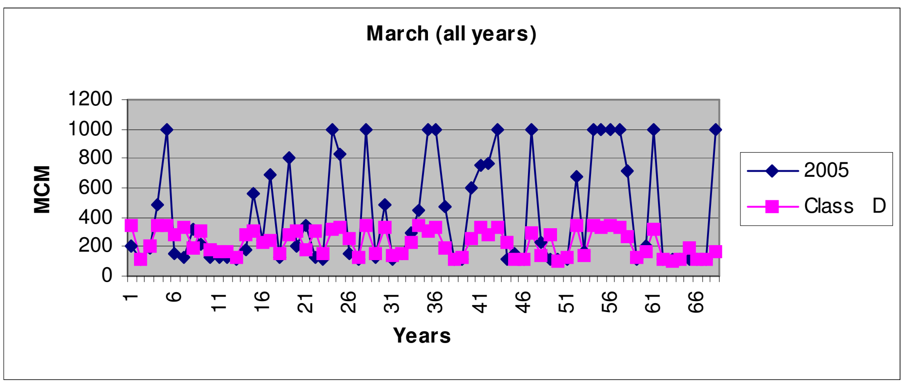

Figure 2-11: Year-on-Year Monthly Volumes for March: 2005 and Class D. Upper Range of Capped at 1000 MCM to Increase Resolution in the Lower Range

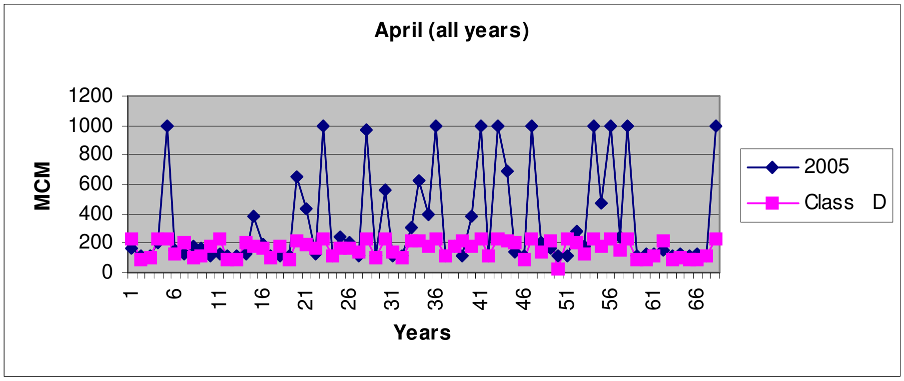

Figure 2-12: Year-on-Year Monthly Volumes for April: 2005 and Class D. Upper Range of Capped at 1000 MCM to Increase Resolution in the Lower Range

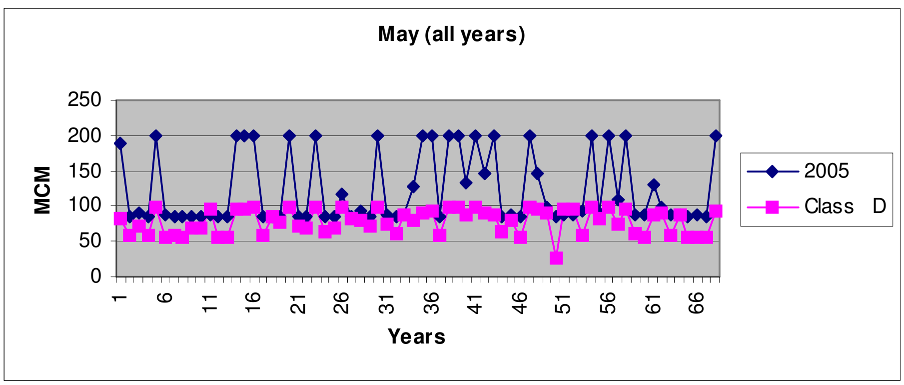

Figure 2-13: Year-on-Year Monthly Volumes for May: 2005 and Class D. Upper Range of Capped at 200 MCM to Increase Resolution in the Lower Range

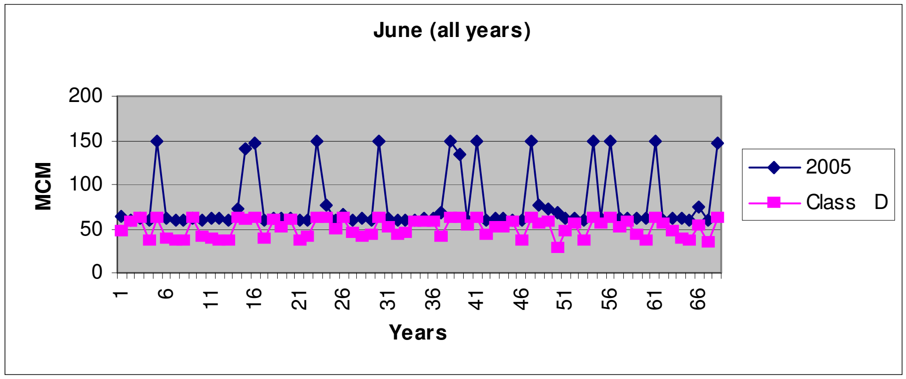

Figure 2-14: Year-on-Year Monthly Volumes for June: 2005 and Class D. Upper Range of Capped at 150 MCM to Increase Resolution in the Lower Range

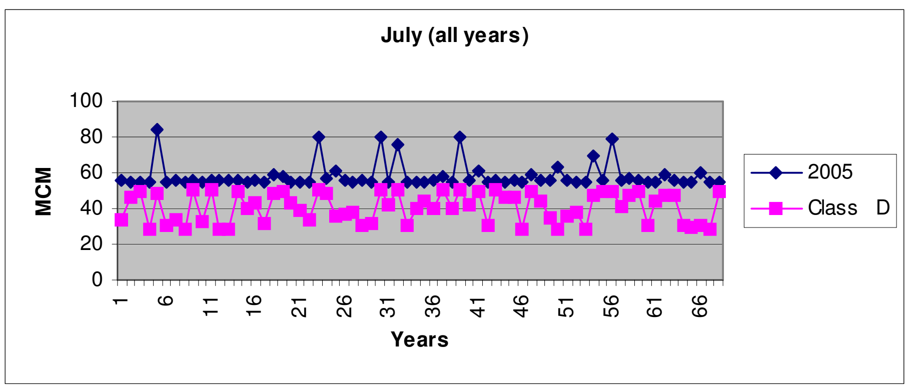

Figure 2-15: Year-on-Year Monthly Volumes for July: 2005 and Class D. Upper Range of Capped at 80 MCM to Increase Resolution in the Lower Range

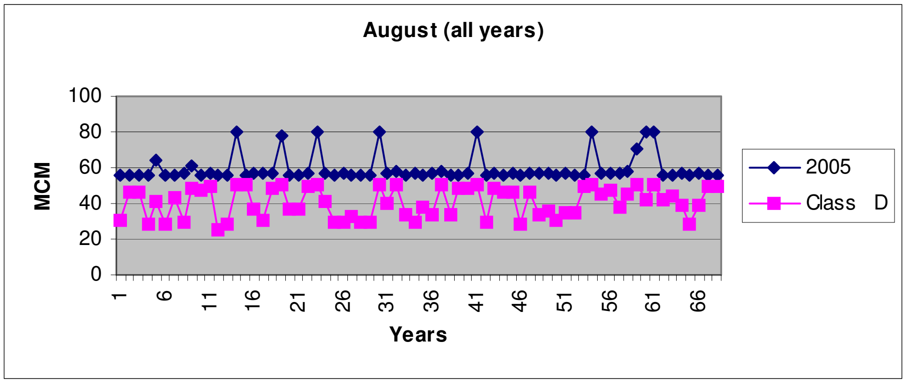

Figure 2-16: Year-on-Year Monthly Volumes for August: 2005 and Class D. Upper Range of Capped at 80 MCM to Increase Resolution in the Lower Range

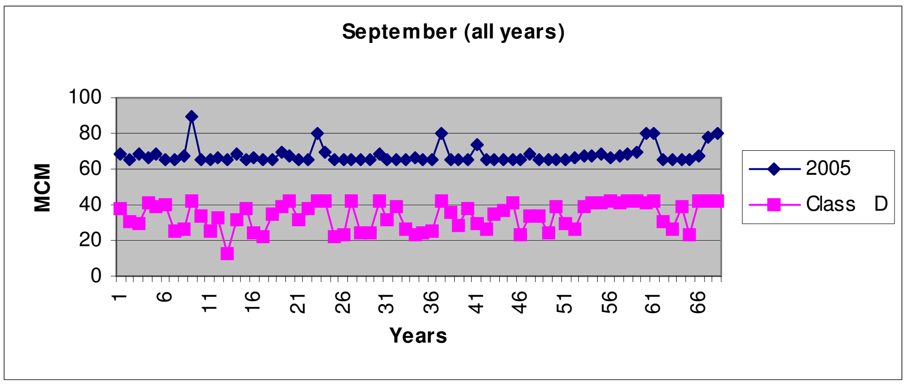

Figure 2-17: Year-onYear Monthly Volumes for September: 2005 and Class D. Upper Range of Capped at 80 MCM to Increase Resolution in the Lower Range

Question: How important (ecologically) is year-on-year variability?

3. LOWER ORANGE RIVER (BOEGOEBERG TO VIOOLSDRIFT): CHEMICAL STATUS (WATER QUALITY) CHARACTERIZATION

This Section is a review of the chemical status of the LOR, based on existing data and available scientific and management literature. The purpose of the characterization is to inform the PES and Reference Condition assessments for this study.

3.1 Background and Scope

Two sets of data were utilized for this characterisation:

- Data from the routine DWAF monitoring programme; and
- Data collected during a three-month (September to November) source to sea sampling conducted during 2002 (Orange River 2003 Expedition, ORE).

No primary data were collected for the specific purpose of this assessment. The data available were only supportive of a general characterization as no data pertaining to trace metals, organic pollutants, volatile organics, organochlorines, pharmaceuticals or other priority pollutants, whether in water, sediments or bioaccumulated, were obtainable within the scope of this work. It is reasonable to argue that, while an assessment of general water chemistry parameters lacks value in terms of linking to biotic impacts, the existence of several large impoundments upstream of the target section will attenuate the impacts of potentially noxious chemicals generated higher in the catchment. No provision was made for a comparative analysis of water quality changes upstream of the target section.

3.2 Target Section of River

The water quality characterization focuses on the LOR from upstream of Boegoeberg Dam (Zeekoebaart), to Vioolsdrift (see **Figure 3-1**). A number of DWAF water quality monitoring stations exist within this section (**Table 3-1**). For the purposes of this characterization, five stations with relatively continuous or consistently collected spans of data were selected, *viz.*:

- D7H008 Zeekoebaart
- D7R001 Boegoeberg Dam
- D7H005 Upington
- D8H004 Onseepkans
- D8H003 Vioolsdrift

Table 3-1: List of DWAF Water Quality Monitoring Stations (East to West). Highlighted Stations Selected for Further Data Interrogation

		Station ID	Lat	Long	Start	End	Detail
1	PRIESKA	D7H002	29.65139	22.74639	1952	1997	Continuous for TSS, otherwise fragmented
2	KOEGAS	D7H009	29.32778	22.31806	1971	1977	8 records
3	BOEGOEBERG	D7H008	29.02972	22.18778	1966	2003	Near continuous weekly/monthly
4	BOEGOEBERG DAM	D7R001	29.04222	22.20194	1976	2003	Near continuous
5	UPINGTON	D7H005	28.46083	21.24889	1970	2003	Fragmented
6	KAKAMAS	D8H002	28.64111	20.42889	1968	1968	7 records
7	ONSEEPKANS	D8H004	28.73556	19.30611	1971	2000	Near continuous
8	VIOOLSDRIFT	D8H003	28.76083	17.73028	1959	2002	Near continuous

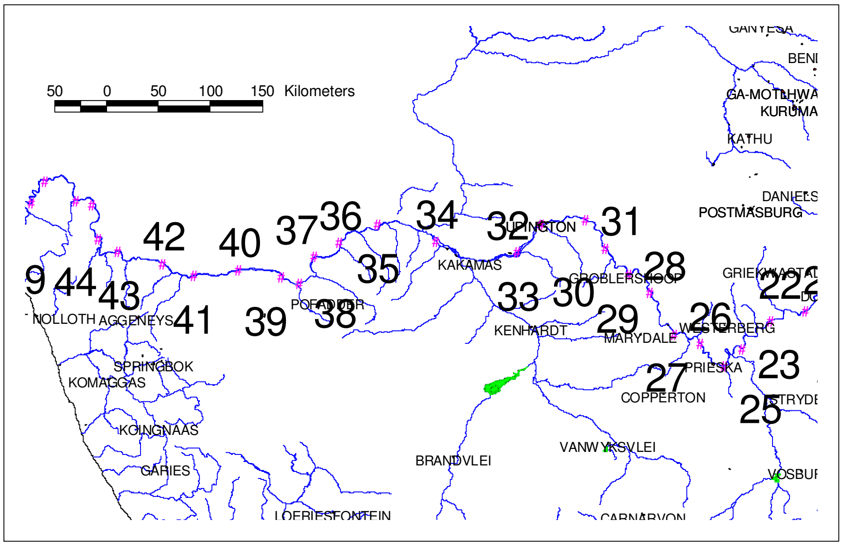

Figure 3-1: Water Quality Target Section

(Numbers refer to the Orange River 2002 Expedition (ORE) measurement sites referred to in the text. The section starts at Boegoeberg Dam (Site 28) and ends at Vioolsdrif (Site 42). Onseepkans is situated approximately 15 km upstream of Site 38.

3.3 Data Handling

Summarized water quality statistics, supplied by the DWAF, for the selected stations are provided in **Appendix 2**. The data sourced from the DWAF had not been cleaned for obvious outliers or capture errors. Accordingly, the data utilized here was subjected to a cursory screening process prior to use for trend analysis. This process was not applied to the summarized data in **Appendix 2**.

3.4 General Characteristics

The following water quality determinants assessed for this work, and encompassing the revised (DWAF) water quality methodology, included the following (data sources in parentheses):

3.4.1 Physico-chemical

- Water temperature (ORE);
- Conductivity (ORE; DWAF);
- Major ionic composition (ORE, DWAF);
- Alkalinity (ORE, DWAF);
- pH (ORE, DWAF);
- Suspended solids (DWAF);
- Water (Secchi Disk) clarity (ORE);
- Nitrate-nitrogen (ORE, DWAF); and
- Phosphorus (total P and ortho, as P) (ORE, DWAF).

3.4.2 Biological

Details of the phytoplankton assemblage are pertinent to the management of the Orange River, and such data as were available are characterized here. The data are supported by (temporally) limited sets of chlorophyll-a data for certain stations.

3.5 Assessment

3.5.1 Water Temperature

Water temperature data were limited to those collected during the one-off traverse of the river during the ORE. Apart from the effects (cooler water) induced by the major impoundments, water temperatures increased steadily from 18ºC at source to 25ºC at Alexander Bay (**Figure 3-2**; Note: The target section was travelled in Days 28 to 42 of the ORE survey). In this section, water temperatures increased from 20ºC below Boegoeberg Dam to 24ºC upstream of Vioolsdrift.

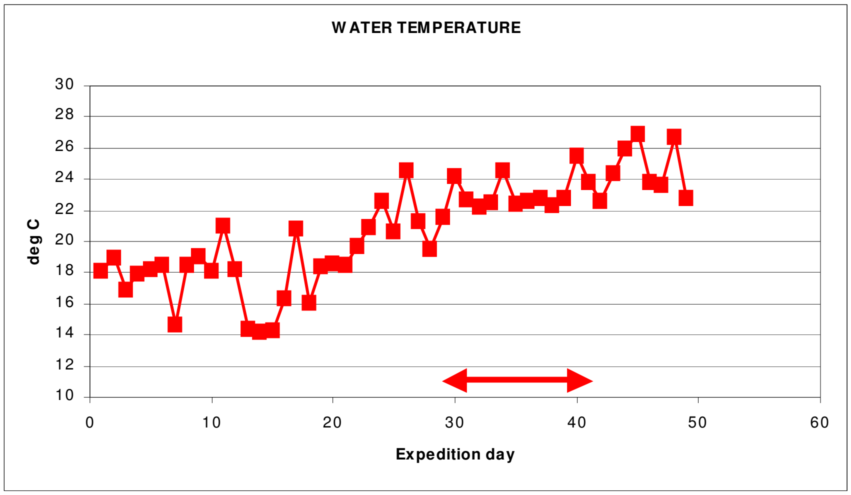

Figure 3-2: Water Temperatures Measured in the Orange River during the 2002 September/November ORE. Arrow Spans Target Section Assessed Here

3.5.2 Conductivity

The DWAF data essentially provide a 25-year data set (1971-2002) for the stations representing the target reach. These show a gradual inter-annual increase of the order of 10-15 mS m^{-1} during this period. The values measured are presented in

Figure 3-3.

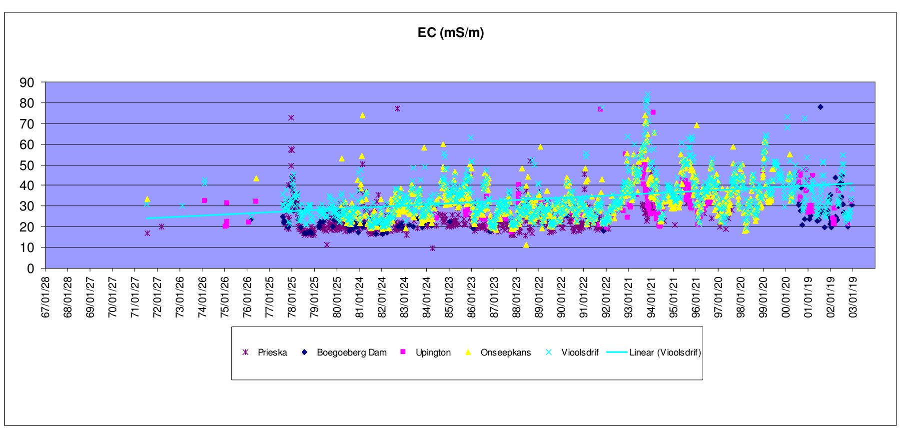

Figure 3-3: Historical (1972-2002) EC Data for the Orange River between Prieska (Upstream of Target Section) and Vioolsdrift. Trendline for Vioolsdrift Data Included

An examination of median and 95%ile values for the full data set, and the last 12 years (**Table 3-2**) revealed minimal fluctuation between the two periods:

Table 3-2: Electrical Conductivity Data (mS m^{-1})

Station	1971-2002		1990-2002	
	Median	95%ile	Median	95%ile
Zeekoebaart	25	41	27	43
Boegoeberg Dam	23	40	26	42
Upington	29	48	31	50
Onseepkans	31	51	34	55
Vioolsdrift	32	54	36	59

Data from the ORE showed an overall increase of 14 mS m^{-1} (17-41) over the full length of the river, and an increase of 5 mS m^{-1} across the target section, i.e., in accordance with the historical data presented above.

3.5.3 Alkalinity

The levels of alkalinity in the river were low and unchanged downstream of Upington, with slight increases of the order of 10 mg ℓ^{-1} downstream thereof (**Table 3-3**).

Table 3-3: Alkalinity Data (mg ℓ^{-1})

Station	1971-2002		1990-2002	
	Median	95%ile	Median	95%ile
Zeekoebaart	88	108	88	107
Boegoeberg Dam	83	106	86	107
Upington	97	131	102	133
Onseepkans	112	163	122	168
Vioolsdrift	115	160	124	167

Ionic composition *(major anions and cations)*

At all stations through the target reach the ionic composition was Ca > Na > Mg > K : SO4 > Cl. Concentrations of potassium (K) remained relatively low (< 2.5 mg ℓ^{-1}) and did not reflect any marked runoff containing inorganic fertilizers. Water from the Upper Orange is noted for magnesium dominance (e.g. Keulder 1979), with ion ratios of Ca > Mg>Na>K.

pH values

Trends in pH showed marked change over the period 1977-2002, and with two distinct phases (stepped) between 1989 and 1990 (it is assumed that such a marked step was not due to a procedural- or instrumentation-induced error?). The data are presented in **Figure 3-4**.

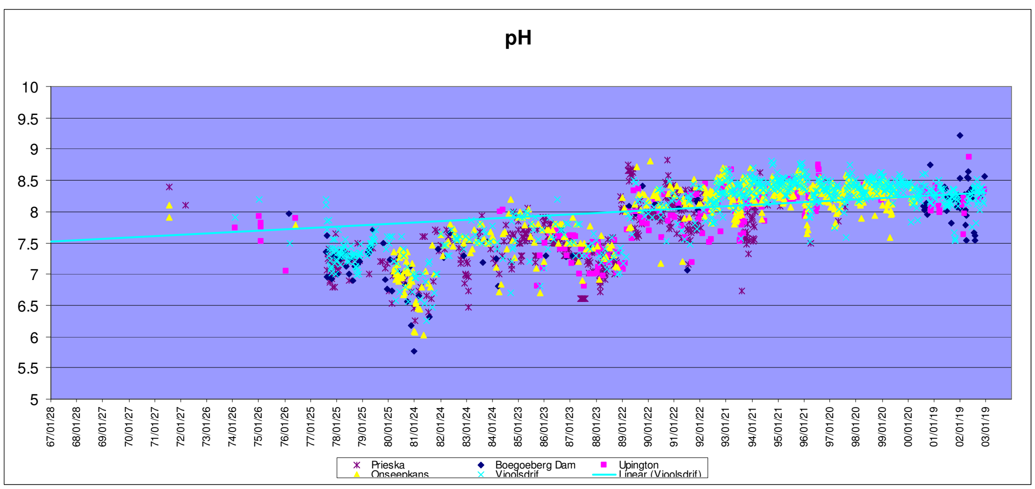

Figure 3-4: pH Data

Given that the data sets are not always continuous or have temporal consistency, pH values in the target section increased (at all stations) from neutrality to in excess of 8 during the period spanned by the data (**Table 3-4**). This increase is significant, and likely to be a consequence of increased primary production and possibly irrigation return flows (Benade 1993). No studies of diel pH change, i.e., that would indicate the role of phytoplankton in this increase, were identified.

With the exception of an increased median pH level in Boegoeberg Dam, the change in pH was not apparent from the inter-period analysis – this is a consequence of the bulk of the data underpinning the determination of the median having been collected during the last 12 years.

Table 3-4: pH Data

Station	1971-2002		1990-2002	
	Median	95%ile	Median	95%ile
Zeekoebaart	8.2	8.6	8.2	8.6
Boegoeberg Dam	7.7	8.5	8.2	8.6
Upington	8.2	8.5	8.2	8.5
Onseepkans	8.2	8.5	8.3	8.6
Vioolsdrift	8.3	8.6	8.4	8.6

Data from the ORE showed a small overall increase of 1.5 pH units over the full length of the river, and with pH values in excess of 8 (typical, see LHDA 1999) measured from the source (see **Figure 3-5**). Within the target section, pH values remained consistently around 8.2, i.e., in accord with the data presented above.

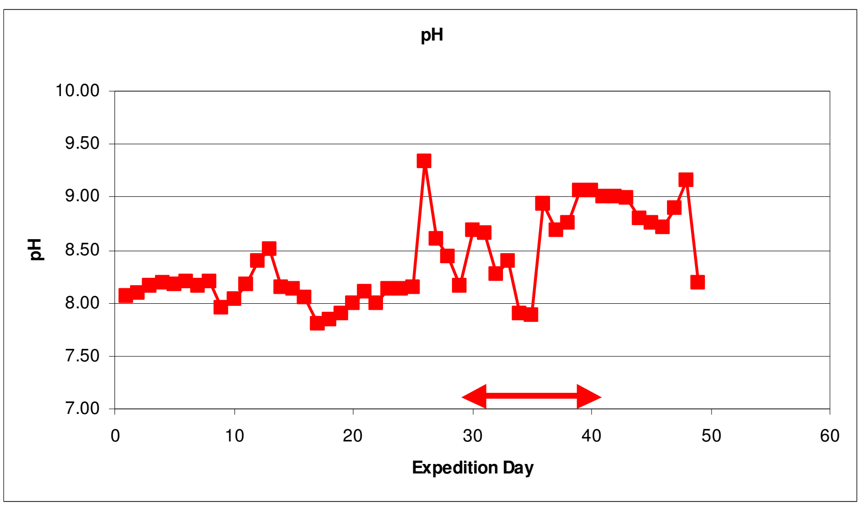

Figure 3-5: Variation in pH with Distance from the Source of the Orange River (Data from ORE). Arrow Spans Target Section Assessed Here

3.5.4 Suspended Solids

The DWAF suspended solids (ss) data do not readily support trend analysis, nor do they consistently span overlapping periods (see **Figure 3-6**). It is assumed that the data were collected in support of sedimentation studies for planned impoundments. No breakdown that would indicate the organic carbon component (i.e., algal biomass) was available.

Only two sites from the target reach provided ss values. Accordingly, an additional site (Prieska) upstream of Zeekoebaart, was included for comparative purposes.

Concentrations of suspended solids were generally high (100-1000 mg ℓ^{-1}) at Prieska and Upington between 1973 and 1991. Thereafter, when the data resumes post-1999, values an order of magnitude lower were measured at Upington, consistent with values reported for Boegoeberg Dam (see **Figure** 3-6).

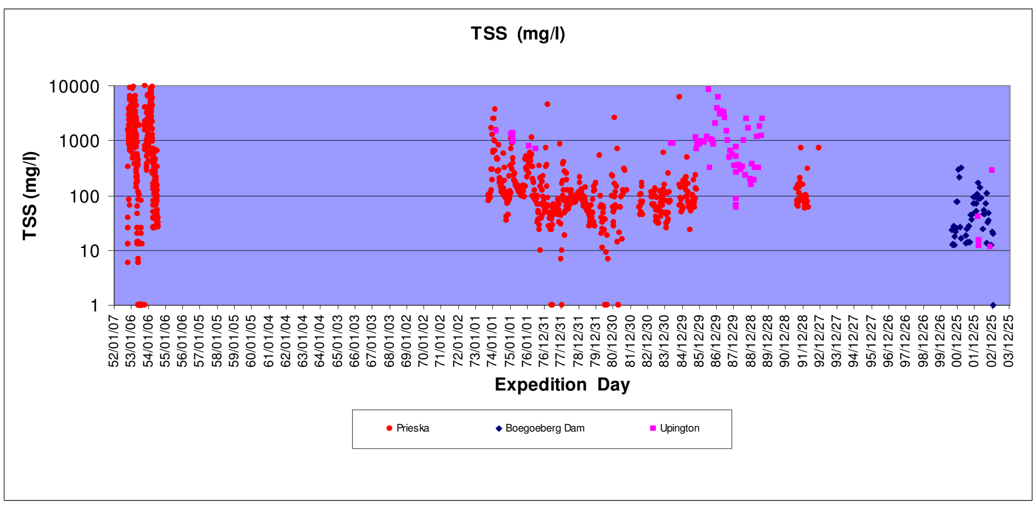

Figure 3-6: Historical Total Suspended Solids (TSS) Data for Selected Stations. Note Log Scale on Y-Ordinate

3.5.5 Water Clarity

Measurements of Secchi disk (Sd) water clarity were limited to those collected during the ORE, but are nonetheless indicative of conditions prevailing in the river during the spring. Apart from a sample collected near the source (Sd = 0.6 m), transparencies were generally low, ca. 0.3 m for the upper to mid-reaches of the Orange River, and Sd< 0.3 m in the section downstream of Augrabies. Water clarity in the target section ranged from Sd 0.31-0.35 m upstream of Kakamas, decreasing rapidly to Sd 0.25-0.28 downstream thereof **Figure 3-7**).

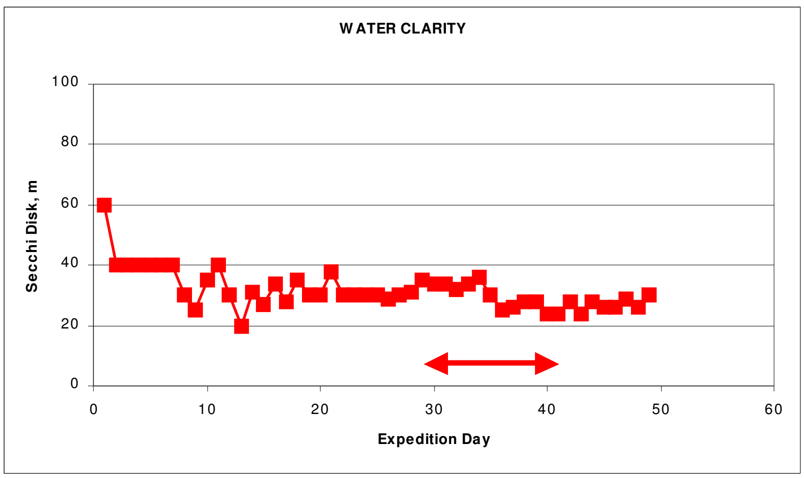

Figure 3-7: Water Transparency Measurements taken during the 2002 ORE. Target Section Arrowed

3.5.6 Nutrients – Nitrogen Forms

Ammonia Nitrogen

Reported (DWAF) concentrations of ammonium-nitrogen (NH_4-N) were consistently low (**Appendix 3**) and of negligible concern if converted to ammonia (NH_3). The ORE data revealed an irregular pattern of ammonium pollution followed by denitrification.

Nitrates

Levels of nitrate-nitrogen (NOx) showed decreasing trends at all stations between 1980 and 2002 **Figure 3-7**). Median concentrations remained constant between Zeekoebaart and Upington, decreasing markedly through the 250 km reach downstream thereof to Onseepkans (0.300 to 0.050 mg ℓ^{-1}) (**Figure 3-8**).

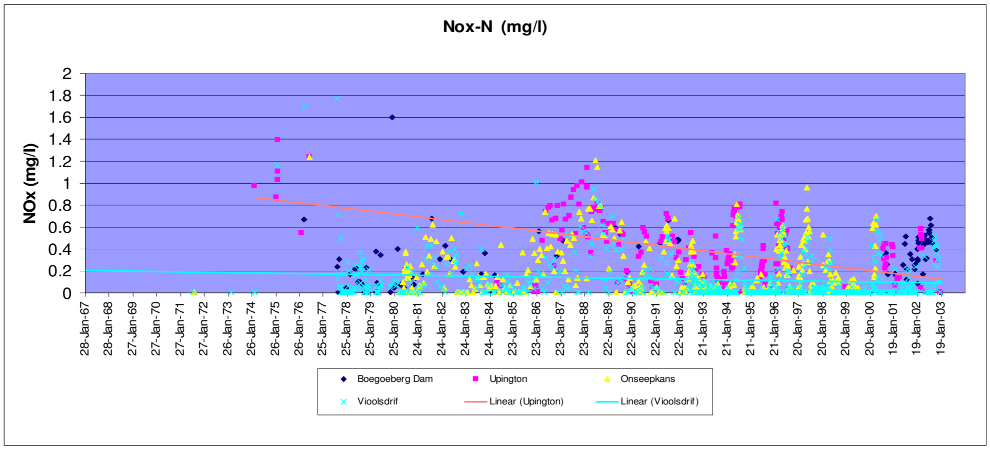

Figure 3-8: Historical Nitrate-N Data for Selected Stations within the Target Section (Trendlines for Upington and Vioolsdrift Included

Comparison of the full data period versus that for the last twelve years showed that median levels of nitrates have increased in Boegoeberg Dam, and was lower at Upington and at the limit of detection downstream of Onseepkans.

Data from the ORE showed a steady decline in NOx, decreasing from 0.383 to 0.084 mg ℓ^{-1} through the target reach (**Figure 3-9**).

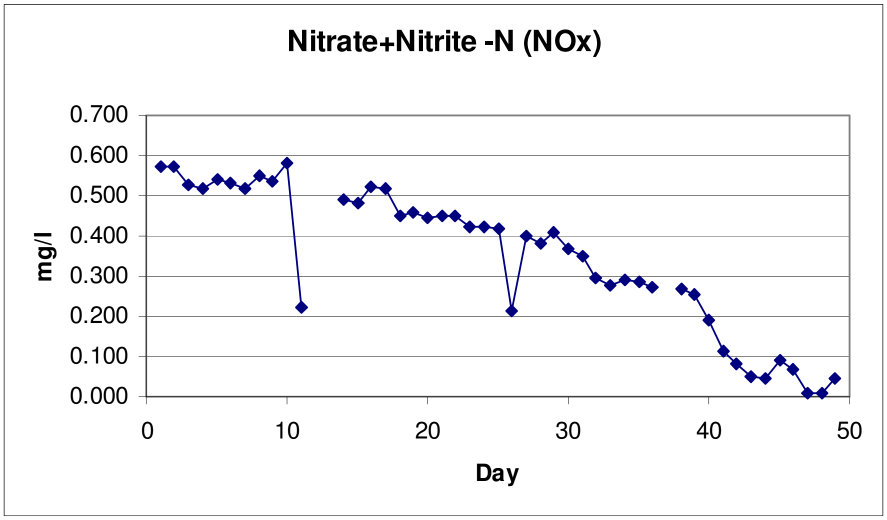

Figure 3-9: Variation in Concentration of Nitrate-N down the Orange River (ORE)

Table 3-5: Nitrate-Nitrogen as N (mg ℓ$^{-1}$)

Station	1971-2002		1990-2002	
	Median	95%ile	Median	95%ile
Zeekoebaart	0.294	0.691	0.317	0.700
Boegoeberg Dam	0.305	0.604	0.441	0.590
Upington	0.307	0.915	0.225	0.767
Onseepkans	0.047	0.625	0.010	0.597
Vioolsdrift	0.020	0.526	0.010	0.481

Kjeldahl Nitrogen

Given that the ammonia levels are low (see above), examination of the concentrations of Kjeldahl nitrogen provides an indication of the level of organic material present in the water column (the data represent the period 1990-2002). The data show consistent high (0.5 – 0.6 mg ℓ$^{-1}$) concentrations of Kjeldahl nitrogen throughout the target section (**Table 3-6**) – this reflecting, primarily, the level of phytoplankton biovolume present in the system.

The concentrations of nitrogen were relatively low for a river draining highly developed areas.

Table 3-6: Kieldahl Nitrogen (mg ℓ^{-1})

STATION	1971-2002		1990-2002	
	Median	95%ile	Median	95%ile
Zeekoebaart	No data		No data	
Boegoeberg Dam			0.512	1.000
Upington			0.614	1.219
Onseepkans			0.608	1.083
Vioolsdrift			0.561	1.070

Samples collected during the ORE showed that concentrations of Kjeldahl increased in an irregular fashion from the headwaters to the Atlantic, and oscillated about a mean of 0.900 mg ℓ^{-1} through the target section for this study, i.e., at concentrations approaching the 95%ile.

3.5.7 Nutrients – Phosphorus Forms

Total Phosphorus

Inclusion of measurements of total phosphorus into the DWAF monitoring programme was relatively recent, with few data being available pre-1993. The data reflect regular seasonal peaks and no apparent inter-annual trends (**Figure 3-10**) Median and 95%ile values for the target section characterized here are presented in **Table 3-7**.

The data for both total-P and orthophosphate (**Figure 3-11**) showed a high level of spatial and temporal constancy, as well as generally low availability concentrations in terms of limitation to phytoplankton development (orthophosphate concentrations of *c.* 0.020 mg ℓ^{-1}). This scenario suggests that the assemblage of phytoplankton, embodying the bulk of the total phosphorus component, develops upstream of the target reach, and is simply transported through it. Any pool of surplus biologically reactive phosphorus such as may be introduced into the target reach (see peaks of orthophosphate in seasonal analysis) from its adjacent shorelines is being taken up by the algae such that only a limiting concentration of dissolved P remains in the water column.

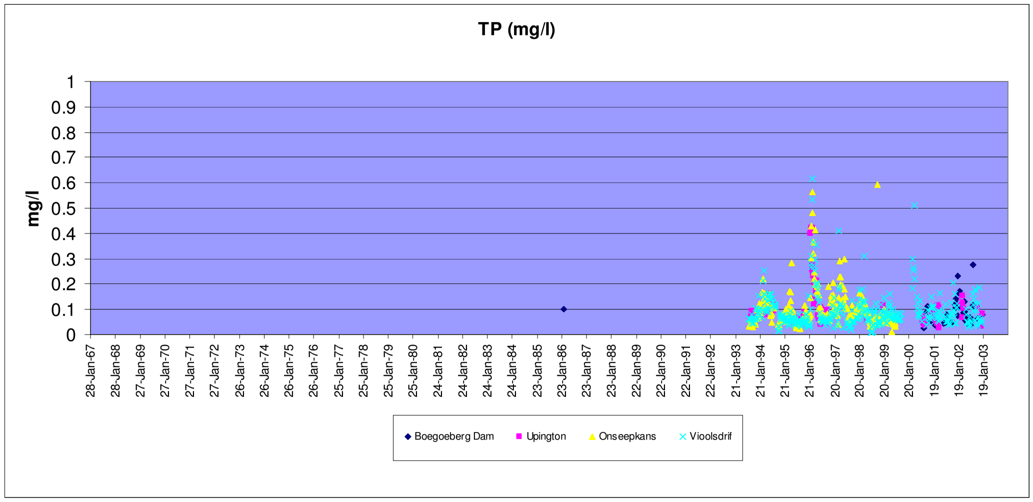

Figure 3-10: Historical Total Phosphorus Data for Selected Stations within the Target Section

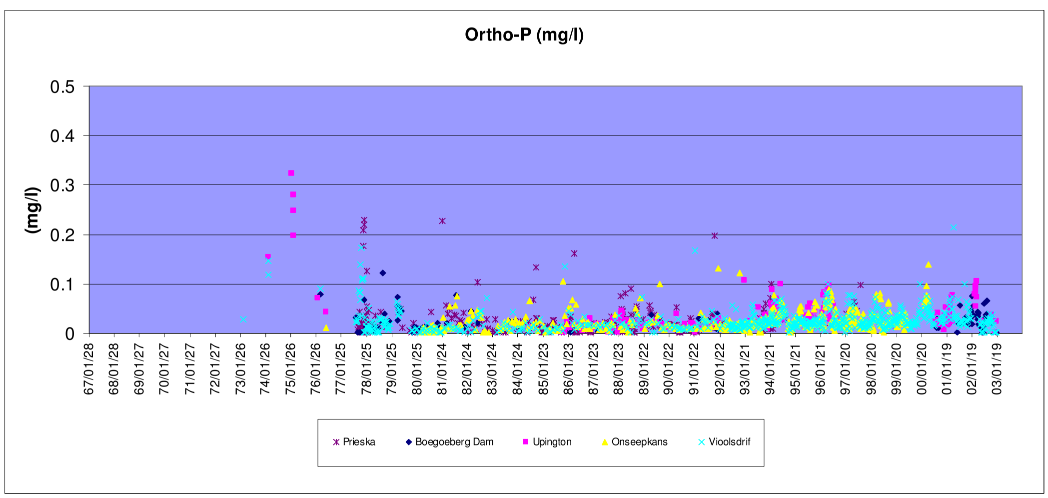

Figure 3-11: Historical Total Phosphorus Data for Selected Stations within the Target Section

By contrast, the ORE data show both high and consistently increasing concentrations of total phosphorus (from 0.050 mg ℓ^{-1} at source to > 0.120 mg ℓ^{1} at Alexander Bay) and orthophosphate (0.024 to 0.090 mg ℓ^{-1}, respectively) during the period of high flows between September and November 2003 (see **Figure 3-12**and **Figure 3-13**). Within the target section, both forms of phosphorus increased from the start of the section to Kakamas, followed by a sharp decrease to a point downstream of Onseepkans. The data summarized in **Appendix 2** show the upper limits of these values to be representative of conditions characterizing the 75%.

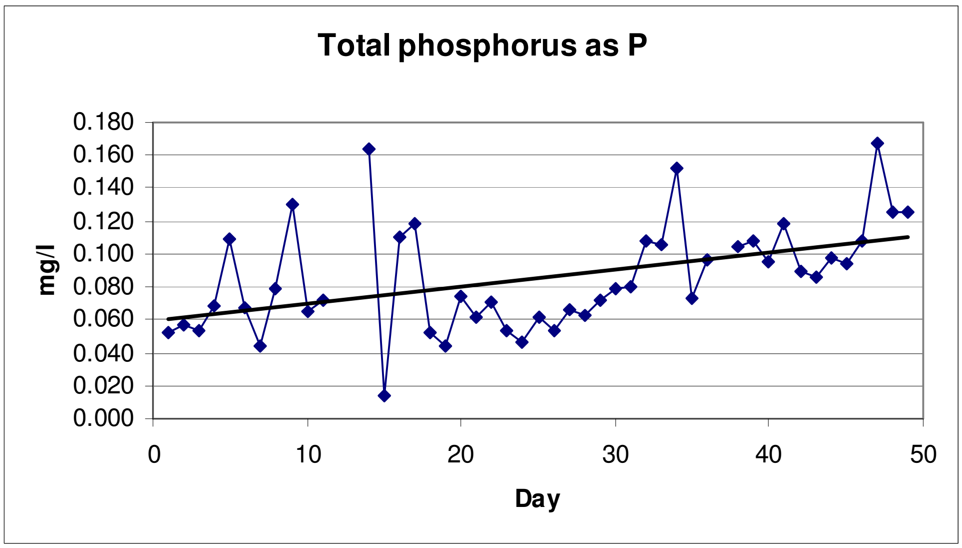

Figure 3-12: Variation in Concentration of Total-Phosphorus with Distance from the Source of the Orange River, as Measured during ORE 2002

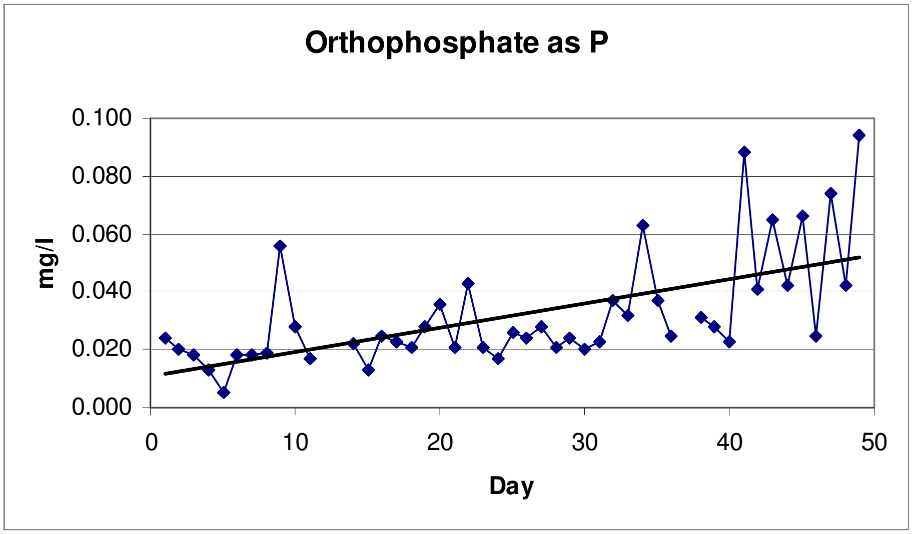

Figure 3-13: Variation in Concentration of Orthophosphate-Phosphorus with Distance from the Source of the Orange River, as Measured during ORE 2002

Table 3-7: Total Phosphorus as P (mg ℓ$^{-1}$)

Station	1971-2002		1990-2002	
	Median	95%ile	Median	95%ile
Zeekoebaart	No data		No data	
Boegoeberg Dam			0.065	0.203
Upington			0.070	0.213
Onseepkans			0.077	0.222
Vioolsdrift			0.069	0.207

Orthophosphate (as P)

Discussion incorporated with that for total-P (**Table 3-8**).

Table 3-8: Orthophosphate as P (mg ℓ$^{-1}$)

Station	1971-2002		1990-2002	
	Median	95%ile	Median	95%ile
Zeekoebaart	0.022	0.058	0.023	0.057
Boegoeberg Dam	0.020	0.070	0.022	0.062
Upington	0.024	0.087	0.027	0.083
Onseepkans	0.019	0.064	0.020	0.066
Vioolsdrift	0.021	0.064	0.022	0.063

3.5.8 Biological Determinants

Chlorophyll-a

Small sets of chlorophyll-a (Chla) data were available for Boegoeberg Dam (n=45) and Upington (n=22). These data reveal median concentrations of 5 and 8 µg ℓ$^{-1}$ Chla for Boegoeberg Dam and Upington, respectively. Maximum values of 36 and 22 are reported for the same stations. The data are interesting in that in both cases the level of Chla breakdown product, viz. phaeophytin, exceeds the concentration of Chla, with median levels of 7 and 10 µg ℓ$^{-1}$ for Boegoeberg Dam and Upington, respectively. This confirms the above hypothesis that developed phytoplankton populations, in near stationary growth phase, are transported into the target section, and that the population reaches an advanced level of decay and autolysis within and/or shortly after Boegoeberg Dam. This further suggests that Boegoeberg Dam may provide a vital point at which to implement phytoplankton management in order to limit further progress of cyanobacterial blooms down river.

Phytoplankton Assemblage

During late-April 2003, the Orange River evidenced a strongly green hue, typical of eutrophic waters, but without any evidence of buoyant cyanobacterial scums on reeds, rocks or exposed shorelines, i.e., as would be typical of genera such as *Microcystis* or *Anabaena*. The algal assemblage was comprised of three genera of cyanobacteria (*Cylindrospermopsis*, *Anabaena* and *Oscillatoria*), two species of diatoms (*Fragilaria* and *Melosira* *granulata*) and one species of Chlorophyta (*Scenedesmus quadricauda*), and with *Cylindrospermopsis* and *Fragilaria* as dominants.

No epiphytic or benthic filamentous macroalgae were observed during the May 2003 site visit, other than an isolated miniscule mat of *Rhizoclonium* attached to *Isolepis* at Raap-en-Skraap.

The phytoplankton assemblage is extremely poor for a large river (cf., e.g., the Danube with 340 taxa), and reflects the impact of eutrophication and cyanobacterial development in the upper reaches of the Orange River.

This assemblage poses threats to human, animal and ecosystem health (cyanobacteria), as well as physical (blockage) problems in irrigation systems (cyanobacteria and diatoms). The appearance of *Cylindrospermopsis* is a relatively new (2000) addition to the cyanobacteria routinely observed in South Africa, and currently known only from the Orange River. This organism has the propensity to produce an extremely potent and difficult to detect alkaloid toxin, cylindrospermopsin.

3.6 Comments and the Methodology Used Here

The revised methodology as used in this report should not be to base management decisions, either on instream quality or on impounded quality in new or existing dams. The methodology looks at water quality constituents that are at best primary indicators of water quality, and not really of pollution - herein lies the risk of rating (classifying) systems into a category higher than they should be in. The increased focus on salts makes no allowance for naturalness, and downgrades systems where certain salts are geologically natural, and where biotic tolerance to same will be in-built - consequently the downgrading of condition occurs. Neither the new method nor the old considers toxicant problems in terms of chronic and acute exposure, nor retention time insofar as nutrients and eutrophication are concerned.

4. LOWER ORANGE RIVER (UPINGTON TO ONSEEPKANS): RIPARIAN VEGETATION CHARACTERIZATION

This Section is a review of the status of riparian vegetation on the LOR, based on existing data, preliminary field observations and available scientific and management literature. The information presented here formed the basis for the assessments that follow in **Section 6, 7** and **8**.

4.1 Introduction

The notes presented in this Section represent the results of a study of the relevant literature and observations made during the examination of the vegetation in the field (29 and 30 April 2003).

4.2 Literature Assessment of the Vegetation

The relevant literature for the study area indicates that the following plant communities are present. These plant communities were accepted as being valid units for the current study, primarily because of the very short period available for fieldwork.

4.2.1 Aquatic Communities

Floating Aquatics

Azolla filiculoides (American exotic) occurs in sheltered, lightly shaded, places particularly in reed beds (Benade, 1993), in background information to LORMS, (Benade, 2003), downstream of Boegoeberg Dam. *Lemna gibba* was observed in an irrigation channel near Keimoes during the fieldwork in the present study.

Submerged Aquatics

Benade (2003) recorded the presence of *Potamogeton schwienfurthii*, *P. pectinatus*, *P. crispus*, Ludwigia stolonifera along this section of the Orange River.

4.2.2 Semi-aquatic Reed Beds

Phragmites australis beds are dominant along the middle reaches of the Orange River, particularly between Boegoeberg Dam and Augrabies Falls, but are fewer, further downstream (Benade 2003).

i. *Phragmites australis* (Closed Reedland): Bezuidenhout and Jardine (2001) record this dense community at the water's edge on relatively low-lying sandbanks.
ii. *Arundo donax:* This alien invasive species forms dense stands along this reach.

4.2.3 Riparian Woodlands and Shrublands

i. *Tamarix usneoides* (Open/Closed Woodland): This community is associated with alluvial deposits along the larger drier sandy drainage lines (Bezuidenhout and Jardine, 2001).
ii. *Tamarix usneoides* is the dominant tree, while scattered *Acacia erioloba* individuals occur through the community. Shrubs present include *Acacia mellifera, Maytenus linearis* and *Sisyndite spartea*. Invader shrubs present are *Prosopis glandulosa* and *P. velutina.*
iii. *Zygophyllum simplex* is the dominant annual forb (Bezuidenhout and Jardine, 2001).

***Acacia Karroo* (Closed Woodland)**

This community occurs on sandy islands where the riverbank habitat is drier and more clayey than that of the *Rhus pendulina* Forest (Bezuidenhout and Jardine, 2001). The dominant tree is *Acacia karroo* (Bezuidenhout and Jardine, 2001). *Celtis africana* and *Rhus pyroides are* associated differential species in this community along the Orange River in the Tussen die Riviere Game Farm in the Free State (Werger, 1973a) but do not appear to occur along the LOR.

***Rhus Pendulina* (Forest)**

This community is the most prominent vegetation along the Orange River. It occurs on riverbanks and on sandy islands (Bezuidenhout and Jardine, 2001). The three trees dominate it: *Rhus pendulina, Salix mucronata* and *Ziziphus mucronata*. The shrub layer is dominated by *Diospyros lycioides. Phragmites australis* occurs in patches (Bezuidenhout and Jardine, 2001). It closely resembles the *Ziziphus mucronata* Closed Woodland (Bezuidenhout, 1996).

The vegetation in the Augrabies NP was found to be in excellent condition and the alien invasive species, namely, *Nicotiana glauca* and *Ricinus communis* were sparse (Bezuidenhout and Jardine, 2001). Werger and Coetzee (1977) note that both the presence of *Erythrophyllum* and the absence of *Rhus lancea* from the *Rhus pendulina* Forest are interesting phytogeographical phenomena. Bezuidenhout and Jardine (2001) observed two specimens of *Combretum erythrophyllum* and similarly never observed any *Rhus lancea* in the riparian vegetation along the 100 km they studied along the river between Blouputs and Onseepkans (Bezuidenhout and Jardine, 2001). *Rhus lancea* is absent to very rare along the Orange River, but occurs commonly in the riparian forest along the Vaal River (Werger, 1973b). *Salix mucronata* is consistently present along the Orange River from the highlands in Lesotho to the Richtersveld (C. Boucher pers. obs.).

Invaded Riverine Vegetation

Prosopis glandulosa and *Rhigozum trichotomum* have invaded riverine vegetation (Hoffman, 1996). In contrast, Bezuidenhout and Jardine (2001) note that while *Rhigozum trichotomum* was not found to be invading riverine areas along the Lower River, alien plants downstream of the farm Raap-en-Skraap were replacing the riverbank and island vegetation. Near Onseepkans, the *Rhus pendulina* Forest is virtually totally displaced by *Eucalyptus camaldulensis, Nicotiana glauca, Prosopis glandulosa, P. velutina* and *Ricinus communis.* Bezuidenhout and Jardine (2001) consider the *Acacia karroo* Closed Woodland and the *Rhus pendulina* Forest to be threatened in this area. Sesbania invasions have also been noted, particularly in the middle and lower reaches (Palmer 1996).

4.2.4 Schotia Afra Open Scrub

Up to 6.0-m tall shrubs to low trees of the *Schotia afra* Scrub community lines sandy drainage lines on the flats and penetrates into the Orange River Canyon below Augrabies Falls in between piles of rock and boulders (Werger and Coetzee, 1977). Grasses and dwarf shrubs are present (10% cover) forming a lower sub-stratum here.

4.3 Observations Made at Selected Sites during Fieldwork 29 and 30 April 2003

Note that values given in parentheses after plant names refer to Braun-Blanquet cover-abundance values. These values indicate the contribution by each species to the lateral riparian vegetation zonation patterns recognised on site which was estimated using the Braun-Blanquet cover-abundance scale, where 'R '= rare or species covers less than 0.1% of the area; '+' = present, but not abundant, covering less than 1% of the area; '1' = numerous, but not abundant, covering 1–5% of the area; '2' = numerous and covering 5–25% of the area; '3' = covering 25–50% of the area; '4' = covering 50–75% of the area; '5' = covering 75–100% of the area (Werger 1974).

4.3.1 Stop 1. Approximately 5 km Downstream of Onseepkans Bridge

- The river was rated as D-category on the left and the right banks.
- The river appears to have a single channel.
- The conspicuous indigenous plants observed, include *Phragmites australis* (5).
- Conspicuous, common exotics observed, include *Arundo donax* (1), *Ipomoea falx* (+), *Prosopis glandulosa* (2), *Ricinus communis* (+) and *Salix babylonica* (+).

- A levee has been constructed along the left-hand bank of the river to protect fields of cotton, lucern and vines from floods.
- *Prosopis glandulosa* has invaded along the levee in particular where there has been physical disturbance. (Note: This species concept might include some *P. velutinosa* individuals as well. The short time spent at each site pre-empted any detailed work required for positive identification.)
- *Prosopis glandulosa* was seen to be sprouting with coppice shoots after fire. The hard-coated seeds would survive and germinate well after fire thereby increasing the density of stands.
- *Prosopis glandulosa* was said to be bad for cattle, which cannot move freely through the dense stands. Goats and pigs are unaffected and probably benefit far more from the herbage and seedpods.
- *Phragmites australis* was considered to be denser here than it should be, probably because of the burning regime adopted by the farmers and because they recover rapidly from physical disturbance. (They sprout from stolons.)
- Indigenous trees were thought to have declined here because of regular short interval fires and agricultural disturbance. There is too short an interval between fires for recruitment of indigenous trees to occur or for damaged plants to recover. Fires are also hotter because of an increase in *Phragmites australis* and because of a loss of the cooling effect of a wet substrate through generally lower water levels through increased abstraction and a reduction in natural fluctuation.
- *Phragmites australis* apparently dies after being submerged for two weeks.
- Indigenous trees and shrubs would have declined because of floods being reduced through dams so less spreading of disseminules (seeds and parts of plants) would occur.
- Draining agricultural lands where fertilizers have been applied, and where salts have been drawn to the surface through evaporation, leads to higher salinity levels in the river during low flow periods. This would benefit *Phragmites australis* and *Tamarix usneoides* and have a negative effect on *Salix mucronata.*
- The presence of a levee would influence the effects of high water flows. After larger floods, silt deposition would be present from water trapped behind the levee but it would in all probability be less than without the levee being present because less silt-laden water would penetrate the area. The levee would concentrate most of the flows into a narrower

channel, which would keep it relatively free from deposited materials.

- Water stored at Boegoeberg, as opposed to the proposed Vioolsdrift Dam, could be manipulated to meet ecological flow requirements and simultaneously to provide water for Namibia and the estuary.

4.3.2 Stop 2. Onseepkans Bridge

- The river was rated as C-category on the left, middle and right banks.
- The river has a number of channels and a rocky substrate. These are particularly apparent below the bridge. The basement rocks prevent the river from developing a single incised channel as is present downstream at previous site where rocks are absent.
- The conspicuous indigenous plants observed are :
  - Wetbank – *Gomphostigma virgata* (+) (only in rocks), *Phragmites australis* (5), *Salix babylonica* (+), *Salix mucronata* (+) and *Sporobolus virginicus* (2).
  - Drybank - *Acacia karroo* (+), *Rhus pendulina* (2), *Tamarix usneoides* (2) and *Ziziphus mucronata* (1).
- Conspicuous, common exotics observed, include *Arundo donax* (1), *Prosopis glandulosa* (2), *Ricinus communis* (+) and *Salix babylonica* (+).
- Abundant use of fire by farmers is causing *Phragmites australis* to extend its distribution from the Wetbank Zone laterally into the Drybank Zone. This process involves the regular reduction of the indigenous tree and shrub cover leading to an invasion by the pioneer reeds.
- *Phragmites australis* observed to extend runners of at least three meters length into the open water. Roots develop at the nodes. This is a vegetative means to spread rapidly over some distance onto sand bars for instance.
- Does degradation of the riverbank vegetation, through disturbance by farming, occur more rapidly when flows are reduced. Conversely, if the natural flow regime is re-instated in this river, but agricultural riparian ecosystem degradation practices nevertheless continue - will this pre-empt the river from recovering? If this is the case, then we would be wasting water to try and reinstate a natural flow regime. An active campaign to correct bad farming practices would have to be put in place simultaneously to the introduction of a natural flow regime in this scenario.

4.3.3 Stop 3. Raap-en-Skraap Farm

- The river was rated as D-category on the left and middle and C-category on the right banks.
- The river has bedrock in this section with a few channels present. Pools occurred upstream. The central channel appears to have a gravel base with a lesser proportion of sand and silt. The deepest channel flowed along the left bank, past the pump abstraction point where a rock berm, and a channel have been constructed to protect pumps and assist with water abstraction. Four pumps on rails, with six pipes each, draw water from the river. The water was pumped into a single large pipe to deliver water to the farm (mainly vineyards).
- The river has few, but very large, multiple stemmed *Prosopis glandulosa* here. This suggests an early stage of infestation that could rapidly expand because of a build-up of a seed bank in the soil should farming practices change to disturb the present dense riparian vegetation. The cleared campsite has some young plants appearing in it.
- *Phragmites australis* beds appeared to be larger immediately downstream of the abstraction point, but this could have been a localized effect. Clumps of this plant occurred on sandy islands through the bed of the river.
- A reduction in flow would enable the *Phragmites australis* to expand its distribution and to accumulate more sediments, thereby effectively blocking the channel during small floods, but resulting in large disturbances when they are washed out during large floods. The reed mats could then cause blockages downstream exacerbating the effect of floods.
- *Gomphostigma virgata* clumps occurred in mid-channel rocks. This plant is known colloquially as "otter bush", probably because it affords some protection to otters while they utilize the rocks for feeding or resting. These clumps could also accumulate sediments during floods.

4.3.4 Stop 4. Ararat, Augrabies National Park

- The river was rated as C-category on the left and right banks.
- The river has a single channel with basement rock causing rapids and runs with some pools.

- The river water appeared to have a heavy algal bloom with much foaming scum on the water over the riffles and rapids.
- The riparian bank vegetation is very sparse because of the rapid flow volumes experienced in the narrow steep-sided gorge.
- Local sand accumulations occur around the inside of bends that support *Schotia affra* trees. *Phragmites australis* beds are encroaching on this sand. There is possibly more sand due to increased agricultural activity upstream and less small floods together with shorter interval large floods able to wash it away. Some vegetated sand accumulations are probably of a temporary nature, as large floods would probably erode these away.
- Large *Ficus cordata* and *Boscia albitrunca* plants occur on the rock faces.
- No exotic *Prosopis glandulosa* plants were observed.

4.3.5 Stop 5. Renosterkopeiland at Ski-boat Club

- The river was rated as E-category on the left bank and D-category on the right bank.
- The left bank was examined at the Boat Club Launch Site. It is a cleared area with a constructed levee protecting the vineyards from small floods. Long pool area with weir downstream in an area of bedrock.
- The left Wetbank shows a bank-erosion step associated with an unnatural change in water levels. This might arise from lengthy inundation at an above normal depth because of the weir during the normal wet season (100 cumec releases), followed by a lengthy constant exposure in the dry season at a lower level following abstraction when the flow is 55 cumecs and the water level drop is in the order of 1.0-1.2 m below the wet season level, coupled with wave action erosion from the wakes produced by ski-club boats.
- The Wetbank vegetation on both banks has been reduced by the artificial creation of a pool. *Phragmites australis* is particularly patchy on the right bank. Fluctuations in water level are unnatural; mainly being associated with water abstraction extent and constant volume dam releases. These artificial fluctuations in water level have a negative effect on the Wetbank vegetation as it is destroyed during longer periods of inundation under deeper water levels and does not have sufficient time to readjust downward during lowflows because of dam releases.
- The left bank levee has damaged most of the Drybank vegetation here.

- The Drybank vegetation on the right bank appears to be in good condition except for local disturbance at a pump site. It looks as if a levee has been constructed against the Drybank vegetation on the right bank, but this was inaccessible so the extent of damage, if any, could not be assessed. Some farming activity does appear to be happening directly opposite the boat club launch site.
- Beds of the pioneer, *Phragmites australis,* dominate the indigenous natural vegetation on the left bank, intruding into the Drybank Lateral Zone, which is probably indicative of extensive artificial disturbance, including regular fires. *Cynodon dactylon* forms a lawn in the cleared areas around picnic sites.
- The indigenous natural vegetation on the right bank is composed of small patches of *Phragmites australis* (1) together with *Acacia erioloba* (+), *Acacia karroo* (2), *Rhus lancea* (2), *Salix mucronata* (1), *Tamarix usneoides* (2) and Ziziphus *mucronata* (+).
- The apparent absence of *Prosopis glandulosa* is noteworthy.

4.3.6 Stop 6. Renosterkopeiland 500 m Downstream of Ski-boat Club

- The river was rated as E-category on the left bank and D-category on the right bank.
- At the site of a low weir built across the river to assist with abstraction. A levee has been built on the left bank to protect the vineyards from low floods. The levee has destroyed most of the Drybank vegetation. Some dumping of rubble has taken place on the levee. The right bank has a substantial rocky step confining the lateral spread of high flows with vineyards behind.
- In-stream *Phragmites australis* beds are substantially more widespread below the weir than in the pool area above the weir. This might be because lower flows, because of abstraction, has allowed encroachment into the river, under low flow conditions (July-August), as much as the upstream dams having reduced the scouring effect of low to medium floods through flow attenuation.
- Exotic plants include *Arundo donax, Melia azedarach, Ricinus communis, Salix babylonica* and *Solanum glaucum* on the disturbed left Drybank. These plants were not seen upstream at the ski-boat club and probably indicate greater disturbance levels along the bank.

4.3.7 Stop 7. Neusberg

- The river was rated as D-category.
- Extensive dense *Phragmites australis* beds extend through the anatomising channel below the weir. It was suggested that the dry season encroachment by *Phragmites* encourages sediment deposition, which plant roots then bind, and that the channel is gradually reducing under the present annual flow regime. This holds implications for larger floods, when they come, as channel capacity is reduced initially and destructive washouts will then occur, either laterally into the banks, or large debris masses will be dislodged that can cause blockages downstream.

4.3.8 Stop 8. Muggie Falls (between Kakamas and Keimoes)

- The river was rated as D-category.
- Three major channels occur with well-vegetated islands between.
- At least three debris flood-lines are present. It was suggested that the intermediate debris line was caused by the 1996 1 500 cumec flood. The debris was mainly fire blackened *Phragmites* litter with brown material above and below it. *Tamarix usneoides* plants were distributed up to the top of the 1996 line, suggesting a zonal association with this flood-level (Tree-shrub Lateral Zone).
- The left bank Drybank Zone vegetation is disturbed through agricultural activities, such as heavy goat grazing. *Phragmites australis* beds are extensive and have encroached into the Drybank Zone, which is also indicative of disturbance.

4.3.9 Stop 10. Long Island, Hock Weir, Kanoneiland

- The river was rated as D-category on the left bank and B-category on the island. The right bank was not formally inspected, but appeared to be in a C-class.
- The gauging weir wall (built approximately 70 years ago) varies from approximately 1.6 – 2.0 m above the downstream riverbed.
- The left bank is disturbed by agriculture penetrating into the Drybank Zone. Remnant Drybank vegetation is still present. The right bank has moderate Drybank vegetation left, but it was not inspected to determine its condition.

- Long Island is densely wooded with a subsidiary channel along the eastern side. Apparently, the island is not utilized for agriculture.
- The natural vegetation forming the wooded Drybank Riparian Forest on the island, with an estimated canopy cover of 100% (no large animals are present to disturb the under-canopy either), consists of *Acacia erioloba* (+), *Acacia karroo* (1), *Lycium* sp. (+), *Phragmites australis* (1), *Rhus pendulina* (2), Salix *mucronata* (1), *Tamarix usneoides* (R) and *Ziziphus mucronata* (1). This Drybank vegetation looks generally healthy, both above and below the weir.
- Only a few *Salix mucronata* plants occur bordering the pool area above the weir, similarly, *Phragmites australis* only occurs in sporadic very small clumps here. This is attributed to inundation of the Wetbank by artificial constant higher water levels killing most of these that normally occupy the Wetbank. Resetting of the Wetbank is slow because of the relative absence of physical disturbance, such as through agriculture. Below the weir, fairly large *Salix* plants are common, while *Phragmites* is abundant and appears to be invading the riverbed.
- A small fire has burnt a part of the island a few metres upstream of the weir. This offers insight into processes as here, and here only, *Phragmites australis* is penetrating into the burnt Drybank Riparian Forest here. It is clearly acting as a fire pioneer. As the indigenous trees recover (sprouting), they should again form a dense canopy, which will inhibit the *Phragmites*. This supports the argument that *Phragmites* has increased elsewhere along the river, because the farmers have burnt it at a far shorter cycle than would naturally occur. They burn it to stimulate young growth for grazing and as protection, because stock losses apparently occur in the older dense stands where they become trapped in debris accumulations (Bezuidenhout and Jardine, 2001).

5. LOWER ORANGE RIVER (UPINGTON TO ONSEEPKANS): FISH CHARACTERIZATION (C. BENADE)

This section is a review of the status of the fish communities in the LOR, based on existing data and available scientific and management literature. The information presented here, forms the basis for the assessments in **Sections 6**, **7** and **9**.

5.1 Introduction

The notes presented in this Section, represent the results of a study of the relevant literature and observations made during the examination of the available fish habitat in the field (29 and 30 April 2003).

5.2 Literature Assessment of the Fish Community

Although situated in the driest part of the country, the freshwater fish species diversity of the LOR (Augrabies Falls to Orange River Mouth), listed in **Table** 5-1, is the highest of any of the Orange River System, with 13 of the Orange River Systems' total of 15 indigenous freshwater fish species, naturally distributed in this river stretch. Of the fish species listed in Table 5-1:

- *Oreochromis mossambicus*, is an introduced indigenous species; and
- *Cyprinus carpio* is an alien species.

Table 5-1: Checklist of the Freshwater Fish Species found between Augrabies Falls and the Orange River Mouth (Skelton 1993; Benade 1993). (L = Large; M = Medium; S = Small; E - Endemic; I = Indigenous; V = Vulnerable; R = Red Data; In = Introduced; A = Alien)

FAMILY	SPECIES			STATUS					
	Scientific Name	**Common Name**		**E**	**I**	**V**	**R**	**In**	**A**
ANGUILLIDAE	*Anguilla mossambica*	Longfin Eel	L		X				
CYPRINIDAE	*Mesobola brevianalis*	River Sardine	S		X				
	Barbus trimaculatus	Threespot Barb	S		X	X			
	B. hospes	Namaqua Barb	S	X			X		
	B. paludinosus	Straightfin Barb	S		X	X			
	B. kimberleyensis	Largemouth Yellowfish	L	X			X		
	B. aeneus	Smallmouth Yellowfish	L	X					
	L. capensis	Orange River Mudfish	L	X					
	Cyprinus carpio	Carp	L						X
AUSTROGLANIDIDAE	*Austroglanis sclateri*	Rock Catfish	M	X			X		
CLARIIDAE	*Clarias gariepinus*	Sharptooth Catfish	L		X				
CICHLIDAE	*Pseudocrenilabrus philander*	Southern Mouthbrooder	S		X				
	Tilapia sparrmanii	Banded Tilapia	S		X				
	Oreochromis mossambicus	Mozambique Tilapia	M					X	

- *Mesobola brevianalis* (River Sardine) is restricted to the LOR (Jubb, 1967), where it is the most common and abundant fish species (Skelton and Cambray 1981; Cambray 1984; Benade 1993), found in the open water habitats of the mainstream, quiet backwaters, as well as flowing channels and rapids (Skelton and Cambray 1981; Benade 1993).
- *Barbus paludinosus* (Straightfin Barb) prefers quiet to slow flowing, moderately vegetated bays, shores, backwaters, pools and impounded areas, although its numbers are rather low (Skelton and Cambray, 1981).
- The three cichlids, *Pseudocrenilabrus philander* (Southern Mouthbrooder), *Tilapia sparrmanii* (Banded Tilapia) and *Oreochromis mossambicus* (Mozam-bique Tilapia) prefer quiet, well-vegetated water for breeding purposes. *Pseudocrenilabrus philander* and *Tilapia sparrmanii* are the most abundant species in the well-vegetated, (extremely) slow flowing Vaal River section within the Northern Cape Province.
- *Clarias gariepinus* (Sharptooth Catfish), an omnivorous scavenger (Jubb 1967), which does not occur in large quantities under riverine conditions (Skelton and Cambray, 1981; Cambray 1984; Benade 1993) is equipped with suprabranchial organs (pseudo lungs) with which it can

survive in water of low oxygen content, and spawns in grassy places inundated by floodwaters of high oxygen content (Jubb, 1967).

- *Barbus trimaculatus*' (Threespot Barb) habitat preference is rapid areas and its breeding is triggered by flow (Benade, 1993).
- *Barbus hospes* (Namaqua Barb) is endemic to the Orange River stretch between Augrabies Falls and the Orange River Mouth (Jubb, 1967), being most abundant downstream from Goodhouse (Cambray 1984; Benade 1993) and is Red Data listed (Skelton, 1987), favouring open flowing water, a sandy substrate and little vegetation (Cambray, 1984) in and around rapids (Benade, 1993), and appears to be a stream spawner (Benade, 1993).
- *Barbus kimberleyensis* (Largemouth Yellowfish) is a Red Data listed endemic (Jubb, 1967) Orange River System predator (Jubb and Farquharson 1965; Mulder 1973), preferring clear, fast-flowing water with a sandy to gravel substrate (Mulder, 1973). It takes approximately seven years to mature sexually (Benade, 1993) and breeds in and below rapids (Skelton and Cambray, 1981) during the first post-winter floods (Tomasson and Allanson, 1983).
- *Barbus aeneus* (Smallmouth Yellowfish) is the most abundant large fish species in the LOR (Benade, 1993), and is an endemic (Jubb, 1967) opportunistic omnivore (Tomasson, 1983) preferring clear, fast-flowing water and a sandy to gravel substrate (Mulder, 1973; Skelton and Cambray 1981), for spawning (Jubb, 1967) during the first post-winter floods (Tomasson and Allanson, 1983).
- *Labeo capensis* (Orange River Mudfish), the dominant large Orange River System fish species (Mulder 1973b; Skelton and Cambray 1981) (although its numbers are declining towards the LOR [Benade, 1993]). It is an endemic (Jubb, 1967) detritivore (Groenewald,1957; Jubb 1967), which appears to be utilizing all aquatic habitat types (Mulder 1973b; Cambray 1984), breeding in floodplains, main streams and rapids (Cambray, 1985).
- *Austroglanis sclateri* (Rock Catfish) is an endemic Red Data listed (Skelton, 1987) omnivore (Jubb, 1967), which is not common, even in its preferred habitat (Skelton and Cambray, 1981), and appears to be highly specialised regarding its habitat requirements consisting basically of a

rock/sand/gravel substrate, and ranging from bedrock with/without scattered rocks and sandy to gravel substrates, to rocky pools, rapids (Skelton and Cambray 1981; Cambray 1984; Benade 1993) and riffles, with the surrounding aquatic environment adhering to specific water quality standards (Benade, 1993). The river stretch below Muggie Falls appears to be ideal *A. sclateri* habitat.

5.3 Observations Made at Selected Sites during Fieldwork 29 and 30 April 2003

5.3.1 General

The low flow and greenish colour of the river water (as a result of algal growth), as well as the changes observed in *Phragmites* reed settlement and encroachment on both the river banks and the bedrock outcrops (with the resultant narrowing and deepening the river channel in places), and the effect of impoundments such as the Neusberg Weir on the immediate downstream river channel, are major concerns with respect to the health of fish communities.

The observed conditions are symptoms of river deterioration as a result of improperly managed river regulation and catchment utilisation. Major dams constructed in the upper catchments, where most of the runoff is generated of rivers, such as the Orange River, have a damping effect on floods in the lower reaches. Such impoundments absorb the minor to medium floods required for the ecological/environmental maintenance of the river system (Benade, 1993). In the case of the Orange, further developments, if not managed properly, will aggravate the situation.

No fish data were collected during the field trip, and the results presented here are based on observations made of the river's general condition during the field trip and the author's knowledge of and experience in the environmental issues of the Orange River as they manifest in the river's freshwater fish populations.

Table 5-2 provides an indication of the expected condition in the reaches visited.

Table 5-2: Qualitative Integrity Ratings in respect of Freshwater Fish Species of the Sites Visted. (D=Downstream; U=Upstream) - See Appendix 4 for Explanation of Method Used

Resource unit	ONSEEPKANS				RAAP-EN-SKRAAP	ABOVE AUGRABIES FALLS	
	D	U	U	D			
Native species richness.	3	3	3	3	3	3	3
Presence of native intolerant species.	2	2	2	2	2	2	4
Abundance of native species.	3	3	3	3	3	3	3
Frequency of occurrence of native.	3	3	3	3	3	4	3
Health/condition of native and introduced species.	2	2	2	2	2	2	2
Presence of introduced fish species.	2	2	2	2	2	3	3
In-stream habitat modification.	3	3	3	3	3	3	3
TOTAL SCORE	**18**	**18**	**18**	**18**	**18**	**20**	21
%	**51.4**	**51.4**	**51.4**	**51.4**	**51.4**	**57.1**	60.0
FISH ASSEMBLAGE CATEGORY	**D**	**D**	**D**	**D**	**D**	**D**	**C**

5.3.2 Stop 1. Approximately 5 km Downstream of Onseepkans Bridge

Excessive growth (encroachment) of *Phragmites* reeds along both the South African (left) and Namibian (right) riverbanks, limiting access to the river, as well as on in-stream islands. Most of these islands presumably developed as a result of reeds getting stuck to rocky outcrops during lowflows.

5.3.3 Stop 2. Onseepkans Bridge

Excessive growth of *Phragmites* reeds along both the South African (left) and Namibian (right) riverbanks, as well as on in-stream islands. On the upstream side of the bridge, the reed encroachment has already brought about a narrowing, as well as deepening of the river's main and side channels, resulting in the characteristic rapid and/or riffle areas of this river section disappearing under the water.

5.3.4 Stop 3. Raap-en-Skraap Farm

Signs of serious *Phragmites* encroachment were clearly visible on both riverbanks and *Phragmites* islands have also started developing within this wide main river channel on bedrock outcrops.

5.3.5 Stop 4. Ararat, Augrabies National Park

It appeared as though the rapid and riffle rich, and historically "*Phragmites*-clear" ravine below the Augrabies Falls was showing signs of reed settlement in places.

5.3.6 Stop 5 and 6. Renosterkopeiland

Being at the bottom end of a long stretch of intensive riparian and floodplain irrigation, most of the smaller riverside channels had already been totally infested with *Phragmites* reeds, while the banks of the main river channel, as well as bedrock outcrops show serious signs of reed settlement and encroachment.

5.3.7 Stop 7. Neusberg

The present, Neusberg diversion and gauging weir, constructed in 1994 (Benade *et al*. 1995), is the first weir in South Africa to incorporate a properly motivated for, designed, model tested (Benade 1990; van der Merwe *et al*. 1991) and monitored fishway (Benade *et al*. 1995). The weir forms a 900-m barrier across the Orange River (Benade 1990; Benade *et* al. 1995) on a wide stretch of river bedrock, which was a natural fish migration route around the downstream Vaalkop Island. As the weir had been constructed with its lowest notch towards the river's left bank, the right bank channel around Vaalkop Island had been completely cut-off and presently mainly flows only during higher flows when the second notch, situated towards the right bank, overtops (Benade 1990; Benade *et* al. 1995). Apart from serious *Phragmites* reed settlement and encroachment close to the weir and around Vaalkop Island, as well as into the right river channel since the weir's construction, Vaalkop Island had also been developed into a large intensive floodplain irrigation unit, aggravating the river reed problem in the area.

5.3.8 Stop 8. Muggie Falls (between Kakamas and Keimoes)

The river stretch below Muggie Falls is fairly pristine in terms of reed settlement and encroachment, and appears to consist mainly of river bedrock with scattered rocks. It presents good fish habitat.

5.3.9 Stop 10. Long Island, Hock Weir, Kanoneiland

Long Island was visited on suggestion of the author mainly for the sake of the team's botanist, Dr Charlie Boucher, as this island is considered to be one of an extremely few, if not the only "pristine" island in the Upington Island area.

5.4 Additional Notes

As part of their River Ecoregion Level II Project, the DWAF's Institute for Water Quality Studies generated a series of maps indicating these ecoregions (**Appendix 5**). Ecoregion 20 (Orange River Gorge) is the smallest of all the identified South African ecoregions and comprises the Orange River section between Augrabies Falls and Vioolsdrift, and possibly as far as Sendelingsdrift (B. Benade, pers. comm.). It is important to take cognisance of the fact that the LORMS study area overlaps with this ecoregion. Furthermore, the ecoregion has unique features (**Table 5-3**) and should, as a precautionary measure, be treated as sensitive. Four reaches of the Orange River between the 20º latitude line and the Orange-Fish confluence (**Appendix 5**) have been identified in a Desktop study as being considered to be of ecological importance (**Table 5-3**). It is suggested that these four river reaches are further investigated for their ecological importance by an in-depth aerial photograph study and/or an aerial survey.

Table 5-3: River Reaches in the Orange River Stretch 20º Latitude to the Orange-Fish Confluence considered to be of Ecological Importance

	River Reach		Reason
	From	To	
1.	29º39'00"S; 19º29'40"E	28º50'15"S; 19º15'00"E	Inland delta
2.	28º57'20"S; 19º04'20"E	28º53'30"S; 18º30'30"E	Inland delta
3.	28º42'20"S; 17º28'30"E	28º27'30"S; 17º20'20"E	Unique riverbed
4.	28º19'30"S; 17º22'30"E	28º06'00"S; 17º10'40"E	Unique riverbed

6. REFERENCE CONDITIONS FOR THE LOWER ORANGE RIVER

This Section provides an indication of the biophysical characteristics (*viz.* water quality, geomorphology, riparian and instream vegetation, macroinvertebrates and fish) of the Orange River that would be expected in the absence of anthropogenic influences. This constitutes a hypothetical natural or reference condition. Similarly, the hypothetical biophysical characteristics of the Orange River that would be expected if the river were in a Category B, C, D or E ecological condition, are also described.

The information presented in this Section was used to assess the PES, and a benchmark for the other assessments of changes to ecological condition presented in the report.

6.1 Introduction

The reference condition of a particular component of a river describes the natural condition for that component prior to anthropogenic change. Historical information and data, and/or data from similar minimally impacted sites elsewhere are used to describe the reference conditions for the water quality, geomorphology, riparian and instream vegetation, macroinvertebrates and fish. Often, the reference condition does not represent the pristine condition of a river, but a best estimate of a minimally impaired baseline state (the lack of data on pristine rivers being one reason for this).

If the river is deemed to be unchanged relative to its reference condition, then its *present ecological state* can be described as Categroy A, which denotes that it is a natural or minimally impacted state, and thus the PES (**Section 7**) is the same as the reference condition. The range of PES Category below A, *viz.* B-F, represents the extent of degradation from reference condition.

6.2 Water Quality

6.2.1 Reference Conditions

No un-impacted reference sites exist for the Target Section. Notwithstanding this, there are clear indications that the Reference Condition for the mid- to LOR would have been characterized by:

- low total dissolved solids (TDS);
- pH range of 6.5 to 7.5;
- low concentrations of dissolved nutrients (nitrogen and phosphorus); and
- high turbidity (inorganic).

This would have been in marked contrast to the condition of the Upper Orange, which would have been characterized by clear water originating off basalt, and with very low levels of TDS.

The A-Category characterization, as generated by the (revised) Methods for Assessing Water Quality in Ecological Reserve Determinations for Rivers (V2.15, DWAF 2003), provides a reasonable estimation of the Reference Condition for the target section (**Table 6-1**).

Table 6-1: Criteria - Category A

Water Quality Constituent	Units	Value
$MgSO_4$	mg $ℓ^{-1}$	16
Na_2SO_4	mg $ℓ^{-1}$	20
$MgCl_2$	mg $ℓ^{-1}$	15
$CaCl_2$	mg $ℓ^{-1}$	21
NaCl	mg $ℓ^{-1}$	45
$CaSO_4$	mg $ℓ^{-1}$	350
pH		6.5-8.0
Orthophosphate-P as P	mg $ℓ^{-1}$	0.005
Total inorganic nitrogen as N	mg $ℓ^{-1}$	0.25
Ammonia nitrogen as N	mg $ℓ^{-1}$	0.007
Dissolved oxygen	mg $ℓ^{-1}$	8.0

6.2.2 Characteristics for Categories B to E

Categories B-D may be usefully characterized for water quality, using the same expedient as above, namely the conditions generated by the draft methodology (**Table 6-2**). Category E would amount to any exceedance of the criteria specified for Category D.

Table 6-2: Characterisation on Categories B to D

Water Quality Constituent	Units	Category		
		B	C	D
$MgSO_4$	mg ℓ^{-1}	25	28	37
Na_2SO_4	mg ℓ^{-1}	33	38	51
$MgCl_2$	mg ℓ^{-1}	30	36	51
$CaCl_2$	mg ℓ^{-1}	57	69	105
NaCl	mg ℓ^{-1}	191	243	389
$CaSO_4$	mg ℓ^{-1}	709	837	1195
Ph		5.9-8.8	5.6-9.2	5.0-10.0
Orthophosphate-P as P	mg ℓ^{-1}	0.056	0.074	0.125
Total inorganic nitrogen as N	mg ℓ^{-1}	1.83	2.40	4.00
Ammonia nitrogen as N	mg ℓ^{-1}	0.046	0.061	0.100
Dissolved oxygen	mg ℓ^{-1}	6.5	5.5	4.0

6.3 Geomorphology

6.3.1 Reference Conditions

The natural state of the Orange River between Augrabies and Onseepkans represents a system where discharge is well channelised flowing energetically in this steep gradient channel section. Scour features indicate that flow at high discharge conditions may even be highly erosive in places. Channel morphology in this part of the river is closely related to the discharge of the mean annual flood and to bank full discharge. These parameters, together with the relative ratios and volumes of gravely bed load and silt and fine grained-sand suspension load, determine the size and morphology of the river channel that is best suited to accommodate the discharge requirements of the river system.

6.3.2 Characteristics for Categories B to E

Category B: Slight reduction in discharge, very little change from above.

Category C: Substantial reduction in discharge changing sediment composition forming silt blankets.

Category D: Largely modified: Very low discharge changing sediment composition and river morphology.

6.4 Riparian and Instream Vegetation

6.4.1 Reference Conditions

The Reference Condition described for the riparian and instream vegetation is based on the vegetation observed during the two-day expedition mounted for the present study, in particular the vegetation observed at Long Island, Hock's Weir, at the head of Kanoneiland and is supported by descriptions of the vegetation provided by Bezuidenhout and Jardine (2001) and Werger and Coetzee (1977).

The natural vegetation forming the wooded Drybank Riparian Forest would have an estimated canopy cover of 95%. Some large indigenous animals (buffalo, elephant, giraffe and hippo) would be present to disturb both the upper and lower canopies. Fires would occur at sporadic intervals. The conspicuous trees in the Drybank Zone would include scattered emergent, 6–10 m tall, *Acacia erioloba*, while *Acacia karroo*, *Combretum erythrophyllum*, *Rhus pendulina*, *Tamarix usneoides* and *Ziziphus mucronata* would form the basic forest canopy. Bezuidenhout and Jardine (2001) describe the following three variations of riparian forest or woodland, based on differences in habitats and associated variations in the dominant taxa:

- *Tamarix usneoides* Open/Closed Woodland occurring on alluvial deposits and in the larger sandy drainage lines.
- *Acacia karroo* Closed Woodland on dry, clay-rich riverbanks.
- *Rhus pendulina* Forest on moist sandy riverbanks. This is the commonest type. This resembles the *Ziziphus mucronata* Closed Woodland described by Bezuidenhout (1996).

No clear distinction between these units and any particular riparian habitats was apparent during the current brief expedition. All constituent species were observed together with varying degrees of dominance.

The content of the shrub and herbaceous lower strata in the Wetbank and Drybank Zones are not distinguished and have not been described in any detail in the literature. They were not investigated during the current expedition although the following low trees or shrubs should be conspicuous, particularly in the Back Dynamic Zone: *Acacia mellifera, Diospyros lycioides, Maytenus linearis, Sisyndite spartea* and *Zygophyllum simplex* (Bezuidenhout and Jardine, 2001). Various forbs, grasses and herbs would also be present to form the herbaceous stratum.

Beds of *Phragmites australis* and a line of emergent, 3–5 m tall, *Salix mucronata* would dominate the Wetbank Zone vegetation. Some herbs, sedges and grasses are expected to be present in open sandy patches.

The Aquatic Zone in larger pools, with natural downstream controls, either in shallow submerged stable (gravel beds) flats in the pools or around their shelving stable margins, would support local areas in which patches of *Ludwigia stolonifera*, *Potamogeton crispus*, *P. pectinatus* or *P. schwienfurthii* are present (Benade, 2003).

6.4.2 Characteristics for Categories B to E

Different factors and differing magnitudes would cause different degrees of change. Local habitats might differ in degree of response to unnatural conditions. Some factors on their own could cause a change in category even though all possible causes for a reduction in category are listed for each category.

Factors Causing Degradation:

Flow-related

a. Lower general water or flow levels through upstream dams or abstraction.
b. Higher water levels through low weirs but not complete inundation.
c. Insufficient fluctuation in water levels.
d. Reduced within year flood peaks as absorbed by upstream dams.
e. Reduced number and size of 2-20 year flood events as attenuated by upstream dams.

Non flow-related[6]

f. Physical disturbance of the vegetation such as clearing by individuals or by agriculture.
g. Increase in sand and silt deposits.
h. Increase in turbidity or in silt loads due to upstream agriculture.
i. Change to salinity levels of water because of lower than natural lowflows or because of fertilizer applications.
j. Nutrient enrichment benefiting some species and a reduction of densities of others.
k. Shortening intervals between fires benefits some pioneer species while can inhibit climax species.
l. Alien plants present.
m. An increase in *Phragmites australis* or of an exotic alien species can result in increased fire temperatures because of increased biomass or greater combustibility.
n. An increase in *Phragmites australis* causes an increase in silt deposition.

Category B

- The aquatics in the Aquatic Zone could be slightly reduced until reset (only if suitable substrate is present) (factors = a, b, d, g, i[7]). An increase in the density of beds could occur (factor = c).
- The Wetbank Zone could be slightly reduced in width with less *Phragmites australis* and *Salix mucronata* (factor = b). Resetting would

[6] These are often a secondary consequence of flow change.

[7] Refers to flow and non-flow related factors listed under Factors causing degradation (Section 6.4)

depend on time interval, which is influenced by physical disturbance levels and fluctuations in water levels. There could be a slight increase in the proportion of *Tamarix usneoides* (factor = c).

- Some *Phragmites australis* and young *Salix mucronata* individuals are penetrating into the Drybank Zone vegetation (factor = b). The Drybank Zone vegetation has an occasional, scattered, mature individual alien plant in natural or artificially disturbed areas (factor = k). Destruction of the Back Dynamic Zone vegetation only has taken place, or there are small clearings in the Tree-Shrub Zone (factor = f).

Category C

- There is no Aquatic vegetation present in suitable habitats. Algal blooms are commonplace under low flow conditions.
- The Wetbank Zone vegetation is very reduced. No *Salix mucronata* plants are present.
- The Drybank Zone vegetation has numerous aliens present but they do not form extensive dense stands and disturbance is fairly commonplace but the dominant species, although reduced are still commonplace.

Category D

- There is no Aquatic vegetation present in suitable habitats. Algal blooms are commonplace under low flow conditions.
- The Wetbank Zone vegetation is absent or some members (e.g., *Phragmites australis*) are penetrating extensively into the Aquatic or Drybank Zones.
- The Drybank Zone vegetation has numerous aliens present that form extensive dense stands and disturbance is commonplace but the dominant species, although reduced are still present in patches.

Category E (F)

- There is no Aquatic vegetation present in suitable habitats. Algal blooms are commonplace under low flow conditions.
- The Wetbank Zone vegetation is absent or some members (e.g., *Phragmites australis*) are dominant in either or both the Aquatic and or Drybank Zones, with a corresponding reduction in vegetation elements

typical of these zones.

- The Drybank Zone vegetation is virtually completely dominated by extensive dense stands of exotic plants and disturbance is commonplace. Very few indigenous plants are still present. Bare eroded areas are commonplace. The vegetation could also be physically destroyed entirely in places.

6.5 Macroinvertebrates

6.5.1 Reference Conditions

The invertebrate fauna of the middle and LOR under natural conditions is likely to have been characterised by a low diversity of species capable of tolerating periodic cessation of flow, and extreme floods that carried high levels of suspended material. Prior to the building of dams in the 1970s, the middle and lower section of the river sometimes ceased flowing in winter, and was reduced to isolated pools. The seasonally variable flow conditions allowed the coexistence of a number of species, without one species dominating for extended periods. Periodic drying is likely to have precluded the evolution of a typical lowland fauna. The dominance of feeding groups are likely to have varied seasonally, as trophic status changed with changes in flow and river conditions. Pest outbreaks of blackflies are reported prior to impoundment, but the problem never persisted for long. The fauna is characterised by species with life histories adapted to cope with variable flow conditions, such as the following:

Desiccation-resistant eggs. Mud collected from the mainstream near Upington, and kept in a plastic bag in a cupboard, was hydrated and aerated after 65 days, produced numerous Caenidae mayflies, Bdelloid rotifers and *Polypedilum* sp. Chironomidae.

Desiccation-resistance. The sponge, *Ephydatia fluviatilis* and the Bryozoa *Plumatella* sp., both common during low flows, are both capable of withstanding complete desiccation. Drought-resistant stages of certain Bryozoa are known to withstand desiccation for up to four years (Pennak 1989: 278).

Survival in damp sands. An examination of the survival capabilities of the bivalve *Corbicula fluminalis* from Upington showed that they can survive in damp sand for up to 19 days. The larger bivalve *Unio caffer*, is also likely to withstand cessation of flow.

Diapuase eggs. The eggs of the blackfly,S*imulium chutteri* are suspected of entering diapase, which allows them to tolerate unpredictable and variable conditions.

Asynchronous hatching. The development rate of *Simulium* eggs is asynchronous, and this ensures that some eggs may be kept in reserve to cope with unpredictable conditions.

Rapid life histrories. Many species in the middle and LOR have rapid development times and large numbers of offspring.

Endemic Blackfly. The unusual blackfly, *Simulium gariepense* is endemic to the Orange River, and is highly specialised for feeding under conditions of extreme high flows with high concentrations of suspended material.

6.5.2 Characteristics for Categories B to E

Table 6-3 describes characteristics of the PES Classes for aquatic invertebrates in the middle and LOR.

Table 6-3: Description of Various PES Categories for Aquatic Invertebrates in the Orange River

Category	State	Description
A	Natural	(described in Reference conditions above)
B	Largely natural:	A small change in community structure may have taken place but ecosystem functions are essentially unchanged. No persistent dominance of any one taxon or feeding group.
C	Moderately modified:	Community composition lower than expected due to loss of some sensitive forms. Basic ecosystem functions are still predominantly unchanged. Periodic dominance of individual taxa or feeding groups.
D	Largely modified:	Basic ecosystem functions have changed, with persistent dominance of individual taxa and feeding groups. Fewer taxa present than expected, due to loss of most intolerant forms.
E	Seriously modified:	An extensive loss of basic ecosystem functions has occurred. Few aquatic families present, due to loss of most intolerant forms.

6.6 Fish

6.6.1 Reference Conditions

See discussions in **Section 5.2**.

7. PRESENT ECOLOGICAL CONDITIONS FOR THE LOWER ORANGE RIVER, AND TRAJECTORY OF CHANGE

This Section provides each specialist's discipline-specific assessment of the LOR along with their assessment of the reasons for the PES and an indication of the trajectory of change in condition for their discipline. These individual assessments formed the basis of the discussions at the workshop.

7.1 Introduction

PES of a river is described as being changed relative to the reference condition. The range of PES Category below A, *viz*. B-F, represents the extent of change from reference condition.

The Trajectory of Change describes the direction of change in river condition, *viz.* positive (improving), negative (degrading) or stable. The rate of change is provided as the PES predicted for the short term (< 5 years) and the long-term (> 20 years) assuming no additional impacts on the riverine ecosystem.

In this Section, the PES is expressed separately for each component of the river ecosystem, namely, water quality, geomorphology, riparian and instream vegetation, aquatic macroinvertebrates and fish. If PES is not an A Category, the reasons for this are provided.

Integration of these different PES ratings was undertaken during discussion at the Cape Town Workshop.

7.2 Water Quality

7.2.1 Present Ecological Status (PES)

The PES for the target section is assessed as being Category B/C, as per the **Table 6-2**, and based on the water quality as determined at Upington, Onseepkans and Vioolsdrift.

The ecological specifications are presented in **Table 6-1** and **Table 6-2** (**Section 6**). While the levels of inorganic salts deteriorate slightly with progression downstream, the overall condition remains good. The concentrations of magnesium sulphate constituted the only instance of unacceptable water quality amongst the assessed inorganic salts. With respect to nutrients, the condition, in terms of dissolved phosphorus, improved downstream from a D to C category. While the condition in terms of algal response is extremely poor, this is deemed to be largely a consequence of the transport of biovolume into the target section from upstream, and not as a consequence of algal development within it.

This assessment is made with High confidence, and is summarized for Upington, Onseepkans and Vioolsdrift in **Tables 7.1** to **7.3**, respectively.

Table 7-1: Characterization of the Water Quality in the Orange River at Upington (-) Denotes not Assessed or No Data Available

Variable group	Variable	Value	Category
Inorganic salts concentration (95th percentile) (Values for the individual salt concentrations are derived from the a spreadsheet set up by the DWA, (DWAF 2001)	Na_2SO_4 (mg ℓ$^{-1}$)	2	A
	$MgCl_2$ (mg ℓ$^{-1}$)	26	B
	$CaCl_2$ (mg ℓ$^{-1}$)	43	B
	KCl (mg ℓ$^{-1}$)	Not assessed	-
	$MgSO_4$ (mg ℓ$^{-1}$)	64	E
	$CaSO_4$ (mg ℓ$^{-1}$)	0	A
	NaCl (mg ℓ$^{-1}$)	0	A
Nutrients (50th percentile)	PO_4-P (mg ℓ$^{-1}$) (as P)	0.078	D
	Inorganic N (total) (mg ℓ$^{-1}$)	-	
Physical variables	Temperature (°C)	-	
	Dissolved oxygen (mg ℓ$^{-1}$)	-	
	Turbidity (NTU)	-	
	pH (range)	7.1-8.5	A/B
Response variables	Biotic community composition	-	
	Algal abundance (Chl-a, µg ℓ$^{-1}$)	22	D
Toxicity		-	

7.2.2 Why is it in the PES Category?

The target section (Upington to Vioolsdrift) of the Orange River lies in the lower mid-section of the Orange River. Rainfall in this area is low (<= 300 mm a^{-1}), and flow additions to the river are minimal (effluent river system). However, this section is situated downstream of several major impoundments (Gariep, Cook's Lake, Disaneng, Lotlamoreng and Modimola) all of which have Trophic Status classifications of eutrophic to hypertrophic (DWAF 2002), and which act as growth nurseries for algal development, chiefly cyanobacterial (blue-green algae). The populations of algae produced in these dams are transferred into a highly-regulated, slow-flowing (large proportion of the year), warm and turbid environment, punctuated by numerous weirs of varying capacities, i.e., the algae occurring with the target section are transported into it rather than developing within it. Each of these weirs provides a pool environment that increases the overall hydraulic retention time (HRT) of the river and, despite the relatively poor optical properties, supports the further development of phytoplankton. It should be noted that the effect of sediment attenuation by the large upstream dams has resulted in an overall improvement in light penetration into the water column.

Table 7-2: Characterization of the Water Quality in the Orange River at Onseepkans. (-) Denotes Not Assessed or No Data Available

Variable group	Variable	Value	Category
Inorganic salts concentration (95th percentile) (Values for the individual salt concentrations are derived from the a spreadsheet set up by the Department of Water affairs, (DWAF 2001)	Na_2SO_4 (mg ℓ^{-1})	6	A
	$MgCl_2$ (mg ℓ^{-1})	30	B
	$CaCl_2$ (mg ℓ^{-1})	49	B
	KCl (mg ℓ^{-1})	Not assessed	-
	$MgSO_4$ (mg ℓ^{-1})	79	E
	$CaSO_4$ (mg ℓ^{-1})	0	A
	NaCl (mg ℓ^{-1})	0	A
Nutrients (50th percentile)	PO_4-P (mg ℓ^{-1}) (as P)	0.064	C
	Inorganic N (total) (mg ℓ^{-1})	-	
Physical variables	Temperature (°C)	-	
	Dissolved oxygen (mg ℓ^{-1})	-	
	Turbidity (NTU)	-	
	pH (range)	7.0-8.5	A/B
Response variables	Biotic community composition	-	
	Algal abundance (Chl-a, µg ℓ^{-1})	-	-

Table 7-3: Characterization of the Water Quality in the Orange River at Vioolsdrift. (-) Denotes Not Assessed or No Data Available

Variable group	Variable	Value	Category
Inorganic salts concentration (95th percentile) (Values for the individual salt concentrations are derived from the a spreadsheet set up by the Department of Water affairs, (DWAF 2001)	Na_2SO_4 (mg ℓ$^{-1}$)	6	A
	$MgCl_2$ (mg ℓ$^{-1}$)	29	B
	$CaCl_2$ (mg ℓ$^{-1}$)	57	C
	KCl (mg ℓ$^{-1}$)	Not assessed	-
	$MgSO_4$ (mg ℓ$^{-1}$)	78	E
	$CaSO_4$ (mg ℓ$^{-1}$)	0	A
	NaCl (mg ℓ$^{-1}$)	0	A
Nutrients (50th percentile)	PO_4-P (mg ℓ$^{-1}$) (as P)	0.063	C
	Inorganic N (total) (mg ℓ$^{-1}$)	-	
Physical variables	Temperature (°C)	-	
	Dissolved oxygen (mg ℓ$^{-1}$)	-	
	Turbidity (NTU)	-	
	pH (range)	7.1-8.3	A/B
Response variables	Biotic community composition	-	
	Algal abundance (Chl-a, µg ℓ$^{-1}$)	-	

The available water quality data, supported by measurements of algal pigments, indicate that conditions within the target section tend towards being limiting for algal development and that algal senescence and breakdown rates exceed growth for a considerable portion of the time. This condition is unlikely to improve using flow manipulations. Accordingly, management activities for this section of the Orange River should target the upstream environment. Reduced flows combined with increased nutrient (phosphorus) availability will exacerbate the present conditions.

Table 7-4: Present Ecological Status Summary

Effect	Causes	Sources	Flow-related?	Management actions	Confidence
Slightly elevated TDS ($MgSO_4$ only)	Erosion and irrigation return flows	Landuse activities	No	Improved land-use management. The precise biotic impact of this salt within this environment is unclear.	Medium
Slightly elevated levels of phosphorus	Landuse and waste management practices	Catchment runoff (upper Orange)	No	Nutrient attenuation at the level of the watershed	High
Elevated levels of phytoplankton	Transport and nutrient enrichment	Upstream impoundments incl. ? weirs	Partially	Land-use and impoundment management	High

7.2.3 Trajectory of Change and Reasons

The analysis in **Table 7-5** assumes no specific impact mitigation over and above that currently related to present land-use.

Table 7-5: Trajectory of Change and Reasons: Water Quality

Component	Trajectory	PES	5 years	20 years	Confidence (0-5)
Inorganic salts	Negative (gradual)	Good B/C Category	Fair C- Category	Fair/Poor C/D - Category	4
Nutrients (phosphorus)	Negative	Good B/C Category	Fair C- Category	Fair/Poor C/D - Category	4
Algae	Unknown – likely to be negative	Poor D - Category	Unacceptable E - Category	Unacceptable E/F - Category	4

7.3 Geomorphology

7.3.1 Present Ecological Status

The PES of the lower reaches of the Orange River exhibits a Category C.

Under present-day conditions, the middle reaches of the Orange River exhibits a typical braided stream pattern. The bars and even thalweg can shift within unstable channel sections but seem to be fixed in bedrock-controlled sections. Sediment load volumes are large in this part of the river and silt, sand and gravel up to cobble size, make-up a significant fraction of the sediment load. The channel width is variable but is relatively large compared with the depth exhibiting a high width: depth ratio.

7.3.2 *Why is it in the PES Category?*

River bank vegetation and in particular reeds are well established in pool sections of the river. Vegetation encroachment from the banks of the river and from mid-channel bars into the channels results in a ponding effect of the river causing a local reduction in water surface gradient. This ponding effect may eventually result in increased sedimentation rates that would cause the channel gradient to decrease. This effect may be partially reset by large floods, depending on the frequency of such large floods and thus the opportunity for vegetation to stabilise the sediments. Vegetation induced ponding is not evident in riffle sections of the river probably because the scouring effect of the river is still maintaining the channel morphology as a result of the prevailing high-energy conditions.

7.3.3 *Trajectory of Change and Reasons*

5 years: PES = .Class C
20 years: PES = Class D

Ponding in low gradient sections of the Orange River, middle reach will probably be enhanced during reduced discharge conditions in the river. Under low stage flow conditions, high sedimentation rates of mainly fine-grained sand and silt size sediment will take place in the pools, in particular along the vegetated banks. Immediately upstream from the pools, the river will not be able to transport gravel through the low gradient pool sections. Here, gravel will accumulate in the thalweg causing over-steepening of the channel and thus expanding the pool section into the upstream riffle section.

7.4 Riparian and Instream Vegetation

7.4.1 *Present Ecological Status*

An overall assessment is that the river over the assessed reach belongs to a D-Category at present.

Each site visited during the field visit was evaluated and categorized into its PES Category, even distinguishing between banks where these are different (see **Section 4**).

7.4.2 Why is it in the PES Category?

Flow induced changes:

The effects of lower all season flows on the river banks:

- Floating aquatics increase with a reduction in flows. This negative change would be induced mainly from a reduction in wet and dry season lowflows.
- Physical change to the shape of the Wetbank Zone, because the lower water levels cause the banks to dry out more rapidly, together with temporary exposure of unprotected banks (plants do not root at deeper inundation levels) resulting in bank collapse with a vertical step developing and a lower flattening out in the new inundated area. This was observed at Renosterkopeiland, for instance. This negative change would be induced, mainly from a reduction in both dry season lowflows and dry season intra-annual floods.
- Botanically, lower flow levels generally benefit aquatic plant communities. This was observed, for instance, at Renosterkopeiland weir. This negative change would be induced, mainly from a reduction in all flows (wet and dry season lowflows and wet and dry season intra-annual floods).
- A reduction in flow would benefit the pioneer reed, *Phragmites australis* (Closed Reedland), which tends to increase (both in patch size and in distribution) in rivers below abstraction weirs or dams. It tends to accumulate sediments, and would therefore effectively block the channel during small floods, but results in large disturbances when it is washed out during large floods. The reed mats could then cause blockages downstream exacerbating the effect of floods. This negative change would be induced, mainly from reductions in all flows, namely, wet and dry season lowflows and wet and dry season intra-annual floods.
- Indigenous trees are thought to have declined because of regular short interval fires. Fires are hotter because of an increase in *Phragmites australis* through lower flows and, because of a loss of the cooling effect of

a wet substrate through generally lower water levels, because of increased abstraction and a reduction in natural fluctuation. This negative proximal change would be induced, mainly from a reduction in proximal and distal change to wet and dry season lowflows but also of wet and dry season intra-annual floods.

- Indigenous trees and shrubs would have declined because of floods being reduced through dams so less spreading of disseminules (seeds and parts of plants) would occur. Normal rainfall as well as sporadic wetting by short interval higher flows contributes to the establishment of these plants. This negative change would be induced, mainly from a distal reduction in variability in all flows, but particularly in proximal dry season lowflows and distal wet and dry season inter-annual floods.
- Gallery Forest is best developed where flooding and alluvium deposition occurs most frequently (Werger, 1973). A negative change would be induced, mainly from a distal reduction in wet and dry season inter-annual floods.
- Agricultural encroachment into the riparian vegetation tends to occur if flows are reduced because of the shorter period with waterlogged soil from less and smaller annual floods. Active agricultural expansion into the Drybank, with destruction of riparian woodlands, was observed happening on Kanoneiland during our visit. This change would be induced, mainly from a distal reduction in wet and dry season intra-annual floods.

Flow stabilization effects:

- Rooted aquatic communities have increased because of flow stabilization and river regulation (Ben Benade, 1993 per LORS 2003 background information). Proximal and distal regulation of wet and dry season lowflows and a distal reduction of scouring wet and dry season intra-annual floods cause this change.
- Higher constant flow water levels reduce the extent of *Phragmites australis* and *Salix mucronata* through compression of the Wetbank Zone. This was observed at Hock Weir, Long Island. This negative change would be induced proximally mainly from wet and dry season lowflows.
- *Phragmites australis* apparently dies after being submerged for two weeks. This negative change would be induced proximally mainly from

constant wet and dry season lowflows.

- Less variability in flows would cause a compression of the Wetbank Zone through a resultant general drier regime being enforced. This negative change would be induced, mainly from a distal (dams) and proximal (weirs) reduction in variability of dry season lowflows and dry season intra-annual floods.

Non-flow induced changes

Agricultural disturbance:

- Aquatic and semi-aquatic communities have increased because of catchment utilization effects (Ben Benade, 1993 per LORS 2003 background information).
- *Prosopis glandulosa* increases where areas have been physically disturbed. This was observed 5 km downstream of Onseepkans. This negative change would be induced proximally from disturbance.
- *Phragmites australis* increases in physically disturbed areas. This was observed 5 km downstream of Onseepkans. This negative change would be induced proximally from disturbance.
- *Phragmites australis* Reedlands are fired by farmers to stimulate grazing and for safety reasons (Bezuidenhout and Jardine, 2001). *Phragmites australis* increases where fires are commonly used to reduce the riparian vegetation biomass. For example, it was observed invading the Drybank in a burnt patch at Hock Weir, Long Island. This was considered to be happening 5 km downstream of Onseepkans. This negative change would be induced proximally.
- Indigenous trees, particularly in the Drybank Lateral Zone, were thought to have declined because of regular short interval fires and agricultural disturbance. Fires burn into the riparian vegetation. The fires are possibly of natural and manmade origins. Regrowth is generally vigorous except in the case of *Salix mucronata,* which, as in Lesotho (Boucher and Tlale, 1999), does not respond well to burning (Bezuidenhout and Jardine, 2001). There is too short an interval between fires for recruitment to occur or for damaged plants to recover. Fires are also hotter because of an increase in biomass of the pioneer *Phragmites australis* through regular burning. This was observed 5 km downstream of Onseepkans, at

Renosterkopeiland boat slip, and at the downstream weir. This negative change would be induced proximally.

- Draining agricultural lands where fertilizers have been applied, and where salts have been drawn to the surface through evaporation, leads to higher salinity levels in the river during low flow periods. This would benefit *Phragmites australis* and *Tamarix usneoides* and have a negative effect on *Salix mucronata.* This was considered to be another reason for the dominance by reeds 5 km downstream of Onseepkans. This negative change would be induced distally.
- *Acacia karroo* Closed Woodland and the *Rhus pendulina* Forest and habitat has changed because of expansion of irrigated crop farming, grazing pressure and upstream dam construction. Irrigated crop farming has apparently physical damaged (cleared) the forest and adjacent vegetation units or has resulted in their replacement upstream of the Augrabies NP (Bezuidenhout and Jardine, 2001). This negative change would be induced proximally.
- The presence of levees would influence the effects of high water flows. After larger floods, silt deposition would be present from water trapped behind the levee, but it would in all probability be less than without the levee being present, because less silt-laden water would penetrate the area. The levee would concentrate most of the flows into a narrower channel, which would keep it relatively free from deposited materials. This was considered to be happening 5 km downstream of Onseepkans. This negative change would be induced proximally.

7.4.3 Trajectory of Change and Reasons

The present trajectory of change over the river reach under consideration is negative, that is, it is deteriorating.

5 years: PES = D
20 years: PES = E.

The main reasons for the predicted trajectory are:

Reduction in short interval flow variability through interception by dams and constant releases. Weirs are causing abnormal pools and are intercepting small-scale flow variations.

Reduction in water clarity as algal blooms increase from nutrient enrichment.

Reduction in scouring of sand as floods are reduced (captured in dams).

Reduction in the extent of the river channel through vegetation invasion and increased trapping of sediments.

Reduction in channel flood retention capacity as the riverbank and floodplain vegetation is removed, and levees installed, thereby cutting of access to area that would normally absorb floodwaters.

Increase in agricultural activity invading the riparian zone (illegally?).

Increase in *Phragmites* beds, which are invading into the river channels and into the Drybank vegetation.

Increase in fine sediment loads from soil erosion from agriculture.

Increase in runoff of salt laden (from fertilizers) irrigation water to the river during lowflows, which negatively affects the Aquatic and Wetbank communities.

Increase in erosion where the vegetation along the banks is disturbed.

Increase in the use of fire to “control” *Phragmites* invasion.

Increase in exotic plants as disturbance increases and controls are not implemented. These plants interfere with the functioning of the indigenous vegetation and some utilize more water than indigenous species. They increase biomass and thus temperatures during fires, thereby increasing the damage done by fires.

7.5 Macroinvertebrates

7.5.1 Present Ecological Status

The PES of the aquatic invertebrates in the middle and LOR is clearly Largely Modified (Category D).

7.5.2 Why is it in the PES Category?

The main reason for classifying the PES of the invertebrates as Largely Modified is the overwhelming and persistent abundance of filter-feeders, in particular the pest proportion numbers of the blackfly, *Simulium chutteri*. The large-scale programme to control this pest, using aerial applications of insecticides, highlights the extent of the problem (Palmer, 1997). The outbreaks are attributed to stable flow conditions, in particular high winter flows, deterioration in water quality and encroachment of instream vegetation. These changes are explained as follows:

High winter flows. High winter flows allow over-wintering of larval blackfly populations. Larvae that develop in winter are significantly larger and carry larger fat reserves than larvae that develop in warm temperatures. As water temperatures rise in spring, the winter larvae pupate, and the adults that emerge carry large fat reserves and are suspected to be able to lay their first batch of eggs without the usual need for a blood meal. These eggs hatch and the larvae develop quickly because of warmer water temperatures. By the time they emerge as adults, the first generation of winter adults are still alive, and this leads to an overlapping of generations, which leads to rapid increases in population size (i.e., pest outbreaks). Under natural conditions this occurred from time to time, but not persistently every year.

Water quality. Deterioration in water quality has provided ideal conditions for filter-feeding invertebrates. The deterioration is partly attributed to the construction of dams, which allow the developments of micro-algae not normally associated with river systems. Increased clarity following impoundment has caused a shift in trophic status from a dominance of terrestrial-derived organic matter to a dominance of autochthonous primary production, and this has favoured filter-feeding invertebrates. Deterioration in water quality is also attributed to the decomposition and burning of *Phragmites* reeds, which is likely to contribute significant quantities of fine particulate and dissolved organic material, upon which filter-feeding invertebrates feed. Water quality is also likely to have deteriorated from agricultural return flows carrying elevated nutrients, particularly nitrates.

Phragmites reeds. The encroachment of *Phragmites* reeds is a recent phenomenon related primarily to disturbance of riverbanks. Photographs taken as recently as 1976 show an almost complete absence of reeds. There are sections of river, particularly in the lower reaches, where reeds are absent except where the bank is disturbed. Upstream of the estuary the riparian vegetation is dominated by the Cape willow (*Salix mucronata*), except at a pumping station, where *Phragmites* sp. are abundant. It is clear that *Phragmites* reeds are pioneer plants, quick to colonise disturbed areas. The extent of bank disturbance may be appreciated when one considers that almost the entire length of the river between Grootdrink and Kanoneiland (over 110 km) has been channelised. Reeds trailing in the current significantly increase the surface area available for blackfly larval attachment. It is likely therefore that the blackfly problem in the Orange River has been aggravated by reed encroachment, both because of the increased surface area for larval attachment, and because of the suspected increase in fine organic material. The rampant growth of reeds is also likely to have had a significant impact on particle retention.

Other reasons for classifying the invertebrates as Moderately Modified are as follows:

Unseasonal winter releases from Vanderkloof Dam, as occurred in June 1994, were shown to have detrimental impacts on aquatic invertebrates at least as far downstream as Upington, over 600 km downstream. The release led to a significant increase in the abundance of the pest blackfly, *S.chutteri*, an almost complete disappearance of the midge, *R. fuscus* (previously abundant), and a significant drop in the abundance of the predaceous caddisfly, *C. thomasseti*.

Construction work at Gifkloof Weir on 10-16 March 1992 caused an increase in silt loads and a sudden drop in the abundance of benthic algae. Taxa whose abundance dropped following construction included the mayfly, *T. discolor*, the caddisfly, *A. scottae* and the midge, *C. africanus*. It is likely that similar impacts would occur with construction of the numerous weirs throughout the river.

Periodic blooms of the blue-green algae *Microcystis* sp. that develop in Vanderkloof Dam, particularly in autumn, coincide with a slight decline in the total number of invertebrate taxa, and a significant change in the abundance of certain species. Taxa whose abundance declined during *Microcystis* sp. blooms included the blackfly, *S. chutteri*, the limpet, *Burnupia* sp., the beetle, *Aulonogyrus* spp., the flatworm, Turbellaria and the stonefly, *N. spio*. By contrast, the abundances of the mayfly, *T. discolor, S. damnosum* s.l. and the caddisfly, *C. thomasseti* were unaffected by *Microcystis* sp. blooms. Indeed, highest numbers of the pest blackfly, *S. damnosum* were recorded in June 1995, following a *Microcystis* sp. bloom in the previous month.

Periodic draining of Boegoeberg Dam releases large quantities of fine silt, and this has a detrimental impact on the downstream environment. Water temperatures at Gifkloof, situated 145 km downstream, dropped by 5ºC following the releases. This did not have a major impact on the invertebrate composition at Gifkloof, but further upstream the impacts are likely to have been significant.

Large-scale application of insecticides to control blackfly populations have had significant implications for non-target fauna such as the rare, endemic and threatened blackfly, *S. gariepense* (Palmer 1993; Palmer and Palmer 1995). For example in 1996 a total of 33 500 l of insecticide was applied to the river between Hopetown and Onseepkans.

Application of fention to control red-billed quelea between Boegoeberg and Upington undoubtedly had significant implications for non-target fauna, although this is no longer practised (Palmer, 1994).

Rare and endemic blackfly. The lower turbidities in the Middle and Lower Orange River, following impoundment, have almost certainly selected against the rare, endemic and threatened blackfly, *S. gariepense*.

Mayflies. Two species of mayfly (*Baetis bellus* and *Pseudocloeon vinosum*) were found in the Middle and Lower Orange by Agnew (1965), but were not found during intensive surveys between 1991 and 1996. The reason for their apparent disappearance is not known.

The snail *Gyraulus costulatus* was recorded at Onseepkans in 1960 (Agnew, 1965). Athough it was common downstream of Lake Gariep in February 1992, and found once on woody debris at Gifkloof, its numbers in the Lower Orange appear to have dropped. The reason for its apparent drop numbers is not known.

The snail *Gyraulus connollyi* was not recorded during this study, but was recorded by de Kock *et al* (1974) at several sites, particularly downstream of Boegoeberg Dam. The reason for its apparent disappearance is not known.

The alien invasive snail *Physa acuta* was first recorded in the Orange River in the vicinity of Boegoeberg Dam in 1971 (de Kock *et al*,. 1974). This species has subsequently spread dramatically; in 1993 specimens were found in the vicinity of Upington and Augrabies Falls, and in 1994 specimens were found near the river mouth.

The snail *L. columella* was recorded between Boegoeberg Dam and Vioolsdrift in the 1970s (de Kock *et al* 1974; Pretorius *et al.* 1974). The authors anticipated that this species would spread upstream, and indeed, *L. columella* was recorded in marginal vegetation in the vicinity of Upington and directly downstream of Lake Gariep during the blackfly surveys.

The snail *Lymnaea natalensis* was common and widespread in the 1970s (de Kock *et al.* 1974), but was not found during intensive surveys between 1991 and 1996. It is possible that this species has been displaced by the invading *Lymnaea columella* and/or *Physa acuta.*

The large elmid beetle sp. 'C', thought to be *Potomadytes brincki*, is the only known obligatory wood gauger (feeder) in the Orange River. The species is highly vulnerable to change, both because of its specialised diet (which is being chopped out and burnt), and because of its longevity. The large-scale replacement of riparian trees by reeds has undoubtedly affected this species.

The freshwater shrimp *Caridina nilotica* was not found during a snap-survey in 1960 (Agnew, 1965), but was common and widespread in the Middle and Lower Orange River in 1982 and 1983 (Cambray, 1984), and between 1991 and 1996.

Leech. It is likely that the leech species, which are known to be parasitic on hippopotami, became extinct in the Orange River in the 1930's, when the last hippopotamus was shot.

7.5.3 Trajectory of Change and Reasons

Aquatic invertebrates in the Orange River are on a negative trajectory of change.

5 years: PES = Category D.

20 years: PES = Category D/E.

The arid surroundings of the middle and lower Orange River isolate the river biogeographically. Recolonisation potential from adjacent rivers and wetlands is therefore low. Consequently, the river is highly vulnerable, and this emphasises the need for protection.

With the likely future reductions in flow, the Middle and Lower Orange River is likely to assume a character more typical of the Vaal River. There is likely to be a spread of pest species, such as the introduced snail, *Physa acuta*, the aquatic weed, *Myriophylum* spp., the blackfly, *S. damnosum* s.l., and *Hydra*. Further disturbance of riparian zones is likely to encourage the spread of *Phragmites* spp. reeds, with associated implications for increased habitat availability for aquatic invertebrates, particularly blackflies.

The following section summarises the results of five years of monthly biomonitoring at Gifkloof, with particular reference to the implications of changes in flow (**Table 7-6**). The data provide an indication of the likely implications for aquatic invertebrates of future flow scenarios. Significant differences in invertebrate abundance and species composition were noted between visits and between years. On several occasions, the abundance of certain taxa changed suddenly for no apparent reason, but overall the changes in the abundance and diversity of taxa were related to changes in river conditions, and in particular, changes in flow and water temperature. Five flow categories were recognised, ranging from very low flow to very high flow. The categories were based on the probability of exceedance of the daily average flow at Boegoeberg Dam at the 10th, 40th, 60th and 90th percentiles before impoundment (1944-1966).

Table 7-6: River Conditions and Invertebrates in the Orange River Typically Associated with Each of Five Flow Categories, and the Scores of Selected Metrics in Each Category. Shading Indicates High Values

Flow category	Very low	Low	Moderate	High	Very high
Discharge (m^3s^{-1})	<16	16-59	60-142	143-670	>670
Mean flow ($m\ s^{-1}$)	<0.3	0.3-0.6	0.6-0.8	0.8-1.4	>1.4
Sample size (n)	5	33	16	5	1
Typical Secchi depth (cm)	> 47	47-25	25-17	17-8	<8
Typical TSS (mg/l)	>16	16-42	42-80	80-260	>260
Median Planktonic algal abundance (cells/ml)	270	1,300	3,900	500	-
Average Total number of Taxa	29	26	26	22	24
Average No. of SASS4 families	18	16	15	13	15
Average Total invertebrate abundance	157	134	97	76	107
Average SASS4 score	114	109	107	94	97
Average Score per Taxon	6.8	6.7	7.2	6.9	6.5
Trophic groups	Filterers Spongivores	Filterers Gatherers	Filterers Predators	Filterers Predators	Filterers Predators
Typical invertebrates	*R. fuscus* *S. adersi,* *S. ruficorne* *E. fluviatilis*	*C. africanus* *A.peringueyi* *B. glaucus,* *E. elegans* *S. damnosum* *S. mcmahoni* *E. fluviatilis*	*A. scottae* *S. chutteri* *T. discolor*	*A. scottae* *S. chutteri,* *S. gariepense*	*maxima,* *A. scottae* *S. chutteri,* *S. gariepense*

The most important aspect of the flow regime for maintaining or improving the current ecological condition is the winter lowflows and the November freshet.

Very low flow: During very low flow (<16 $m^3 s^{-1}$) the river was characterised by clear water (Secchi depth >47cm) and low concentrations of planktonic algae. The average number of taxa (29), the average number of SASS4 families (18), and the average total abundance of invertebrates (157) was highest during these flow conditions. Taxa typically associated with very low flow included the filter-feeding midge, *Rheotanytarsus fuscus,* the sponge, *Ephydatia fluviatilis* and the blackflies *Simulium adersi* and *S. ruficorne*. The most abundant trophic groups during very low flow were filterers and spongivores.

Low flow: During low flow (16 to 59 $m^3 s^{-1}$) the river was characterised by moderate clarity (Secchi depth 25 to 47 cm) and moderate concentrations of planktonic algae. Numerous taxa were associated with lowflows, including the mayflies *Afronurus peringueyi, Baetis glaucus* and *Euthraulus elegans*, and the blackflies *Simulium damnosum* s.l. and *S. mcmahoni.* The mayfly, *B. glaucus* was present under a wide range of flow conditions, but highest numbers were recorded during low flow. The most abundant trophic groups during low flow were filterers and gatherers. Although scrapers were uncommon in the Orange River, they were most abundant during low flow.

Moderate flow: During moderate flow (60 to 142 $m^3 s^{-1}$) the probability of planktonic algal blooms was high. Taxa typically associated with moderate flows were the caddisfly, *Amphipsyche scottae* and the blackflies *Simulium chutteri* and *S. gariepense*. The Average SASS4 Score per Taxon (ASPT) was highest under moderate flow conditions. The most abundant trophic groups during moderate flow were filterers and predators. One of the most significant results is that the abundance of several taxa dropped when flows exceeded 70 $m^3 s^{-1}$, while the ASPT increased significantly. The reasons for this are not understood, but it is likely that light limitation plays a role. When the flow in the Orange River is 70 $m^3 s^{-1}$, the Secchi depth is usually about 23 cm (Palmer, 1997). The depth to which photosynthesizable radiation penetrates is not known, neither is the average depth of rapids in the Orange River known. However, the relation between flow and the abundance of benthic algae in the Orange River shows clearly that light limitation starts to occur when flow is greater than 130 $m^3 s^{-1}$. This suggests that factors in addition to light limitation are involved in the inflection of invertebrate abundance and species composition at 70 $m^3 s^{-1}$. The most likely factor is the availability of habitat. In 1995, DWAF surveyed five profiles in the Middle and Lower Orange River. The surveys examined the relation between flow, depth and average water velocity. There was no obvious inflection in these parameters at 70 $m^3 s^{-1}$.

High Flow: During high flows, the probability of planktonic algal blooms was minimal, and taxa typically associated with these conditions included the blackflies, *S. chutteri* and *S. gariepense*, and the caddisflies, *A. scottae* and *A. maxima*. The most abundant trophic groups during high and very high flows were filterers and predators.

Very High flow: Dramatic changes in species composition and abundance were recorded after a flood in January 1996, when daily flows of up to 2400 $m^3 s^{-1}$ were recorded. Species whose abundance increased after the flood included the blackfly, *S. chutteri*, the mayfly, *Tricorythus discolor*, and the caddisflies, *Cheumatopsyche thomasseti* and *Aethaloptera maxima*. Species that disappeared after the flood included the mayfly, *A. peringueyi*, the caddisfly, *Ecnomus thomasseti*, the sponge, *E. fluviatilis*, the blackfly, *S. mcmahoni* and the midge, *R. fuscus.* The flood also resulted in the mass mortality of the bivalve *C. fluminalis*, indicating that this species is sensitive to high silt levels (700 mg l^{-1}).

Fluctuating flows: The abundance of several taxa responded to variations in flow, measured as the coefficient of variation of daily average flow over 21 days prior to sampling. Taxa, whose abundance increased when flows fluctuated, were the leech *Salifa perspicax*, the mayflies *T. discolor* and *B. glaucus*, the caddisflies *A. scottae* and *A. maxima* and the blackfly, *S. chutteri*. The number of SASS4 families and total SASS4 scores were unaffected by flow variation, but invertebrate abundance dropped as flow variation increased. The abundance of gatherers, scrapers and spongivores decreased as flow variation increased, whereas the abundance of predators increased as flow variation increased.

Stable flows: The direction and intensity of changes in flow were measured as the slope of the linear regression of daily average flow over 21 days prior to sampling. No metrics responded to a drop in flow (indicated by a negative slope), but several metrics responded to an increase in flow. The pest blackfly, *S. damnosum,* became abundant during a long period of stable, low-flow conditions in 1993. Other taxa whose abundance increased during stable flow conditions were the stonefly, *Neoperla spio*, Turbellaria and the midges, *Cardiocladius africanus* and *R. fuscus,* the muscid fly, *Xenomyia* sp. and the sponge, *E. fluviatilis.* Taxa, whose abundance declined during extended periods of constant flow, included the caddisflies, *A. scottae* (after 20 days) and, *C. thomasseti* (after 30 days), the leech, *S perspicax* (after 20 days) and the stonefly, *N. spio,* complex (after 30 days) (**Table 7-7**). The overall abundance of caddisflies and predators started declining after 20 days of constant flow, whereas the abundance of gatherers started declining after 15 days of constant flow. The abundance of scrapers started increasing after 20 days of constant flow.

Table 7-7: Number of Days Taken for Selected Metrics to Show a Response Following Prolonged Periods of Constant Flow Conditions

Metrics which Increased	Number of Days	Metrics which Decreased	Number of Days
Amphipsyche scottae	20	Porifera gemmules	5
Cheumatopsyche thomasseti	30	Abundance of scrapers	20
Salifa perspicax	20	*Xenomyia* sp.	30
Neoperla spio	30		
Abundance of Trichoptera	20		
Abundance of Gatherers	15		
Abundance of Predators	20		

Timing and size of first spring freshet: Two important considerations in the assessment of ecological flow requirements are the seasonal periods of drought, and the timing and size of the first spring freshet. An analysis of historical flow data from Boegoeberg Dam showed that before impoundment, the driest month was September, during which flows were less than 15 m^3/s in nearly 40% of the years between 1933 and 1969. The first spring freshet was most often (60% of years) in

November, and was usually over 1000 m^3/s in size (**Figure 7-1**). After impoundment, there was no winter drought and no consistent spring freshet, and high flows were most often in March. This was at the end of the rainy season, when water was released from Lake Vanderkloof to provide buffering capacity for floods, anticipated the following season.

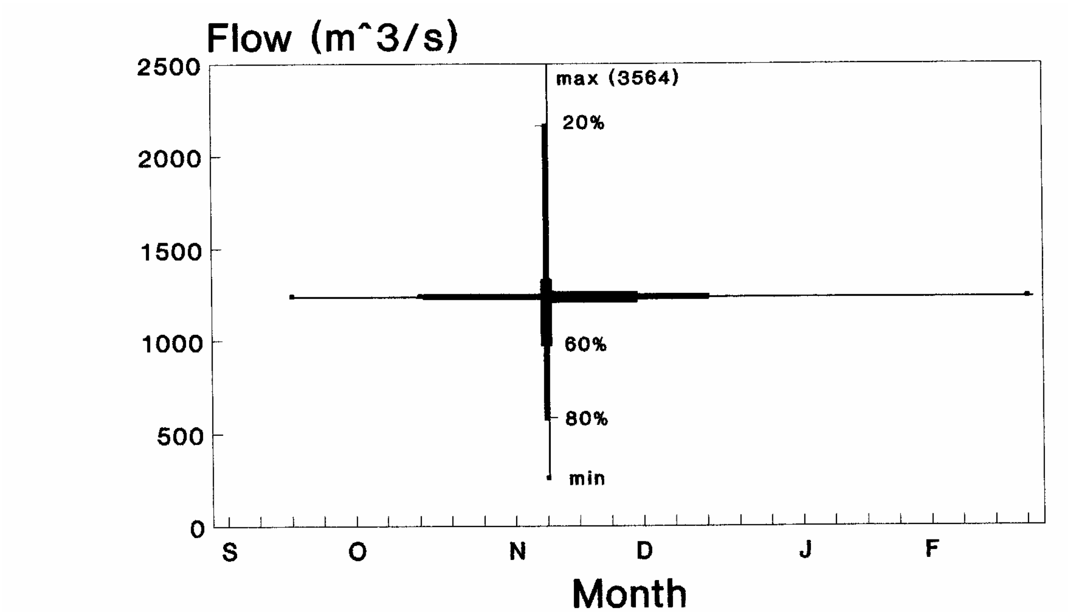

Figure 7-1: Timing and Size of the First Spring Freshet Recorded at Boegoeberg Dam (D7H008) Before Major Impoundment (1933-1966). Data are presented as Percentiles, and Include the Ranges. [Data: DWAF, Pretoria]

Seasonality: Highest total numbers of taxa and highest SASS4 scores were usually recorded in October or November, whereas the highest ASPT was usually recorded in January or February. The total abundance of filterers and gatherers showed no obvious seasonal trends, but scrapers were most abundant from August to October, whereas predators were most abundant in December.

Several taxa were common or abundant at certain times of the year only. The mayfly, *A. peringueyi* and the caddisfly, *Pseudoleptocerus ?schoutedeni,* were most abundant in October, whereas the mayfly, *E. elegans,* was most abundant in mid-winter to early spring (July to September). The mayfly, *T. discolor* was abundant during warmer months, and was consistently scarce in August and September. In both 1992 and 1993, large numbers of recently hatched *T. discolor* were noticed in the last week of September.

Taxa typical of the summer and autumn fauna included the caddisfly, *Amphipsyche scottae* (December to May) and *Aethaloptera maxima* (March to April). The mayfly, *P. maculosum* was present in December and February only.

The blackfly, *S. mcmahoni* was present throughout the year, with highest numbers in October and November, whereas *S. adersi* was most abundant in late autumn to early winter (April to July). Larvae and pupae of the muscid fly *Xenomyia* sp. were common or abundant in spring only (mostly October). Taxa, whose abundance showed no seasonal trends, included the sponge, *Ephydatia fluviatilis* and the caddisfly, *C. thomasseti*.

7.6 Fish

7.6.1 Present Ecological Status

The PES of the fish communities in the Middle and Lower Orange River is Largely Modified (Category D) (see **Section 5**).

7.6.2 Why is it in the PES Category?

Flow-related:

Stabilisation of flows: The major flow regime aspect, which caused a decline in the river condition in the past, was stabilisation of the summer/winter flow patterns from a natural annual median of 82% winter-18% summer flow to a 59% summer-41% winter median flow pattern (Benade, 1993).

The Middle and Lower Orange River stretches only contribute approximately 2% of the Orange River's mean annual runoff (Kriel 1972). These two river stretches are intensively utilised for riparian irrigation, while the upper catchment, especially the Vaal River, which was described as far back as 1981 by the Vaal River Catchment Association as "Africa's hardest working river" and "the main artery of the South African heartland", is also intensively utilised by the country's mining industry (±79%), agriculture (±42%) and urban population (±42%) (Braune, 1986). All the pollutants from these sectors, including seepage from the Vaal-Harts irrigation area (via the Harts River), eventually accumulate in the LOR. This situation is aggravated by maintaining a low flow regime through an area where evaporation is extremely high (2000 mm/a, and more). This can result in the river, or sections thereof becoming eutrophied. Apart from eventually pushing the system's natural cleansing abilities beyond its threshold, this situation is also contradictory to the true spirit of integrated water course/catchment/environmental management where, theoretically, the end users of a river system, including the aquatic and semi-aquatic environment, should have the biggest say in the quality, quantity and seasonal distribution of the water they receive.

Non Flow-related:

Poor water quality is conducive to increases in fish (and other aquatically based) parasite populations and also put the fish populations under environmental stress, making them more susceptible to parasite infestations. Poor water quality can also result in fish kills due to habitat requirements not being met, i.e., a species itself or its food resource may not be tolerant to whatever water quality parameter goes wrong within a river section.

Algal blooms: Observations had been made in the Vaal River at Riverton on fish kills during extreme algal blooms.

***Phragmites* reed settlement and encroachment**, on and along the riverbanks and bedrock outcrops (narrowing and deepening the river channel in places), resulting from water regulating structures and/or low flow management, can definitely have serious impacts on the LOR's fish populations. In the encroachment process, *Phragmites* reeds not only create habitat for other organisms, but also, by enhancing river regulation, create habitat for themselves and contribute substantially to evapotranspiration.

Some fish species benefit from *Phragmites* settlement and encroachment in the LOR, such as those seeking shelter and/or refuge from predators, *viz*. the indigenous *Mesobola brevianalis* (River Sardine), *Barbus paludinosus* (Straightfin Barb) (although its numbers are rather low) and the three cichlid species, *Pseudocrenilabrus philander* (Southern Mouthbrooder), *Tilapia sparrmanii* (Banded Tilapia) and the introduced indigenous *Oreochromis mossambicus* (Mozambique Tilapia).

Fish species negatively affected by *Phragmites* settlement and encroachment in the LOR (**Table 7-8**) are the open water and stream preferring ones, i.e., the vulnerable indigenous *Barbus trimaculatus*' (Threespot Barb), the endemic, Red Data *Barbus hospes* (Namaqua Barb) and *Barbus kimberleyensis* (Largemouth Yellowfish), as well as the endemic *Barbus aeneus* (Smallmouth Yellowfish) and *Labeo capensis* (Orange River Mudfish). The endemic, Red Data listed *Austroglanis sclateri* (Rock Catfish) will also be negatively affected by *Phragmites* reeds encroaching its basic habitat requirements ranging from a rock/sand/gravel substrate with/without scattered rocks to rocky pools, rapids (Skelton and Cambray 1981; Cambray 1984; Benade 1993) and riffles (Benade 1993).

Table 7-8: Key Freshwater Fish Species Expected to be Negatively Affected by *Phragmites* Settlement and Encroachment and/or Further River Regulatory Structures in the LOR stretch between 20^{o} Latitude and the Orange-Fish Confluence

KEY FRESHWATER FISH SPECIES		STATUS			
Scientific Name	**Common Name**	**E**	**I**	**V**	**R**
Barbus hospes	Namaqua Barb	X			X
B. kimberleyensis	Largemouth Yellowfish	X			X
Austroglanis sclateri	Rock Catfish	X			X
Barbus aeneus	Smallmouth Yellowfish	X			
Labeo capensis	Orange River Mudfish	X			
Barbus trimaculatus	Threespot Barb		X	X	
B. paludinosus	Straightfin Barb		X	X	

(E=Endemic; I=Indigenous; V=Vulnerable; R=Red Data)

7.6.3 Trajectory of Change and Reasons

Fish in the Orange River are on a negative trajectory of change.

5 years: PES = Category D.

20 years: PES = Category D/E.

The main reasons for this negative trajectory are the deviation from the natural flow and deterioration in water quality. Flow changes, as a result of river regulation, are considered to be the major culprit.

The aspects of the flow regime causing a decline in the river's condition include:

- the absence of seasonal natural flow patterns;
- the absence of minor to medium maintenance floods; and
- higher winter volumes for hydropower generation.

It should be kept in mind that ±98% of the Orange River's runoff, including the bigger bulk of these maintenance floods, is generated in the system's upper catchment, above the major dams within the SA borders.

Note: Flow is only one of several basic habitat requirement of the organisms living in aquatic ecosystems, albeit one of the easiest to manage. It remains important, however, that attention be given to habitat requirements as a whole, of which flow is a major component, instead of focussing on flow *per se* as a solution to any, and all aquatic ecosystem problems.

8. SUMMARY OF PRE-WORKSHOP ASSESSMENTS

This Section summarises the most pertinent information in **Sections 2**, **6** and **7**.

8.1 Summary of Present Ecological Status and Trajectories

Table 8-1 is a summary of the PES for each of the disciplines considered in Task 8.3. In general, the ecological condition of the river is deemed to be on a negative trajectory, with all disciplines expecting one-category deterioration in condition in the next twenty years. River systems function as an integrated whole, and changes made in one part of a system will inevitably lead to changes in another part, and so it is unsurprising that the disciplines predict similar trends.

Table 8-1: Summary of the PES for Each of the Disciplines Considered in Task 8.3, Their Predicted Trajectory of Change for 20 Years and an Indication of whether These Changes Documented/Expected are Related to Changes in the Flow Regime of the Orange River.

Discipline	PES	Trajectory	20-year prediction	Flow-related	Non flow-related
Water quality	B/C - Category	Negative	C/D - Category	No	Yes
Geomorphology	C- Category	Negative	D - Category	Largely	Channel manipulation - levees
Algae	D - Category	Negative	E/F - Category	Partly - not flushed	Partly - imported from u/s
Vegetation	D - Category	Negative	E - Category	Some	Predominately
Macroinvertebrates	D - Category	Negative	D/E-Category	Some	Predominately
Fish	D - Category	Negative	D/E-Category	Partly	WQ also
Overall	D - Category	Negative	D/E-Category	ONLY PARTLY	Predominately

Category	A	B	C	D	E/F
Colour used	green	blue	purple	yellow	red

8.2 Changes to the Flow Regime Most Likely to have contributed to Present Ecological Status

There has been a reduction in the volume of water flowing down the Orange River, *viz.* natural Mean Annual Runoff (nMAR) = *c.* 10 587.30 MCM (median *c.* 5 100 MCM) and 2005 Mean Annual Runoff ($_{2005}$MAR) = *c.* 4 382.12 MCM (40% nMAR). In general, relationships between reductions in nMAR from elsewhere in South Africa and ecological condition of the affected riverine ecosystem show strong correlations, particularly when this is accompanied by a change in the natural distribution of flows. However, much of the reduction in ecological condition in the LOR can be attributed to mechanical manipulation of the riverbanks and floodplain.

The most important aspects of the flow regime for maintaining or improving the current ecological condition are reinstating the winter lowflows (i.e., reducing current flows) and the November freshet. In summary, the flow-related contribution factors identified were:

- unseasonal winter releases;
- lack of very low flow periods;
- lack of the November freshet;
- reduction in volume;
- reduction in wet and dry season inter-annual floods; and
- lack of variability.

9. SPECIALIST WORKSHOP – PROCESS AND DISCUSSION

This Section describes the process adopted at the workshop and highlights some of the key discussions, including the Habitat Integrity assessments, where the PES statements given in **Section 7** were crosschecked by doing the assessments from a slightly different approach in a group situation. Comments provided here are in addition to those given in earlier Sections.

9.1 Participants

Mike Luger	Ninham Shand	Chair
Cate Brown	Southern Waters	Facilitator
Delana Louw	IWR Source to Sea	Co-Facilitator
Bettie Conradie	Northern Cape DWAF	River management
Frikkie Becker	Alexander and Becker	Observer
Chris Brown	Namibian Nature Foundation	Observer
Marnie Mare	WRP Hydrology	
Johan Hattingh	Creo Engineering	Geomorphology
Bill Harding	Southern Waters	Water quality
Charlie Boucher	University of Stellenbosch	Vegetation
Rob Palmer	Afridev	Macroinvertebrates
Ben Benade	Eco-Impak	Fish
Kamal Govender	Ninham Shand	Scribe.

9.2 Agenda

Day 1: Items discussed (09h30 – 17h30)

- Background to LORMS.
- Background to Task 8.3.
- Comparison between natural and present day hydrological data
- PES and Ecological Sensitivity and Importance (EIS) Assessments (see **Section 9.3**).
- Identification of flow-related origins.
- Conflicts between Desktop D and proposed hydrological scenarios.

Ecological consequences associated with presence/absence of different components of the flow regime.

Day 2: Items discussed (08h00 – 16h00)

Modification of D-Category EFR demand file for planning purposes.

Discussion and agreement on procedure for creation of the Environmental Flow Top-up Demand File.

Ecological consequences of proposed dam options for the Orange River.

9.3 Habitat Integrity Assessment Undertaken at the Workshop

The individual PES assessments presented in Section 7 were crosschecked, using a formal Habitat Integrity at the Workshop in order to:

- approach the assessments from a slightly different perspective, incorporating considerable group discussion and debate, to see whether similar assessments resulted, i.e., verification of results presented in Section 7;
- determine the overall PES and trajectory of change for the reach between Upington and Onseepkans; and
- to separate out the effects of flow and non-flow related impacts on river condition.

Table 9-1 and **Table 9-2** provide the agreed scoring for Instream and Riparian Habitat Integrity, respectively. For the entire study reach, Upington to Onseepkans, the resultant Habitat Integrity was a D-Category. This improved to a C-Category in the relatively undisturbed sections such as those between Raap-and-Skraap and Onseepkans, where mechanical disturbance of the bed and banks is negligible but the effects of modifications to the flow regime and the mainly “imported problems”, such as algae, still manifest themselves.

Table 9-1: Instream Habitat Integrity

INSTREAM HABITAT INTEGRITY	**Upington to Onseepkans**	**Mechanically undisturbed sections**
Primary impacts		
WATER ABSTRACTION (IMPACT 1 - 25)	12	12
FLOW MODIFICATION ((IMPACT 1 - 25	16	16
BED MODIFICATION (IMPACT 1 - 25)	11	6
CHANNEL MODIFICATION (IMPACT 1 - 25)	8	6
WATER QUALITY (IMPACT 1 - 25)	7	7
INUNDATION (IMPACT 1 - 25)	16	3
TOTAL (OUT OF 150)	70	50
Secondary impacts		
EXOTIC MACROPHYTES (IMPACT 1 - 25)	8	3
EXOTIC FAUNA (IMPACT 1 - 25)	3	3
RUBBISH DUMPING (IMPACT 1 - 25)	3	0
TOTAL (OUT OF 75)	*14*	*6*
INSTREAM HABITAT INTEGRITY SCORE	**45**	**62**
INSTREAM HABITAT INTEGRITY CATEGORY	**D**	**C**

Table 9-2: Riparian Habitat Integrity

RIPARIAN HABITAT INTEGRITY	**Upington to Onseepkans**	**Mechanically undisturbed sections**
Primary impacts		
VEGETATION REMOVAL (IMPACT 1 - 25)	13	2
EXOTIC VEGETATION (IMPACT 1 – 25)	10	8
BANK EROSION (IMPACT 1 – 25)	2	2
CHANNEL MODIFICATIONS (IMPACT 1 – 25)	17	5
WATER ABSTRACTION (IMPACT 1 – 25)	4	4
INUNDATION (IMPACT 1 – 25)	5	0
FLOW MODIFICATION (IMPACT 1 – 25)	11	11
WATER QUALITY (IMPACT 1 – 25)	3	3
TOTAL (OUT OF 200)	*65*	*35*
RIPARIAN HABITAT INTEGRITY SCORE	**43**	**75**
RIPARIAN HABITAT INTEGRITY CATEGORY	**D**	**C**

Conclusion:

Overall Habitat Integrity: Category D (20-year trajectory: E).

In undeveloped areas: Category C (20-year trajectory: C/D).

Thus, this very simple analysis indicates that the present flow regime in the system is maintaining the river in a Category C, and that the river is degraded to a Category D by mechanical manipulation of its floodplain, banks and bed. Flow manipulation and much of the water abstraction takes place outside of the reach between Upington and Onseepkans, but there is no doubt that it has had negative ecological impacts on the reach.

Furthermore, the entire ecosystem is deemed to be on a negative trajectory, with the condition of the system in the developed areas anticipated to decline faster than the sections only influenced by changes to the flow regime.

9.3.1 Summary Comments to Support PES Assessments

Water Quality: The main water quality problem in Upington to Onseepkans stretch is the import of algal 'plugs' from the catchment upstream. These algal problems are exacerbated by the low discharge in the river (the river is essentially a series of lakes rather than a river for much of the year) and by increased light penetration as a result of sediment trapped in reservoirs and behind weirs.

The slightly elevated salt content of the Orange River water is unlikely to affect the biota. Nutrient levels are slightly problematic (and elevated nutrient levels are probably exacerbating the *Phragmites* growth), but it is mainly event driven occurrences of poor water quality that tend to exacerbate the algal problem.

It is worth remembering that the water quality assessments are made without access to measurements of many determinants, such as vinyl carbons, trace metals and sediments.

For instance, not much is known about the import of heavy metals from the Vaal River. There are occasional large inflows from the Vaal catchment into the Orange River, and while there are some indications that there is not much mixing during floods, i.e. the flood waters tend to move over the top of the resident water, there are also reports of poor water quality following floods from the Vaal River (B. Conradie, pers. comm.).

The method currently used to determine Water Quality PES (See **Section 5**) has tendency to overestimate condition.

Geomorphology: Reduced discharges combined with encroachment of vegetation results in ponding so that the river becomes a series of lakes rather than a river for much of the year (see Water Quality). Over time, this slowing down of the river and ponding of pool sections results in a reduction of gradient through deposition of fine material and the slow flowing areas 'migrate' upstream to riffle areas, which can then become inundated. This process is periodically reset by floods passing through the system. The ponding of the river is increased by the proliferation of weirs, which affect 50 - 70% of the river near Upington.

During flood events the flow of water is concentrated in the channel by levees and the *Phragmites* reed beds, increasing scour and progressively narrowing and deepening the channel.

Vegetation: Floodplain developments have all but removed the floodplain vegetation in riparian areas near to Upington, Kakamas and Onseepkans. Similar activities are also in evidence at Raap and Skraap, but are not serious outside of these areas. Removal of this vegetation reduces the river's buffer against nutrients and sediments being washed off the surrounding farmlands.

In the heavily developed areas the effects of water abstraction are masked by mechanical damage to the riparian zone.

Flow reductions and a more constant flow regime have contributed towards the spread of *Phragmites* reeds into the channel. Here again, management of the reed through burning has increased the damage to the riparian vegetation and promoted the occurrence of densely rooted reed beds (see Geomorphology).

Macroinvertebrates: see **Section 7**.

Fish: Carp in system affect habitat through their feeding habits, which churn up deposited sediments. *Oreochromis mossambicus* is highly tolerant species aggressive spreading in the LOR. There is some anecdotal evidence to suggest that parasite loads in the fish are elevated (B. Benade, pers. comm.).

9.3.2 Summary Comments on the Predicted Negative Trajectory of Ecological Condition of the Orange River

Assuming no further developments and continuation of current management practices, the ecological condition of the Orange River between Upington and Onseepkans is predicted to decline to an E/F Category within 20 years.

Water Quality: That with the exception of the nutrient loading from the Upington Waste Water Treatment Works, an impact, which disappears by the time Onseepkans is reached, the water quality in the study reach is dictated by events upstream of it, and ostensibly with major variations being generated in spills from the Vaal system. The algal problem is for the moment being generated in the Spitskop Dam and passed into the reach via the Harts River. It is difficult to rate the water quality of a downstream reach without the opportunity to extend upstream to see what is driving a 'driver'. It is likely that the trends currently observed will continue. Approximately 15 years ago, the dams started loosing volume as a result of sedimentation and started releasing water previously that was stored and flushing more. They do not act as sinks for poor water quality coming in from upstream. In the target reach, there is no dilution effect because the poor water quality comes from upstream reaches.

The low discharges and reduced flushing (flood frequency drastically reduced) means that the algal detris and germinating algae imported from upstream will stay in the system. It is highly likely therefore that the present algal problems will worsen faster than any measurable changes in water quality.

Geomorphology: Sedimentation can only increase as the present system is deprived of sufficient discharge to prevent sedimentation where it would not have occurred naturally.

Vegetation: The low discharges and reduced flood frequency means that sufficient new recruitment is not occurring and the trees are dominated by mature specimens, which will eventually die.

Macroinvertebrates: see **Section 7**.

Fish: The low discharges have resulted in compartmentalisation of the river, with the result that inbreeding is occurring, which will eventually reduce the viability of the species' gene pool.

9.4 Ecological Importance and Sensitivity

The EIS of a river is an expression of its contribution towards ecological diversity and functioning on local and wider scales. Ecological sensitivity (or fragility) refers to the system's ability to resist disturbance (resistance) and to recover from disturbance once it has occurred (resilience). Both abiotic and biotic components of the system are taken into consideration in the assessment of ecological importance and sensitivity (DWAF 1999 - Volume 3).

EIS is generally assessed for natural conditions, i.e., how important the river would have been if it was in its original condition, and present day conditions, i.e., how important the river is under current conditions.

In South African Reserve determinations, the EIS is generally used to determine the condition for which the recommended flow regime for a site is set. The following ‘rules’ (among others) are used as a general guideline:

- If the EIS is High or Very High, the ecological specialists will recommend a flow regime that will allow an improvement of the PES, if PES is lower than a Class B.
- If the EIS is Low or Moderate, the ecological specialists will recommend a flow regime that will maintain the PES. Unless PES is lower than a Class D, in which case it will require improvement regardless of the EIS.

The EIS assessments for the LOR between Upington and Onseepkans are provided in **Table 9-3**. The LOR scores a High EIS for both natural and present day conditions. This is not unexpected, as the river runs through desert for much of its length, and as such provides vital and irreplaceable habitat for any organisms dependent or partially dependant on an aquatic habitat. Furthermore, the river’s course passes through areas of recognised and celebrated natural beauty and diversity, many of which are declared national or international conservation areas.

If a Reserve determination were undertaken for LOR it is highly likely that the recommended flow regime would be aimed at facilitation of a C-Category river.

9.5 Comments on the Ecological Implications of the Various Flow Regimes Presented in Section 2

In line with the pre-workshop summary presented in **Section 8**, the following aspects of the flow regime were identified as those primarily responsible for the flow-related declines in ecological conditions:

- increased dry season flows, and the absence of a very-low or stop-flow condition;
- the absence of mid-range intra-annual flood events;

- the dampening of year-on-year variability; and
- the dampening of seasonal and daily/monthly variability.

Table 9-3: Ecological Importance and Sensitivity Assessment for the Orange River from Upington to Onseepkans

	NATURAL		PRESENT		COMMENTS
DETERMINANTS	**Score**	**Confidence**	**Score**	**Confidence**	
BIOTA (RIPARIAN and INSTREAM)	(0-4)		(0-4)		
Rare and endangered (range: 4=very high - 0= none)	4	4	4	4	
Unique (endemic, isolated, etc.) (range: 4=very high - 0= none)	3	4	3	4	
Intolerant (flow and flow related water quality) (range: 4=very high - 0= none)	2	2	2	2	
Species/taxon richness (range: 4=very high - 1=low/marginal)	3	2	3	2	Fish motivation
RIPARIAN and INSTREAM HABITATS	(0-4)		(0-4)		
Diversity of types (4=Very high - 1=marginal/low)	3	3	3		Pools, runs, riffles, waterfalls, rapids, backwaters, marginal veg, reed beds
Refugia (4=Very high - 1=marginal/low)	3	2	3	2	
Sensitivity to flow changes (4=Very high - 1=marginal/low)	2	2	2	2	
Sensitivity to flow related water quality changes (4=Very high - 1=marginal/low)	2	3	1	3	
Migration route/corridor (instream and riparian, range: 4=very high - 0= none)	4	4	4	4	
Importance of conservation and natural areas (range, 4=very high - 0=very low)	2	4	2	4	
MEDIAN OF DETERMINANTS	**3.00**		**3.00**		
ECOLOGICAL IMPORTANCE AND SENSITIVITY CLASS (EISC)	**HIGH**		**HIGH**		

The ecological motivations for these aspects of the flow regime, plus an indication of the ecological implications of their not being achieved were discussed at length, and the essence of the discussion is reported below (see also **Table 9-4**).

Table 9-4: Different Kinds of River Flow, and Their Importance to Ecosystem Functioning (from King *et al.* 2002)

Flow component	Importance to ecosystem
Lowflows	The lowflows are the daily flows that occur outside of high-flow peaks. They define the basic seasonality of the river: its dry and wet seasons, and degree of perenniality. The different magnitudes of low-flow in the dry and wet seasons create more or less wetted habitat and different hydraulic and water-quality conditions, which directly influence the balance of species at any time of the year.
Small floods	Small floods are usually of great ecological importance in semi-arid areas in the dry season. They stimulate spawning in fish, flush out poor-quality water, mobilise smaller sediments and contribute to flow variability. They re-set a wide spectrum of conditions in the river, triggering and synchronising activities as varied as upstream migrations of fish and germination of riparian seedlings.
Large floods	Large floods trigger many of the same responses as do the small ones, but additionally provide scouring flows that influence the form of the channel. They mobilise coarse sediments, and deposit silt, nutrients, eggs and seeds on floodplains. They inundate backwaters and secondary channels, and trigger bursts of growth in many species. They re-charge soil moisture levels in the banks, inundate floodplains, and scour estuaries thereby maintaining links with the sea.
Flow variability	Fluctuating discharges constantly change conditions through each day and season, creating mosaics of areas inundated and exposed for different lengths of time. The resulting physical heterogeneity determines the local distribution of species: higher physical diversity enhances biodiversity.

9.5.1 Dry Season: Extreme Lowflows (Including Stop-flow Conditions)

The main motivation for extreme dry-season lowflows is to promote environmental variability thereby promoting species diversity. For instance, as flows in the system drop, light penetration increases and feeding guilds change. In the LOR, low flow periods are characterised by large populations of filter feeding sponges, which have a symbiotic relationship with peri- and ephiphytic algae. Many insect species only feed on sponges, e.g., certain neuropterans. Under elevated (and more constant) dry flow conditions, pest species, such as black fly, are able to out-compete these species and dominate the macroinvertebrate community.

Lowflow periods are also required to trigger certain life-stage events. For instance, many of the fish species in the system start maturing sexually for spawning in the dry season. Higher flows during this period trigger false spawning and recruitment failure. Conversely, in some species, constant flows retard spawning.

Note: Prolonged periods of very low dry season flows will promote algal blooms in the system, particularly since these are not off-set by naturally high wet season flows, which would flush the system and prevent setting of algal detris and germinating algae imported from upstream. Furthermore, given the reliance of people on the river for water, there is some considerable doubt as to whether extremely low flows in the system are achievable.

Stop-flow Conditions

The DWAF gauging weirs in the LOR do not record lowflows accurately, nonetheless there is some evidence that the river at Upington did stop flowing from time to time, albeit relatively infrequently. The initial estimates yield a frequency of 1:5-8 years. Most species in the Lower Orange can tolerate short-term cessation of flow for some part of their life cycle and it is likely that these events promoted species diversity, particularly in vegetation, fish and macroinvertebrate communities. As with major floods, naturally occurring droughts form part of the functioning force of the system. They promote biodiversity and resilience and serve as natural controls against dominance by a single species. The relative infrequency of the stoppages, however, means that they are unlikely to fulfil a major ecological function in the river. There are indications that the flow stoppages would facilitate control of black fly populations, however, if black-fly control were the purpose of the stoppages then mid-July would be the best time for them to occur, whereas if the purpose were to promote species diversity, then September would be the best time for them to occur (R. Palmer, pers. comm.).

9.5.2 Intra-annual Flood Events (and Consideration of Drought Periods)

Intra-annual flood events are arguably the most difficult to provide in a regulated system. They are also one of the most important components of the flow regime for the ecosystem (**Table 9-4)**. At the workshop, the following motivations for increased intra-annual variability, through the provision of small and medium flood events were provided.

- Flushing algal plugs from the system.
- Transporting and distributing sediments, thereby promoting habitat maintenance and diversity.
- Maintaining wetbank riparian vegetation.
- Maintaining lower dynamic zone free of pioneers and alien vegetation, thereby reducing the impact of large flood events.
- Washing salt out of banks, thereby promoting riparian vegetation growth.
- Triggering life history events, such as hatching and emergence of invertebrates and spawning behaviour in fish. Changes in temperature are also major triggers of life history events, and the relationship between water quality and quantity in these triggers is unclear, which makes artificial provision of triggers very difficult. Some species, e.g., barbell, migrate during flood events and spawn in newly flooded areas. Their fry then enter the mainstem on the receding floodwaters.

Larger floods form part of the functioning force of the system, promote biodiversity and resilience, and serve as natural controls against dominance by a single species - much like the concept of time-share. Each species will respond differently to prevailing conditions, and variability of conditions will ensure that each species will have some time when conditions are ideal. For this very reason, reduced diversity usually equates to reduced resilience. This is already evident in the LOR where the high-flow specialist, *Simulium gariepense*, faces extinction, and the constant-flow specialist, *Simulium chutteri*, reaches pest proportions.

The absence of intra-annual flood events promotes invasion by alien species, in particular alien vegetation and alien fish species.

The magnitudes of the intra-annual floods vary and events of different magnitude and duration will have markedly different effects on the river system. No data were collected during this study to assist with determination of the magnitude and durations of intra-annual flood events. In an EFR determination, such evidence is gathered, using the zonation of riparian vegetation on the banks, the location and elevation of required habitats and various other structural aspects of the river. For instance, anecdotal evidence suggests that there is an inflection point in the parts of the channel on LOR that this may equate to a flood with a fairly frequent occurrence.

From a management perspective, flood events with peaks flows ≥300 cumecs create problems with flooding of pump infrastructure.

There is also some doubt as to whether intra-annual flood events could be managed from Vanderkloof Dam (the nearest upstream flow regulating structure).

Drought Periods:

Under natural drought conditions, the frequency of intra-annual floods is considerably lower than in wetter periods, and in particularly severe droughts, they may cease all together. As is the case with other aspects of the flow regime, this will benefit some species and prejudice others. The chances of permanent habitat changes and /or loss of species, however, increases with time without flood events. This is particularly true for the LOR as there are no viable perennial tributaries where species can seek refuge from adverse conditions and thereafter recolonise the mainstem.

The observed records for Zeekoebaart (D7H008) suggest that even in natural droughts some of the smaller intra-annual floods would still have occurred.

9.5.3 Year-on-Year Variability

Year-on-year variability, as with all other forms of natural variability, promotes erosion and sedimentation cycles, which in turn promote biodiversity and resilience. The species present in the river have adapted over millions of years to the natural variability of the system, and the physical template that that creates. If systems stay the same year-on-year, this will favour some species to the detriment to others – and result in reduced biodiversity and reduced resilience. In effect, the river becomes "domesticated". In general, variability was felt to be more important in the wet season than in the dry season.

The LOR shares many similarities with the Murray Darling River in south-eastern Australia, and it is perhaps worth learning from the management experiences on the Murray Darling in order to avoid the costly rehabilitation measures that are having to be put in place (see Box below).

9.6 Comparisons between the Flow Regimes

9.6.1 Limitations

Most of the data available for analysis in Task 8.3 were monthly data. Furthermore, no reliable gauge records were available with which monthly data could be disaggregated into daily flow sequences. This limited the analyses in the following ways:

1. Daily and monthly variability could not be adequately explored.
2. The number and frequency of flood events versus lowflows cannot be determined.
3. Short-term distributional clashes between modelled scenarios and environmental flow requirements cannot be determined.
4. No hydraulic investigations were undertaken, and volumetric considerations could not be linked to velocity, wetted area or depth in the river channel itself.

A Comprehensive EFR Determination for the LOR will necessitate the development of reliable daily flow records for natural and present-day conditions.

The Murray-Darling River (from King and Brown 2002)
The Murray-Darling River in Australia is seriously degraded, due to over-abstraction of water and increasing nutrient and salinity levels. Algal blooms are one very visible symptom of declining river health. Flow regulation by dams and weir pools, and abstractions, primarily for irrigation areas, have resulted in markedly changed river-flow patterns, particularly in the lower reaches. Far less flow than natural is available to dilute and transport away increasing volumes of nutrient-rich agricultural runoff and urban wastewaters. Reaches with constant low flow and high nutrient concentrations have created still conditions for algal growth, and resulted in blue-green algae, which are natural components of the life of rivers, sometimes increasing to problematic proportions as algal blooms. When present as blooms, the algae produce toxins that can cause liver damage, stomach upsets and disorders of the nervous systems. They can also cause livestock deaths, mass fish mortalities, skin and eye irritations, odorous and distasteful water, and clog water-supply equipment. The toxins can only be removed by advanced water-purification systems. In 1991, the largest riverine bloom of blue-green algae recorded anywhere in the world developed along a thousand-kilometer stretch of the Darling River, causing the New South Wales Government to declare a state of emergency. A limit ("Cap") has been placed on abstractions as a first move to halt river degradation, and prevent the expensive and damaging effects of ecosystem malfunctions. If this does not achieve the desired level of river health, water allocations to offstream users may be reduced and re-allocated for river maintenance. The Cap is not an environmental flow, because it is not (yet) based on consideration of ecosystem functioning, but is seen as a move to limit abstractions until an environmental flow assessment can be done and environmental flows implemented.

9.6.2 Comparison between Flow Regimes

A summary comparison between the flow regimes, in terms of the aspects identified in Section 9.2, is provided in **Table 9-5**. It was concluded that:

- the annual distribution of flows represented by the scenarios did not conflict with the Desktop D and C Category estimates for the EFR;
- year-on-year variability was far greater for the Desktop D and C Category estimates for the EFR, than for the scenarios, but this would be extremely difficult to implement;
- the Desktop D and C Category estimates for the EFR encompassed intra-annual flood requirements, which because they were modelled as priority requirements, placed considerable onus on the yield from the dams;
- using monthly data, it was not possible to comment on short-term (daily or monthly) flow variability, however, it was accepted that this was likely to be extremely low (relative to natural) for the development scenarios.

Table 9-5: Summary Comparison of Flow Regimes

Scenario Description	Scenario No.*	Increased Dry Season Flows	Stop-flow Conditions	Intra-annual Flood Events[8]		Variability	
				Normal/Wet	Drought	Year-on-Year	Short-term
Natural flow	Natural	No	Yes	Yes	Yes	Very high	Very high
1991-2000 Observed	Present Day	Yes, in particular autumn	No	Reduced	No	Dampened	Much reduced
2005 (2005)	1-M	No	No	No	No	Very low	Cannot determine
Vanderkloof lower level storage	1-P	No	No	No	No	Very low	
Vioolsdrift reregulating dam	1-Q	No	No	No	No	Very low	
Large Vioolsdrift	1-R	No	No	No	No	Very low	
Hydropower release incl.	Hydro	Yes, in particular autumn	No	No	No	Very low	
Category D Desktop	D-Desk	No	No	Reduced	Yes	Low-moderate	Reduced[9]
Category C Desktop	C-Desk	No	No	Reduced	Yes	Low-moderate	Reduced

[8] Relative to the natural situation

[9] The Desktop Model only provides a flood volume and we have assumed that this related to a single flood. This could in effect be a volume that related to several smaller floods each with relatively short durations.

Furthermore, and importantly for the aims of Task 8.3:

- the annual distribution of flows for the future scenarios did not differ significantly from the present-day flows in the river (with the possible exception of the HYDRO Scenario), *which were maintaining the river on a gradual C to C/D Category trajectory*;
- modelling the Desktop D Category EFR estimate as a priority demand on Vanderkloof Dam, resulted in shortfalls against present-day and future demands from off-stream users (M. Maré, pers. comm.). This is because the EFR was modelled as a separate, non-consumptive user, and demands downstream of the EFR site was not allowed to utilise the environmental flow, with the exception of the evaporation requirements from the river.

Thus, instead of adjusting the Desktop D or C Category estimates, it made sense to rather use the Desktop D, excluding the high flows and to adjust the "Top-up" environmental demand files being used in the modelling, and then to evaluate the actual expected flow regime at the target reach (i.e., Augrabies) in terms of its implications for the river condition.

The processes adopted for adjusting the demand file and the outcome of the evaluations at Augrabies and at the mouth, are provided in **Section 10**.

9.7 A Summary of Ecological Issues Pertaining to the Construction of a Large Dam in the Lower Orange River

The final session of the workshop was devoted to a summary assessment of the ecological opportunities and constraints that may be associated with the construction of a large dam in the LOR. Although not strictly part of the ToR for Task 8.3, a catalogue of the ecological concerns associated with the construction of a large dam in the LOR, does form part of the overall tasks for LORMS, and it was decided to make maximum use of the cross-disciplinary expertise that was available at the workshop to develop an initial summary of the main issues (**Appendix 7**).

The information contained in **Appendix 7** will be augmented and presented in a separate report dealing specifically with the proposed dams, and is only included here for completeness sake.

10. SPECIALIST WORKSHOP – OUTPUTS

This Section describes the outputs of the workshop, including the process adopted to arrive at the “Top-up” D demand file that was recommended for use in the hydrological modelling required for LORMS. The final decision on the process to be adopted was based on the information presented in the preceding sections, which was cross-checked and discussed in some detail at the workshop. Nonetheless, it is worth reiterating that all of the assessments done in this study are based on existing (and of poor) biophysical data, and on monthly modelled flows. The limitations (and great margin for error) inherent in the use of such data as a basis for the sorts of discussions and recommendations made here has been outlines in several places in this report but cannot be over-emphasised.

10.1 Process for Changes to the Desktop-D Demand Files

The following process was agreed on and adopted:

1. The Desktop D Category EFR estimations were split into their lowflow and highflow components.
2. The lowflow requirements ONLY were used as a demand file for the yield modelling from Vanderkloof Dam.
3. The monthly flow duration curves for the resultant flow regime (using the lowflow ONLY demand file) at Augrabies were compared with the (total) Desktop D Category EFR estimations for Augrabies.
4. For months where the (total) Desktop D Category EFR estimations exceeded the actual flows at Augrabies obtained with the lowflow ONLY demand file, the difference was calculated as a flood. The volume of water equating to the required flood was then added back into the lowflow ONLY demand file where required. An example of the flow duration curves that were evaluated at the workshop is provided in **Figure 10-1**. The Desktop D Category EFR estimations exceeded the actual flows at Augrabies obtained with the lowflow ONLY demand file in place (see **Figures 10.2 – 10.13**). In order to ‘replace’ some of this ‘lost’ volume February was adjusted, i.e. more volume added to ‘supply’ flood

flows during that month and the resultant monthly distributions checked (**Figures 10.15 –10.17**).

5. The resultant demand file comprised the lowflows ONLY for the Desktop D, and selected 'top-up' flood volumes (provided in **Appendix 6**).
6. This demand file was developed for planning purposes and is NOT the EFR, and the term "Top-up" D Demand File was coined to describe the resultant demand file.
7. The EFR was considered to be the actual flows in the river at Augrabies, and the "Top-up" D Demand File merely part of the operating rules for achieving those flows.

Note: For **Figures 10.1 – 10.12** the low assurance highflows appear much higher for the actual flows at Augrabies than for the Desktop D. This is because the Desktop D does not stipulate flows > 1:2 year flood, as these are assumed to occur anyway.

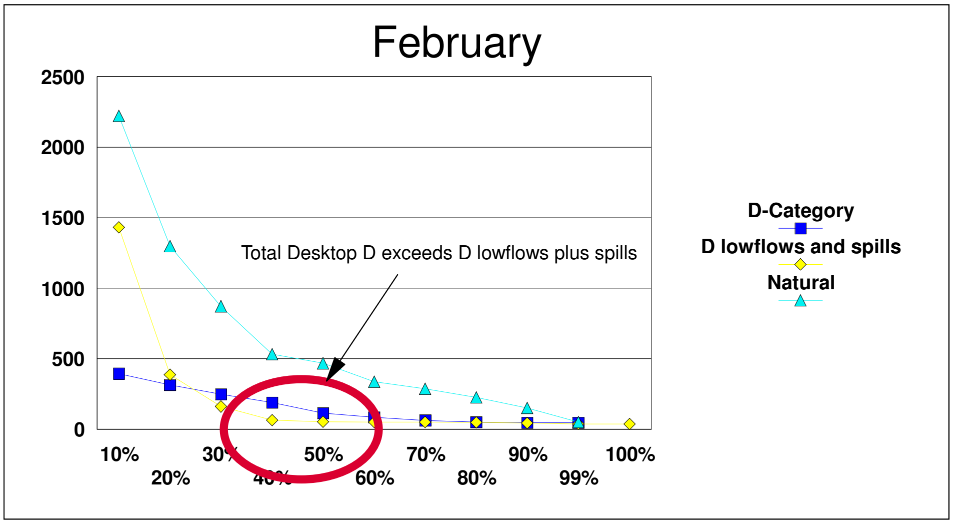

Figure 10-1: February Flow Duration Curves at Augrabies for the Total Category D, the Resultant Flows with Only the D Lowflows as a Demand File and Naturalised Flows

Where the (total) Desktop D Category EFR estimations exceeded the actual flows at Augrabies obtained with the lowflow ONLY demand file water volume was added back into the lowflow file to create the "top-up" D Demand File.

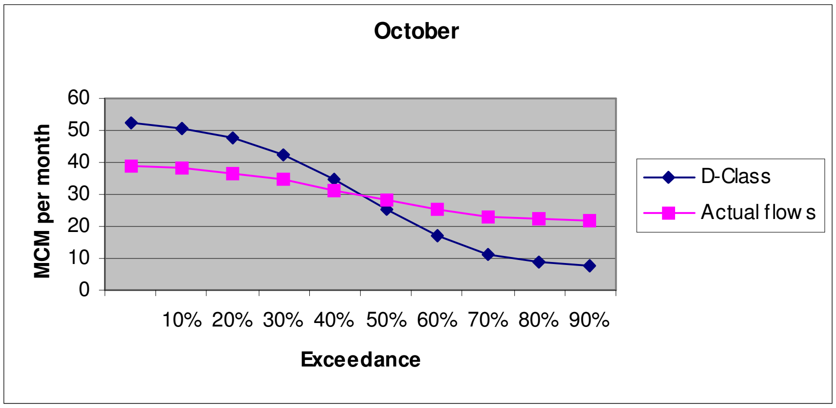

Figure 10-2: October Flow Duration Curves at Augrabies for the Total Category D and the Resultant Flows with only the D Lowflows as a Demand File

Where the (total) Desktop D Category EFR estimations exceeded the actual flows at Augrabies obtained with the lowflow ONLY demand file water volume was added back into the lowflow file to create the "top-up" D Demand File.

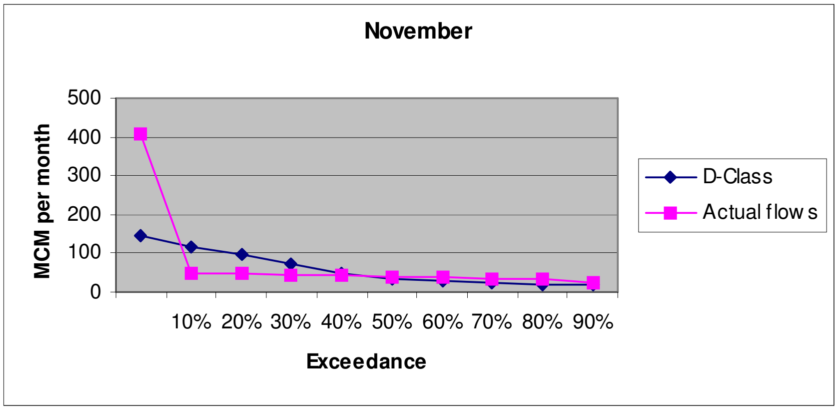

Figure 10-3: November Flow Duration Curves at Augrabies for the Total Category D, the Resultant Flows with only the D Lowflows as a Demand File and Naturalised Flows

Where the (total) Desktop D Category EFR estimations exceeded the actual flows obtained with the lowflow ONLY demand file water volume was added back into the lowflow file to create the "top-up" D Demand File.

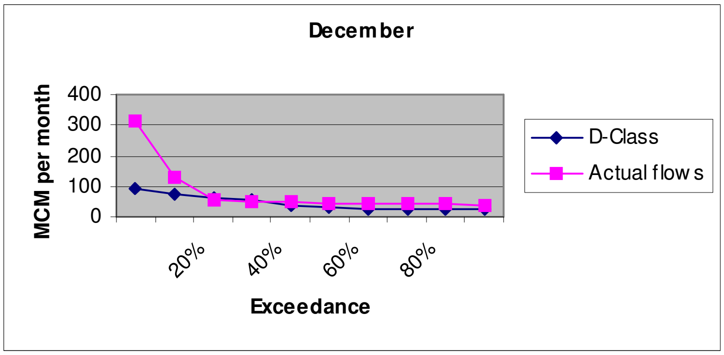

Figure 10-4: December Flow Duration Curves at Augrabies for the Total Category D and the Resultant Flows with only the D Lowflows as a Demand File

Note that the (total) Desktop D Category EFR estimations did not exceed the actual flows obtained.

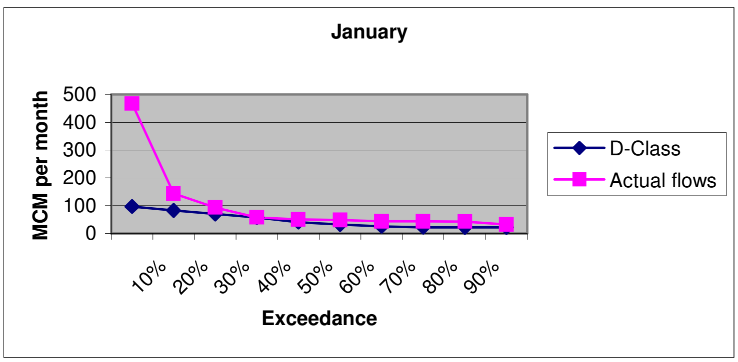

Figure 10-5: January Flow Duration Curves at Augrabies for the Total Category D and the Resultant Flows with only the D Lowflows as a Demand File

Note that the (total) Desktop D Category EFR estimations did not exceed the actual flows obtained.

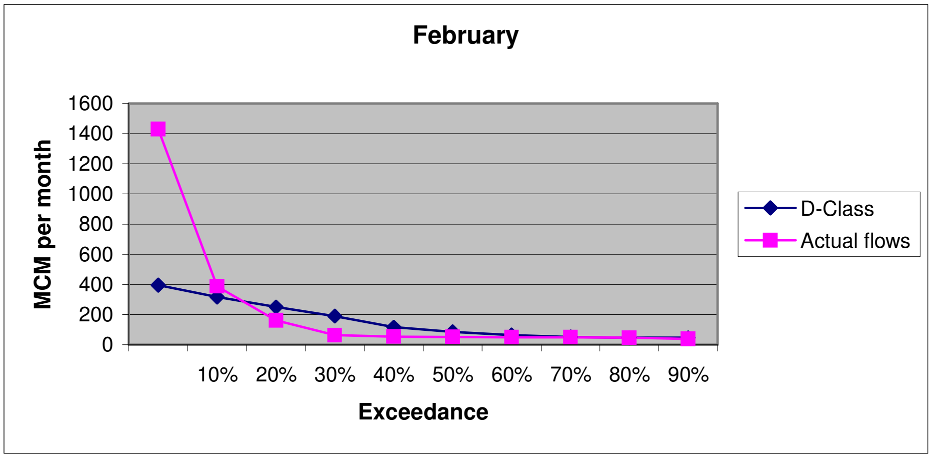

Figure 10-6: February Flow Duration Curves at Augrabies for the Total Category D and the Resultant Flows with only the D Lowflows as a Demand File (same as Figure 10-1)

Where the (total) Desktop D Category EFR estimations exceeded the actual flows at Augrabies obtained with the lowflow ONLY demand file water volume was added back into the lowflow file to create the “top-up” D Demand File.

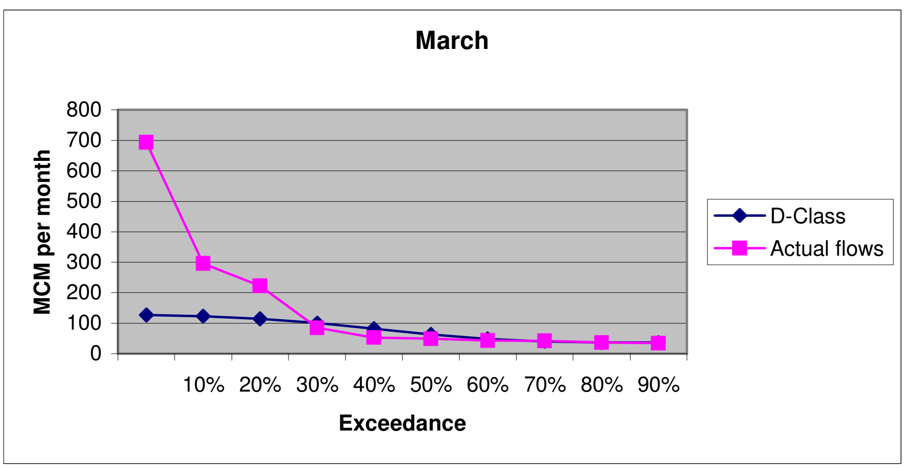

Figure 10-7: March Flow Duration Curves at Augrabies for the Total Category D and the Resultant Flows with only the D Lowflows as a Demand File

Where the (total) Desktop D Category EFR estimations exceeded the actual flows at Augrabies obtained with the lowflow ONLY demand file water volume was added back into the lowflow file to create the "top-up" D Demand File.

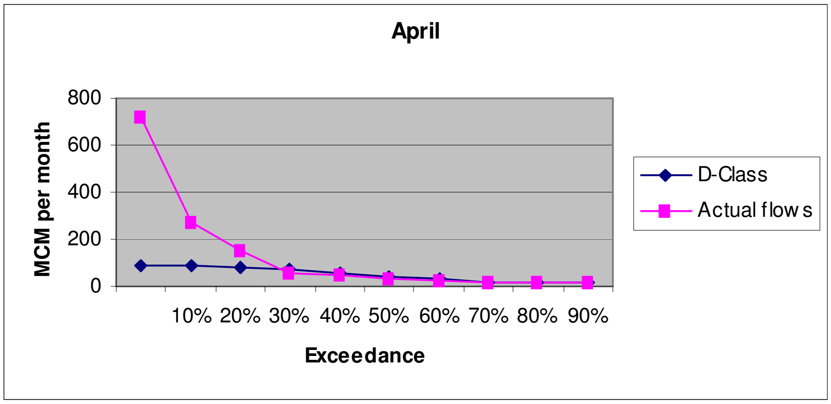

Figure 10-8: April Flow Duration Curves at Augrabies for the Total Category D and the Resultant Flows with only the D Lowflows as a Demand File

Note that the (total) Desktop D Category EFR estimations did not exceed the actual flows obtained.

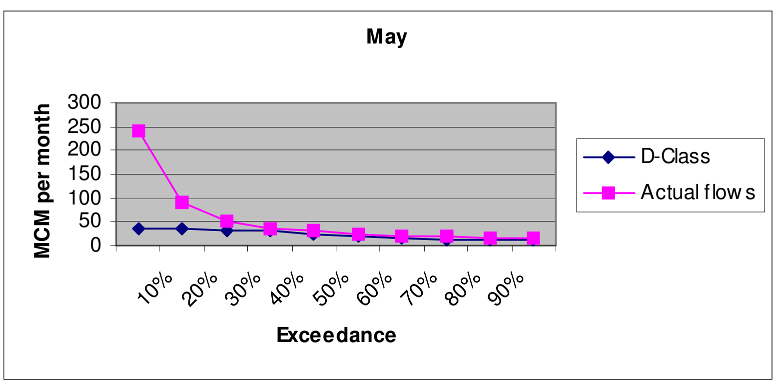

Figure 10-9: May Flow Duration Curves at Augrabies for the Total Category D and the Resultant Flows with only the D Lowflows as a Demand File

Note that the (total) Desktop D Category EFR estimations did not exceed the actual flows obtained.

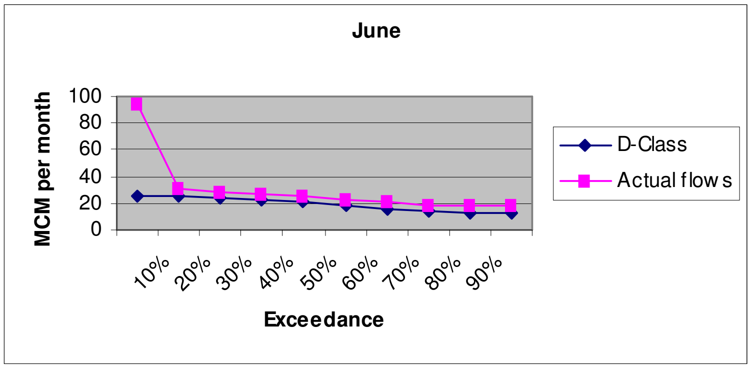

Figure 10-10: June Flow Duration Curves at Augrabies for the Total Category D and the Resultant Flows with only the D Lowflows as a Demand File

Note that the (total) Desktop D Category EFR estimations did not exceed the actual flows obtained.

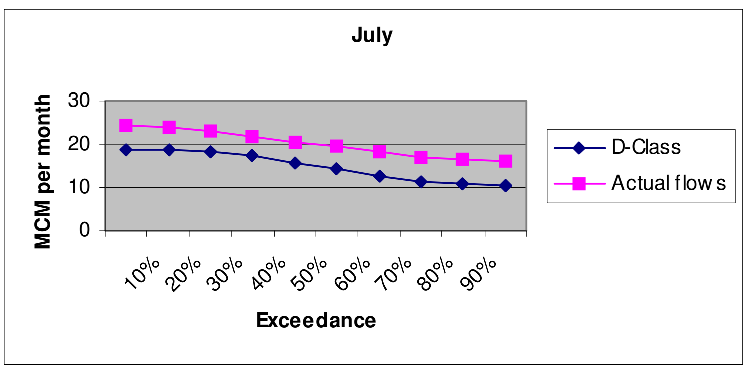

Figure 10-11: July Flow Duration Curves at Augrabies for the Total Category D and the Resultant Flows with only the D Lowflows as a Demand File

Note that the (total) Desktop D Category EFR estimations did not exceed the actual flows obtained.

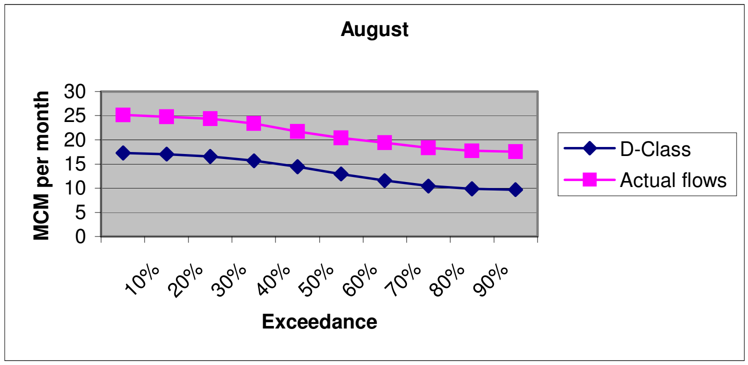

Figure 10-12: August Flow Duration Curves at Augrabies for the Total Category D and the Resultant Flows with only the D Lowflows as a Demand File

Note that the (total) Desktop D Category EFR estimations did not exceed the actual flows obtained.

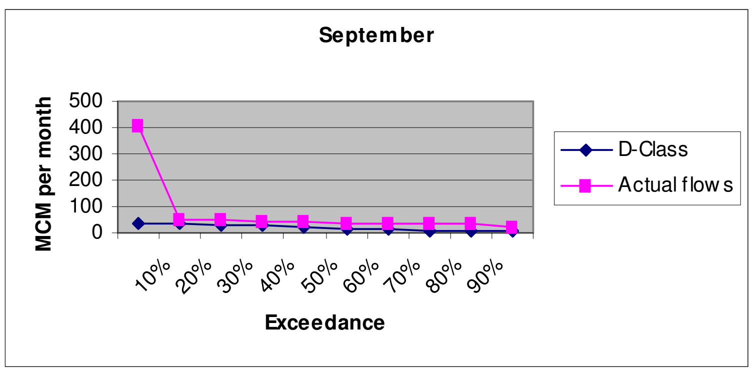

Figure 10-13: September Flow Duration Curves at Augrabies for the Total Category D and the Resultant Flows with only the D Lowflows as a Demand File

Note that the (total) Desktop D Category EFR estimations did not exceed the actual flows obtained.

10.2 Comparison between Total Desktop-D and Actual Flows at Augrabies Using the "Top-up" D Demand File

Figure 10-14 gives the annual hydrographs for the Naturalised flows, 1991-2000 Observed flows, 2005 Scenario, the Desktop D-Category EFR, the Desktop C-Category EFR and the resultant flows at Augrabies, using the "Top-up" D Demand File plus spills. The graphs clearly indicate that at the level of bulk annual flows, the "Top-up" D Demand File and spills (red dashed line) closely approximate both the 2005 scenario and the 1991-2000 Observed flows. Significantly, the 1991-2000 Observed flows were deemed by the specialists to be maintaining the river on a gradual C to C/D Category trajectory.

Figure 10-15 and **Figure 10-16** provide an indication of the expected monthly flows at Augrabies with the "Top-up" D Demand File, and the "Top-up" D Demand File plus spills, respectively. **Figure 10-17** shows the expected flows at Augrabies with the Desktop D Category EFR estimate implemented as a priority demand on Vanderkloof Dam.

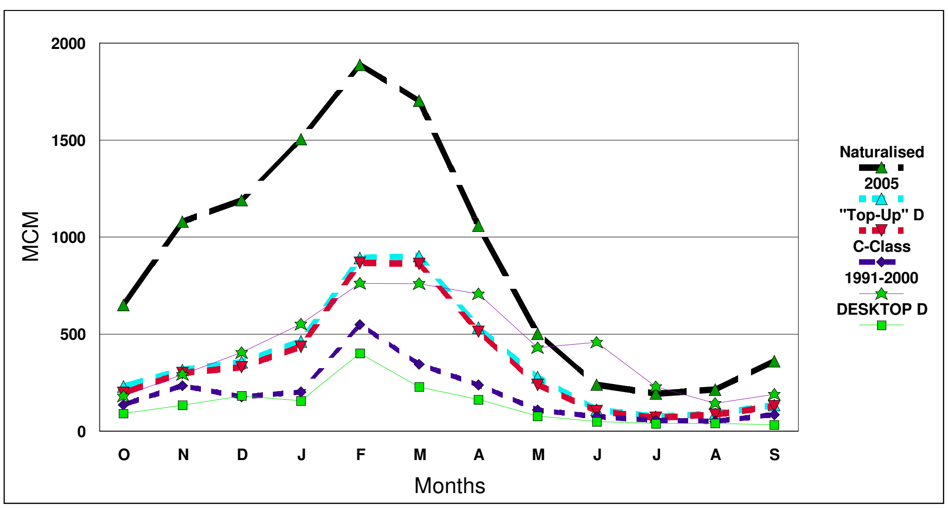

Figure 10-14: Annual Hydrographs for a Range of Modelled Scenarios Presented at the Workshop

Note: The evaluations in this Section are done using monthly hydrological data. Thus, conclusions on daily variations, e.g., lowflows versus floods, cannot be drawn from the information. The assessment is limited to comments on bulk monthly flows. Assessments of the EFRs at the level of daily flows may highlight clashes between the various scenarios that are not apparent using monthly data. Furthermore, as highlighted elsewhere in this report, variation in the flow regime is a key factor affecting ecosystem health.

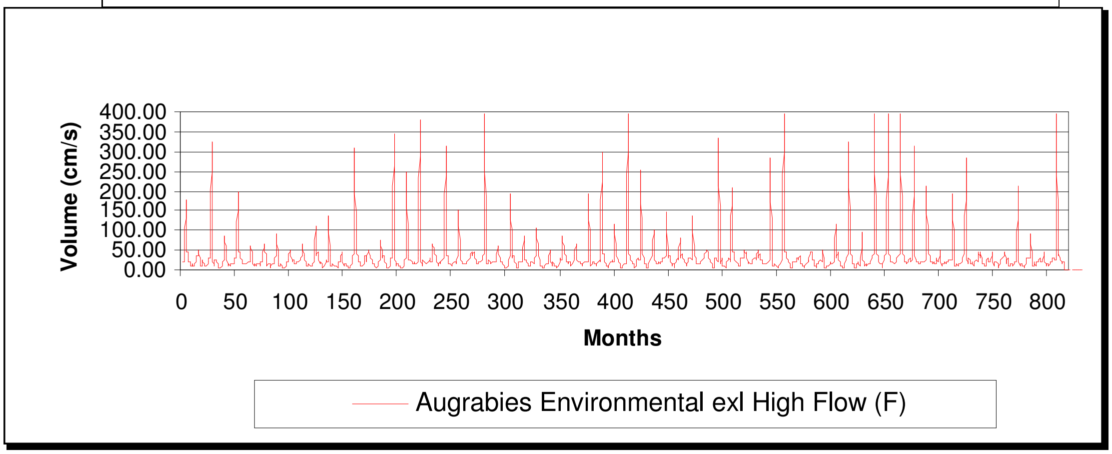

Figure 10-15: Flows at Augrabies that Represent the Desktop D Lowflows plus "Top-up" D Demand

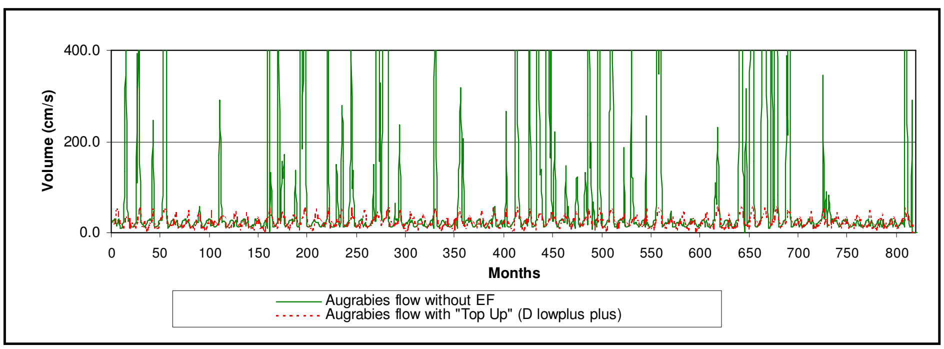

Figure 10-16: Flows at Augrabies that Represent the Desktop D Lowflows with "Top-up" D Demand and Spills Included

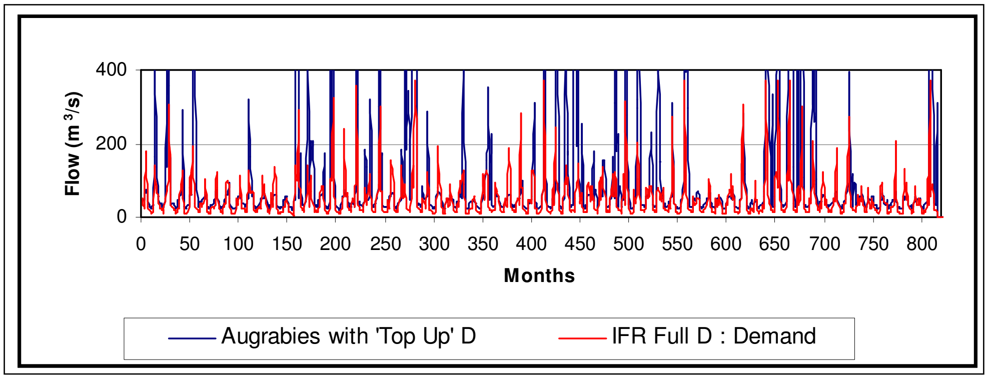

Figure 10-17: Expected Flows at Augrabies with Implementation of TOTAL D Demand File, and Expected Spills in Comparison with the Total Flow at Augrabies when the Desktop D Lowflow and "Top-up" Demand was Imposed on the System

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10.2.1 Expected Ecological Consequences

Essentially the implementation of the "Top-up" D Demand File provides a slightly more varied flow regime that would be achieved with the lowflows ONLY option, but has the advantage of not affecting the yield as negatively as reported in the LORMS' January 2002 Progress Report.

The resultant flow regime at Augrabies, if the "Top-up" D Demand File is run in conjunction with other planning scenarios, should maintain the current gradual C to C/D Category trajectory. The extent to which the negative trajectory can be halted will depend on the degree of variability that can be managed in the system, and cannot be assessed in this task. This variability will include:

- reinstatement of year-on-year variability;
- provision of intra-annual floods; and
- capping of winter releases.

The recommended category for a Comprehensive Reserve Determination would be a C-Category.

10.3 Comparison between Total Desktop-D and Actual Flows at the Mouth using the "Top-up" D Demand File

10.3.1 Extrapolation to the Mouth

The data for the hydrological comparisons at the mouth of the Orange River were generated using the same "Top-up" D Demand File at the mouth as was used for Augrabies. The actual flows file indicates the flows at the mouth for the "Top-up" D Demand File, and spills, i.e., flow down the river that is not abstracted for of stream use.

10.3.2 Comparison

Figure 10-18 provides an indication of the expected monthly flows at the mouth with the "Top-up" D Demand File and spills. **Figure 10-19** shows the expected flows at the mouth with the Desktop D Category EFR estimate implemented as a priority demand on Vanderkloof Dam.

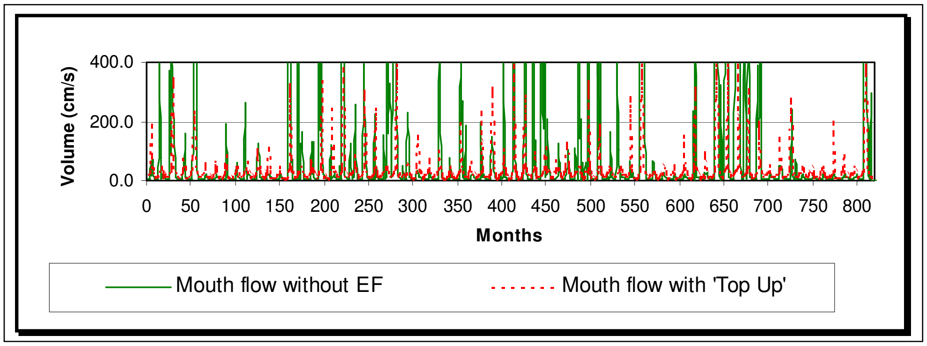

Figure 10-18: Expected Flows at the Mouth with Implementation of "Top-up" D Demand File, and Expected Spills

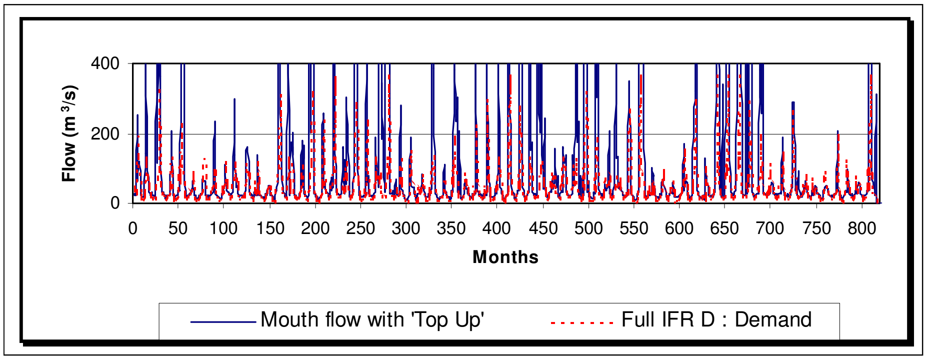

Figure 10-19: Expected Flows at the Mouth with Implementation of TOTAL D Demand File, and Expected Spills

10.3.3 Expected Ecological Consequences

As was the case for Augrabies, the implementation of the "Top-up" D Demand File for the mouth provides a slightly more varied flow regime that would be achieved with the lowflows ONLY option, but has the advantage of not affecting the yield as negatively as reported in the LORMS' January 2002 Progress Report. It is, however, expected that variability will be even more affected at the mouth than at Augrabies. Nonetheless, the resultant flow regime should maintain the current gradual C to C/D Category trajectory, i.e., declining ecological condition. The extent to which the negative trajectory can be halted will depend on the degree of variability that can be managed in the system, and cannot be assessed in this task (see **Section 10.2**).

The section of the Orange River downstream of Onseepkans was not the focus of this Task 8.3; however, general discussion during the workshop suggested strongly that the recommended category for a Comprehensive Reserve Determination for that section of the river would be a C-Category.

The expected flows at the mouth with implementation of "Top-up" D demand file, and expected spills were used as a scenario for evaluation in the estuarine process that accompanied the river work done for Task 8.3.

11. RECOMMENDATIONS FOR FUTURE WORK AND WORKSHOP CLOSING COMMENTS

11.1 Recommendations for Future Work

It was the consensus opinion of the all of the people involved in Task 8.3 that a **Comprehensive Reserve/EFR Determination on the LOR** should be undertaken as a matter of priority.

Furthermore, the Study Team stressed the importance of controlling mechanical manipulation of the river bed, banks and floodplain, as these factors are major contributors towards the decline in the condition of the riverine ecosystem and, together with changes to the flow regime, will eventually lead to its complete collapse (see The Murray Darling River in **Section 9**).

11.2 Workshop Closing Comments

Mike Luger called for closing comments and asked workshop participants to voice any issues of concern that they may have.

Bill Harding:	Noted that dams, especially in South Africa, are not natural lakes and do not function as such. The water levels in SA dams undergo large fluctuations, and artificial lakes do not have the requisite ecosystem structure (i.e., no structural habitat or established food webs) to enable them to assimilate the various inputs. Hence, artificial lakes are effectively sterile and with respect to water quality, and provide little or no buffering against poor water quality generated in their upstream catchments.
Charlie Boucher:	Added that dams also do not have the substrate for rooted water plants, as inundation levels often extend away from the natural riparian/floodplain areas into areas with very shallow and/or very poor soils, which

	makes it difficult for plants to establish themselves. However, artificial lakes do provide an ideal habitat for water hyacinth or other floating macrophytes to flourish.
Rob Palmer:	Provided an example where a dam was able to perform some lake functions with respect to water quality buffering. Bill Harding agreed but suggested that the process being observed was not sustainable.
Johan Hattingh:	Noted that geomorphology would be severely as impacted by changes in the flow regime as would the other disciplines. He stated that he strongly supports off-channel dams as they avoid the complications of an in-stream dam but maintain the benefit of storage capacity. He suggested that Koa Valley might be an ideal location for an off-channel dam.
Bill Harding:	Reiterated that off-channel dams would need to be filled without large in-channel abstraction weirs as these would defeat the purpose of having off-channel storage.
Frikkie Becker:	Mentioned that there was an international law team working on the LORMS as well. In addition, the four basin countries were obligated to inform each other of activities they undertake on their respective sections of the river. There are also agreements to the effect that activities undertaken must not harm the respective countries. Mr Bekker concluded by saying that it had been a very valuable workshop.
Chris Brown:	Chris stated that he enjoyed the workshop, that he learned a lot and thanked everyone for their input.
Charlie Boucher:	Raised the point about the amount of wood that collects at the estuary. He stated that this wood probably performs many functions, such as providing snag habitat, and hence may be valuable. Constructing a dam on the river would stop wood being washed down to the estuary, and the impacts of this would need to be investigated. Charlie concluded by thanking everyone.

Bettie Conradie:	Bettie thanked everyone for their input. She also emphasised that the environmental issues/ concerns notwithstanding, DWAF was very much aware of the need for water and the international implications of proposed planning scenarios.
Rob Palmer:	Rob said that he felt uncomfortable working with monthly flows and that he was not sure that the issue of high winter flows had been adequately addressed. Rob concluded by noting that the condition of the Orange River is on a negative trajectory and "seems to be going the way of the Vaal River".
Delana Louw:	Delana stated that the findings at the study area needs to be extrapolated down to the mouth of the Orange River in order to provide information for the estuary team. She also stated that no matter how carefully the report is written, misunderstandings may still arise. Therefore she wanted a disclaimer added to the report stating that no decisions that would affect the user can be made on the basis of the flow scenarios provided for planning estimates as documented in this report.
Manie Mare:	Thanked everyone and stated that he had also learnt a lot at the workshop.

Mike Luger thanked everyone for attending and closed the workshop.

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APPENDIX 1: BACKGROUND INFORMATION TO THE SECTION BETWEEN BOEGOEBERG DAM AND VIOOLSDRIFT. NOTES TAKEN BY THE ORANGE RIVER EXPEDITION BOAT TEAM – OCTOBER AND NOVEMBER 2002.

This information was obtained from a debriefing of the Orange River 2002 Expedition, of which Southern Waters was a sponsor.

Boegoeberg Dam to Upington

- The river is generally wide, flat and easy to navigate.
- There are places (particularly as the river gets closer to Upington) where the river splits into 2 or more channels and downriver visibility is obscured.
- There are a fair number of weirs (6-10) – although these are generally small (1–2 metres).
- One large weir was encountered at Lamprecht's Drift. This weir was right across the river (about 250m wide at this point), was approx. 5m. high with a 30m flume.
- There are also (again, particularly as one nears Upington) a multitude of abstraction pumps on both banks. Most of these pumps seem to be small "1 man show" affairs, but there are also a fair number (about 20%) that are on a far larger scale and are obviously for much larger scale irrigation. Arrays of up to a dozen pumps occur in places.
- Most of the pumps are electric, with only the odd one or two being diesel powered.
- The general vegetation was thick and strong growing. Away from the river itself, it was definitely starting to get drier and more arid, but still good.
- Wildlife was abundant. Particularly birds such as Egyptian Geese (flocks often comprising 100+ individuals), Spurwing Geese, Darters and Cormorants.
- Also noted were a variety of fish, Leguaans, Vervet Monkeys and Chacma Baboon.
- Identifications of fish were not performed but their presence was constantly noted by soundings and ripples in the water all around the boats – with, often,

large splashes as they leaped out of the water ahead of us. Fish are abundant here.

- On 2 occasions otters (Cape Clawless) were spotted playing/hunting (once, a pair) in the more fast flowing sections of the river – particularly in rapids. Their average length was c. 500 mm, and they were always fast moving.
- Insects were a huge problem on this leg. Primarily huge swarms of miggies/gnats – which bit everybody to bits and were literally swarming everywhere, but also biting flies. These flies, I believe, are called "blind flies" (at least, locally). They are approximately the same size as the average housefly, but are grey and seem to have different eyes. They settle on any exposed flesh and, once settled, within 10 seconds or so, bite with a ferocious sting – much like a horsefly. These bites/stings leave welts similar to a mosquito bite and itch like mad. Mosquitos were never really a problem.

Upington to Augrabies Falls (31-10-03 to 2-11-03)

- This stretch (we found) was very heavily populated (compared to previous stretches) and agriculture was intensive on both sides of the river.
- Mostly grapes and citrus, but some maize, etc. as well.
- Large numbers of pumps everywhere without any apparent regulation (?).
- A corollary to this water usage and agriculture was, of course, lots of weirs (not marked on the 1:250 000 scale mapping) with no apparent plan to their siting and/or construction. For example, there would be 4 or 5 different channels at a given point along the river, with a weir across only 1 channel – often not even the main and/or largest channel – with no real evidence of any intensive pump stations, etc. utilising the water that backs up behind these weirs – sometimes for 2 or 3 kilometres.
- The river course itself is an absolute nightmare – for most of the distance to Augrabies, splitting into (sometimes) dozens of high flow (20+ kph) rate channels – all heavily wooded, with thick stands of reeds, etc.
- Wildlife was prolific – predominantly birds, but still lots of fish, monkeys and baboons as well.
- Generally, the area is very lush near the river, but, away from the river, getting drier all the time.
- Insects on this stretch were much less obvious.
- The geography of this stretch too, was different to pre-Upington. Here, it was

very rocky in places and a lot more rapids. The river gradient generally seemed steeper compared to the pre-Upington leg.

- Water temperatures were warmer too

Augrabies Falls to Onseepkans

- Here the terrain becomes steadily drier towards the Richtersveld.
- The river generally flat and quite sluggish – with very few channels now – and temperatures still rising (39 to 42 degrees Celsius average).
- Vegetation reduced by as much as 60 % over previous, with, basically, just thin strips of green along each bank and semi-desert beyond that.
- Wildlife and birds also very much reduced.
- Very few insects.
- Agricultural activity limited to within 30 km downstream of Augrabies, and negligible thereafter.
- Nomadic (seemingly) fishermen in small groups seemed to be quite prevalent on this stretch. Most of their catch consisted of big barbell. Average size seen on drying racks on the banks was up to 2m.. We were able to get a close look at this specimen and take some measurements. A specimen measured in the river was approx 2.8 m. in length and weighed close to 45 kg, and a mouth width of 300+ mm.
- Large groups of barbel (40+ individuals) were observed unconcernedly surface feeding in quiet eddies. They seemed to be “vacuuming” the detritus that gathers on the surface.

Onseepkans to Vioolsdrif

- Temperatures always over 40 Celsius.
- A mountainous area.
- Wildlife now very scarce – as well as birds.
- No agriculture apart from the odd homestead.
- Very large barbel beneath the falls.
- Pella Drif and Klein Pella provide small oases in the desert and home to lots of Vervet monkeys (troops of 60+ individuals – the largest troops I have ever seen) They seem to feed on the date palms.
- Yellowfish caught at Witdrif. They appear to be prolific in the river.

- Goodhouse. On the Namibian side here, there is a huge, green farm, which is very well run. On the S.A. side, there's nothing except a pump station, which was recently built to irrigate a huge planned collective paprika farm that is to be established here.
- Came across a local woman who had been hired by DWAF to mark all the alien vegetation along the river for cutting and she had some pretty sophisticated G.P.S. equipment with her.
- The only weir that the Boat Team came across on this stretch was about 15 km upriver from Vioolsdrif and is very large – about 20m high and holds back the water for a good 7-8 km behind it.
- One thing to note about this "mini dam" is that there seem to be a lot of locals who fish here using drift nets with floats, and which trap everything indiscriminately. We were told that these guys take huge hauls of fish out of the river on a regular basis and are (evidently) rapidly depleting the fish stocks.
- Huge and impenetrable reed banks around Vioolsdrif.

APPENDIX 2: NATURALISED, 2005 AND DESKTOP HYDROLOGICAL DATA

File Name : Augrabies Naturalised

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	TOTAL
1948	176.72	212.04	92.99	464.04	477.49	636.30	267.40	231.09	118.81	73.75	49.67	29.73	2830.03
1949	153.34	1088.73	1822.99	882.21	806.37	3117.87	3566.44	2113.31	518.93	382.96	1044.16	414.86	15912.17
1950	143.33	94.90	1429.83	1559.01	693.93	617.25	547.61	247.50	161.63	130.95	105.80	102.74	5834.48
1951	1810.83	553.33	253.48	499.85	1287.33	645.64	318.16	136.81	123.01	564.42	352.95	213.12	6758.93
1952	136.04	694.82	752.43	358.40	2871.90	1192.45	1042.69	383.79	129.81	69.80	71.15	56.29	7759.57
1953	543.36	626.10	865.83	605.80	1138.73	3326.90	1111.90	290.90	184.34	111.34	45.64	25.08	8875.92
1954	65.36	413.08	600.27	3447.36	6484.45	1850.86	795.20	464.04	191.32	146.57	89.36	34.73	14582.60
1955	171.13	640.63	1340.05	685.56	2202.28	3085.08	1743.07	488.59	186.31	112.89	69.04	49.67	10774.30
1956	327.73	1138.91	4764.89	2336.71	1007.62	1003.22	475.24	120.62	109.61	425.52	466.76	4896.45	17073.28
1957	5111.82	1773.65	1259.25	3779.87	1192.72	389.31	763.85	972.50	381.67	110.67	68.39	144.75	15948.45
1958	98.58	924.78	1398.66	769.96	780.44	484.52	1066.39	1726.54	384.22	504.65	241.33	71.84	8451.91
1959	461.98	938.36	1655.41	915.84	1174.26	1270.42	798.93	380.07	169.66	130.04	236.73	174.40	8306.10
1960	441.64	816.59	1894.06	1133.90	472.11	2424.70	2507.20	802.83	874.62	255.72	367.96	88.93	12080.26
1961	63.05	1246.52	1792.52	609.62	3649.57	1330.53	409.29	422.93	116.79	71.41	50.13	60.44	9822.80
1962	61.87	1339.10	690.54	3708.54	1499.75	2296.68	2387.81	376.94	161.75	512.76	257.91	127.40	13421.05
1963	215.02	1752.18	1129.89	1077.83	481.46	1229.73	1081.54	175.70	161.77	176.91	156.15	157.80	7795.98
1964	2487.90	1879.02	880.26	1049.13	502.71	151.19	908.90	285.34	216.02	176.71	170.29	296.83	9004.30
1965	289.20	347.78	161.11	2819.56	2666.22	309.26	89.71	78.71	59.93	39.90	37.07	26.58	6925.03
1966	59.19	288.25	910.80	4484.99	5375.75	1641.29	3343.14	1448.38	1067.30	286.82	163.85	118.95	19188.71
1967	104.54	704.25	577.05	171.66	86.26	558.31	574.20	699.97	177.90	145.10	70.83	125.57	3995.64
1968	74.67	93.96	760.80	210.99	280.69	1335.10	1171.50	459.01	238.79	86.27	81.40	33.48	4826.66
1969	929.14	460.85	882.90	426.36	569.60	100.10	24.89	27.80	32.62	46.24	55.80	189.51	3745.81
1970	847.06	505.67	1112.35	1148.68	1131.71	479.25	1435.82	626.16	140.85	92.78	73.09	84.24	7677.66
1971	91.42	495.55	904.43	2769.72	3321.20	3766.83	994.22	630.08	180.40	98.77	74.96	61.45	13389.03
1972	202.53	329.19	162.83	50.99	928.99	545.85	490.20	117.12	70.52	40.19	320.19	221.20	3479.80
1973	269.18	392.39	1084.08	5323.86	7948.32	6093.12	2013.47	879.60	461.07	185.77	1183.14	314.61	26148.61
1974	88.34	1981.69	1915.40	2089.42	5682.56	3205.61	794.96	310.22	178.20	279.26	153.23	302.24	16981.13
1975	566.08	1620.11	3379.11	6148.30	7482.69	7232.91	2769.62	1786.76	692.48	355.15	211.16	410.44	32654.81
1976	4124.26	2406.35	633.35	911.93	3166.94	2694.20	657.18	254.55	154.73	123.58	91.82	313.53	15532.42
1977	978.42	615.19	681.23	3419.88	1593.21	1301.22	3375.33	594.81	238.22	193.12	148.04	501.94	13640.61
1978	680.33	282.09	2037.26	446.88	555.60	454.48	113.10	132.09	117.71	267.36	1181.93	710.13	6978.96
1979	1042.19	686.09	860.51	733.88	1332.37	804.47	181.98	71.21	61.13	65.90	127.69	298.01	6265.43
1980	286.54	545.23	923.78	2279.97	2644.05	2134.80	460.16	362.89	551.30	148.58	802.90	720.32	11860.52
1981	219.69	499.91	1001.15	507.71	327.92	338.72	1397.19	459.70	176.70	185.98	126.05	98.57	5339.29
1982	470.21	1768.89	243.54	116.61	125.00	107.09	113.24	129.53	145.23	191.80	142.71	60.89	3614.74
1983	302.02	1150.49	1457.18	1589.56	304.17	333.85	331.43	374.17	82.09	64.49	95.26	217.56	6302.27
1984	232.51	443.58	319.78	397.89	1580.15	952.38	238.12	56.78	79.68	52.59	39.89	25.95	4419.30
1985	351.96	1365.79	2272.87	987.00	849.72	385.31	236.89	94.97	171.77	63.15	98.98	339.65	7218.06
1986	1007.78	3070.56	566.92	398.21	304.94	395.60	464.55	79.75	42.24	45.33	288.44	3407.27	10071.59
1987	3607.68	2143.06	1708.73	763.16	9775.23	783.73	2010.16	551.66	352.95	317.93	324.96	1509.64	23848.89

File Name : Augrabies 2005

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1947	75.80	84.86	92.33	98.14	74.31	958.18	269.43	40.68	28.64	24.20	30.51	40.91	1817.99
1948	75.80	84.86	92.33	98.14	74.31	65.21	54.26	40.68	28.65	24.21	30.51	40.91	709.87
1949	75.80	84.86	92.33	98.14	74.31	65.21	54.25	205.20	90.90	100.15	561.82	40.90	1543.87
1950	75.80	84.86	92.33	98.14	74.31	65.21	54.25	40.68	28.64	24.20	30.51	40.91	709.85
1951	75.80	84.86	92.33	98.14	74.31	65.21	54.25	40.68	28.65	24.20	30.51	40.91	709.85
1952	75.80	84.86	92.33	98.14	74.31	65.21	54.25	40.68	28.64	24.21	30.51	40.91	709.86
1953	75.80	84.86	92.33	98.14	74.31	65.21	452.42	83.20	28.64	24.20	30.51	40.91	1150.52
1954	75.80	84.86	92.33	98.14	2039.00	430.75	329.72	164.87	28.64	24.20	30.50	40.91	3439.72
1955	75.80	84.86	92.33	98.14	74.31	945.36	909.29	171.56	28.64	24.20	30.51	40.91	2575.91
1956	75.80	84.86	610.87	540.20	326.12	370.84	54.25	40.68	28.64	24.20	30.50	1194.66	3381.63
1957	2255.74	732.43	258.99	1675.28	335.60	65.21	54.25	619.44	142.83	24.20	30.51	40.91	6235.39
1958	75.80	84.86	92.33	98.14	74.31	65.21	54.25	536.22	100.48	180.88	30.50	40.91	1433.89
1959	75.80	84.86	92.33	98.14	250.48	548.58	316.53	85.96	28.64	24.20	30.50	40.90	1676.93
1960	75.80	84.86	92.33	98.14	74.31	470.36	993.19	380.51	521.39	24.20	30.50	40.91	2886.51
1961	75.80	84.86	92.33	98.14	2236.51	716.41	54.25	100.63	28.64	24.21	30.51	40.91	3583.20
1962	75.80	84.86	92.33	583.56	655.34	1790.11	1906.37	138.94	28.64	24.20	30.50	40.91	5451.56
1963	75.80	84.86	166.50	98.14	74.31	72.26	624.32	40.68	28.64	24.21	30.51	40.91	1361.15
1964	188.75	123.36	92.33	98.14	74.31	65.21	54.25	40.68	28.65	24.21	30.51	40.91	861.31
1965	75.80	84.86	92.33	98.14	617.43	65.21	54.26	40.68	28.65	24.21	30.51	40.91	1253.00
1966	75.80	84.86	92.33	98.14	435.73	498.08	2039.79	1013.51	749.83	24.20	30.50	40.91	5183.69
1967	75.80	84.86	92.33	98.14	74.31	65.21	54.25	40.68	28.64	24.20	30.51	40.91	709.85
1968	75.80	84.86	92.33	98.14	74.31	65.21	54.25	40.68	28.64	24.21	30.51	40.91	709.86
1969	75.80	84.86	92.33	98.14	74.31	65.21	54.26	40.68	28.65	24.21	30.50	40.90	709.85
1970	75.80	84.86	92.32	98.14	74.30	65.21	54.25	40.68	28.64	24.21	30.51	40.91	709.84
1971	75.80	84.86	92.32	98.14	74.30	272.16	54.25	40.68	28.64	24.21	30.51	40.91	916.80
1972	75.80	84.86	92.33	98.14	74.31	65.21	54.25	40.68	28.65	24.21	30.50	40.90	709.84
1973	75.80	84.86	92.33	98.14	1558.63	4438.85	958.82	616.78	225.23	24.21	862.55	40.91	9077.11
1974	75.80	84.86	182.75	98.14	978.52	1318.71	54.25	40.68	28.64	24.20	30.50	40.91	2957.98
1975	75.80	84.86	365.72	2691.60	3804.94	4709.16	1914.36	943.70	322.86	45.47	30.50	40.90	15029.87
1976	2476.16	1431.29	92.33	98.14	691.97	1950.99	86.78	40.68	28.64	24.20	30.51	40.90	6992.59
1977	75.80	84.86	92.33	98.14	230.07	165.44	2229.28	221.08	28.64	24.20	30.50	40.90	3321.25
1978	75.80	84.86	148.66	98.14	74.31	65.21	54.26	40.68	28.65	24.20	30.50	40.90	766.18
1979	75.80	84.86	92.33	98.14	74.31	65.21	54.25	40.68	28.65	24.21	30.51	40.91	709.86
1980	75.80	84.86	92.33	98.14	74.31	248.30	54.25	84.15	276.19	24.20	211.07	142.01	1465.60
1981	75.80	84.86	92.33	98.14	74.31	65.21	54.25	40.68	28.64	24.20	30.51	40.91	709.85
1982	75.80	84.86	92.33	98.14	74.31	65.21	54.26	40.68	28.65	24.20	30.51	40.91	709.87
1983	75.80	84.86	92.33	98.14	74.31	65.21	54.25	40.68	28.65	24.21	30.51	40.91	709.86
1984	75.80	84.86	92.33	98.14	74.31	65.21	54.25	40.68	28.65	24.21	30.51	40.91	709.86
1985	75.80	84.86	92.33	98.14	74.31	65.21	54.25	40.68	28.64	24.21	30.51	40.90	709.84
1986	75.80	84.86	92.33	98.14	74.31	65.21	54.25	40.68	28.65	24.21	30.50	40.90	709.84
1987	75.80	84.86	92.33	98.14	5961.47	5679.51	1134.07	216.65	115.26	24.20	30.50	826.30	14339.09

IFR Modified Flow Data Management Category D

YEAR	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	TOTAL
1947	132.103	78.034	258.256	190.157	270.008	344.671	230.273	80.739	40.669	30.453	29.251	24.270	1708.884
1948	52.159	56.480	68.017	88.140	133.406	144.324	95.981	71.899	41.985	31.490	29.851	24.250	837.983
1949	47.912	182.958	314.862	120.822	212.209	339.083	233.150	98.634	62.098	50.166	50.835	42.138	1754.867
1950	46.864	55.592	250.946	199.127	168.171	135.080	138.629	74.225	52.011	42.369	39.987	31.316	1234.317
1951	143.419	104.239	69.622	90.049	453.513	148.856	99.311	61.288	42.899	50.443	50.414	39.381	1353.434
1952	46.100	139.066	105.034	84.046	678.331	225.625	211.870	88.941	44.377	30.693	33.842	26.066	1713.991
1953	125.617	122.703	127.065	95.760	294.960	340.073	217.122	79.347	56.523	39.590	29.037	23.960	1551.756
1954	35.071	65.525	87.124	277.573	900.922	312.208	180.889	91.461	56.888	43.936	38.031	24.655	2114.281
1955	51.144	126.389	231.308	101.722	592.228	338.720	227.724	92.155	56.626	39.813	32.356	25.505	1915.690
1956	95.573	187.110	385.728	241.517	260.627	195.411	122.751	59.211	39.700	50.255	50.642	42.775	1731.300
1957	144.530	211.146	219.467	277.800	352.566	119.474	174.553	97.951	61.388	39.494	31.898	35.846	1766.114
1958	41.466	169.164	244.128	111.904	194.841	127.864	213.668	98.498	61.405	50.362	48.549	27.985	1389.836
1959	117.472	170.942	275.867	123.494	332.869	249.189	181.643	88.824	53.613	42.278	48.449	37.585	1722.224
1960	114.263	155.004	327.486	145.228	133.261	329.970	231.793	97.247	62.413	48.919	50.449	29.581	1725.613
1961	34.804	196.016	305.822	96.046	821.729	275.206	106.880	90.179	41.546	31.018	29.944	26.417	2055.606
1962	34.668	197.899	96.085	277.751	520.544	326.590	231.198	88.500	52.043	50.373	49.261	34.356	1959.270
1963	64.903	210.123	204.112	137.857	133.513	231.578	214.818	63.716	52.048	46.479	46.042	36.612	1441.800
1964	143.714	215.573	129.949	134.084	135.866	117.859	201.349	78.691	58.071	46.468	46.830	41.075	1349.528
1965	88.150	60.722	68.076	253.318	641.787	117.909	89.520	55.907	35.582	28.290	28.558	24.054	1491.872
1966	34.668	57.956	136.054	278.282	898.890	293.781	233.052	98.398	62.486	49.591	46.471	33.321	2222.950
1967	42.802	140.300	84.819	84.046	86.260	131.875	141.842	96.852	55.246	43.788	33.617	34.132	975.580
1968	36.283	55.592	106.244	84.046	129.792	277.184	218.183	91.319	58.466	34.411	35.943	24.554	1152.016
1969	139.981	71.647	130.477	85.462	143.143	100.100	24.890	27.800	32.620	28.501	30.875	38.471	853.967
1970	137.857	91.700	198.663	147.171	287.469	127.415	223.031	95.352	46.541	36.149	34.240	29.143	1454.731
1971	39.861	81.871	134.780	252.100	760.007	342.157	208.193	95.426	55.742	37.623	34.623	26.556	2068.940
1972	56.848	59.529	68.081	50.990	243.618	131.198	128.569	58.762	36.089	28.290	49.995	39.610	951.579
1973	84.293	63.805	189.881	278.855	902.994	344.711	229.226	97.542	61.899	46.987	50.899	41.535	2392.628
1974	39.170	216.175	331.277	226.761	899.453	339.499	180.840	81.601	55.306	49.428	45.688	41.331	2506.528
1975	126.598	203.616	385.212	278.998	902.751	344.945	232.188	98.520	62.283	50.107	47.931	42.127	2775.277
1976	144.315	217.982	90.408	123.183	731.012	334.389	155.171	75.057	50.178	41.349	38.323	41.517	2042.885
1977	141.275	119.934	95.161	276.040	530.013	262.520	233.101	94.756	58.456	47.385	45.060	42.358	1946.059
1978	131.533	57.837	352.923	87.225	141.684	125.308	89.520	60.993	41.746	49.170	50.898	42.552	1231.388
1979	142.173	137.924	126.002	106.603	482.297	167.732	91.024	55.320	35.647	29.879	42.596	41.131	1458.327
1980	87.638	102.108	140.086	238.185	639.419	322.315	117.663	87.047	62.179	44.137	50.754	42.553	1934.084
1981	67.915	86.106	164.120	90.473	130.014	118.364	222.202	91.339	55.008	46.999	42.397	30.749	1145.685
1982	118.751	210.946	69.101	84.046	125.000	107.090	89.520	60.595	47.653	47.313	44.414	26.479	1030.909
1983	90.620	188.069	256.929	201.317	129.792	118.289	100.181	88.214	37.163	29.584	38.733	39.552	1318.443
1984	77.229	68.060	72.638	84.638	528.690	187.293	94.061	55.320	36.845	28.979	28.696	24.014	1286.462
1985	100.114	198.442	363.465	129.147	226.470	119.085	93.987	56.845	54.031	29.469	39.175	41.949	1452.180
1986	142.046	219.674	84.162	84.642	129.799	120.087	118.594	55.988	35.001	28.425	49.619	42.741	1110.778
1987	144.203	216.861	280.961	110.905	903.948	165.268	229.207	93.937	60.475	49.973	50.056	42.628	2348.423
Mean	***91.974***	***134.965***	***183.716***	***156.918***	***402.164***	***229.168***	***164.603***	***78.211***	***49.999***	***40.422***	***40.653***	***33.788***	***1606.583***

APPENDIX 3:SUMMARY OF THE WATER QUALITY STATISTICS USED IN THIS STUDY

Statistic	pH	TKN	Nox	NH4	Talk	Na	Mg	Si	TP	PO4-P	SO4	Cl	K	Ca	TEMP	EC	SAR	NTU	Chla	TSS	Phae	Hard
D7H008 Boegoeberg																						
Number of Records	552		547	533	547	547	547	533		533	546	547	533	547	1	753	541	4				127
Minimum	6.73		0.02	0.02	32	3	4.059	0.63		0.003	2	1.5	0.15	7	18	15.6	0.2	6.9				49.33
5% Percentile	7.2		0.02	0.02	70.82	7.06	6.63	2.862		0.006	6.1	4.6	1.22	17.88	18	18	0.36	8.1				73.18
25% Percentile	7.9		0.115	0.02	80.5	9.9	7.8	5.79		0.015	12.6	7.8	1.57	20.4	18	20.9	0.46	13				84.35
L95% Conf Limit	8.02		0.288	0.04	87.57	14.84	9.572	6.475		0.024	22.7	14	2.27	23.06	18	25.99	0.63	6.1				94.47
Median	8.16		0.294	0.04	87.6	12.6	9.1	6.97		0.022	19.18	12	1.95	22.76	18	24.5	0.58	16				93.86
U95% Conf Limit	8.09		0.325	0.05	89.88	16.47	10.07	6.767		0.027	26.17	16	2.49	23.99	18	27.24	0.68	33				104.1
75% Percentile	8.32		0.469	0.06	96.38	18.3	11	7.79		0.031	31.04	18	2.92	24.99	18	29.8	0.79	22				106.6
95% Percentile	8.55		0.691	0.11	107.9	31.27	15.22	8.7		0.058	59.58	32	4.6	32.84	18	41.38	1.19	35				144.5
Maximum	9.32		0.982	0.46	169.1	96.5	30.89	13.98		0.192	200.6	135	16.7	64.7	18	92.2	2.77	39				267.2
Mean	8.06		0.307	0.04	88.73	15.65	9.822	6.621		0.026	24.44	15	2.38	23.52	18	26.62	0.65	19				99.28
Standard Deviation	0.4		0.219	0.04	13.82	9.751	2.986	1.723		0.02	20.67	12	1.33	5.53	0	8.772	0.29	13				27.68
% Variation Coefnt	5.06		71.4	83.3	15.58	62.29	30.4	26.02		79.39	84.57	85	55.7	23.51	0	32.96	45.2	70				27.88
D7R001 Boegoeberg Dam																						
Number of Records	111	50	111	109	111	110	110	109	50	110	110	110	110	110		121	110	4	45	51	45	49
Minimum	5.76	0.179	0.02	0.02	62.8	5.5	3.3	3.62	0.025	0.003	2	1.5	0.45	10.7		16.4	0.29	0.5	0.5	2.5	1	69.64
5% Percentile	6.745	0.278	0.02	0.02	68.74	6.914	6.545	5.452	0.039	0.003	2.945	3.545	1.103	16.39		17.4	0.344	0.842	1	12.7	2.5	76.7
25% Percentile	7.24	0.451	0.11	0.02	75.29	8.675	7.3	6.653	0.052	0.011	8.125	5.725	1.493	18.9		20.5	0.41	2.21	2.05	21.1	2.5	84.4

Statistic	pH	TKN	Nox	NH4	Talk	Na	Mg	Si	TP	PO4-P	SO4	Cl	K	Ca	TEMP	EC	SAR	NTU	Chla	TSS	Phae	Hard
L95% Conf Limit	7.563	0.512	0.259	0.041	81.91	11.79	8.667	7.301	0	0.013	15.12	10.54	1.726	20.78		23.85	0.53	0.992	5.028	42.7	5.539	94.14
Median	7.7	0.512	0.305	0.04	82.6	10.91	8.413	7.72	0.065	0.02	14.3	10.32	1.76	21.21		23.1	0.51	5.6	4.67	36.4	6.73	97.15
U95% Conf Limit	7.798	0.642	0.344	0.082	93.31	14.36	10.12	7.883	0.337	0.058	20.17	13.68	1.94	23.62		26.75	0.626	9.908	9.758	79.1	9.095	120
75% Percentile	8.207	0.693	0.466	0.06	91.99	14.45	9.898	8.4	0.107	0.032	21.85	14.44	2.096	23.4		27.8	0.638	8.84	8.65	76.67	8.73	114.6
95% Percentile	8.535	1.004	0.604	0.114	105.8	29.26	15	9.92	0.203	0.07	48.91	33.47	2.926	29.64		40.1	1.095	9.848	27.72	192	16.72	138.4
Maximum	9.213	1.347	1.6	1.028	359.2	46.7	39.94	13.69	4.366	1.272	59.72	35.62	4.033	87.05		78	2.168	10.1	35.54	318	32.53	381.9
Mean	7.681	0.577	0.302	0.062	87.61	13.07	9.396	7.592	0.169	0.036	17.65	12.11	1.833	22.2		25.3	0.578	5.45	7.393	60.9	7.317	107
Standard Deviation	0.63	0.235	0.229	0.11	30.64	6.866	3.901	1.552	0.607	0.12	13.52	8.418	0.571	7.593		8.132	0.257	4.549	8.094	66.31	6.084	46.1
% Variation Coefnt	8.21	40.69	75.94	177.9	34.97	52.51	41.52	20.44	359.6	330.8	76.6	69.52	31.19	34.21		32.14	44.44	83.46	109.5	108.9	83.15	43.06
D7H005 Upington																						
Number of Records	248	140	248	242	248	248	248	242	140	248	248	248	248	248		248	246		22	80	21	40
Minimum	5.54	0.291	0.02	0.02	53.1	4.9	6.3	1.31	0.027	0.003	5.6	4.2	0.96	8.5		17.4	0.25		1	2	2.5	76.43
5% Percentile	7.104	0.423	0.02	0.02	68.11	9.455	7.2	3.244	0.037	0.007	9.336	7.335	1.333	18.82		21	0.456		1.596	5.99	2.5	82.27
25% Percentile	7.745	0.547	0.071	0.02	80	12.8	8.81	5.93	0.054	0.016	15.38	11.3	1.78	21.87		25.17	0.57		5.802	57.05	5.97	93.3
L95% Conf Limit	7.942	0.654	0.328	0.036	94.15	18.18	10.6	6.453	0.079	0.029	23.64	17.04	2.342	24.18		30.46	0.755		7.593	638.6	7.982	104
Median	8.165	0.614	0.307	0.02	97.15	16.05	10.2	7.055	0.07	0.024	21.3	15	2.185	23.9		29.15	0.695		8.265	509	10.03	103.8
U95% Conf Limit	8.055	0.754	0.408	0.045	99.16	20.79	11.3	6.879	0.101	0.038	27.45	20.11	2.58	25.38		32.69	0.839		13.41	1241	13.72	118.3
75% Percentile	8.31	0.768	0.581	0.052	112.7	23.83	12.6	7.948	0.102	0.037	32.15	22.7	3.013	26.92		35.93	0.957		16.41	1099	11.85	130
95% Percentile	8.457	1.219	0.915	0.08	131	39.99	17.2	8.658	0.213	0.087	52.95	36.31	4.52	32.97		48.1	1.41		22.42	3273	21.14	145.5
Maximum	8.861	2.254	2.017	0.44	152.8	88.3	23.1	9.33	0.423	0.323	119.1	126.4	5.67	50.9		76.6	2.58		22.89	8522	29.34	164.7
Mean	7.999	0.704	0.368	0.04	96.66	19.49	11	6.666	0.09	0.034	25.55	18.58	2.461	24.78		31.58	0.797		10.5	939.9	10.85	111.1
Standard Deviation	0.451	0.303	0.319	0.036	20.14	10.49	3.06	1.693	0.065	0.037	15.3	12.34	0.957	4.825		8.946	0.333		6.961	1375	6.707	22.93

Statistic	pH	TKN	Nox	NH4	Talk	Na	Mg	Si	TP	PO4-P	SO4	Cl	K	Ca	TEMP	EC	SAR	NTU	Chla	TSS	Phae	Hard
% Variation Coefnt	5.647	43.1	86.65	88.9	20.84	53.8	27.8	25.39	72.7	109.1	59.89	66.41	38.89	19.47		28.33	41.76		66.29	146.3	61.82	20.63
D8H004 Onseepkans																						
Number of Records	553	290	549	543	549	545	545	543	290	543	545	545	543	545		943	532					8
Minimum	6.02	0.246	0.02	0.02	56.9	6.8	5.3	0.2	0.013	0.003	5.3	3.7	1.01	17.3		11.3	0.33					99.4
5% Percentile	6.988	0.352	0.02	0.02	76.5	10.72	8.02	2.532	0.034	0.005	9.82	7.4	1.31	20.04		21.1	0.51					102.4
25% Percentile	7.8	0.5	0.02	0.02	93.5	16.6	9.9	5.655	0.057	0.013	17.2	12.5	1.59	23.9		26.15	0.71					110
L95% Conf Limit	8.004	0.632	0.149	0.032	112	23.41	12.23	6.545	0.091	0.022	28.58	19.06	2.329	27.02		32.01	0.908					111.1
Median	8.24	0.608	0.047	0.02	112.1	21.3	11.7	7.17	0.077	0.019	26	17.1	2.11	27.2		31	0.86					124.8
U95% Conf Limit	8.086	0.693	0.185	0.038	116.4	25.47	12.86	6.913	0.108	0.025	31.62	21.14	2.508	27.84		33.2	0.969					126.9
75% Percentile	8.38	0.78	0.25	0.047	130.2	29.4	14.2	8.095	0.114	0.029	37.6	24	2.99	30.6		36.7	1.083					125.6
95% Percentile	8.53	1.083	0.625	0.078	162.9	47.58	19.98	9.889	0.222	0.064	64.7	44.88	4.646	35.86		51.48	1.624					130.3
Maximum	8.81	2.305	1.24	0.52	216.5	87.4	28.9	11.79	0.592	0.14	134.5	102.5	6.09	50.4		74.1	2.92					132.3
Mean	8.045	0.662	0.167	0.035	114.2	24.44	12.54	6.729	0.1	0.024	30.1	20.1	2.419	27.43		32.61	0.939					119
Standard Deviation	0.494	0.265	0.22	0.031	26.13	12.24	3.777	2.186	0.076	0.019	18.05	12.37	1.066	4.881		9.322	0.361					11.44
% Variation Coefnt	6.14	40.11	131.9	88.1	22.89	50.07	30.11	32.48	76.12	78.94	59.98	61.55	44.06	17.8		28.59	38.45					9.612
D8H003 Vioolsdrif																						
Number of Records	735	401	732	721	732	729	727	721	396	725	729	729	725	726		1164	709	22		7		139
Minimum	6.26	0.086	0.02	0.02	55	7.3	6.276	0.2	0.008	0.003	2	4.9	0.15	15.04		19.1	0.36	0.5		170		80.1
5% Percentile	7.148	0.34	0.02	0.02	81.8	10.54	8.106	1.1	0.035	0.005	9.4	6.54	1.38	20.4		21.9	0.49	5.332		173		88.23
25% Percentile	7.71	0.466	0.02	0.02	96.3	16	10.1	4.94	0.052	0.013	18.1	13	1.74	24.4		26.9	0.68	14.38		228		107.4
L95% Conf Limit	8.03	0.595	0.108	0.037	115.6	23.94	12.57	6.11	0.083	0.024	29.51	20.34	2.465	27.99		33.59	0.911	21.4		47.52		122.7

Statistic	pH	TKN	Nox	NH4	Talk	Na	Mg	Si	TP	PO4-P	SO4	Cl	K	Ca	TEMP	EC	SAR	NTU	Chla	TSS	Phae	Hard
Median	8.26	0.561	0.02	0.02	115.1	21.7	12.1	6.77	0.069	0.021	25.8	18.3	2.22	28.45		32.15	0.86	26.05		491		124.1
U95% Conf Limit	8.1	0.649	0.148	0.051	119.3	25.86	13.15	6.481	0.097	0.027	32.37	22.24	2.625	28.75		34.75	0.968	49.59		1490		132.1
75% Percentile	8.41	0.699	0.11	0.047	134.9	29.7	14.66	7.99	0.104	0.031	40	25.3	3.12	31.9		39.03	1.09	46.68		671		145
95% Percentile	8.553	1.07	0.526	0.102	159.7	50.86	20.3	9.99	0.207	0.064	64.26	46.02	4.67	36.3		53.58	1.67	78.88		2260		177.6
Maximum	8.81	2.752	3.09	1.961	214.6	96.8	32.8	13.14	0.617	0.215	145.5	94	6.947	48.53		83.8	3.03	153		2923		224.4
Mean	8.065	0.622	0.128	0.044	117.4	24.9	12.86	6.295	0.09	0.026	30.94	21.29	2.545	28.37		34.17	0.94	35.5		768.9		127.4
Standard Deviation	0.481	0.275	0.271	0.097	25.44	13.24	3.991	2.544	0.069	0.022	19.66	13.15	1.097	5.269		10.12	0.387	33.74		973.7		28.09
% Variation Coefnt	5.968	44.35	211.6	220	21.67	53.16	31.02	40.42	76.62	84.88	63.53	61.75	43.09	18.57		29.6	41.24	95.04		126.6		22.04

APPENDIX 4: FISH INDEX

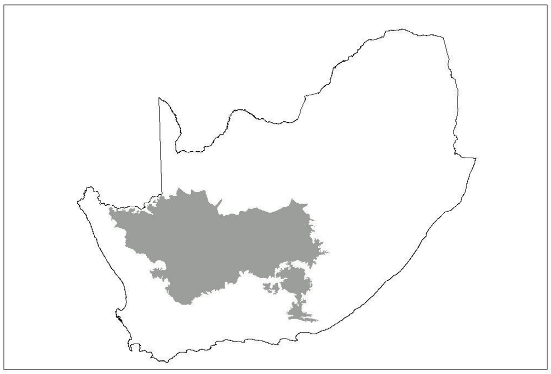
DETERMINANTS CONSIDERED FOR ESTIMATION	RIVER ZONE OR DEFINED RESOURCE UNIT (scoring/assessment criteria; provide comments for each score)
Native Species Richness	Number of species expected: number of species currently present (most recent). Score according to: None of expected present=0 Only few of expected present=1-2 Majority of expected species present=3-4 All/almost all of expected present=5
Presence of Native intolerant Species	No intolerant species present=0 Few intolerant species =1-2 Majority of intolerant species present =3-4 All/almost all intolerant species present (OR no intolerants naturally present)=5
Abundance of native species	No fish=0 Only few individuals=1-2 Moderate abundance=3-4 Abundance as expected for natural conditions=5
Native species Frequency of Occurrence	Fish absent at all sites=0 Fish present at only very few sites=1-2 Fish present at most sites=3-4 Fish present at all sites=5
Health/condition; native & introduced species	All fish seriously affected/fish absent=0 Most fish affected=1-2

	Most fish unaffected=3-4 Only single/few individuals affected=5
Presence of introduced fish Species	Predaceous species and/or habitat modifiying species with a critical impact on native species=0 Predaceous species and/or habitat modifiying species with a serious impact on native species=1-2 Predaceous species and/or habitat modifiying species with a moderate impact on native species=3-4 Predaceous species and/or habitat modifiying species no impact on native species=5
Instream habitat modification	Water quality/Flow/Stream bed substrate, critically modified, no suitable conditions for expected species=0 Water quality/Flow/Stream bed substrate, seriously modified, little suitable conditions for expected species=1-2 Water quality/Flow/Stream bed substrate, moderately modified, moderately suitable conditions for expected species=3-4 Water quality/Flow/Stream bed substrate, little/no modification, abundant suitable conditions for expected species=5
FISH PES: ESTIMATED OVERALL FISH ASSEMBLAGE INTEGRITY	TAKING INTO ACCOUNT THE ABOVE INFORMATION: RATE FISH ASSEMBLAGE INDEX CATEGORY A – F (cf. Table 1) BASED ON GENERAL SCORING GUIDELINES: Category — % of total expected score A: 90 – 100 B: 80 – 90 C: 60 – 80 D: 40 – 60 E: 20 – 40 F: 0 – 20

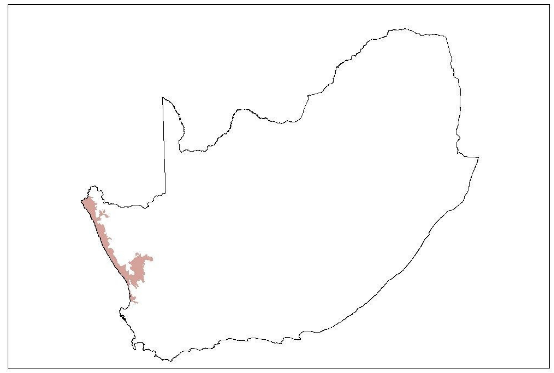
APPENDIX 5: ECOREGION MAPS

RELEVANT ECOREGION MAPS

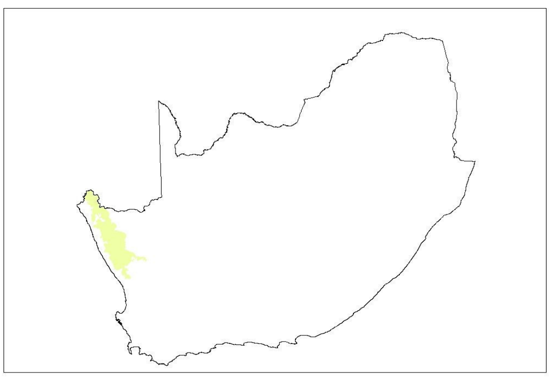
(Kleynhans, Thirion, and Moolman [2002])



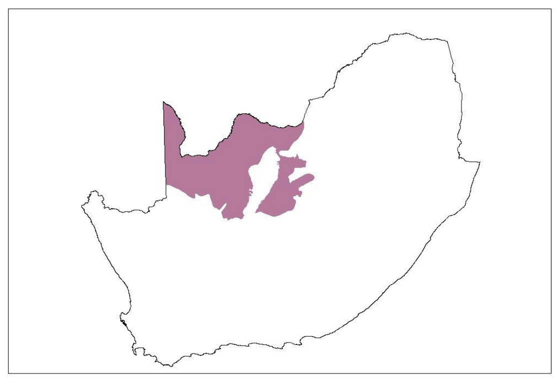
ECOREGION 14: Nama Karoo



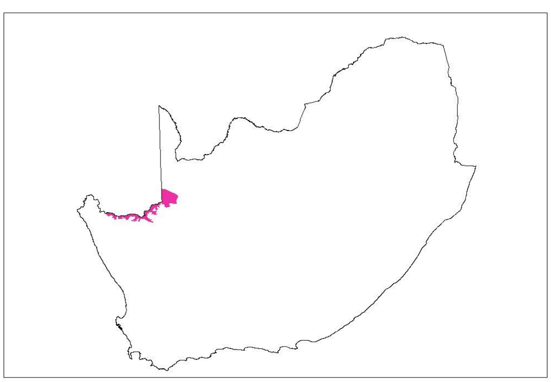
ECOREGION 15: Western Coastal Belt

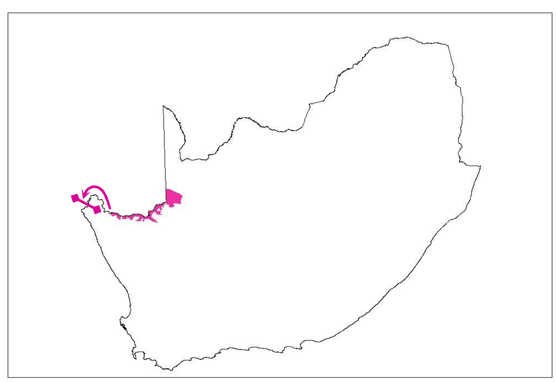


ECOREGION 16: Namaqua Highlands



ECOREGION 17: Southern Kalahari





ECOREGION 20: Orange River Gorge (left: as identified by Kleynhans, Thirion and Moolman [2002]; right: extention as recommended by Benade [2003]).

APPENDIX 6: "TOP-UP" D DEMAND FILE AT AUGRABIES

1920	59.57	51.64	51.68	54.51	430.98	138.81	120.38	68.09	46.94	33.99	28.08	39.05	1123.72
1921	27.37	75.98	88.43	90.71	124.14	81.13	25.86	31.16	59.70	46.00	42.66	24.48	717.62
1922	56.11	77.38	74.89	107.38	791.38	104.21	30.44	54.79	64.05	49.98	41.89	22.49	1474.98
1923	15.83	39.70	51.62	63.42	204.30	138.81	119.41	31.14	33.81	29.04	26.31	44.18	797.57
1924	46.29	75.42	87.10	85.15	479.89	138.81	123.65	93.81	65.62	48.57	37.55	41.22	1323.06
1925	43.51	47.08	52.30	58.48	148.95	122.44	50.54	29.18	35.66	30.28	26.17	42.07	686.66
1926	30.16	39.76	54.44	52.55	161.98	136.37	106.82	32.60	33.19	33.99	39.85	15.38	737.09
1927	44.30	42.90	61.69	100.02	225.04	100.16	35.87	30.23	33.41	28.67	26.48	16.19	744.97
1928	27.01	58.03	55.88	69.05	124.31	129.82	46.50	48.49	65.62	50.47	44.36	47.69	767.24
1929	59.55	68.50	87.48	91.86	162.11	97.85	84.48	50.31	39.15	32.49	43.29	31.84	848.90
1930	30.02	38.05	51.58	86.68	269.85	92.84	123.13	90.94	36.24	50.47	45.65	14.71	930.17
1931	33.78	66.55	54.05	51.35	331.67	94.73	26.69	29.07	33.27	28.87	23.50	29.60	803.13
1932	16.24	39.13	52.89	51.35	113.99	81.84	26.32	28.55	33.16	28.88	26.05	7.35	505.75
1933	11.02	77.38	88.43	108.06	747.70	123.01	101.50	90.22	64.50	49.87	46.27	27.40	1535.38
1934	50.41	77.38	88.43	54.58	125.45	129.48	91.21	91.87	62.50	39.80	46.02	39.00	896.13
1935	15.86	38.21	52.10	67.21	188.32	109.14	80.17	93.81	64.61	43.64	33.36	13.86	800.30
1936	49.59	77.38	86.21	107.46	838.49	114.44	35.18	33.67	36.12	32.13	27.81	12.71	1451.21
1937	16.80	38.00	69.92	84.87	608.04	88.86	84.11	73.77	62.61	48.42	44.35	33.98	1253.73

1938	58.10	43.44	79.15	105.41	927.83	121.93	27.56	63.25	51.32	49.83	45.80	40.72	1614.34
1939	58.12	75.69	66.23	52.63	154.90	130.98	115.57	93.30	63.56	43.65	33.29	47.69	935.60
1940	41.77	64.14	80.60	100.94	769.51	98.25	93.32	51.98	35.07	38.91	33.37	26.88	1434.74
1941	51.15	38.12	51.57	90.25	374.34	130.64	82.58	47.83	39.32	34.23	45.27	37.95	1023.27
1942	55.01	69.55	88.43	93.93	114.08	90.91	123.65	93.81	65.62	50.47	46.27	47.56	939.28
1943	59.57	77.38	88.43	102.63	965.09	132.75	40.30	42.42	65.54	48.90	37.16	47.37	1707.55
1944	58.04	50.55	51.56	51.35	143.40	136.30	75.68	49.21	50.75	35.89	27.05	12.76	742.55
1945	15.33	23.03	51.55	99.72	475.56	114.87	74.70	93.48	64.64	37.36	26.79	13.06	1090.09
1946	56.03	52.82	52.83	53.01	208.82	83.48	64.00	71.43	45.65	38.17	30.29	46.76	803.29
1947	55.04	43.44	83.29	92.17	262.63	138.81	122.52	67.06	40.21	30.71	26.73	13.29	975.90
1948	22.87	38.22	46.40	53.54	121.02	88.59	30.05	53.80	41.24	31.69	27.27	13.26	567.95
1949	21.50	68.94	86.75	71.01	204.04	137.51	123.65	93.81	65.50	50.26	46.27	46.79	1016.03
1950	20.91	38.05	82.66	95.82	154.55	87.95	56.63	57.11	53.36	42.55	36.54	26.62	752.73
1951	59.57	49.80	51.94	54.57	465.19	88.90	32.29	35.90	42.29	50.47	45.80	41.01	1017.73
1952	20.49	58.24	61.34	51.35	727.29	108.72	109.81	79.59	43.99	30.82	30.92	17.01	1339.58
1953	51.39	54.28	67.03	57.62	289.51	137.92	113.53	64.93	58.81	39.76	26.53	12.95	974.25
1954	15.78	40.83	56.67	108.06	965.09	131.06	88.53	83.24	59.03	44.12	34.75	13.85	1641.02
1955	22.54	55.17	81.01	61.81	622.44	137.44	120.82	84.36	58.87	39.98	30.57	15.62	1330.63
1956	40.16	69.93	88.43	105.41	252.65	100.92	46.99	33.92	39.64	50.47	46.27	47.69	922.50
1957	59.57	75.69	79.53	108.06	353.34	81.31	84.16	93.48	64.66	39.66	30.47	35.07	1105.00
1958	18.12	65.54	82.08	66.24	192.53	83.48	111.08	93.81	64.68	50.47	44.35	20.28	892.68

1959	49.08	65.97	85.10	72.44	331.51	114.81	89.05	79.42	55.30	42.46	44.23	38.35	1067.73
1960	47.77	62.11	86.88	81.33	120.69	135.57	123.65	92.36	65.62	49.25	45.86	23.79	934.88
1961	15.76	72.06	86.45	57.82	813.99	121.52	40.30	81.37	40.73	31.18	27.36	17.88	1406.41
1962	15.75	72.70	59.44	108.06	502.07	134.56	123.21	78.92	53.40	50.47	44.64	32.27	1275.48
1963	27.83	75.56	77.16	79.19	121.26	110.26	111.89	40.66	53.41	46.66	42.07	36.52	822.47
1964	59.57	75.97	67.79	78.10	122.57	80.95	102.61	63.93	59.79	46.64	42.45	44.56	844.95
1965	37.13	39.46	51.58	106.56	695.09	81.13	25.52	29.19	33.56	28.21	26.13	13.05	1166.60
1966	15.72	38.91	69.39	108.06	965.09	127.46	123.65	93.81	65.62	49.80	42.28	30.32	1730.12
1967	18.65	58.54	55.96	51.35	78.31	85.97	60.17	91.68	57.27	43.97	30.87	31.85	664.59
1968	16.00	38.05	61.60	51.35	113.86	122.04	114.33	83.01	60.50	34.54	33.08	13.70	742.04
1969	58.15	42.42	67.93	52.66	129.49	75.62	7.08	13.82	25.35	28.76	28.37	40.02	569.67
1970	57.17	44.89	76.54	81.89	281.21	83.36	117.87	89.47	46.75	36.22	31.33	22.83	969.52
1971	17.48	43.85	69.05	106.44	785.24	138.81	107.20	89.58	57.86	37.77	31.73	18.10	1503.12
1972	24.37	39.29	51.58	22.46	234.56	85.55	48.99	33.51	34.54	28.41	45.66	41.35	690.26
1973	35.56	40.15	75.53	108.06	965.09	138.81	121.82	92.87	65.14	47.15	46.27	45.39	1781.85
1974	17.21	76.25	86.92	103.23	965.09	137.68	88.50	68.38	57.34	49.67	41.75	44.82	1736.83
1975	51.94	74.64	88.43	108.06	965.09	138.81	123.65	93.81	65.62	50.13	43.55	46.78	1850.52
1976	59.57	77.38	57.68	72.27	771.74	136.65	70.80	58.38	51.15	41.52	35.02	45.34	1477.51
1977	58.33	53.61	59.16	108.00	518.29	118.25	123.65	88.53	60.48	47.56	41.18	47.06	1324.07
1978	54.74	38.86	87.15	53.05	126.67	82.80	25.79	35.33	40.96	49.46	46.27	47.69	688.77
1979	58.56	57.97	66.75	64.35	473.02	93.97	26.59	28.86	33.61	30.45	38.92	44.62	1017.67

1980	36.92	48.97	69.85	104.92	691.62	133.29	45.15	76.70	65.62	44.32	46.27	47.69	1411.33
1981	29.13	44.30	72.59	54.80	113.98	81.16	117.35	83.04	56.98	47.16	38.74	25.76	765.00
1982	49.60	75.68	51.81	51.35	113.47	80.90	25.79	35.01	48.10	47.49	40.59	17.98	637.77
1983	38.14	70.16	83.16	96.71	113.92	81.16	32.87	78.49	35.69	30.31	35.39	41.19	737.19
1984	32.68	41.85	52.76	52.11	516.02	98.83	28.76	28.22	35.45	29.17	26.26	13.00	955.12
1985	42.01	72.88	87.59	75.46	216.32	81.22	28.71	30.98	55.80	30.19	35.80	46.56	803.50
1986	58.44	77.38	55.83	52.12	113.92	81.45	45.57	29.24	32.83	28.70	45.16	47.69	668.34
1987	59.57	76.68	85.63	65.89	965.09	93.31	121.81	87.23	64.01	49.95	45.68	47.69	1762.55

APPENDIX 7: SUMMARY OF ECOLOGICAL ISSUES PERTAINING TO THE CONSTRUCTION OF LARGE DAMS IN THE LOWER ORANGE RIVER

Location	Boegoeberg	Komsberg	Vioolsdrift
Size	15% MAR (60 m)	15% MAR (60 m)	15% MAR (60 m) - reregulation dam c. 30 m.
Access road	Done	Difficult.	Difficult.
Purpose	Large dams: Save operational loses and storage.	Re-reg to save operational losses (300 MCM). Large dams: Save operational loses and storage.	Originally for managing the mouth of the Orange River. - not for river management. Re-reg to save operational losses (300 MCM). Large dams: Save operational loses and storage.
Ranking from an ecological perspective	Best option.	Second worse option.	Worst option.
Inundation	Orange River Broken Veld - rare. But relatively small proposrtion affected???? Check. Asbestos mine dumps may have to be moved.	Shortest inundation - steepest but highest wall. 60 m to lower lip of lower falls. Narrow rocky gorge - half gorge structure inundated - Charlie aesthetic loss.	
Substrate	What is the nutrient state of the geology????		
Water quality	Stratification will need to be checked to sort out Temps - can cause shocks to d/s biota - already occur at VDKloof.		
	Eutrophication		

Location	Boegoeberg	Komsberg	Vioolsdrift
Geomorphology	Sand banks being pushed downstream. Nat processes of scouring erosion and deposition altered - through loss of Q and loss of sediments. Armouring d/s. Change in gradient - gravel and sand deposit. Fine grains stay in suspension. Gravel need to be introduced to river if flow not competent to transport - gravel will not move downstream and d/s becomes gravel poor. Bar will not form d/s as they require gravel first. Further d/s reaches will become coated in silt and any floods will disturb silt. Flood 99-00 in Fish influenced Richtersveld - substrate composition almost same as OR. Both prone to deliver clay material.		
			Reregulation dam best option BUT all bad.
Algae	Create a nursery for algal growth - noxious algae. Good bear in mind recent change in Vaal (8-10 yrs) Othisitoria - spimopsis have moved into the system - very dangerous. Indicates significant of eutrophication and loss of stabilising buffers. Typical of over regulated river - virtually converted to longitudinal dam. Useful life fairly short ito WQ. Decrease in sedimentation results in increased light penetration and increased algae. Dams will capture poor flood waters from Vaal.		
Other			Copper mine proposed in south of Nam - but if big flood comes will flush the effluent from copper mine into the Vioolsdrift dam. Better to have dam situated higher - in this particular context. Very bad for algae.
Vegetation		Orange River represents a very important strip oasis	
	Raising where infrastructure - etc. least destructive. Already Prosopis invested. Least damaging re vegetation.	Impinges on Augrabies. Rocky gorge - starving of sediments. The expectation is that the sections of river downstream of Augrabies that are in relatively good condition will decrease the condition.	Upstream fairly natural and effect Richtersveld d/s. Despite release - partly because of sediments partly lack of variability. Worst.
Fish		Near to a natural barrier. Small fish species cannot more past Augrabies.	Will split range of endemic fish (*Barbus hospus*).
	Create haven for alien fish - carp and *Tilapia mosambicensis*	Upstream barrier	

Location	Boegoeberg	Komsberg	Vioolsdrift
		Most diverse fish assemblage in whole OR system!!	
		Situating the dam further downstream would be better from fish perspective.	
Invertebrates	First choice. Because already impacted. Already cause invasions of snails. D/s to Upington river cannalised and vey limited functioning (ecologically) - could also trap poor water from Vaal if did come.	Last choice. One of the few areas left in river in reasonably good nick. River structure very sensitive to flow / sediment changes and ecosystem functions failry unique. Proposed transfrontier park. Damaras Farm has already been bought by Augrabies NP.	Not much happening from functioning point of view - fairly depaupaurate. Snags etc provide most of habitat.
Bilharzia		Possible threat because ToC higher.	Possible threat because ToC higher.
Environmental Flows			
Size	Less than 1 MAR less damage - possibly look at pd MAR though.		
Opportunities	Boegoeberg and Komsberg - divide river into three equal section - beneficial for management of the river.		
	Best option - have advantage of putting in structure which can used to manage the the EF. Will provide opportunities for managing lower river. Also to regulate flows for black fly control - further d/s less opportunity for doing that. But this will be limited by irrigation infrastructure - pumps etc.	Ability to control floods increases upstream - but capacity of dams too small to control damaging floods.	

<table>
<tr><th>Location</th><th>Boegoeberg</th><th>Komsberg</th><th>Vioolsdrift</th></tr>
<tr><td></td><td></td><td colspan="2">Can release large flood required by estuary but will armour / mess up the lower section, which are not as damaged. Costs of release structures are high and they require testing, which damages the downstream riverine ecosystem. Difficult to buffer impact.</td></tr>
<tr><td>Constraints</td><td></td><td></td><td>Only can be useful for OR Mouth management.</td></tr>
</table>