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

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PG VAN ROOYEN	(Date)	**A TANNER**	(Date)
Task Leader		Study Leader	

PERMANENT WATER COMMISSION

Approved for the Planning Committee of the Permanent Water Commission by:

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P Heyns (NAM)	(Date)	**PH van Niekerk**	(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
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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

PRE-FEASIBILITY STUDY INTO MEASURES TO IMPROVE THE MANAGEMENT OF THE LOWER ORANGE RIVER

HYDROLOGY, WATER QUALITY AND SYSTEM ANALYSIS: VOLUME A – SYSTEM ANALYSIS

EXECUTIVE SUMMARY

INTRODUCTION

The Orange River has the largest river basin south of the Zambezi. It rises in the Drakensberg Mountains in Lesotho at an altitude of about 3 300 m, from where it flows to the west for approximately 2 200 km to the sea. It has a total catchment area in excess of 1 million km², 600 000 km² of which is located in South Africa and the rest in the three neighbouring states of Lesotho, Namibia and Botswana. From 20°E longitude westwards, it forms the nearly 600 km long international border between Namibia and South Africa.

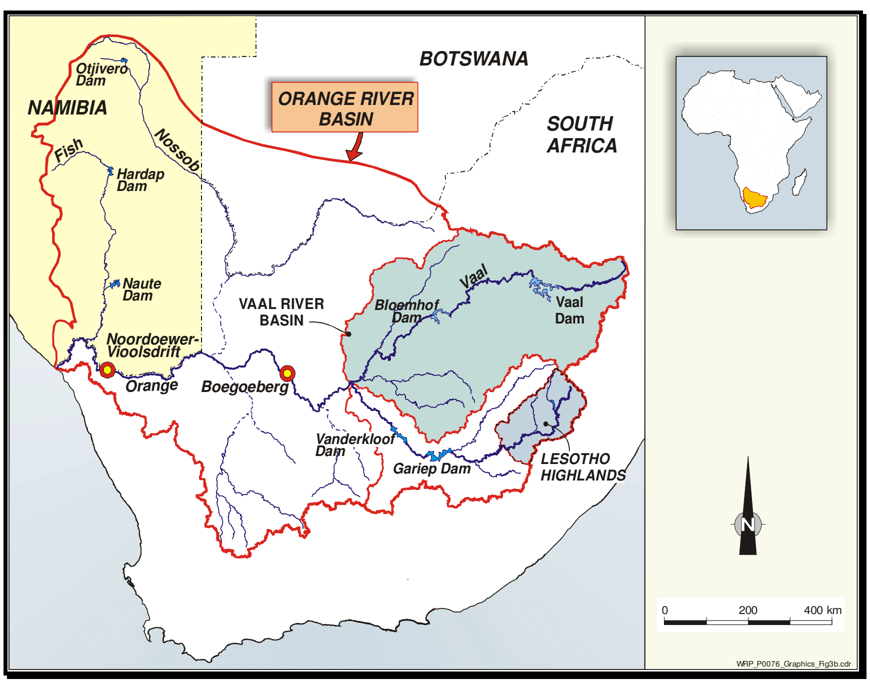

Figure 1: Orange River Basin

*This Common Border Area (CBA) has an arid climate. Here the Orange River passes through some of the most rugged and isolated terrain, but with fertile soils in narrow corridors along its banks. A map of the river catchment is included as **Figure 1**.*

The natural runoff of the Orange River Basin is in the order of 11 300 million m^3/a of which only 800 million m^3/a is contributed by the catchment downstream of the Orange/Vaal confluence. The runoff originating from the Orange River downstream of the Orange Vaal confluence is highly erratic and cannot be relied upon to support the various downstream demands unless further storage is provided in the Lower Orange River (LOR).

It is the objective of this study to investigate measures to improve the availability of water along the Lower Orange River. Three important strategies that can be used to increase the water yield/use efficiency of the river system are:

- *Additional storage facilities in the Lower Orange River that can capture some of the 800 Mm^3/a run-off that is contributed by the catchment downstream of the Orange/Vaal confluence, and spills from the dams in the Middle and Upper Orange River.*
- *Reduction of operating losses from the releases made at the Vanderkloof Dam.*
- *Water Demand Management (WDM) initiatives.*

Scope of this Report

This report was sub-divided into two separate volumes, Volume A and Volume B. The purpose of Volume A is to provide summarised details of the hydrological database, the land-use developments, the associated water requirements, as well as full details on the water supply systems, system yield and planning analyses.

Volume B contains a detailed description of the updated hydrology of the Fish River (Namibia), as well as a review of the existing Republic of South Africa (RSA) hydrology.

Procedure Followed

The yield analyses and system modelling were undertaken in six phases:

- *Phase 1: Model configuration for the Water Resources Yield Model (WRYM).*
- *Phase 2: Based on historic firm yield analyses determine the need and initial timing of proposed development measures.*
- *Phase 3: Determine the supply capability of the proposed development measures.*
- *Phase 4: Carry out selective long-term stochastic analyses and short-term stochastic yield analyses.*

- *Phase 5: Model configuration for the Water Resources Planning Model (WRPM).*
- *Phase 6: Carry out selective planning analyses using the Water Resources Planning Model, and obtain the refined and final results with regards to the need and timing of proposed developments.*

The Water Resources Yield Model data sets, obtained from the Orange River Development Project Replanning Study (ORRS), were used as the base data sets and were updated with the latest hydrology, system demands and infrastructure changes. This system configuration excludes the detail of the Integrated Vaal River System upstream of the confluence of the Vaal and the Riet Rivers. At this point, the outflows for the Vaal were obtained from the detailed Vaal River Water Resources Planning Model system analysis, and used as the inflow to the Orange in the Water Resources Yield Model analysis. The most recent Water Resources Planning Model data sets for the Integrated Vaal River System were used as the basis for the planning analyses (Phase 6) and extended to include the whole Orange River System.

Description of the System

The main water supply system considered in this analysis is referred to as the Orange River System. Gariep and Vanderkloof Dams are the two resources used to supply the large number of users. Water is released from the dams to supply users along the entire Orange River from Gariep Dam to the Orange River Mouth. Gariep Dam also supports the irrigation and limited urban requirements in the Eastern Cape. For this purpose, water is transferred through the Orange/Fish tunnel and released into the upper reaches of the Fish River. Water from Vanderkloof Dam is also transferred via a canal system to the Riet/Modder catchment to support mainly irrigation.

Development upstream of Gariep Dam such as the Lesotho Highlands Water Project (LHWP), Welbedacht and Knellpoort Dams in the Caledon catchment, as well as various other small dams and users, are affecting the yield available from Gariep and Vanderkloof Dams. None of the upstream dams are, however, used to support the Gariep and Vanderkloof Dams.

There are large developments in the Vaal River System (Riet/Modder included) that will affect the inflows from the Vaal into the Orange River downstream of Vanderkloof Dam. These inflows are currently not utilised in the Orange River downstream of the *confluence of the two rivers due to the following:*

- *The Vaal River is operated to minimise spills into the Orange River and it is therefore mainly during floods that significant volumes of water enter the Orange from the Vaal.*
- *Vanderkloof Dam is located approximately 200 km upstream of the confluence of the Orange and Vaal Rivers, and 1 300 km upstream of the river mouth. Releases from Vanderkloof Dam take approximately one month to reach the river mouth. It is therefore important that releases be made well in advance to supply the downstream users in time, making it very difficult to utilise inflows from the Vaal.*

Local inflows from the catchmen,t downstream of the Orange/Vaal confluence, is sporadic and contributes less than 7% of the total runoff under natural conditions. The largest inflow to the Orange River from tributaries, downstream of the Orange/Vaal confluence, is that from the Fish River (Namibia), which enters the Orange approximately 150 km upstream of the river mouth. These inflows are also sporadic and there are not many users located downstream of the confluence with the Fish River, that can utilise spills from the Fish River.

All the developments upstream and downstream of the Gariep and Vanderkloof Dams are included in the system model, as they will all affect the surplus yield available in the system.

Scenario Descriptions and Historic Firm Yield Results

A specific reference scenario (Reference Scenario 1) was defined and used as the benchmark for the Water Resources Yield Model analysis. The results from other scenarios were compared with the reference scenario yield result, to determine their effect on the system yield. Due to a number of uncertainties with regards to the growth in the irrigation requirements, it was decided to use the existing irrigation demands (Year 2000) in all the analyses.

A detail description of Reference Scenario 1 is given in ***Table 4.1*** *in* ***Section 4*** *of this document with a brief description given below.*

<u>Reference Scenario 1:</u>

This scenario represents the current system with 2005 development level urban, industrial and mining demands imposed on the system. Current irrigation demands were included. It was assumed that the full phase 1 of the Lesotho Highlands Water Project is in place. The minimum operating levels in the Gariep and Vanderkloof Dams were set equal to the Orange/Fish tunnel and canal outlets, respectively. These levels are slightly lower than the minimum operating levels applicable to hydropower generation in both dams. Hydropower is only generated with the water released into the river for downstream users below both dams, and no additional releases for hydropower generation were made. Spills from the Vaal, as well as any inflows from Lower Orange catchments, were not utilised by users along the Orange River. Environmental requirements as currently released from Vanderkloof Dam were included. These environmental requirements were obtained from the ORRS.

Several other scenarios or options were defined and analysed to determine the incremental yield benefit of possible developments, as well as sensitivity analyses to obtain an improved understanding of the system. These scenarios used Reference Scenario 1 as the basis and selected components were changed as described hereafter:

- *<u>Scenario 1a</u>: As Reference Scenario 1, but with urban/industrial and mining developments at 2015-development level.*
- *<u>Scenario 1b:</u> As Reference Scenario 1, but with urban/industrial and mining developments at 2025-development level.*
- *<u>Scenario 1c:</u> The lower level storage in Vanderkloof Dam was used to supply downstream requirements and to pump water into the Vanderkloof canals.*
- *<u>Scenario 1d:</u> Used the minimum operating level (m.o.l.) related to hydropower generation for both dams.*
- *<u>Scenario 1e:</u> Spills from the Vaal were utilised. Water is released from Vaalharts Weir in the Lower Vaal to supply users along the Vaal River upstream of the confluence with the Riet River. More water than the actual downstream requirement is released to cover the operating losses. Some of these operating losses will, however, flow into the Orange. This scenario excludes the Vaal operating losses from the Vaal spills. For this scenario, it was assumed that these spills could be utilised from the Douglas Weir, as well as in the Orange River downstream of the Douglas Weir.*

- *<u>Scenario 1f:</u> Spills from the Vaal were utilised. For this scenario, the Vaal operating losses are included as part of the Vaal spills. It was assumed that these spills could be utilised from the Douglas Weir, as well as in the Orange River downstream of the Douglas Weir.*
- *<u>Scenario 1g:</u> The lower level storage in Vanderkloof Dam was used to supply downstream requirements, and to pump water into the Vanderkloof canals as for Scenario 1c, but also included the utilisation of the spills from the Vaal (operating losses included), as described for Scenario 1f.*
- *<u>Scenario 1h:</u> The ecological requirements, as obtained from the Orange River Replanning Study, were replaced with Desktop estimates for a Class C river. For this scenario, it was assumed that the spills from the Vaal, as well as the runoff generated from the Lower Orange River catchment can be utilised to supply the ecological requirements. The lower level storage in Vanderkloof Dam was also utilised for this scenario.*
- *<u>Scenario 1i:</u> The ecological requirements, as obtained from the Orange River Replanning Study, were replaced with Desktop estimates for a Class D river. For this scenario, it was assumed that the spills from the Vaal, as well as the runoff generated from the Lower Orange River catchment, can be utilised to supply the ecological requirements. The lower level storage in Vanderkloof Dam was also utilised for this scenario.*

*<u>Results from the historic firm yield analyses</u> are summarised in **Table 1**. The surplus yield available in the system for Reference Scenario 1 is 120 million m³/a. This result shows that the system is almost in balance as the 120 million m³/a surplus represents less than 4% of the total system yield of 3 250 million m³/a.*

The growth in urban/industrial and mining components have a relative small impact on the system yield as it reduces the system yield from 2005 to 2025 by only 86 million m³/a.

A similar reduction in yield (80 million m³/a) will occur when the current hydropower minimum operating level is used in stead of the minimum operating level specified for Reference Scenario 1.

Table 1: Summary of Yield Results for Reference Scenario 1 and Related Scenarios

Scenario No.	Description	Units	Surplus/Deficit Yield	Increase/ Decrease
1	Reference Scenario 1 (2005-development level)	million m^3/a m^3/s	120 3.8	0 0
1a	Reference Scenario 1 (2015-development level)	million m^3/a m^3/s	67 2.1	-53 -1.7
1b	Reference Scenario 1 (2025-development level)	million m^3/a m^3/s	34 1.1	-86 -2.7
1c	Vanderkloof lower level storage (2005-development level)	million m^3/a m^3/s	271 8.6	151 4.8
1d	Hydro-power m.o.l. in both dams (2005-development level)	million m^3/a m^3/s	40 1.3	-80 -2.5
1e	Include Vaal spills operating losses excluded (2005-development level)	million m^3/a m^3/s	172 5.5	52 1.6
1f	Include Vaal spills operating losses included (2005-development level)	million m^3/a m^3/s	264 8.4	144 4.6
1g	Vanderkloof lower level storage plus Vaal spills operating losses included (2005-development level)	million m^3/a m^3/s	483 15.3	363 11.5
1h	Desktop Class C EFR with Vanderkloof lower level storage plus Vaal spills operating losses included (2005-development level)	million m^3/a m^3/s	-417 -13.2	-537 -17.0
1i	Desktop Class D EFR with Vanderkloof lower level storage plus Vaal spills operating losses included (2005-development level)	million m^3/a m^3/s	-201 -6.4	-321 -10.2

Results from Scenarios 1e and 1f show that the surplus yield can be increased by up to 144 million m³/a when the spills from the Vaal are fully utilised by the existing users. In practise, however, it will not be possible to obtain that without additional storage. Some of it can, however, be utilised by means of improved management and operating procedures.

The planning estimates for the environmental flow requirement (EFR), as obtained from the Desktop Model for the Orange River, are significantly different from that given in the Orange River Replanning Study. The environmental requirements from the Orange River Replanning Study are constant annual values with a specific monthly distribution, and are currently supplied by means of releases from the Vanderkloof Dam. The most recent methodology, as used for the LORMS environmental flow requirement planning estimates, links the environmental flow requirement for a specific month to the natural flow generated for that month. When the environmental flow, based on this methodology, is analysed in a system context, it requires that one utilise the spills available in the system, to partly supply the *environmental requirement and only obtain the remaining deficit by means of releases from an upstream storage dam. The yield results indicated that deficits in excess of 400 million m³/a, could be experienced in the system when the Desktop estimate of the environmental flow requirement for a Class C river has to be met.*

Due to the significant reduction in yield, it was considered necessary to define a second reference scenario in which the environmental requirements obtained from the Desktop Model for a Class D river was included, instead of the Orange River Replanning Study environmental requirements.

At the time when Reference Scenario 2 was discussed, as part of the Lower Orange River Management Study (LORMS), updated environmental releases determined by Lesotho for the Lesotho Highlands Water Project, became available. These releases are higher than those specified in the Treaty between the Republic of South Africa and Lesotho. Lesotho was at that time already in the process of implementing the updated environmental releases and it was therefore decided to replace the Treaty environmental releases with the updated releases, as part of Reference Scenario 2. A brief description of Reference Scenario 2 is given below:

Reference Scenario 2:

This scenario is as Reference Scenario 1, with the following changes:

- *Desktop environmental requirements for a Class D river were used instead of the Orange River Replanning Study environmental requirements.*
- *Spills from the Vaal were utilised to support the environmental requirements. The spill record used for the Vaal included the effect of the operating losses in the Vaal.*
- *The recently updated environmental requirements from the Lesotho Highlands Water Project were used.*

Some sensitivity analyses were also carried out, relating to Reference Scenario 2, and include the following:

- *Scenario 2a: As Reference Scenario 2, but included the Treaty environmental releases for the Lesotho Highlands Water Project, as used in Reference Scenario 1.*
- *Scenario 2b: As Reference Scenario 2, but allowed the Vaal River to contribute its part to the environmental requirement in the Lower Orange River. For this purpose, the Desktop Model was used to obtain an environmental requirement for*

a Class D river at the lower end of the Vaal River. Bloemhof Dam was used to support this environmental requirement.

*Results from the historic firm yield analyses are summarised in **Table 2**.*

Reference Scenario 2 results in a deficit of almost 300 million m³/a in the system. This deficit will increase by 67 million m³/a when the Treaty environmental flow requirements are considered instead of the updated releases. This also means that the updated environmental flow requirement releases from the Lesotho Highlands Water Project will increase the Orange River System yield by approximately 70 million m³/a.

Table 2: Yield Results for Reference Scenario 2 and Related Scenarios

Scenario No.	Description	Units	Surplus/Deficit Yield	Increase/ Decrease
2	Reference Scenario 2 (2005-development level)	million m³/a m³/s	-299 -9.5	0 0
2a	Reference Scenario 2 with treaty releases from LHWP (2005-development level)	million m³/a m³/s	-366 -11.6	-67 -2.1
2b	Reference Scenario 2 with Vaal River EFR contribution (2025-development level)	million m³/a m³/s	-104 -3.3	195 6.2

When the Vaal River is used to supply it's portion of the environmental flow requirement in the Orange, the deficit in the Orange River can be reduced significantly by 195 million m³/a.

Results from Reference Scenarios 1 and 2, as well as the related scenarios, showed large differences in the yield available from the Orange River System, depending on the environmental requirement that is imposed on the system. From these results, it was clear that further work is required to determine the environmental flow requirement, which will be suitable for planning purposes as part of the Lower Orange River Management Study. An additional task was therefore approved to examine the relationship between the current flow regime in the river and the environmental flow requirement recommended by the Desktop Model. A more feasible environmental flow requirement was proposed from this task to be used for planning purposes in this Study. This environmental flow requirement is referred to as the Top-up environmental requirement. The Top-up environmental requirement was then used in the final set of scenarios to be analysed for this Study and Reference Scenario 3 was *defined for this purpose. A brief description of Reference Scenario 3 is given below:*

Reference Scenario 3:

This scenario is as Reference Scenario 1, with the following changes:

- *The Top-up environmental requirements were included, as determined from the additional Lower Orange River Management Study environmental task, instead of the Orange River Replanning Study environmental requirements.*
- *Spills from the Vaal were utilised to support the environmental requirements. The spill record used for the Vaal included the effect of the operating losses in the Vaal.*
- *The recently updated environmental requirements from the Lesotho Highlands Water Project were used.*
- *The reduced Lesotho Highlands Water Project transfer, as result of the updated environmental releases, will be used. The reduced transfer rate from the Lesotho Highlands Water Project to the Vaal was determined as 780 million m^3/a for the full Phase 1 of the Lesotho Highlands Water Project.*

Several other scenarios or options were also defined and analysed to determine the incremental yield benefit of possible developments, as well as sensitivity analyses to obtain an improved understanding of the system. These scenarios used Reference Scenario 3 as the basis and some components were changed as described hereafter:

- *Scenario 3a: As Reference Scenario 3, but with urban/industrial and mining developments at 2015-development level.*
- *Scenario 3b: As Reference Scenario 3, but with urban/industrial and mining developments at 2025 development level.*
- *Scenario 3c: The surplus from the Vaal was used to support the Orange River. This surplus is in excess of 100 million m^3/a in 2005, but will reduce over time between (2015 & 2020) to zero.*
- *Scenario 3d: The spills from the Vaal were utilized by implementing real time modelling.*
- *Scenario 3e: The Lower Level storage in Vanderkloof Dam was utilized.*
- *Scenario 3f: The incremental yield benefit for a large Vioolsdrift Dam was determined (3 sizes were analysed). The live storage suggested for the 3 dam sizes are:*
    - *500 million m^3*
    - *1500 million m^3*
    - *2400 million m^3*

- *Scenario 3g: The incremental yield benefit for a large Boegoeberg Dam was determined (3 sizes were analysed). The live storage suggested for the 3 dam sizes are:*
  - *500 million m³*
  - *1500 million m³*
  - *2400 million m³.*
- *Scenario 3h: Re-regulating dams at either Vioolsdrift or Boegoeberg Dam sites were included to reduce operating losses.*
- *Scenario 3i: Water conservation and demand management (WC&DM) measures were included. Focus on the area between Gifkloof and the Namibian border, as this area is expected to provide the highest returns.*
- *Scenario 3j: A large Vioolsdrift Dam (3 sizes was included, as for Scenario 3f. For this scenario the yield gained from a large Vioolsdrift Dam will be used for additional development upstream of Vioolsdrift Dam and not downstream of the dam as for Scenario 3f. To accommodate this, the yield benefit was determined at Vanderkloof Dam and not at Vioolsdrift Dam. The live storage suggested for the three dam sizes are:*
  - *500 million m³*
  - *1 500 million m³*
  - *2 400 million m³*

*Results from the historic firm yield analyses are summarised in **Table 3**. From **Table 3**, it can be seen that Reference Scenario 3 resulted in a surplus yield of 14 million m³/a at 2005-development level.*

*Scenarios 3a and 3b: When only the growth in the urban/industrial/mining requirement is allowed in the system, the surplus in the system will become zero between 2007 and 2008, with a deficit of 42 million m³/a in 2015 and a 75 million m³/a deficit in 2025. It is, however, important to note that surplus and deficit in yield given in **Table 3** exclude the effect of possible growth in irrigation.*

When the effect of the most probable irrigation growth is included, the surplus yield for Reference Scenario 3 will reduce to a deficit of 47 million m³/a at the 2005-development level. This deficit will increase further to 308 million m³/a in 2015 and to 418 million m³/a by 2025.

Table 3: Yield Results for Reference Scenario 3 and Related Scenarios

Scenario No.	Description	Units	Surplus/Deficit Yield	Increase/ Decrease
3	Reference Scenario 3 (2005-development level)	million m³/a m³/s	14 0.4	0 0
3a	Reference Scenario 3 (2015-development level)	million m³/a m³/s	-42 -1.3	-56 -1.7
3b	Reference Scenario 3 (2025-development level)	million m³/a m³/s	-75 -2.4	-89 -2.8
3c	Vaal surplus – 2005	million m³/a m³/s	94 3.0	94 3.0
	2010	million m³/a m³/s	28 0.9	28 0.9
	2015	million m³/a m³/s	10 0.3	10 0.3
3d	Real time modelling	million m³/a m³/s	80 2.5	0 0
3e	Vanderkloof Lower level storage utilisation	million m³/a m³/s	157 5.0	143 4.5
3f	Large Vioolsdrift Dam - 44m spill height (500 million m³ live storage)	million m³/a m³/s	*281 – 135 (197) *8.9 – 4.3 (6.2)	*267 – 121 (183) *8.5 – 3.8 (5.8)
	54.6m spill height (1 500 million m³ live storage)	million m³/a m³/	*358 – 258 (311) *11.3 – 8.2 (9.9)	*344 – 244 (297) *10.9 7.7 (9.4)
	54.6m spill height (2 400 million m³ live storage)	million m³/a m³/	*429 – 332 (379) *13.6 – 10.5 (12.0)	*415 – 318 (365) *13.2 – 10.1 (11.6)
3g	Large Boegoeberg Dam – 35.4m spill height (500 million m³ live storage)	million m³/a m³/s	*203 – 0 *6.4 - 0	*189 –(-14) *6.0 – (-.4)
	42.1m spill height (1 500 million m³ live storage)	million m³/a m³/s	*292 – 110 *9.3 – 3.5	*278 – 96 *8.8 – 3.0
	44.6m spill height (2 400 million m³ live storage)	million m³/a m³/s	*329 – 149 *10.4 – 4.7	*315 – 135 *10.0 – 4.3
3h	Re-regulation dam - Boegoeberg Dam (90 million m³ live storage)	million m³/a m³/s	62 2.0	62 2.0
	Komsberg Dam (100 million m³ live storage)	million m³/a m³/s	126 4.0	126 4.0
	Vioolsdrift Dam (110 million m³ live storage)	million m³/a m³/s	170 5.4	170 5.4

Scenario No.	Description	Units	Surplus/Deficit Yield	Increase/ Decrease
3i	WCDM Gifkloof to Namibian border	million m³/a	55	55
	By 2010	m³/s	1.7	1.7
	By 2014	million m³/a	118	118
		m³/s	3.7	3.7
3j	Vioolsdrift Dam yield channel at Vanderkloof 44m spill height (500 million m³ live storage)	million m³/a	264	250
		m³/s	8.4	7.9
	54.6m spill height (1 500 million m³ live storage)	million m³/a	332	318
		m³/s	10.5	10.1
	54.6m spill height (2 400 million m³ live storage)	million m³/a	332	318
		m³/s	10.5	10.1

*Note: *- The first value represents the yield before the effect of sediment was taken into account and the second value after the effect of the estimated 50-year sediment volume was included. For the Vioolsdrift scenario, the yield value in brackets represents the yield where the evaporation area at the minimum operating level was adjusted to accommodate possible effects of the 50-year sediment.*

*Scenario 3c: As result of the Lesotho Highlands Water Project, there will be a temporary surplus in the Vaal System, which can be utilised in the Orange River System, if required. The results given in **Table 3** include the effect of transfer losses. 94 million m³/a of the 2005 Vaal surplus can be utilised in the Orange. This will reduce to only 10 million m³/a in 2010. The Vaal River surplus water may, however, be too expensive for the low to medium priority users, as the water needs to be pumped from the Tugela System to make the surplus available in the Vaal River.*

Scenario 3d: Real time modelling will enable the operator at Vanderkloof Dam to reduce releases from Vanderkloof Dam at the required time, to be able to utilise the inflows from the Vaal for users in the Lower Orange. Results from a combination of hydraulic river modelling and Water Resources Yield Model system modelling indicated that the surplus yield in the system can be increased by 80 million m³/a when real time modelling is used to utilise inflows from the Vaal more effectively. It is, however, important to note that this additional 80 million m³/a can not be added to the surplus yield indicated for Reference Scenario 3, or any of the other scenarios related to Reference Scenario 3. The reason for this is that when the most recent methodology is used to model the effect of the environmental flow requirement on the system, it is automatically assumed that the required infrastructure and techniques are in place to utilise spills from the system to support the environmental flow requirements. The benefit of the 80 million m³/a is therefore already included in the results from Reference Scenarios 2 and 3, but not for Reference Scenario 1 where the Orange River Replanning Study environmental flow requirements were modelled.

<u>Scenario 3e</u>: The 143 million m³/a increase in yield, as result of the utilisation of the lower level storage in Vanderkloof Dam, is relative to the minimum operating level, as defined for Reference Scenario 3. When the hydropower minimum operating level is used as the reference, the incremental yield benefit is expected to increase with another approximately 80 million m³/a.

<u>Scenario 3f & 3g</u>: Sedimentation is a real problem for dams located at the Vioolsdrift and Boegoeberg Dam sites. The expected 50-year sediment volumes for the two dams were estimated at 600 and 710 million m³, respectively. Live storage volumes of 500, 1 500 and 2 400 million m³ were analysed for each of the possible dams (live storage over and above the 50-year sediment). The applicable 50-year sediment volume is therefore a substantial portion of the gross volume required for each reservoir. For the purpose of the analyses, it was assumed that directly after completion of the dam, a dead storage of 100 million m³ would be sufficient for each dam. The live storage available for use in the first couple of years will therefore be significantly more than that available at the end of the 50-year period. Two yield benefit figures are therefore supplied for each possible dam size analysed for Vioolsdrift and Boegoeberg Dams. The higher yield value represents the yield available just after completion of the dam and the lower yield after 50-years, when the effect of the 50-year sediment is taken into account.

Although estimations of the 50-year sediment volume can be made fairly easily, it is very difficult to know what the effect of the sediment will be on the area of evaporation from each dam. Evaporation from these two dams is significant, and the reason for the zero yield from a 500 million m³ Boegoeberg Dam (50-year sediment included) is the large evaporation area. For the analyses, it was assumed that the evaporation area from the reservoir surface has not changed due to sedimentation over the years. With a dead storage of 600 million m³ and 710 million m³ for Vioolsdrift and Boegoeberg Dams respectively, the area of evaporation of the two dams at these storages are significant.

Results from the analyses clearly indicated that Vioolsdrift Dam is the better option, and therefore, a third analysis for each of the Vioolsdrift Dam sizes was done. In this analysis, it was assumed that the evaporation area at the dead storage volume of 600 million m³ would be the same as for the 100 million m³ dead storage used as the initial dead storage. This yield result is represented by the value given in brackets for *each of the dam sizes analysed for Vioolsdrift Dam.*

*Scenario 3h: Results from the hydraulic river modelling task (see **Table 3**) clearly indicated that for the purpose of a re-regulation dam, the Vioolsdrift option provides a significantly higher benefit with regards to the reduction in operational losses than that obtained by a similar dam at the Boegoeberg site, and even the Komsberg site. It is also important that there should be sufficient users downstream of the re-regulation dams, to utilise the saving in operational losses. The current demands downstream of the Vioolsdrift re-regulating dam are therefore sufficient to utilise the indicated saving of 170 million m³/a. These demands accumulate to a total of 193 million m³/a and exclude the river mouth environmental requirement.*

Scenario 3i: For the purpose of water conservation and demand management, the area from Gifkloof to the Namibian border was identified as the area with the highest potential savings at the lowest cost. The potential savings that have been identified are:

- *Proper scheduling: 7%.*
- *Metering and pricing of water use: 7%.*
- *Improvement of irrigation systems, 15% for Gifkloof to Neusberg and 20% for Neusberg to the Namibian border.*

For the purpose of this scenario, it is accepted that no water conservation and demand management is in place in 2005, and that the effects of scheduling and metering-pricing will only reach their full potential at the beginning of 2010. These will be followed by the effect from improved irrigation systems with the full potential only reached at the start of the year 2014. A significant saving of 118 million m³/a can be obtained from water conservation and demand management measures in these areas.

Scenario 3j basically considers the possibility of utilizing the incremental yield gained from a large Vioolsdrift Dam, upstream of Vioolsdrift Dam. The implication of this option is that the total requirement from the existing users downstream of Vioolsdrift Dam should be sufficient to utilize a volume in excess or equal to the incremental yield benefit.

Results from this analysis indicated that almost the same yield benefit can be obtained for the 500 and 1 500 million m³ storage dams (approximately 6% reduction) when the future developments utilising the Vioolsdrift yield benefit are located upstream of Vioolsdrift Dam. The incremental yield benefit for a 2 400 million m³ Vioolsdrift storage dam reduced with almost a 100 million m³/a if the water is utilized upstream of the dam. This indicates that for such a large Vioolsdrift storage dam, it is important that a significant portion of the future developments should be located downstream of the dam.

Stochastic yield analyses:
The stochastic analyses are used to determine the yield available at different levels of assurance. For the purpose of the long-term stochastic analysis, 501 stochastic sequences, with a record length of 68 years each, were analysed. Reference Scenario 3 was used for this analysis and results are summarised in ***Table 4****. For the historic firm yield analyses, the surplus yield was always shown for each of the scenarios analysed. For the purpose of the stochastic yield analysis, it is, however, required to determine the total system yield so that the total system demand can be allocated to different assurance levels. The environmental requirement and river evaporation for this scenario were still imposed as demands on the system and therefore not included as part of the system yield. The main reason for this is that spills from the Vaal and Fish Rivers, as well as local runoff, were utilised to partly supply these requirements. To be able to compare the historic firm yield with the stochastic yield, the total system yield from a historic yield analysis was also determined for Reference Scenario 3 (see* ***Table 4****).*

Results show that the historic firm yield has a recurrence interval of 1 in 100 years. The total demand imposed on the system is 2 162 million m³/a at 2005-development level. When all the demands are supplied at a 1 in 100 year assurance (this means that there is a possibility of not supplying the demand in full only once in a 100 years), there will still be a small surplus of 56 million m³/a available in the system. This surplus will increase to 288 million m³/a if the demands are supplied at a 1 in 50 year assurance, which is significantly more than the 14 million m³/a surplus from the historic firm yield analysis.

Table 4: Reference Scenario 3, Summary of Long-term Stochastic Yield Results

Scenario Description	Historic Firm Yield Recurrence Interval (Years)	Long-term Stochastic Firm Yield at Indicated Recurrence Intervals			
		1: 20 year (million m³/a)	1: 50 year (million m³/a)	1: 100 year (million m³/a)	1: 200 year (million m³/a)
Reference Scenario 3	100 (2 218)*	2 825	2 450	2 218	2 000

*Note * : Value in brackets refers to the historic firm yield in million m³/a.*

*In practise, however, all the demands are not supplied at the same assurance level and the assurance levels, as required for different categories of users in the Orange River System, is provided in **Table 5**. The results in this table show that almost 50% of the total demand needs to be supplied at a low assurance of 1 in 20 years, which is as result of the large irrigation component.*

Table 5: User Categories and Priority Classifications used for the LORMS

User Category	Priority Classification & Assurance of Supply (million m³/a)			Total (million m³/a)
	Low 1 in 20 year	Medium 1 in 100 year	High 1 in 200 year	
Urban	12	18	30	60
Irrigation	1 062	531	177	1 770
Losses	0	0	332	332
Total	**1 074**	**549**	**539**	**2 162**

These demands, as allocated to the different assurance classes, were imposed on the long-term stochastic yield curve, which showed that there is still a surplus of 480 million m³/a available at a 1 in 20 year assurance level. Further sensitivity analyses indicated that the surplus can reduce to 338 million m³/a, if a different priority classification is used, such as that currently implemented for the Integrated Vaal River System.

According to the historic firm yield analysis and the stochastic analyses, the available surplus in the system differs significantly and so too does the resulting time when intervention is required, to ensure that the growing need of water users are met.

There are two main reasons for these differences:

- *The first is that the historic firm yield is representative of a 1 in 100 year recurrence interval. This means that for the historic yield analyses, all the demands are supplied at a 1 in 100 year assurance. For the stochastic analyses,* *approximately 50% of the demands are allocated to a 1 in 20 year assurance, and the remaining to the 1 in 100 and 1 in 200 year assurances.*

- *Secondly, the demand growth curve for the Orange River System is relatively flat, so a small difference in the calculated yield will make a significant difference in the timing required for intervention measures.*

It should also be noted that the current surplus in the system is of equal magnitude to the margin of error generally accepted for hydrology purposes. The Orange River System, however, has an extremely high system yield of approximately 3 250 million m³/a. Although 10% is an acceptable margin of error, it represents 325 million m³/a, which is a large volume that can still be utilised for various purposes.

A different and more accurate approach is clearly required to obtain improved results with regards to the required timing of intervention measures and the available surplus. It was therefore decided to:

- *Carry out some sensitivity analyses with regards to the long-term stochastic yield. This will also help to set the scene for the short-term stochastic analyses and related assumptions.*
- *Use the Water Resources Planning Model (WRPM) to obtain the required timing when intervention will be required.*

The sensitivity analyses indicated that the stochastic yield results can be improved by means of the following:

- *Analysing the inflow to the Orange from the Vaal stochastically and thereby producing inflow records consisting of 501 flow sequences of 68 years each, instead of a single sequence from a historic analysis.*
- *Setting the river evaporation losses to zero and considering them as part of the system yield.*
- *Excluding the Lower Vaal operational losses from the Vaal inflow record.*

Results from the refined long-term stochastic analysis showed a surplus of 243 million m³/a at a 1 in 20 year assurance level. Based on the results of the sensitivity analyses and the fact that much more detailed stochastic analyses are involved in this refined long-term stochastic analysis result, the surplus of 243 million m³/a is regarded as the most accurate surplus indication from all the long-term stochastic analyses performed.

<u>WRPM Analyses</u>

The WRPM is used to carry out planning or operating analyses using short-term stochastic yield characteristics, obtained from the WRYM as part of the operating rule. The growth projections of all the water requirements are also included in the WRPM, in order to determine when curtailments and, or, intervention measures will be required in future. Using the WRPM to determine the required intervention time will more than likely result in a more conservative and realistic result than that obtained by means of the long-term stochastic yield analysis, as well as a more optimistic result than that from the historic firm yield analyses.

Results from this analysis indicated that curtailment levels are clearly exceeded from 2006 onwards. This means that curtailments are being imposed on the system more often than the given risk criteria.

From the results it is clear that actions need to be taken to improve the supply situation in the Orange River System from 2006 onwards, until a Vioolsdrift Re-regulating Dam can be in place. In practise it will not be possible to have Vioolsdrift Dam in place before 2012.

It is expected that the ORRS EFR will still be released for a number of years with some improvements over time, until the reserve has been determined. The surplus available in the Orange River System is significantly higher with the ORRS EFR imposed on the system than with the LORMS EFR.

Until Vioolsdrift Dam is in operation, the more practical option is to use the ORRS EFRs. The time before the construction of Vioolsdrift Dam should then be used to improve existing gauging structures and to build new ones where required, to be able to measure low flow accurately. This will aid in the implementation of real time modelling during this period in order to improve the timing of releases and to avoid high flows in winter months. These actions will improve the supply to the EFR, specifically at the river mouth. The real time modelling will also enable the operators of the Orange River System to utilise spills from the Vaal, and therefore save on the releases from Vanderkloof to increase the surplus yield of the system.

For the current system with the ORRS EFRs in place, intervention will only be required by 2012 and this can be extended further until 2018 if real time modelling is also used. Using the ORRS EFR initially will provide sufficient time for the construction of a dam at Vioolsdrift. By implementing real time modelling additional surplus will be created in the system, which can be utilised to improve the supply to the environment over time as more data become available. However, the Reserve needs to be implemented when new infrastructure such as a Vioolsdrift Re-regulating Dam is constructed.

As soon as the Vioolsdrift re-regulating dam is in place, one will require an additional development option such as Vanderkloof Lower Level Storage or a Large Vioolsdrift Dam. This is required to supply the higher environmental requirements in combination with the growth in demands up to that time (approximately 2015) and is clearly illustrated on ***Figure 2****. It is also evident from* ***Figure 2*** *that a Vioolsdrift re-regulating dam and Vanderkloof Lower level storage will not be sufficient to supply in the growing demand until 2025 and that additional live storage of approximately 280 million m³ is required for this purpose.*

Depending upon the final results from the parallel Vanderkloof Lower Level Study, it may be possible that the Vanderkloof Dam lower level storage option be excluded as a possible future option. If so, this will require a large storage dam in combination with a re-regulating dam at Vioolsdrift. It should, however, be noted that due to the limited water use downstream of

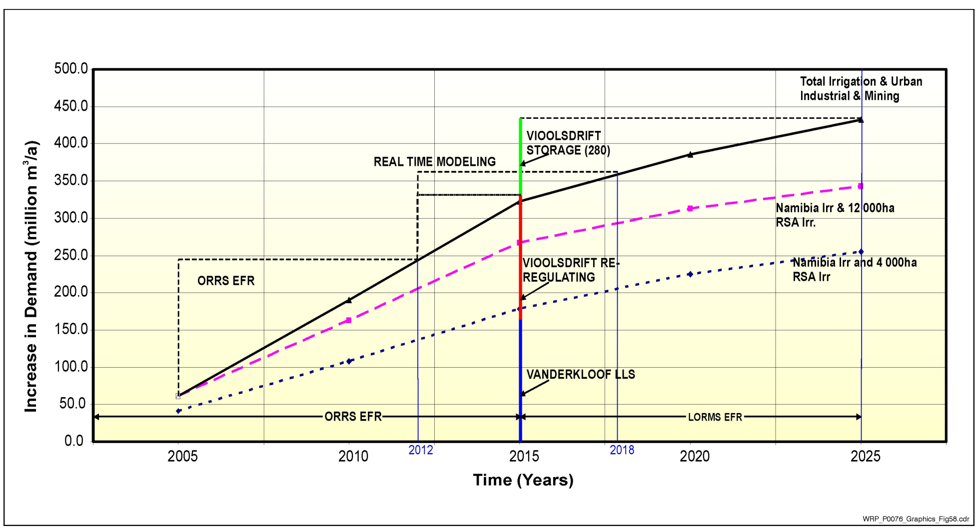

Figure 2: Required Intervention Time for Various Options versus the most probable Demand Growth

Vioolsdrift Dam the maximum live storage for a storage dam at Vioolsdrift is limited to between 1 500 to 2 000 million m³, depending on where future development will take place (downstream or upstream of Vioolsdift Dam). The maximum downstream use will also be affected by the actual river mouth environmental requirement that will be used in future as well as the extent to which flows from the Fish River (Namibia) can be utilized to supply the environmental requirements.

RECOMMENDATIONS

Based on the results from the analyses, the following recommendations are made:

- *Economic and financial analyses must be carried out for the Vioolsdrift re-regulating and large storage dams, the Vanderkloof Lower Level storage option, as well as for the possibility to utilize the current Vaal surplus. Results from the separate study on the impact of Vanderkloof Lower level storage utilisation on hydropower generation should be included in the economic and financial analyses.*
- *Detailed investigations and improved accuracy of low flow monitoring in the Lower Vaal are recommended to obtain improved information on the actual operating losses in the Lower Vaal, as well as for the portion of the losses that is in fact reaching the Orange River as yield results were sensitive to the spills assumed for the Vaal.*
- *Sedimentation has a major impact on the yield from dams in the Lower Orange and there is a lack of relevant data for this area. The processes should be put in place, to in time store and collect the necessary data.*
- *Water conservation and demand management should be strongly promoted in this area, as large volumes of water can be made available though the suggested actions. It is, however, foreseen that the additional water from water conservation and demand management will mainly be utilised by the irrigators themselves, to enable them to irrigate larger areas with the same volume of water, or to trade some of their allocation.*
- *To be able to manage the water supply to the Estuary to satisfy the environmental requirements according to the latest techniques developed and used in the Republic of South Africa, it will be necessary to significantly improve the operational management of the Orange River System. The upgrading of gauging stations and the implementation of real time modelling is therefore recommended as one of the first options to be implemented to improve the*

operational management of the system and to increase the water availability.

- *Different environmental flow requirements resulted in significantly different impacts on the available surplus in the system. It is of utmost importance that processes should be put in place, to in time store and collect the necessary data required enabling specialists to make sound recommendations in future, with regards to the actual environmental flow requirement needed. This will also include the upgrading of current gauging structures to obtain accurate flow values at key points, specifically near the Estuary.*
- *It is recommended to include the Vaal and other major tributaries in future environmental flow requirement assessments for the Orange River, as sensitivity analyses showed that environmental flow requirement contributions from the Vaal alone could have a significant impact on the surplus available in the Orange River System.*
- *Findings from the water quality review indicated that the calibration of the WQT Model (total dissolved solids (TDS)) could possibly be postponed to a later date.*
- *It is strongly recommended that a separate study should be commenced to investigate the algae blooms/nutrients and other related water quality problems in the Lower Orange.*
- *A Vioolsdrift Re-regulating Dam needs to be constructed as soon as possible.*
- *Use ORRS EFRs and real time modelling in the period before the construction of Vioolsdrift Dam to be able to supply in the growing demand, and to improve the supply to the environment.*
- *Use the results from the Vanderkloof Lower Level Study and resulting URV to decide on the implementation of this option.*
- *By 2015 a combination of Vanderkloof Low Level Storage (LLS) and Vioolsdrift Re-regulating Dam is required to supply the needs of the growing demand and improved EFR (LORMS EFR). It is therefore recommended that a combined Vioolsdrift storage/re-regulating dam be constructed at that time or slightly earlier, as a raising of the dam will be required not later than 2016. An additional storage of 280 million m^3 will be required at Vioolsdrift to be able to supply in the growing demand and EFR until 2025 in combination with Vanderkloof LLS.*
- *When Vanderkloof LLS is excluded as a possible future option, a storage dam of at least 830 million m^3 is required in combination with a re-regulation dam at Vioolsdrift.*

- *When a large storage dam is considered at Vioolsdrift, the possibility of a large dam such as Bosberg/Boskraai and Mashai should also be evaluated and compared with the large Vioolsdrift option.*

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a	annum
CBA	Common Border Area
DWAF	Department of Water Affairs and Forestry (South Africa)
EFR	Environmental Flow Requirement
FSL	Full Supply Level
ha	hectare
IB	Irrigation Board
IFR	Instream Flow Requirement for the environment
IVRS	Integrated Vaal River System
LHWP	Lesotho Highlands Water Project
LLS	Low Level Storage
LOR	Lower Orange River
LORMS	Lower Orange River Management Study
MAR	Mean Annual Runoff
Mm^3	million cubic metres
m.o.l.	minimum operating level
ORRS	The Orange River Replanning Study
O/V	Orange/Vaal
RSA	Republic of South Africa
RW	Rand Water
SAM	Social Accounting Matrix
SCC	Storage Control Curves
TDS	Total Dissolved Salts
URV	Unit Reference Value
VRSAU	Vaal River System Analysis Update
WC&DM	Water Conservation and Demand Management
WDM	Water Demand Management
WMA	Water Management Area
WRC	Water Research Commission
WRPM	Water Resources Planning Model
WRYM	Water Resources Yield Model
WUA	Water User Associations

1. INTRODUCTION

1.1 General

The Orange River has the largest river basin south of the Zambezi. It rises in the Drakensberg Mountains in Lesotho at an altitude of about 3 300 m, from where it flows to the west for 2 200 km to the sea. It has a total catchment area in excess of 1 million km², 600 000 of which is located in South Africa and the rest in the three neighbouring states of Lesotho, Namibia and Botswana. From 20°E longitude westwards, it forms the nearly 600 km long international border between Namibia and South Africa. This Common Border Area (CBA) has an arid climate. Here the Orange River passes through some of the most rugged and isolated terrain, but with fertile soils in narrow corridors along its banks. A map of the river catchment is included as shown in **Figure 1.1**.

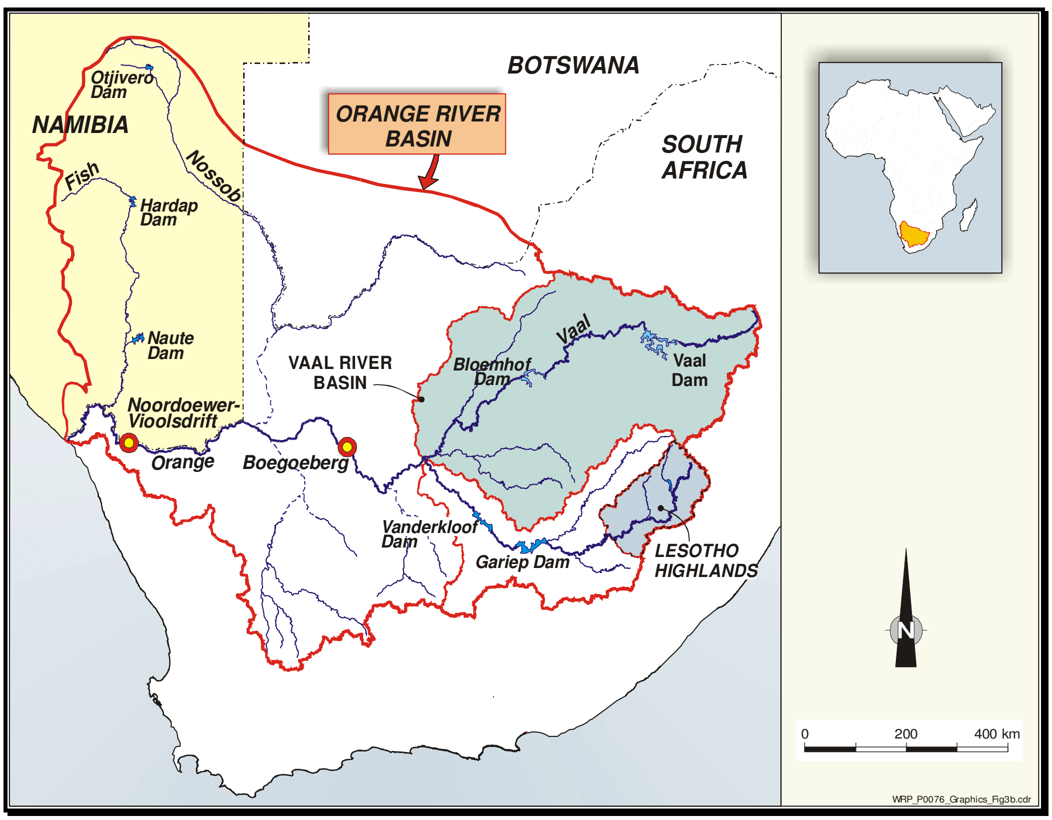

Figure 1.1: Orange River Basin

1.1.1 Runoff

It has been estimated that the natural runoff of the Orange River Basin is in the order of 11 300 Mm^3/a, of which approximately 4 000 million originate in the Lesotho Highlands and approximately 800 million from the contributing catchment downstream of the Orange/Vaal confluence. The remaining 6 500 Mm^3/a originate from the areas contributing to the Vaal, Caledon, Kraai and Middle Orange Rivers (See **Figure 1.2**). Much of the runoff originating from the Orange River downstream of the Orange Vaal confluence is highly erratic and cannot be relied upon to support the various downstream demands unless further storage is provided.

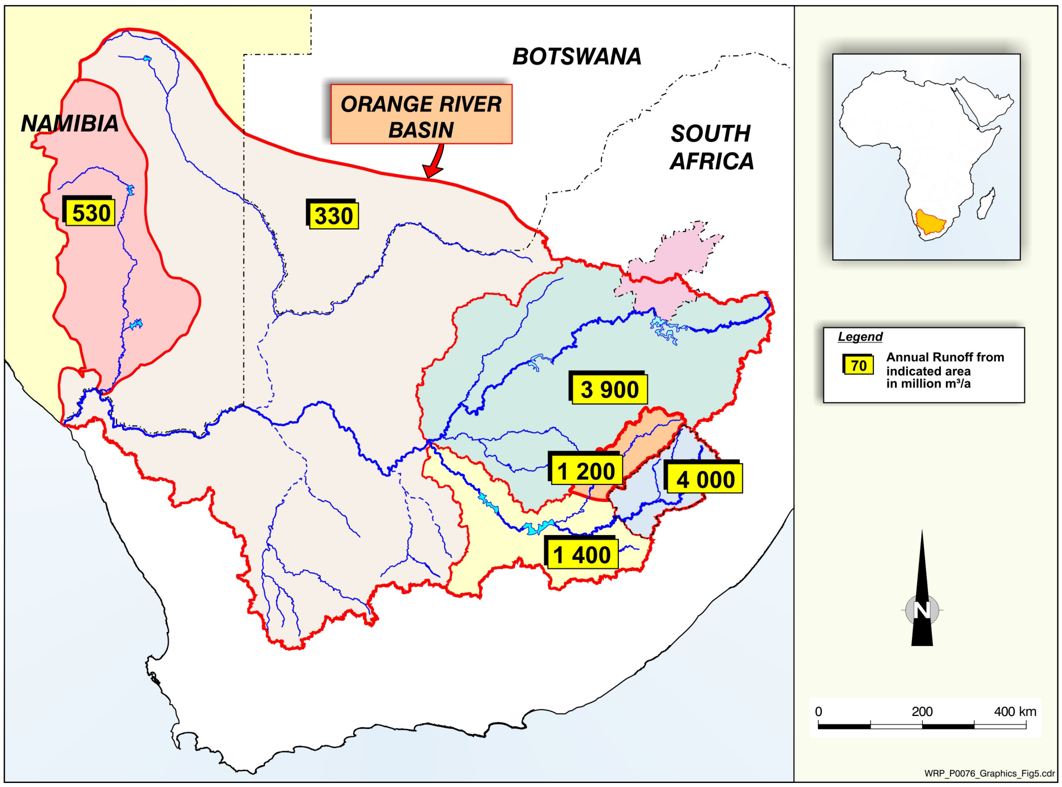

Figure 1.2: Sub-division of Areas of Natural Run-off in the Orange River Basin

Three important factors that will increase the water yield/use efficiency of the river system are:

- Storage in the Lower Orange will capture some of the 800 Mm^3 contributed by the catchment downstream of the Orange/Vaal confluence.
- Reduction of operating losses from the releases made at the Vanderkloof Dam.
- Water Demand Management (WDM) initiatives.

1.1.2 Major Demand Centres of the Orange River

In this report, the major demand centres supplied from the Orange River System are defined as:

1. Vaal River System.
2. Upper Orange River (upstream of the Orange/Vaal confluence).
3. Eastern Cape (transfers through the Orange / Fish Tunnel).
4. Lower Orange River (LOR) (Orange/Vaal confluence to the river mouth).

In this report the LOR is sub-divided into the following main sections:

4(i) LOR – upstream area (Orange/Vaal confluence to the Namibia/RSA border).

4(ii) CBA – (Namibia/RSA border to the river mouth).

The Lower Orange is further sub-divided into irrigation areas and main urban/industrial water use centres, as indicated in **Figure 1.3**.

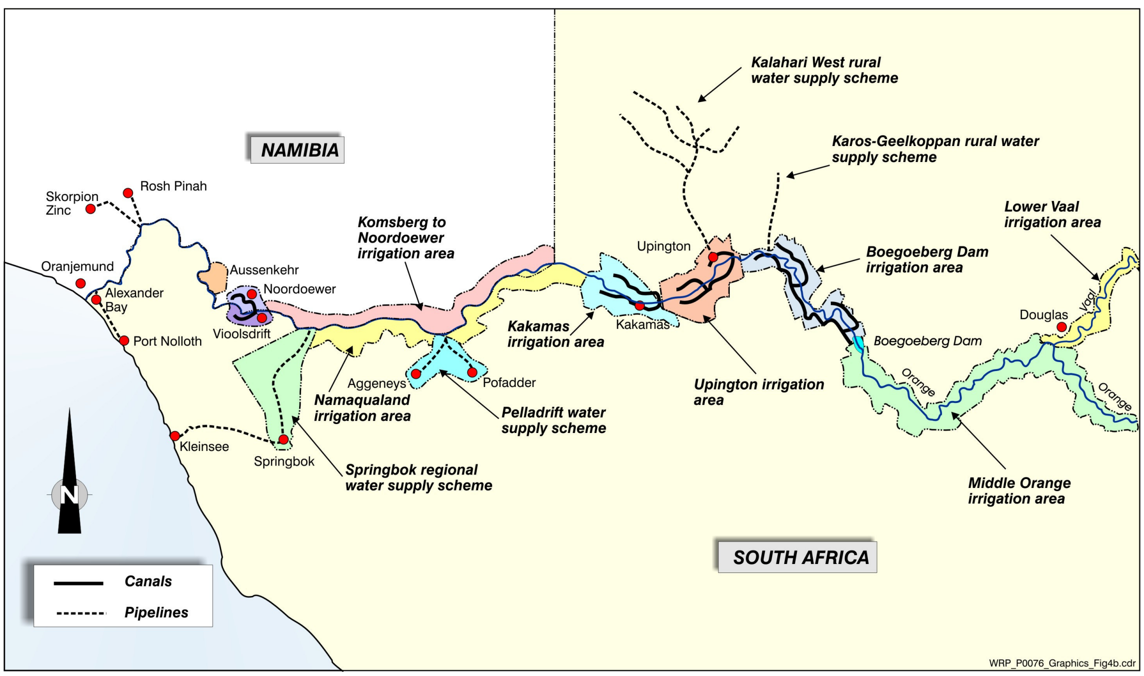

Figure 1.3: Irrigation Areas and other Water Use Centres along the Lower Orange River

Whereas a review and updating of available data was made to determine the water demands upstream of the 20°E longitude, a detailed analysis of water demands in the CBA, which included a site visit to the area, was made.

The region is sparsely populated and is not well served by infrastructure or supporting services.

The intensive dissection of the landscape by the Orange River has resulted in the areas in the vicinity of the river being very mountainous and hilly. Combined with the arid climatic conditions, this dissection has resulted in a restricted flood plain. The potential useable soils are generally scarce and limited to strips of alluvium and terrace gravel alongside the river.

From Augrabies in the Republic of South Africa (RSA) to Vioolsdrift/Noordoewer, the geology consists mainly of gneisses and schists, as well as granite and pegmatite. In the region of Noordoewer and Kotzéshoop, shale, limestone, arcose and phillites of the Nama System are found. West of Kotzéshoop, the Orange River flows through the Richtersveld Igneous Complex. A variety of rocks, varying from the Swaziland System to the young tertiary river terrace-gravel, can be found in this area.

The study area has an arid climate with an annual rainfall, which varies from about 100 mm in the east to less than 50 mm in the west. Mean maximum temperatures for the hottest month vary from 31°C at Oranjemund to more than 40°C at Goodhouse. The mean minimum daily temperature for the coldest month varies from 6.4°C at Goodhouse to 7.9°C at Oranjemund. The area has a very low frost risk. The average annual evaporation is estimated to be approximately 2 800 mm.

1.2 Objective of This Study

The objective of this study is to investigate measures to improve the availability of water along the LOR.

The options investigated include both demand and supply measures. In particular, the study investigated the potential of WDM along the LOR, together with ways to improve the beneficial use of water. It also investigated the need for, and feasibility of, constructing new storage reservoirs in the Lower Orange. Social and environmental issues were assessed, accompanied by full public involvement in the process.

The practical and financial viability of all the options to improve the water availability along the LOR were assessed and the options prioritised. A framework was developed for the allocation of costs of the proposed developments.

1.3 Purpose and Structure of This Report

This report was sub-divided into two separate volumes - Volume A and Volume B. The purpose of Volume A is to provide summarised details of the hydrological database, the land-use developments, the associated water requirements, as well as full details on the water supply systems, system yield and planning analyses.

Volume B contains a detailed description of the updated hydrology of the Fish River (Namibia), as well as a review of the existing RSA hydrology.

2. HYDROLOGY

2.1 General

The surface water resources of the Orange River System have been the subject of various studies aimed at developing and maintaining a reliable hydrological database. The hydrological data that are currently used to operate the system include the following:

- Hydrological time series database for the period September 1920 to October 1995 for Lesotho and Riet Modder catchments, as obtained from the Vaal River System Analysis Update (VRSAU) Study.
- Hydrological data from the Orange River System Analysis Study - Phase 1, covering the period 1920 – 1987. This hydrological data is used for the Caledon River catchment, as well as the Gariep and Vanderkloof Dams incremental catchments.
- Hydrological data for the Fish River (Namibia) was updated as part of the Lower Orange River Management Study (LORMS) and covers the period of 1920 to 2000.
- Hydrological data from the WR90 (Water Research Commission (WRC) Study) was used for the remainder of the Orange River downstream of Vanderkloof Dam. These records cover the period of 1920 to 1989.

The bulk of the hydrology was therefore obtained from previous studies and only the hydrology for the Fish River in Namibia was updated as part of this study. For detailed information on the Fish River hydrology, the reader is referred to **Volume B** of this Report. The hydrology for the remaining Orange and Vaal River catchments was developed as part of previous South African Studies. To increase the transparency of the South African studies, the Namibian Team reviewed the hydrology of the River Basin in South Africa and Lesotho. At the same time, this ensured that the Namibian Team are well acquainted with the hydrology. Details of the review are given in **Volume B** of this report.

2.2 Streamflow

The streamflow data, used in the analysis, is naturalised flow sequences and represents the incremental sub-catchments for various selected key points in the system. These sub-catchments are shown in **Figures A-1** and **A-2** for the Vaal and Orange River catchments, respectively. Naturalised streamflow are used to ensure compatibility between the different node inflows and to enable meaningful stochastic streamflow sequences to be generated. For this purpose, the Water Resources

Yield Model (WRYM) and Water Resources Planning Model (WRPM) require four hydrological flow files to be associated with each node. These include:

- INC = Monthly naturalised streamflow (million m^3);
- IRR = Monthly diffuse irrigation requirements (million m^3);
- AFF = Monthly diffuse afforestation requirements (million m^3); and
- RAN = Monthly point rainfall at the node (mm).

The • **INC** files contain the monthly naturalised streamflows in million m^3 entering the various system nodes. The natural incremental flow for the Orange River is summarised in **Table 2.1** and for the Vaal incremental catchments in **Table 2.2**. The complete monthly flow sequence for each of the incremental catchments is listed in **Appendix A.**

Table 2.1: Summary of Natural Streamflow Data for the Orange River System

Incremental Sub-catchment Name	Catchment Reference Number	Incremental Catchment Area (km^2)	Natural MAR (million m^3/a) (1920 – 1987)	Natural MAR (million m^3/a) (1920 - 1994)	.INC File Name
Riet-Modder					
Aucampshoop	I40	1,847	6.73	6.37	AUCH9.INC
Groothoek Dam	**	+(120)	**	**	
Kalkfontein Dam	I41	8,781	208.81	215.88	KALKF9.INC
Krugersdrift Dam*	I42	5,391	116.69	114.44	KRUG9.INC
Mockes Dam	**	+(1,897)	**	**	
Rustfontein Dam	I43	937	31.57	30.67	RUSTF9.INC
Tierpoort Dam	I44	922	23.92	23.76	TIER9.INC
Tweerivier	I45	2,236	14.01	14.38	TWEE9.INC
Riet-Modder Sub-total		**20,114**	**401.73**	**405.50**	
Lesotho Highlands					
Katse Dam	I27	1,867	552.47	545.54	KAT9.INC
Malatsi Dam	I28	2,628	282.54	281.53	MAL9.INC
Mashai Dam *	I29	5,458	782.85	771.50	MAS9.INC
Matsoku Weir	I30	652	93.40	92.98	MAT9.INC
Mohale Dam	I31	938	302.75	299.38	MOH9.INC
Ntoahae Dam	I32	1,125	146.94	150.34	NTO9.INC
Oranjedraai	I33	9,686	1,557.50	1,543.87	ORAN9.INC
Polihali Dam	*	3,290	*	*	
Taung Dam	*	2,091	*	*	
Tsoelike	I34	2,398	346.96	352.02	TSO9.INC
Sub-total		**24,752**	**4,065.41**	**4,037.16**	
Caledon					

Incremental Sub-catchment Name	Catchment Reference Number	Incremental Catchment Area (km²)	Natural MAR (million m³/a) (1920 – 1987)	Natural MAR (million m³/a) (1920 - 1994)	.INC File Name
Hlotse Dam	I70	960	188.94	-	HLOTS9.INC
Katjiesberg Dam	I71	2,400	296.87	-	KATJE9.INC
Knellpoort Dam	I72	776	20.83	-	KNEL9.INC
Waterpoort Dam	I77	1,082	80.38	-	WATER9.INC
Welbedacht Dam	I78	10,027	629.80	-	WELB9.INC
Sub-total		**15,245**	**1,216.82**	**-**	
Upper Orange					
Aliwal Noord	I67	3,635	229.44	-	ALIW9.INC
Gariep Dummy Dam	I69	9,215	198.27	-	HFDU9.INC
Vanderkloof Dam	I73	17,843	147.41	-	PKDU9.INC
Kraai River	I74	8,688	676.30	-	ROOD9.INC
Gariep Dam	I75	9,214	198.95	-	VERW9.INC
Sub-total		**48,595**	**1,450.37**	**-**	
The remainder of the Orange River Fish excluded can also be subdivided into the following four sub-catchments.					
Boegoeberg Dam	I68		76.80	-	BOEG9.INC
Hartbees incremental	#		#	-	
Vioolsdrift incremental*	I76		141.55	-	VIOOL9.INC
River Mouth inc	#		#	-	
Sub-total		**136,909**	**218.35**		
Namibia Fish					
Hardap dam	I186		190.16	179.0	HARDP.INC
Konkiep	I187		50.16	46.54	KONKP.INC
Low Fish dam	I188		91.65	85.04	LOWF.INC
Naute dam	I189		62.27	60.17	NAUT.INC
Seeheim	I190		360.84	334.8	SEEH.INC
Sub-total generated		95,680	755.08	705.55	
Sub-total real (Effect of losses taken into account)			**529.67**	494.28	
Orange Sub-total (Riet-Modder included)		**341,295**	**7,882.35**		

Note: * Mashai Dam catchment includes Polihali and Taung in the updated hydrology.

** Krugersdrift Dam catchment includes Groothoek and Mockes in the updated hydrology.

Vioolsdrift Dam catchment includes Hartbees and Rivermouth in the updated hydrology.

+ These incremental catchment areas are included in the incremental catchment area given for Krugersdrift Dam.

The • **IRR** and • **AFF** files respectively, contain the diffuse irrigation and afforestation requirements. Summarised information on these files is given in **Section 2.3.**

The natural mean annual runoff (MAR) for the Lower Orange is estimated to be 420 Mm³/a, of which only 218 Mm³/a is expected to reach the Orange River due to losses (pans).

Table 2.2: Summary of Natural Streamflow Data for Vaal System

Incremental Sub-catchment Name	Catchment Reference Number	Incremental Catchment Area (km²)	Natural MAR (million m³/a) (1920 – 1987)	Natural MAR (million m³/a) (1920 - 1994)	.INC File Name
Upper Vaal					
Delangesdrift	I5	4,158	255.49	249.49	DELA9.INC
Frankfort	I7	15,498	753.89	733.31	FRAN9.INC
Grootdraai Dam	I8	7,995	481.10	457.68	GROOTD9.INC
Sterkfontein Dam	I19	195	18.91	18.12	STERK9.INC
Vaal Dam	I21	10,792	539.25	518.65	VAAL9.INC
Vaal Barrage					
Vaal Barrage	I2	2,828	68.48	68.50	BARR9.INC
Klip River	I12	2,282	97.60	96.24	KLIPR9.INC
Suikerbosrant River	I20	3,541	93.41	92.34	SUIK9.INC
Middle Vaal					
Allemanskraal Dam	I1	3,628	100.01	96.13	ALLEM9.INC
Bloemhof Dam	I3	13,894	156.51	153.69	BLOEM9.INC
Boskop Dam	I4	1,756	36.66	35.78	BOSK9.INC
Erfenis Dam	I6	4,724	171.63	167.46	ERF9.INC
Klerkskraal Dam	I9	1,001	38.96	37.69	KLERK9.INC
Possible Klipbank Dam	I10	6,765	157.88	155.05	KLIPB9.INC
Klipdrift Dam	I11	890	21.47	21.08	KLIPD9.INC
Koppies Dam	I13	2,160	58.82	59.14	KOP9.INC
Possible Kromdraai Dam	I14	2,028	43.62	42.84	KROM9.INC
Johan Neser Dam	I15	2,829	52.63	51.68	NESER9.INC
Possible Rietfontein Dam	I16	3,605	61.63	60.52	RIETF9.INC
Rietsruit Dam	I17	1,714	36.70	36.04	RIETS9.INC
Lower Sand/Vet River	I18	8,463	162.04	159.13	SAND9.INC
Lower Vaal					
Wentzel Dam	I181	5,825	44.66	42.69	USWENTZD.INC
Baberspan	I180	434	3.33	3.18	BARBERS.INC
Taung Dam	I182	1,788	13.69	13.09	DSWENTZD.INC
Spitskop Dam	I37	9,205	80.51	77.49	SPITS9.INC
Lower Harts	I183	1,691	11.84	11.69	C3H013.INC
Vaalharts Weir	I39	2,509	11.24	11.16	VHARTS9.INC
Dehoop Weir	I35	3,201	10.87	12.93	DEHOOP9.INC
Douglas Weir	I184	4,168	18.89	18.59	C9H007.INC

Incremental Sub-catchment Name	Catchment Reference Number	Incremental Catchment Area (km²)	Natural MAR (million m³/a) (1920 – 1987)	Natural MAR (million m³/a) (1920 - 1994)	.INC File Name
Vaal sub-total (excluding Riet-Modder)		129,567	3,601.72	3,501.38	
Riet-Modder					
For the purpose of this study the Riet-Modder catchment was treated as part of the Orange River System. This was decided, as water is transferred from the Orange and Caledon Rivers to support the requirements in the Riet-Modder catchment. There is, however, no support from the Vaal to the Riet-Modder catchment or the other way around. The only influence from the Riet-Modder on the Vaal is that spills from the Riet-Modder enter the Vaal River upstream of Douglas Weir and therefore, contribute to the supply of the water demand imposed on Douglas. For this reason, the Vaal River from the Riet-Modder confluence to the Orange Vaal confluence is also included as part of the Orange River System. Summarized hydrological data for the Orange River System is given in **Table 2.1.**					

Point rainfall and evaporation data are required to simulate the full water balance at each reservoir considered in the analysis. In many cases, system nodes are selected at sites of existing and possible future reservoirs and such nodes are associated with a set of hydrological records as discussed earlier in this section. One of these files the • RAN file contains the monthly rainfall in mm at the node. The rainfall data is summarised in **Table 2.3**.

The evaporation data are also given on a monthly basis in units of mm. Due to the lower variability in potential evaporation from one year to another, only 12 monthly values are given for each year in the simulation. A summary of the evaporation data, as used in the analysis for each reservoir, is given in **Table 2.4**.

Table 2.3 Summary of Point Rainfall Data

Hydrology Reference No.	Node Name	File Name	MAP (mm) 1920 - 87
Lesotho Highlands			
I27	Katse Dam	KAT9.RAN	754.4
I28	Malatsi Dam	MAL9.RAN	599.6
I29	Mashai Dam	MAS9.RAN	500.7
I30	Matsoku Weir	MAT9.RAN	765.5
I31	Mohale Dam	MOH9.RAN	853.9
I32	Ntoahae Dam	NTO9.RAN	555.2
I33	Oranjedraai	ORAN9.RAN	729.5
I34	Tsoelike Dam	TSO9.RAN	502.7
Caledon			
I70	Hlotse Dam	HLOTS9.RAN	835,8
I71	Katjiesberg Dam	KATJE9.RAN	814,0

Hydrology Reference No.	Node Name	File Name	MAP (mm) 1920 - 87
I72	Knellpoort Dam	KNEL9.RAN	595,0
I77	Waterpoort Dam	WATER9.RAN	732,4
I78	Welbedacht Dam	WELB9.RAN	595,0
Upper Orange			
I67	Aliwal Noord	ALIW9.RAN	579,7
I69	Gariep dummy Dam	HFDU9.RAN	450,8
I73	Vanderkloof Dam	PKDU9.RAN	349,8
I74	Kraai River	ROOD9.RAN	579.7
I75	Gariep Dam	VERW9.RAN	405,0
Modder Riet			
I40	Aucampshoop	AUCH9.RAN	366.3
I41	Kalkfontein Dam	KALKF9.RAN	411.5
I42	Krugersdrift Dam	KRUG9.RAN	548.8
I43	Rustfontein Dam	RUSTF9.RAN	548.2
I44	Tierpoort Dam	TIER9.RAN	505.7
I45	Tweerivier	TWEE9.RAN	499.4
Lower Orange			
I68	Boegeberg Dam	BOEG9.RAN	0.00
I76	Vioolsdrift	VIOOL9.RAN	0.00
Namibia Fish			
I186	Hardap Dam	HARDP.RAN	189.3
I187	Konkiep	KONKP.RAN	100.6
I188	Low Fish Dam	LOWF.RAN	100.6
I189	Naute Dam	NAUT.RAN	149.6
I190	Seeheim Dam	SEEH.RAN	149.6

Table 2.4 Summary of Lake Evaporation Data for Each Reservoir Considered in the Analysis

Node/Reservoir		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
No.	Name													
21	Katse	127	126	122	135	103	104	73	72	49	58	88	105	1 162
24	Mashai	132	130	123	139	105	104	75	75	52	60	91	109	1 195
27	Mohale	126	125	122	134	102	103	73	71	48	57	87	104	1 152
32	Bosberg	138	163	187	187	173	129	88	68	50	56	81	107	1 427
38	Dummy 3	129	143	156	146	115	102	77	63	49	48	82	106	1 216
44	Knellpoort	142	221	234	219	161	149	105	79	65	60	84	117	1 636
47	Welbedacht	142	221	234	219	161	149	105	79	65	60	84	117	1 636
52	Rustfontein	142	195	220	211	157	141	98	78	62	57	81	114	1 556
54	Groothoek	142	195	220	211	157	141	98	78	62	57	81	114	1 556
55	Mockes	138	195	224	224	168	144	98	72	51	48	72	106	1 540
56	Krugersdrift	187	210	251	225	174	154	114	90	68	76	79	146	1 774
57	Tierpoort	144	205	234	222	174	154	108	79	61	56	81	111	1 629
58	Kalkfontein	158	234	268	265	200	166	118	85	63	56	82	118	2 205

Node/Reservoir		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
No.	Name													
62	Dummy 2	195	228	259	255	226	168	115	90	68	78	115	152	1 949
63	Gariep	202	236	275	277	226	169	116	90	71	82	108	155	2 007
64	Dummy 1	212	246	285	280	229	179	122	97	76	88	120	166	2 100
66	Vanderkloof	230	269	313	315	256	191	132	102	81	93	123	176	2 281
71	Hardap	234	263	283	268	181	156	144	125	108	119	146	185	2 212
75	Naute	245	275	301	328	248	215	178	149	130	124	151	194	2 538
78	Low Fish	232	260	285	310	235	203	168	141	123	117	143	183	2 400
81	Rustfont dum	138	158	183	182	143	125	84	61	43	50	72	107	1 346
84	Mockes dum	138	157	182	181	142	123	83	60	43	49	71	106	1 335
88	Douglas*	173	193	219	212	140	109	94	94	70	75	95	134	1 608
91	Krugersdrift du	180	206	239	236	186	161	109	79	56	65	93	139	1 749
93	Tweerivier du	192	222	252	248	204	176	130	98	78	83	109	150	1 942
94	Tweerivier wei	272	322	365	354	272	224	158	112	85	94	138	204	2 600
96	Tierpoort dum	141	160	184	177	145	129	90	64	48	55	77	108	1 378
98	De Krans weir	158	234	268	265	200	166	118	85	63	56	82	118	1 813
105	Boegoeberg*	190	226	265	264	197	160	112	90	70	78	105	147	1 904
106	Kalkfontein du	150	171	196	188	154	137	95	68	52	58	82	115	1 466
127	Vioolsdrift*	188	228	263	275	237	216	148	93	64	63	93	139	2 007
129	Kabies*	178	213	249	260	211	202	141	104	85	83	97	175	1 998

Notes: *These figures represent the net lake evaporation as it includes the effect of rainfall on the dams.

2.3 Land-use Developments

The water requirements for the various land-use developments were obtained from the "Water Requirements Report", produced as part of this study. The purpose of this section is to provide the reader with summarised information, and to explain the methodology and procedures followed, to include and model the relevant data in the WRYM and WRPM.

For the purpose of the models, the irrigation requirements can be considered as either diffuse or controlled irrigation. Diffuse irrigation is not supported by releases from large reservoirs and is usually in the form of run-of-river irrigation. Such irrigation often experience shortfalls due to low rainfall and run-off and is therefore better suited for low value annual crops. These irrigation demands are in most cases included in the • **IRR** files, as described in **Section 2.2**. The WRYM and WRPM models also allow diffuse irrigation to be modelled in a similar way as controlled irrigation with the only difference being that major storage dams do not support the diffuse irrigation. This option is often used when there are a large number of farm dams that are used to support diffuse irrigation. In this case, part of the diffuse irrigation is supported by the farm dams, and the remaining diffuse irrigation from the available runoff in the river, upstream or downstream of the farm dams, depending on the physical location of the diffuse irrigation. The farm dams are lumped into a single dam referred as a dummy dam with characteristics equivalent to that of all the farm dams combined. A large number of diffuse irrigation was modelled this way and is therefore included in **Table 2-6**, as part of the controlled demands. Water use by afforestation is also regarded as a diffuse demand as it is not supported by storage. The afforestation requirements are included in the • **AFF** files (See **Section 2.2).** The amount of afforestation in the Orange River Catchment is negligible and no demand for this has been included in the model. The diffuse irrigation and afforestation demands are summarised in **Table 2.5** for each of the sub-catchments in the Orange River System, as well as the total diffuse demand as modelled for the Vaal River System.

Controlled irrigation is mainly supported by releases from storage, either via canal or directly from the river. Since the supply of irrigation can be provided at higher assurance, controlled irrigation is better suited for permanent and/or high value crops including citrus, vines, dates, etc. Virtually all of the irrigation downstream of Vanderkloof Dam can be considered as controlled irrigation. The irrigation requirements included in **Table 2-6** represent the net irrigation requirement after the effect of return flows from irrigation canals and irrigation fields were taken into account.

Table 2.5: Diffuse Catchment Developments

Sub-catchment		Incremental Catchment Area (km^2)	Diffuse demands (milliom m^3/a)			File Names, if appropriate
Catchment Reference No.	Catchment Name		Irrigation (1920 -87)	Afforestation (1920 – 87)	Total	
Lesotho Highlands						
All sub-catchments included		24 752	0,00	0,00	0,00	-
Sub-total for Lesotho Highlands		**24 752**	**0,00**	**0,00**	**0,00**	
Caledon						
All sub-catchments included		15 245	0,00	0,00	0,00	-
Sub-total for Caledon		**15 245**	**0,00**	**0,00**	**0,00**	
Upper Orange						
I67	Aliwal Noord	3 635	17,77	0,00	17,77	ALIW9.IRR
I69	Gariep Dummy dam	9 215	*0,00	0,00	0,00	-
I73	Vanderkloof Dam	17 843	*0,00	0,00	0,00	-
I74	Kraai River	8 688	44,24	0,00	44,24	ROOD9.IRR

Sub-catchment: Catchment Reference No.	Sub-catchment: Catchment Name	Incremental Catchment Area (km²)	Diffuse demands (milliom m³/a): Irrigation (1920 -87)	Diffuse demands (milliom m³/a): Afforestation (1920 – 87)	Diffuse demands (milliom m³/a): Total	File Names, if appropriate
I75	Gariep Dam	9 214	0,00	0,00	0,00	-
Sub-total for Upper Orange		**48 595**	**62,01**	**0,00**	**62,01**	
Modder-Riet						
I40	Aucampshoop	1 847	*0,00	0,00	0,00	-
I41	Kalkfontein Dam	8 781	*0,00	0,00	0,00	-
I42	Krugersdrift Dam	5 391	*0,00	0,00	0,00	-
I43	Rustfontein Dam	937	*0,00	0,00	0,00	-
I44	Tierpoort Dam	922	*0,00	0,00	0,00	-
I45	Tweerivier	2 236	*0,00	0,00	0,00	-
Sub-total for Modder-Riet		**20 114**	**0,00**	**0,00**	**0,00**	-
Lower Orange						
All sub-catchments included		****136 909**	**x**	**x**	**x**	**x**
Sub-total for Lower Orange						
Namibia Fish						
All sub-catchments included		**95 680**	**x**	**x**	**x**	**x**
Sub-total for Namibia Fish						
Total		**341 295**	62.01	**0,00**	62.01	-
Total Vaal River Catchment		**129 567**	*0.00	*0.00	*0.00	
Total (Vaal Fish & Orange)		**470 862**				

Notes: * Diffuse irrigation supplied from farm dams and river streams are modelled similar as a controlled demands in the WRYM

** Only catchment areas located in the RSA are included

x No diffuse irrigation and afforestation occur in these areas.

Table 2.6: Details of Controlled Demands Modelled in the System Analysis

Code	Description	File name, if applicable	Annual Demand (million m3/a)		
			2005	2015	2025
	Area 1 Upstream of Gariep				
	Irrigation				
DEM 34	Diffuse irrigation from farm dams Gariep sub-catchment	GAR 05.IRR	145.9	145.9	145.9
DEM 54	Irrigation within Lesotho Caledon River	LES 05n.IRR	8.5	8.5	8.5
DEM 57	Irrigation within the RSA Caledon River	RSA 05n.IRR	32.3	32.3	32.3
DEM 70	Irrigation from Caledon downstream of Welbedacht	WEL 05n.IRR	34.6	34.6	34.6
DEM 131	Irrigation upstream of Gariep downstream Aliwal Noord	KRA 05n.IRR	18.0	18.0	18.0
DEM 132	Irrigation upstream of Bosberg Dam and downstream of Oranjedraai	ORA 05n.IRR	1.7	1.7	1.7
DEM 181	Irrigation upstream of Aliwal Noord and downstream of Bosberg Dam	ALI 05.IRR	9.3	9.3	9.3
		Sub-total	**250.3**	**250.3**	**250.3**
	Urban / Industrial				
DEM 51	Urban demand within the RSA Caledon River	12 monthly values	4.2	4.7	5.2
DEM 52	Urban demands from Orange River Upstream of Gariep	12 monthly values	10.7	12.8	15.3
DEM 66	Lesotho Urban demand (net effect) Caledon River	12 monthly values	11.0	13.7	17.0
DEM 75	Botshabelo Urban demand partly supplied from the Caledon	12 monthly values	15.2	23.0	30.4
DEM 77	Bloemfontein Urban demand partly supplied from the Caledon	12 monthly values	47.4 * (23.1)	55.1 * (26.9)	60.4 * (29.4)
DEM 139	Lesotho/Vaal Transfer	12 monthly values	780	780	780
		Sub-total	**868.5**	**889.3**	**908.3**
	Losses				
LOSS 68	Transfer losses Knellpoort to Welbedacht Dam	10 % of flow	3.7	3.2	2.7
LOSS 73	Transfer losses Welbedacht Dam to Bloemfontein	10 % of flow	4.2	4.4	4.4
LOSS323	Transfer losses Knellpoort to Rustfontein Dam	17.5 % of flow	5.6	6.4	7.3
		Sub-total	**13.5**	**14.0**	**14.5**
Total Area 1			**1 132.3**	**1 153.6**	**1 173.1**

Table 2.6 (Continues): Details of Controlled Demands Modelled in the System Analysis

Code	Description	File Name, if applicable	Annual Demand (million m3/a)		
			2005	2015	2025
	Area 2 Gariep to Orange – Vaal Confluence				
	Irrigation				
DEM 39	Diffuse irrigation from farm dams Vanderkloof sub-catchment	VDK 05.IRR	81.0	81.0	81.0
DEM 43	Orange River irrigation Vanderkloof to Torquay Dam	12 monthly Values	116.7	116.7	116.7
DEM 50	Irrigation demand directly from the Orange/Vaal canal	ORV 05.IRR	15.1	15.1	15.1
DEM 84	Irrigation from compensation releases between Gariep and Vanderkloof	GCMP 05n.IRR	19.7	19.7	19.7
DEM 125	Irrigation from Douglas weir canal and river releases	12 monthly values	65.7	65.7	65.7
DEM 153	Irrigation from Ramah and Vanderkloof main canal	12 monthly values	57.5	57.5	57.5
DEM 178	Irrigation demand directly from the Orange/Riet canal Riet River Settlement and Ritchie	ORI 05n.IRR	130.0	130.0	130.0
DEM 203	Lower Riet River Irrigation Board	LOR 05n.IRR	41.2	41.2	41.2
DEM 207	Scholtzburg Irrigation Board	SCH 05n.IRR	7.9	7.9	7.9
DEM 234	Orange River Torquay Dam to Orange/Vaal confluence	12 monthly values	36.1	36.1	36.1
		Sub-total	**570.9**	**570.9**	**570.9**
	Urban / Industrial				
DEM 130	Orange/Fish transfer : Irrigation (Eastern Cape)	Verw9h.inf	607.3	607.3	607.3
	:Urban/Industrial	Verw9h.inf	20.0	20.0	41.3
DEM 45	Hopetown, Vanderkloof,Orania	12 monthly Value	2.0	2.1	2.1
DEM 97	Douglas Urban Demand	12 monthly	1.2	1.4	1.7
DEM 143	Richie Urban Demand	12 monthly value	0.3	0.4	0.5
DEM 183	Urban demand between Gariep and Vanderkloof	12 monthly value	2.1	2.3	2.5
		Sub-total	**632.9**	**633.5**	**655.4**
	Losses				
DEM 67	River losses Reach 1a	12 monthly values	44.3	44.3	44.3
LOSS 74	Orange/Riet transfer losses	12 % of flow	32.9	32.9	32.9
LOSS 151	Orange/Vaal transfer losses	10,7 % of flow	1.8	1.8	1.8
DEM 238	River losses Reach 1b	12 monthly values	11.8	11.8	11.8
DEM 251	Operating losses **		270	270	270
		Sub-total	**360.8**	**360.8**	**360.8**
Total Area 2			**1 564.6**	**1 565.2**	**1 587.1**

Table 2.6 (Continued): Details of Controlled Demands Modelled in the System Analysis

Code	Description	File Name, if applicable	Annual Demand (million m3/a) 2005	2015	2025
	Area 3 Riet/Modder				
	Irrigation				
	Area 3 Riet/Modder: Irrigation				
DEM 9	Rustfontein Dummy Dam	Rust.DIR	0.9	0.9	0.9
DEM 88	Modder River G.W.S.	KRU 05n.IRR	35.9	35.9	35.9
DEM 89	Tierpoort Irrigation Board	TIR 05n.IRR	6.4	6.4	6.4
DEM 91	Kalkfontein Canal Scheme	KAL 05n.IRR	32.5	32.5	32.5
DEM 119	Rustfontein Main Stream	Rust.MIR	2.6	2.6	2.6
DEM 127	Mockes Dummy Dam	Mock.DIR	1.4	1.4	1.4
DEM 133	Mockes Main Stream	Mock.MIR	4.2	4.2	4.2
DEM 185	Krugerdrift Main Stream	Krug.MIR	7.5	7.5	7.5
DEM 215	Krugerdrift Tributary	Krug2.MIR	4.8	4.8	4.8
DEM 219	Tweerivier Dummy Dam	Twee.DIR	17.8	17.8	17.8
DEM 237	Tierpoort Dummy Dam	Tier.DIR	1.3	1.3	1.3
DEM 239	Tierpoort Main Stream	Tier.MIR	0.4	0.4	0.4
DEM 246	Kalkfontein Dummy Dam	Kalk.DIR	37.4	37.4	37.4
DEM 250	Kalkfontein Mainstream	Kalk.MIR	7.1	7.1	7.1
		Sub-total	**160.1**	**160.1**	**160.1**
	Urban / Industrial				
DEM 85	Thaba'Nchu	12 monthly values	3.2	3.3	3.3
DEM 179	Koffiefontein, Jacobsdal,	12 monthly values	1.7	1.9	2.1
	Koffiefontein Mine demands from Kalkfontein	**Sub-total**	**4.9**	**5.2**	**5.4**
	Losses				
LOSS 79	Transfer losses Mockes Dam to Bloemfontein	5 % of flow	0.5	0.8	1.1
LOSS 81	Transfer losses Rustfontein to Mockes Dam	5 % of flow	2.1	2.4	2.7
		Sub-total	**2.6**	**3.2**	**3.8**
Total Area 3			**167.7**	**168.5**	**169.4**

Table 2.6 (Continued): Details of Controlled Demands Modelled in the System Analysis

Code	Description	File Name, if applicable	Annual Demand (million m3/a) 2005	2015	2025
	Area 4 Orange-Vaal confluence to 20 Longitude				
	Irrigation				
DEM 148	Orange/Vaal confluence to Boegoeberg weir. Irrigation from Orange River.	12 monthly values	135,1	135.1	135.1
DEM 155	Boegoeberg weir to Neusberg. Irrigation directly from Orange River	12 monthly values	64.0	64.0	64.0
DEM 157	Neusberg to Augrabies irrigation directly from Orange River	12 monthly values	31.5	31.5	31.5
DEM 162	Boegoeberg irrigation from canals	12 monthly values	102.1	102.1	102.1
DEM 170	Irrigation from Upington canals	12 monthly values	101.7	101.7	101.7
DEM 176	Irrigation from Keimoes canals	12 monthly values	64.4	64.4	64.4
DEM 188	Kakamas and Augrabies Irrigation from canals	12 monthly values	106.3	106.3	106.3
DEM 194	Namaqualand irrigation Augrabies to Namibian border	12 monthly values	9.8	9.8	9.8
		Sub-total	**614.85**	**614.8**	**614.8**
	Urban / Industrial				
DEM 142	Prieska Urban demand	12 monthly value	2.0	2.7	3.6
DEM 184	Kakamas, Keimoes Urban demand	12 monthly value	2.4	2.9	3.3
DEM 193	Upington, Groblershoop and others urban demand	12 monthly value	17.7	21.4	23.1
		Sub-total	**22.1**	**27.0**	**30.0**
	Losses				
DEM 144	River losses Reach 2	12 monthly values	126.4	126.4	126.4
DEM 180	River losses Reach 3	12 monthly values	130.9	130.9	130.9
DEM 192	River losses Reach 4	12 monthly values	37.1	37.1	37.1
LOSS 158	Boegoeberg net canal losses	6 % of flow	8.0	8.0	8.0
LOSS 167	Upington net canal losses	6 % of flow	8.1	8.1	8.1
LOSS 168	Keimoes net canal losses	6 % of flow	5.3	5.3	5.3
LOSS 199	Kakamas net canal losses	4 % of flow	5.6	5.6	5.6
		Sub-total	**321.3**	**321.3**	**321.3**
	Environmental Requirements:				
DEM 190	Instream Flow Requirement				
	Class D Desktop (average flow) $	New IFR structure	#1 605	1 605	1 605
	Class D Top-Up (average flow) $	New IFR structure	#1 062	1 062	1 062
		Sub-total	**Not Relevant**		
Total area 4 (Exclude IFR)			**958.3**	**963.2**	**966.2**

Table 2.6 (Continued): Details of Controlled Demands Modelled in the System Analysis

Code	Description	File Name, if applicable	Annual Demand (million m3/a)		
			2005	2015	2025
	Area 5 20° Longitude to River Mouth:				
	Irrigation: RSA				
DEM 198	Namaqualand irrigation Namibian border to Vioolsdrift	12 monthly values	35.1	35.1	35.1
DEM 208	Vioolsdrift South irrigation(RSA)	12 monthly values	7.5	7.5	7.5
DEM 218	Alexander Bay Irrigation	12 monthly values	10.0	10.0	10.0
		Sub-total	**52.6**	**52.6**	**52.6**
	Irrigation: Namibia				
DEM 159	Namibia Irrigation from Pelladrift node. (Namibia border to Vioolsdrift)	12 monthly values	18.8	18.8	18.8
DEM 161	Vioolsdrift North, Aussenkehr and others irrigation	12 monthly values	19.5	19.5	19.5
		Sub-total	**38.3**	**38.3**	**38.3**
	Urban / Industrial: RSA				
DEM 200	Namakwa small users	12 monthly values	4.7	9.9	9.9
DEM 118	Springbok (Namakwa) Water Board	12 monthly values	4.6	5.6	6.9
DEM 224	Alexander Bay, small users	12 monthly values	7.3	8.2	5.9
		Sub-total	**16.6**	**23.7**	**22.7**
	Urban / Industrial: Namibia				
DEM 165	Oranjemund and Rosh Pinah urban demand	12 monthly values	8.3	8.3	8.3
DEM 206	Hailb Mine	12 monthly value	0.0	30.0	30.0
DEM 115	Ariamsvlei, Granau, Karasburg & Warmbad+	12 monthly values	0.0 +(0.3)	0.04 +(0.4)	0.04 +(0.4)
DEM 116	Noordoewer, Aussenkehr	12 monthly values	0.2	0.4	0.6
DEM 117	Mines Rosh Pinah, etc	12 monthly values	6.9	7.2	7.7
		Sub-total	**15.4**	**45.9**	**46.6**
	Losses: RSA / Namibia Combined				
DEM 202	River losses Reach 5	12 monthly values	143.9	143.9	143.9
DEM 212	River losses Reach 6	12 monthly values	54.2	54.2	54.2
DEM 216	River losses Reach 7	12 monthly values	66.5	66.5	66.5
		Sub-total	**264.6**	**264.6**	**264.6**
	Environmental Requirements: RSA / Namibia Combined				
DEM 220	River Mouth environmental demand	12 monthly values	#288.9	288.9	288.9
	Class D Desktop (average flow) $	New IFR structure	#1 605	1 605	1 605
	Class D Top-Up (average flow) $	New IFR structure	#1 062	1 062	1 062
		Sub-total	**Not relevant**		
Total Area 5			**387.5**	**425.1**	**424.8**

Table 2.6 (Continued): Details of Controlled Demands Modelled in the System Analysis

Code	Description	File Name, if applicable	Annual Demand (million m3/a)		
			2005	2015	2025
		Area 6 Namibia Fish: Irrigation			
	Irrigation				
DEM 99	Hardap Dam	12 monthly values	41.7	41.7	41.7
DEM 106	Naute Dam	12 monthly values	4.6	4.6	4.6
		Sub-total	**46.3**	**46.3**	**46.3**
	Urban / Industrial				
DEM 113	Hardap Urban (Fish)	12 monthly values	1.0	1.1	1.2
DEM 114	Naute Urban (Fish)	12 monthly values	2.0	2.0	2.0
		Sub-total	**3.0**	**3.1**	**3.2**
	Losses				
DEM 101	Hardap River losses	Hard1.los	112.1	112.1	112.1
DEM 104	Seeheim River losses	Seeh1.los	103.8	103.8	103.8
DEM 108	Naute River losses	Naut1.los	9.2	9.2	9.2
		Sub-total	**225.1**	**225.1**	**225.1**
	Surpus Yield				
DEM 258	Hardap Dam	12 monthly values	0.00	0.00	0.00
DEM 259	Naute Dam	12 monthly values	2.8	2.8	2.8
		Sub-total	**2.8**	**2.8**	**2.8**
Total Area 6			**277.2**	**277.2**	**277.2**
Total	**(Excluding environmental requirements)**		**4 487.5**	**4 552.8**	**4 597.7**

Notes:
- * The value in brackets represents the net effect of the Bloemfontein Demand after taking into account return flows.
- ** Operational losses might differ depending on the scenario analysed the 270 million m³/a represent the current operational losses.
- \+ These towns are currently not supplied from Orange River and will be phased in at 10% of their respective demands from 2010 onwards.
- \# The environmental requirement used depends on the scenario analysed. Currently the 288.8 million m³/a is released from the system.
- $ The environmental requirements based on the new IFR structure vary from year to year as it depends on the natural flow generated each year. The value given in the table represents the average environmental requirement as supplied over the total analysis period.

It is important to note that the growth in irrigation as shown in**Table 2-6** is zero. This is due to the large number of uncertainties with regards to the possible growth in irrigation. It was, therefore, decided to base the yield analysis on the current irrigation development. The effect of possible irrigation growth scenarios will then be included at a later stage (See **Section 4.6.2**).

The effect of return flows from irrigation fields and canals was determined for the main irrigation areas, and the results are summarised in **Table 2.7**. Irrigation return flows from smaller irrigation areas, and in particular from the diffuse irrigation, was assumed to be negligible, and therefore not modelled. Irrigation return flows in the Eastern Cape were not determined as this has no effect on the Orange River System, although it will have a significant effect on the Eastern Cape System itself. The losses in the Fish River System (Namibia) are extremely high and it was therefore assumed that return flows from the Hardap and Naute irrigation areas will have a negligible impact on the flow in the Fish River, and thus the resulting outflow to the Orange River.

In **Table 2.8** details are provided of the actual monthly demands where 12 monthly values were used**.** Where monthly demand files were used, details are given in **Appendix B**. In case of the latter, the data are given for the different file names as specified in **Table 2-6**.

2.4 Losses

Losses from the system represent important "demands" that must be taken into account. The main losses modelled in the system are normal transmission losses and evaporation losses from the reservoirs. Evaporation losses from the reservoirs are modelled by the WRYM and WRPM by using the lake evaporation as given in **Table 2.4** and the corresponding reservoir surface area determined by the model for the specific month under consideration.

In the case of normal transmission losses, the loss is, in most cases, expressed as a percentage of the upstream inflow to a specific system node. The percentages and average values as obtained from the model are given in **Table 2-6**. A second component of the transmission losses is operating losses, which are particularly high in the Orange River System.

Gariep and Vanderkloof Dams are used to support the demands along the LOR from Vanderkloof Dam to the Orange River mouth. These demand centres are located along a river length of approximately 1 380 km which, together with river requirements and inflows from the Vaal and Fish Rivers, contributes to the complexity of operating the system and determining how much water to release from Vanderkloof Dam. A further complication concerns releases from Vanderkloof Dam to generate hydropower, which is sometimes in excess of the downstream demands. The large controlling structures (sluice gates, hydro-power turbines, etc.), at Vanderkloof Dam make it very difficult to release the required flow with accuracy.

The operational losses not only include the effect of inaccurate releases, but also the differences between the actual abstractions and those used in the model. The irrigators do not necessarily abstract exactly their allocated quota and sometimes use less and sometimes more, due to various factors such as weather, market, physical water supply system conditions, etc. Data on actual return flows are almost non-existent and the data in the models are mostly based on assumptions. The effect of all these inaccuracies is therefore included in the operational losses. The operational losses are currently estimated at 270 million m^3/a. The monthly distribution of the operational losses is given in **Table 2.8**. For more detail with regards to the operational losses, the reader is referred to the "Water Requirements" Report, which has been produced as part of this study.

2.5 Environmental and River Requirements

2.5.1 Environmental Requirements

The instream and estuarine flow requirements were determined for the Orange River, downstream of Vanderkloof Dam, as part of the Orange River Development Replanning Study (ORRS). This was done more or less at an intermediate level. The methodology, which was available and used at that time, differs from that which is currently used and accepted. The ORRS environmental requirement was therefore used in the analysis for this study for one of the selected reference scenarios, and then compared with updated environmental requirements determined as part of this study.

For the purpose of this study, the Desktop method was used to obtain updated ecological requirements for a Category C and D river. The Desktop method provides a low-confidence estimate of the quantity component of the South African Ecological Reserve for rivers (See Environmental Reports produced as part of this study for more detail). The environmental flow requirements (EFRs) between the ORRS estimation and that from the Desktop method differ substantially and it was decided that river scientists should carry out further work to assess the options available for ascertaining the EFRs for the LOR. A modified Desktop Class D environmental requirement referred to as the "Top-up" D demand file was obtained from the additional environmental work and was used in the system yield analysis for the final Reference Scenario.

A summary of the typical environmental flows, as used in the analyses, is given in **Table 2.9**. It is, however, important to note that the environmental requirements, as obtained from the ORRS, are fixed monthly values that must be supplied each month for every year. The values given for the Desktop and Top-up environmental requirements represent the average monthly flow simulated for the total record period 1920 to 1987. The current methods used to determine the ecological requirements are not using a fixed value for each month, but a monthly requirement that varies according to the natural flow generated in that month. Typical during high natural runoff, the environmental requirement will also be higher, and for a low natural flow, a low environmental flow will be required. For this reason only, an average monthly flow was included for each month in **Table 2.9**.

During the course of the study, the environmental flow releases from Katse and Mohale Dams have changed, as more recent estimations were made by Lesotho. The initial Reference Scenarios therefore used the environmental flow releases, as described in the Treaty between RSA and Lesotho, and the final Reference Scenarios used the most recent environmental flow releases, as currently released from Katse and Mohale Dams. The previous and most recent environmental flow releases from Katse and Mohale Dams are summarised in **Table 2.10**.

Table 2.7: Summary of Net Irrigation Demands and Return Flows

River Reach / Description	System Analysis Code No.	Irrigated Area (ha)	Water Volume (Area* Quota) (million m3/a)	Gross Irrigation Demand (million m3/a)	Total Return Flow ** (million m3/a)	Net Canal Loss (million m3/a)	Net Irrigation Demand * (million m3/a)
Upstream of Gariep							
Caledon Lesotho Irrigation	DEM 54	±1 150	8.9	8.9	0.4	0.0	8.5
Caledon RSA Irrigation	DEM 57	±4 460	34.0	34.0	1.7	0.0	32.3
Caledon Welbedacht to Gariep	DEM 70	4 775	36.4	36.4	1.8	0.0	34.6
Orange River Oranjedraai to Bosberg	DEM 132	236	1.9	1.9	0.2	0.0	1.7
Orange River Bosberg to Aliwal	DEM 181	1 338	10.7	10.7	1.4	0.0	9.3
Aliwal to Gariep	DEM 131	2 560	20.5	20.5	2.5	0.0	18.0
Sub-total: Irrigation upstream of Gariep #		14 519	112.4	112.4	8.0	0.0	104.4
Riet/Modder Catchment							
Modder River Government Water Scheme (GWS)	DEM 88	3 499	29.4	41.9	6.0	10.1	35.9
Tierpoort Irrigation Board (IB)	DEM 89	708	6.4	8.0	1.6	0.6	6.4
Kalkfontein Scheme	DEM 91	3 046	33.5	39.4	6.9	2.4	32.5
Sub-total # Irrigation supplied from Riet/Modder Catchment		7 253	69.3	89.3	14.5	13.1	74.8
Total # Upper Orange and Riet/Modder Catchments		**21 772**	**180.9**	**201.7**	**22.5**	**13.1**	**179.2**

Note # These totals do not represent all the irrigation in the relevant incremental catchments.

Table 2.7 (Continued): Summary of Net Irrigation Demands and Return Flows

River Reach No.	River Reach Description	System Analysis Code No.	Irrigated Area (ha)	Water Volume (Area* Quota) (million m3/a)	Gross Irrigation Demand (million m3/a)	Total Return Flow ** (million m3/a)	Net Canal Loss (million m3/a)	Net Irrigation Demand * (million m3/a)
Irrigation supplied from Orange River Project (ORP)								
Vanderkloof-Gariep		DEM 84	1 991	21.9	21.9	2.2	0.0	19.7
Ramah + Vanderkloof canal		DEM 153	5 682	62.5	73.5	11.6	4.4	57.5
Orange Riet canal		DEM 178	12 112	133.4	156.9	4.5	22.3	130.0
Lower Riet		DEM 203	3 938	43.3	51.0	2.5	7.3	41.2
Scholtzburg		DEM 207	646	7.1	8.4	0.4	1.2	7.9
Vanderkloof-Toruay		DEM 43	11 532	126.8	126.8	10.2	0.0	116.7
Torquay to Orange Vaal Confluence		DEM 234	3 922	39.2	39.2	3.1	0.0	36.1
Douglas weir + river		DEM 125	7 025	64.2	75.5	9.8	12.6	65.7
Douglas Orange/Vaal (O/V) canal		DEM 50	1 583	14.5	17.0	1.9	1.0	15.1
O/V confluence-Boegoeberg		DEM 148	15 434	154.3	154.3	19.3	0.0	135.1
Boegoeberg canals		DEM 162	7 733	116.0	136.5	26.2	8.2	102.1
Upington canals		DEM 170	7 702	115.5	135.9	26.1	8.2	101.7
Keimoes canal		DEM 176	5 053	75.8	89.8	19.4	5.4	64.4
Boegoeberg-Neusberg River irrigation		DEM 155	4 880	73.2	73.2	9.2	0.0	64.0
Kakamas canal		DEM 188	8 336	125.0	138.9	27.1	5.6	106.3
Kakamas river irrigation		DEM 157	2 469	37.0	37.0	5.6	0.0	31.5
Augrabies-Namibian border		DEM 194	767	11.5	11.5	1.7	0.0	9.8

Table 2.7 (Continued): Summary of Net Irrigation Demands and Return Flows

River Reach		System Analysis Code No.	Irrigated Area (ha)	Water Volume (Area* Quota) (million m3/a)	Gross Irrigation Demand (million m3/a)	Total Return Flow ** (million m3/a)	Net Canal Loss (million m3/a)	Net Irrigation Demand * (million m3/a)
No.	**Description**							
Irrigation supplied from ORP (Continue)								
Namaqwaland-Vioolsdrift (RSA)		DEM 198	2 753	41.3	41.3	6.2	0.0	35.1
Namaqwaland-Vioolsdrift (Namibia)		DEM 159	1 473	22.1	22.1	3.3	0,0	18.8
Vioolsdrift (RSA)		DEM 208	601	9.0	10.6	2.4	0.6	7.5
Vioolsdrift North, Aussenkier and others (Namibia)		DEM 161	1 437	21.6	25.4	5.8	1.5	19.5
Alexander Bay (RSA)		DEM 218	761	11.4	11.4	1.4	0.0	10.0
Sub-total	Orange River Basin (RSA) #		104 920	1 282.9	1 410.6	190.8	76.8	1 157.4
Sub-total	Orange River Basin (Namibia)		2 910	43.7	47,5	9.1	1.5	38.3
Total	**Orange River Basin #**		**107 830**	**1 326,6**	**1 458.1**	**199.9**	**78.3**	**1 195.7**
Sub-total	Eastern Cape (scheduled)		51 513	607.3	607.3	-	-	607.3
Total from ORP System			**159 343**	**1 933.9**	**2 065.4**	**199.9**	**78.3**	**1 803.0**

Note # These totals do not represent all the irrigation in the relevant incremental catchments.

Table 2.8: Monthly Demands Used in the Analysis at 2005 Development Levels (million cub. m/a)

CODE	DESCRIPTION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	ANNUAL
	AREA 1 UPSTREAM OF GARIEP													
DEM 51	CALEDON RSA URB DMD	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	4.200
DEM 52	URBAN DMD KRAAI NODE	0.892	0.892	0.892	0.892	0.892	0.892	0.892	0.892	0.892	0.892	0.892	0.892	10.700
DEM 66	CALEDON LESOTHO URBAN DMD	0.917	0.917	0.917	0.917	0.917	0.917	0.917	0.917	0.917	0.917	0.917	0.917	11.000
DEM 75	BOTSHABELO DMD	1.264	1.264	1.264	1.264	1.264	1.264	1.264	1.264	1.264	1.264	1.264	1.264	15.169
DEM 77	BLOEMFONTEIN DMD	4.243	4.298	4.564	5.011	4.034	3.901	3.424	3.448	3.221	3.358	3.815	4.112	47.430
DEM 139	LHWP TRANSFER	65	65	65	65	65	65	65	65	65	65	65	65	780
	AREA 2 GARIEP TO ORANGE/VAAL CONFLUENCE													
DEM 43	ORANGE RIVER IRR: (Vanderkloof to Torquay)	19.386	3.295	4.801	12.614	9.799	13.413	11.244	1.338	4.712	6.703	11.922	17.471	116.70
DEM 45	HOPETOWN DMD	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	0.167	2.000
DEM 67	ORANGE RIVER LOSSES REACH 1a	4.6294	5.7038	6.2015	6.1857	4.6294	3.7051	2.5122	1.9039	1.3667	1.58	2.3305	3.5076	44.2558
DEM 97	DOUGLAS DMD	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	1.200
DEM 125	IRR FROM DOUGLAS WEIR & CANAL	13.294	3.347	4.033	6.642	4.219	3.850	2.975	0.650	3.117	4.399	7.764	11.409	65.70
DEM 143	RICHIE URB	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.300
DEM 153	RAMAH & VANDERKLOOF IRR	9.252	3.177	4.723	8.030	4.299	4.829	3.975	0.681	2.176	3.062	5.388	7.910	57.502
DEM 183	GARIEP TO VANDERKL URBAN	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175	2.100
DEM 234	ORANGE RIVER IRR: (Torquay to Orange-Vaal Confl.)	5.997	1.019	1.485	3.902	3.031	4.150	3.478	0.414	1.458	2.073	3.688	5.405	36.10
DEM 238	ORANGE RIVER LOSSES REACH 1b	1.2306	1.5162	1.6485	1.6443	1.2306	0.9849	0.6678	0.5061	0.3633	0.42	0.6195	0.9324	11.7642
DEM 251	TOTAL SYSTEM OPERATING LOSSES	15.89	15.38	15.89	15.89	14.53	34.16	50.65	34.16	21.67	20.23	15.89	15.64	270.00

CODE	DESCRIPTION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	ANNUAL
	AREA 3 RIET/ MODDER													
DEM 85	THABA N'CHU DMD	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267	0.267	3.200
DEM 179	KALKFONTEIN URBAN DEM	0.142	0.142	0.142	0.142	0.142	0.142	0.142	0.142	0.142	0.142	0.142	0.142	1.700
	AREA 4 ORANGE RIVER : (Orange/Vaal confl. to 20 degree Longitude)													
DEM 142	PRIESKA URB	0.161	0.186	0.208	0.249	0.202	0.198	0.159	0.138	0.135	0.118	0.131	0.143	2.027
DEM 144	ORANGE RIVER LOSSES REACH 2	13.22	16.31	17.72	17.67	13.22	10.59	7.19	5.44	3.9	4.5	6.67	10.02	126.45
DEM 148	IRR MID ORANGE	22.434	3.814	5.556	14.597	11.339	15.523	13.012	1.549	5.453	7.757	13.796	20.219	135.048
DEM 155	UPINGTON RIVER IRR ABS.	7.242	8.280	10.096	13.617	7.021	4.573	3.008	0.462	1.408	1.768	2.636	3.932	64.043
DEM 157	KAKEMAS RIVER IRR ABS	3.558	4.703	5.147	6.573	3.119	2.122	1.435	0.114	0.770	0.918	1.224	1.797	31.480
DEM162	BOEGOEBERG IRR	11.543	13.197	16.092	21.703	11.190	7.289	4.794	0.736	2.244	2.819	4.202	6.267	102.076
DEM170	UPINGTON IRR	11.566	13.574	15.694	20.991	10.660	7.515	5.132	0.636	2.387	2.951	4.255	6.307	101.669
DEM 176	KEIMOES IRR	7.329	8.601	9.944	13.300	6.754	4.761	3.252	0.403	1.513	1.870	2.696	3.997	64.419
DEM 180	ORANGE RIVER LOSSES REACH 3	13.68	16.87	18.34	18.28	13.68	10.96	7.44	5.63	4.04	4.66	6.9	10.37	130.85
DEM 184	KAKEMAS URB DMD	0.193	0.232	0.265	0.288	0.256	0.228	0.170	0.153	0.141	0.141	0.152	0.162	2.380
DEM 188	KAKEMAS IRR DMD	12.013	15.880	17.377	22.193	10.531	7.163	4.844	0.383	2.600	3.098	4.134	6.068	106.284
DEM 192	ORANGE RIVER LOSSES REACH 4	3.88	4.78	5.2	5.18	3.88	3.11	2.11	1.6	1.15	1.32	1.96	2.94	37.11
DEM 193	UPINGTON AND OTHERS URB DMD	1.432	1.722	1.971	2.143	1.902	1.692	1.262	1.133	1.045	1.047	1.126	1.204	17.680
DEM 194	NAMAQWALAND IRR U/S NAMIBIA	1.105	1.461	1.599	2.042	0.969	0.659	0.446	0.035	0.239	0.285	0.380	0.558	9.779

CODE	DESCRIPTION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	ANNUAL
	AREA 5 ORANGE RIVER : (20 ° Longitude to river mouth) RSA													
DEM 198	NAMAQWALAND IRR D/S NAMIBIA	4.014	4.902	5.916	7.635	3.738	2.106	1.279	0.278	0.768	0.952	1.398	2.109	35.096
DEM 200	URB. DMD SPRINBOK AND PELLADRIFT	0.391	0.448	0.442	0.474	0.476	0.423	0.389	0.344	0.328	0.317	0.335	0.373	4.740
DEM 208	VIOOLSDRIFT AND MINOR IRR	0.771	1.209	1.529	2.059	1.004	0.269	0.156	0.094	0.058	0.071	0.113	0.194	7.528
DEM 218	ALEXANDER BAY IRR	1.104	0.640	0.681	1.500	1.146	1.490	1.225	0.226	0.249	0.338	0.578	0.870	10.045
DEM 118	SPRINGBOK OR NAMAKWA WATER BOARD	0.345	0.389	0.450	0.482	0.471	0.402	0.403	0.378	0.316	0.327	0.345	0.291	4.600
DEM 224	URB.DMD. ALEX.BAY	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.608	0.608	7.300
	AREA 5 ORANGE RIVER : (20 ° Longitude to river mouth) Namibia													
DEM 159	PELLADRIF NAMIBIA IRR	2.151	2.626	3.169	4.089	2.002	1.128	0.685	0.150	0.411	0.510	0.749	1.129	18.80
DEM 161	VIOOLSDRIF NAMIBIA IRR	1.997	3.132	3.962	5.334	2.600	0.697	0.404	0.244	0.151	0.185	0.292	0.502	19.50
DEM 165	ORANJEMUND & ROSH PINAH	0.705	0.746	0.662	1.040	0.748	0.739	0.729	0.571	0.581	0.538	0.639	0.582	8.280
DEM 206	HAIB MINE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DEM 115	ARIAMSVLEI ETC.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DEM 116	NOORDOEWER, ASSENKEHR	0.014	0.016	0.014	0.021	0.018	0.015	0.015	0.012	0.011	0.010	0.011	0.012	0.170
DEM 117	MINES ROSH PINAH ETC.	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	0.571	6.850
	AREA 5 ORANGE RIVER : (20 degree Longitude to river mouth)Combined RSA and Namibia													
DEM 202	ORANGE RIVER LOSSES REACH 5	15.05	18.55	20.17	20.1	15.05	12.05	8.19	6.19	4.45	5.13	7.59	11.4	143.92
DEM 212	ORANGE RIVER LOSSES REACH 6	5.67	6.99	7.6	7.57	5.67	4.54	3.08	2.33	1.67	1.93	2.86	4.29	54.2
DEM 216	ORANGE RIVER LOSSES REACH 7	6.95	8.57	9.32	9.29	6.95	5.57	3.78	2.86	2.06	2.37	3.51	5.27	66.5
DEM 220	RIVER MOUTH ENVIRONMENTAL + IFR	32.141	31.104	32.141	32.141	29.290	32.141	31.104	24.106	15.552	9.374	9.374	10.368	288.85

CODE	DESCRIPTION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	ANNUAL
	AREA 6 NAMIBIA FISH RIVER													
DEM 99	HARDAP IRRIGATION	3.711	3.586	3.194	5.717	5.125	3.936	4.170	2.498	1.914	2.081	2.948	2.819	41.700
DEM 106	NAUTE IRRIGATION	0.413	0.399	0.355	0.636	0.570	0.438	0.464	0.278	0.213	0.232	0.328	0.314	4.640
DEM 113	HARDAP URBAN	0.087	0.086	0.083	0.104	0.092	0.081	0.077	0.072	0.065	0.067	0.066	0.069	0.950
DEM 114	NAUTE URBAN	0.159	0.186	0.151	0.220	0.202	0.145	0.174	0.148	0.145	0.124	0.141	0.155	1.950
DEM 258	HARDAP SURPLUS YIELD	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
DEM 108	NAUTE SURPLUS YIELD	0.233	0.233	0.233	0.233	0.233	0.233	0.233	0.233	0.233	0.233	0.233	0.233	2.80

Table 2.9: Orange River Environmental Flow Requirements (million cub. m/a)

DESCRIPTION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	ANNUAL
ORRS RIVER MOUTH ENVIRONMENTAL + IFR	32.14	31.10	32.14	32.14	29.29	32.14	31.10	24.11	15.55	9.37	9.37	10.37	289
CLASS C DESKTOP AUGRABIES (Average flows)	103.19	157.36	227.53	205.49	493.55	290.40	212.20	109.08	67.74	53.62	53.86	43.66	2 018
CLASS C DESKTOP RIVER MOUTH (Average flows)	93.98	145.91	214.15	201.80	503.27	301.60	206.37	103.49	63.55	49.66	48.99	36.73	1 969
CLASS D DESKTOP AUGRABIES (Average flows)	91.69	134.63	183.39	156.80	401.84	229.11	164.77	78.20	49.96	40.96	40.63	33.69	1 605
CLASS D DESKTOP RIVER MOUTH (Average flows)	83.25	124.33	172.33	157.78	408.32	236.50	159.04	73.51	46.48	37.18	36.65	27.72	1 558
CLASS D TOP-UP AUGRABIES & RIVER MOUTH (Average flows)	38.78	57.03	69.62	77.77	408.01	109.73	77.53	63.61	59.92	40.61	37.12	31.49	1 062

Table 2.10: Environmental Flow Releases from Katse and Mohale Dams (million cub. m/a)

DESCRIPTION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	ANNUAL
KATSE DAM (Treaty releases)	1.34	1.30	1.34	1.34	1.22	1.34	1.30	1.34	1.30	1.34	1.34	1.30	15.78
KATSE DAM (Current releases)	2.84	10.20	4.75	8.30	10.39	5.32	6.70	3.11	3.14	2.45	6.76	2.89	66.85
MOHALE DAM (Treaty releases)	0.80	0.78	0.80	0.80	0.73	0.80	0.78	0.80	0.78	0.80	0.80	0.78	9.46
MOHALE DAM (Current releases)	1.64	3.36	1.92	2.36	9.20	2.38	1.93	1.60	1.13	0.92	3.65	1.09	31.18

Table 2.11: Monthly Distribution of the Proposed River Requirements

Reach	From	To	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	Vanderkloof	Marksdrift	7.83	5.86	4.69	3.18	2.41	1.73	2.00	2.95	4.44	5.86	7.22	7.85	56.0
2a	Marksdrift	Prieska	10.92	8.17	6.54	4.44	3.36	2.41	2.78	4.12	6.19	8.17	10.08	10.95	78.1
2b	Prieska	Boegoeberg	6.75	5.05	4.05	2.75	2.08	1.49	1.72	2.55	3.83	5.05	6.23	6.77	48.3
3a	Boegoeberg	Gifkloof	11.84	8.86	7.10	4.82	3.65	2.62	3.02	4.47	6.72	8.86	10.93	11.88	84.8
3b	Gifkloof	Neusberg	6.44	4.82	3.86	2.62	1.98	1.42	1.64	2.43	3.65	4.82	5.94	6.46	46.1
4	Neusberg	20° E	5.18	3.88	3.11	2.11	1.60	1.15	1.32	1.96	2.94	3.88	4.78	5.20	37.1
5a	20° E	Pella	9.08	6.80	5.44	3.70	2.80	2.01	2.32	3.43	5.15	6.80	8.38	9.11	65.0
5b	Pella	Vioolsdrift	11.02	8.25	6.61	4.49	3.39	2.44	2.81	4.16	6.25	8.25	10.17	11.06	78.9
6	Vioolsdrift	Fish	7.57	5.67	4.54	3.08	2.33	1.67	1.93	2.86	4.29	5.67	6.99	7.60	54.2
7a	Fish	BrandKaros	5.69	4.26	3.41	2.32	1.75	1.26	1.45	2.15	3.23	4.26	5.25	5.71	40.7
7b	BrandKaros	Mouth	3.60	2.69	2.16	1.46	1.11	0.80	0.92	1.36	2.04	2.69	3.32	3.61	25.8
Total			**85.92**	**64.30**	**51.49**	**34.97**	**26.46**	**19.00**	**21.91**	**32.43**	**48.73**	**64.30**	**79.29**	**86.20**	**615.0**

Table 2.12: Proposed River Requirements for the Fish River

From	To	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Hardap	Seeheim	24.05	34.29	30.63	7.44	1.67	0.63	0.18	0.13	0.36	1.92	4.24	6.59	112.1
Seeheim	Orange River Confluence	18.10	36.02	35.86	6.74	0.82	0.26	0.11	0.06	0.08	0.47	1.42	3.90	103.8
Naute	Fish River Confluence	1.41	2.44	3.48	1.08	0.11	0.07	0.00	0.00	0.01	0.00	0.25	0.36	9.2

2.5.2 River Requirements

River requirements are a natural phenomenon to both regulated and unregulated rivers. In the case of unregulated rivers the actual volume of the requirements is seldom quantified, as it is included in the hydrology or natural runoff. In the event of the Orange River where water is released from Vanderkloof Dam and conveyed by means of the river to users as far as 1 380 km downstream from the point of release, it is of utmost importance to obtain a good estimation of the actual volume of the requirements, as they have to be included in the Vanderkloof Dam releases. These requirements are mainly due to evaporation from the river surface area, but also include seepage and evapo-transpiration from the riparian vegetation (See Water Requirements Report produced as part of this study for more detail).

The proposed monthly river requirements for the Orange River are given in **Table** 2.11. The distribution takes into account both the variation in evaporation, as well as the variation in the river flow over the year.

Due to the erratic nature of the runoff from the Fish River Basin, the riverbed can be dry for long periods. When combined with the arid climate, the result is high river requirements or transmission losses in the rivers. The average monthly river requirements, as obtained from the Hydrology Report prepared as part of this study, are given in **Table 2-12**.

3. OPERATION OF THE CURRENT SYSTEM

3.1 General

The total Orange River Catchment can be sub-divided into two main water supply systems, the Integrated Vaal River System and the Larger Orange River System. The total Integrated Vaal River System comprises all the sub-systems of the Vaal River System, i.e., the Komati-Olifants, Usuthu-Olifants, Assegaai-Vaal, Buffalo-Vaal, Tugela-Vaal, Senqu-Vaal and the Vaal River with all its tributaries down to Douglas Weir. The location of the integrated Vaal River System is shown in **Figure A-4**.

The Integrated Vaal River System is operated almost independently from the Orange River System. The only links between the two systems are the water transferred from Katse and Mohale Dams to Vaal Dam and the spills from the Vaal System entering Douglas Weir in the Lower Vaal just before the confluence of the Orange and Vaal Rivers. Transfers from Katse and Mohale Dams to the Vaal Dam is based on an agreement between Lesotho and the RSA and is currently increasing over time until it reaches the maximum long-term transfer volume by 2005, as agreed between RSA and Lesotho. This transfer volume will then each year be transferred to Vaal Dam regardless of the storage levels in the Vaal or Orange River Systems. The Integrated Vaal River System was not updated as part of the LORMS, as the focus of the LORMS is on the LOR. Instead, the Vaal River System was recently updated as part of the VRSAU Study. Demand projections and infrastructure changes for the Integrated Vaal River System are updated on an annual basis as part of the Annual Vaal River System Operating Analysis.

The Larger Orange River System includes all the water resource related to developments in Lesotho (mainly Lesotho Highlands Water Project (LHWP)), the Caledon (Caledon/Modder Transfer Scheme), the Orange River System (Gariep and Vanderkloof Dams and their total supply area), as well as all the water supply schemes in the Riet/Modder catchment and the larger water supply schemes within tributaries of the Orange River downstream of Vanderkloof Dam. The location of the Larger Orange River System is shown in **Figure A-5**.

As part of the LORMS, the system models for the Larger Orange River System (WRYM & WRPM) were extended to include the details of the developments in the Fish River (Namibia). All the system demands, demand projections, as well as current and possible infrastructure changes were updated as part of the LORMS.

The Orange River System, which includes Gariep and Vanderkloof Dams and their total supply area, is the main focus of the LORMS as all the water requirement along the Lower Orange are supplied from these two dams. It is, however, important to include the other water supply systems upstream and downstream of Gariep and Vanderkloof Dams as they will all have an effect on the water supply from the two dams.

3.2 Integrated Vaal River System

The operation of the Integrated Vaal River System is very complex and will not be discussed in detail in this section. Operational analyses are carried out for the Integrated Vaal River System on an annual basis. These analyses are used to determine possible shortages and surpluses in the system and to advise the operators to make adjustments in transfers or impose curtailments in advance, in order to prevent failures in water supply - according to the required assurance levels applicable to the various users.

The purpose of this section is to provide the reader with the necessary background and understanding of the operation of the Integrated Vaal River System to be able understand the effects of the Vaal River System operation on the Larger Orange River System, but more specifically on the Orange River System.

The Integrated Vaal River System is not used to support the Orange River System, but is rather operated to minimize spills into the Orange River. It is important to minimize the spills from the Vaal System, as large volumes of water are transferred into the Vaal River System from neighbouring catchments at high cost to augment the growing demand in the Vaal System.

The bulk of the transfers are coming from the LHWP and the Tugela-Vaal Transfer Scheme. The transfers from the LHWP are flowing into the Vaal Dam at a fixed flow rate regardless of the storage levels in the Vaal System or in Katse and Mohale

Dams. Transfers from the Tugela to the Vaal will only take place until Sterkfontein Dam, located in the upper reaches of the Wilge River, is full. Water from Sterkfontein Dam will only be released to support the Vaal Dam when the Vaal Dam is at a fairly low level. Releases from the Vaal Dam, to support Bloemhof Dam, are only made when the Bloemhof Dam is at a low level.

Grootdraai Dam is generally not used to support the Vaal Dam, although it might be used in cases of emergency. Grootdraai Dam is mainly used to support Sasol and Eskom (Power Stations in the Upper Olifants) with water. Grootdraai Dam is, however, supported with transfers from the Heyshope Dam in the Assegaai River and from Zaaihoek Dam in the Slang River, a tributary of the Buffels River.

This operating rule will therefore result in lower storage levels in the Bloemhof and Vaal Dams, and will consequently reduce evaporation and spillage from the two dams, as well as increase the possibility of the dams to capture local runoff.

3.3 Larger Orange River System

3.3.1 Smaller Sub-systems

The main purpose of the Katse and Mohale Dams is to support the Vaal System and they are therefore not used to support the Gariep and Vanderkloof Dams. The only releases from Katse and Mohale Dams are for environmental purposes. Although some of these releases will reach the Gariep and Vanderkloof Dams, they are needed in the system to be able to supply the environmental requirements downstream of the two dams.

Welbedacht and Knellpoort Dams in the Caledon River are part of the Caledon-Modder Transfer System used to supply part of the water requirements of Bloemfontein, Botshabelo, Thaba Nchu and other small users. Water treated at Welbedacht Dam is transferred directly to Bloemfontein and small users, while water from Knellpoort Dam is transferred to Rustfontein Dam in the upper reaches of the Modder River. Rustfontein Dam is then used to supply Botshabelo and Thaba Nchu and to support Mockes Dam from where water is also abstracted for Bloemfontein. Welbedacht and Knellpoort Dams are therefore not used to support the Gariep and Vanderkloof Dams.

Other dams in the Riet-Modder catchment include Krugersdrift Dam in the Modder River downstream of Mockes Dam, with Tierpoort and Kalkfontein Dams located on the Riet River. All three of these dams are used mainly for irrigation purposes and are not used to support any other dam, and are also not supported from any other dam.

Hardap and Naute Dams, located in the Fish River catchment in Namibia, are used mainly to supply water to irrigation schemes and a small urban component. These dams are operated individually and are not used to support any other dam or users along the main Orange River.

3.3.2 Orange River System

Gariep and Vanderkloof Dams are the two largest reservoirs in South Africa and are used to supply all the water requirements along the Orange River from Gariep Dam to the Orange River Mouth. These demands include all the irrigation, urban, mining, environmental requirements, river evaporation and operational losses. Large volumes of water are also transferred to other neighbouring catchments. These transfers include the following:

- The transfer to the Eastern Cape through the Orange-Fish tunnel to support large irrigation developments and some urban requirements in the Eastern Cape.
- The transfer through the Orange-Riet canal from Vanderkloof Dam to the Riet-Modder catchment, mainly for irrigation purposes.
- Orange-Vaal Transfer through the canal system from Marksdrift Weir in the Orange River to Douglas Weir in the Vaal River, mainly irrigation.
- Transfer from the Lower Orange along the CBA to Springbok and Kleinsee for urban and mining use.

Except for the releases through the Orange-Fish tunnel and those into the Vanderkloof Canals, all the releases from Gariep and Vanderkloof Dams, to supply downstream users, are made directly into the Orange River. These river releases are also used to simultaneously generate hydropower. Any spills from the Vaal or Fish Rivers (Namibia) or any local runoff generated in the Lower Orange are not taken into account when releases are made from Vanderkloof Dam to supply the downstream users. It is, however, extremely difficult to compensate for Vaal, Fish or any other inflows into the Lower Orange by means of reduced releases from Vanderkloof Dam, as releases take approximately one month to reach the river mouth and the existing flow gauging structures in the Orange and Lower Vaal Rivers are inaccurate for the measuring of low flows.

Operating analyses are carried out on an annual basis for the Orange River System in order to determine the available surplus or deficit in the system for the coming year. If there is a surplus available in the system, the surplus is allocated to Eskom to generate additional hydropower over and above that generated by means of the normal releases for downstream users. Eskom utilises this surplus mainly during the winter months when the power demand is high. However, if there is a deficit in the system, curtailments will be imposed, first on the low assurance (1 in 20-year) component of the demand. Only when the low assurance demand component has been curtailed by 100%, will curtailments be imposed on the medium assurance (1 in 100-year) demand component, and thereafter on the high assurance (1 in 200-year) demand component.

The minimum operating levels (m.o.l.) for hydropower generation dams are currently used as the m.o.l. in both dams, and it is only in severe droughts that the dams will be drawn below these levels. Storage control curves (SCCs) were produced for both Gariep and Vanderkloof Dams. These SCCs are relatively close to the full supply levels (FSLs) of the dams and are at higher levels in the winter and lower levels in the summer. The purpose of these SCCs is to minimise spilling from the dams and to increase hydropower generation during wet periods. Limited volumes of water can be routed through the turbines and it is therefore not possible to route large floods through the turbines. As soon as the water spills over the crest of the dam wall, the water will be lost for power generation purposes. The SCC allow the operator to start running the turbines at maximum capacity as soon as the water level in the dam rises above the SCC level for the specific month. When the level drops below the SCC the hydropower releases will again be reduced to be equal to the releases required by the downstream users.

As both the SCC and hydropower generation with surplus water will disappear over time as the system demand grow, leaving very little or no surplus in the system, both components (SCC and surplus used for hydropower generation) were excluded from the operating rules used in the LORMS. It was further decided and agreed upon by both Clients to use the Orange Fish tunnel outlet as the m.o.l. for Gariep Dam, and the Vanderkloof canal outlets as the m.o.l. for Vanderkloof Dam. In both dams, this m.o.l. is lower than the hydropower m.o.l.

4. SYSTEM ANALYSIS

4.1 General

The yield analyses and system modelling were undertaken in six phases.

- Phase 1: Model configuration for the WRYM.
- Phase 2: Based on the yield analyses, determine the need and timing of proposed dam development options.
- Phase 3: Determine the supply capability of the proposed development measures.
- Phase 4: Carry out selective long-term and short-term stochastic analyses.
- Phase 5: Model configuration for the WRPM.
- Phase 6: Carry out selective planning analyses using the WRPM.

Phase 1: The WRYM data sets, as obtained from the ORRS, were used as the basis to develop the data sets as required for this study. The data sets for Base Scenario 20, as defined in the ORRS, were selected for this purpose. A brief description of Scenario 20 from the ORRS is given below:

- The yield is determined at the Gariep and Vanderkloof Dams and represents the surplus yield available from the two dams after all the demands have been supplied.
- The full Phase 1 of the LHWP was in place.
- The urban/industrial demands were at 2030-development level.
- The lower level storage in Vanderkloof Dam was used.
- It was assumed that a re-regulation dam at Vioolsdrift was in place and that operating losses was reduced to only 40 million m^3/a.

These data sets were then adjusted to include the updated hydrology, demands and system changes to represent Reference Scenario 1, as defined for this study (See **Section 4.2.1**).

Phase 2: The surplus yield available from the Orange River System was determined at 2005, 2015 and 2025 development levels, using Reference Scenario 1 as basis. For these analyses, only the growth in the urban/industrial/mining requirements was included. There are a number of uncertainties with regards to future growth in irrigation and it was therefore decided to rather compare the surplus yield available at the different development levels with more than one possible irrigation requirement projection. The need for improved management and or development options, as well as the preliminary timings for the required intervention measures was determined from this comparison.

Phase 3: The supply capabilities of the system for different proposed measures to improve the water supply in the system were determined as part of Phase 3. This also included various sensitivity analyses to evaluate and test the effect of uncertainties and assumptions in the system. One of the main components that were evaluated by means of the sensitivity analysis is the effect of the ecological requirements, as obtained from the ORRS versus the planning estimates of the ecological requirements, as determined with the Desktop method. The yield analysis results from Phase 3 were fed into the economic study, to determine the unit reference value (URV) for each of the proposed measures.

Phase 4: Based on the URV, some of the most promising options were selected and stochastic analyses were carried out for these options, as well as for the Reference Scenario.

Phase 5: The WRPM data sets, as currently used for the annual operating analyses carried out for the Integrated Vaal River System was used as the basis to develop the data sets, as required for this study.

These data sets were then adjusted to include the updated hydrology, demands and system changes to represent Reference Scenario 3, as defined for this study (See **Section 4.4.2**).

Phase 6: The most promising options, as obtained from Phase 4, were analysed with the WRPM to determine a more accurate timing for the phasing of the options.

4.2 Description of Reference Scenario 1 and Related Scenarios (Used ORRS EFRs)

4.2.1 Reference Scenario 1 (Phase 1)

A specific Reference or Base Scenario was defined to be used as the benchmark for the WRYM analyses. Results from other scenarios that include various possible management and development options were compared with the Reference Scenario yield result, to determine their effect on the system yield. The Reference Scenario was discussed with and agreed on by both countries. This scenario is described in detail in **Table 4.1** and is referred to as **Reference Scenario 1**.

Table 4.1: Description of Reference Scenario 1

Scenario Number	Description
1	**Reference Scenario 1**
	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.
	With Phase 1 of the LHWP and urban/industrial demands at 2005 development level. • All the urban/industrial and mine demands imposed on the Orange River System will be at 2005 development level. Current (year 2000) irrigation demands were imposed on the system. • Updated/final existing irrigation demands based on scheduled areas and quota. Effect of return flows will be 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 modeled separately with 2005 development level spills used as inflow to the Orange River System, just upstream of the confluence of the Vaal and Riet River. 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 million m³/a for the full Phase 1, as based on the most recent hydrology that was accepted by both the RSA and Lesotho. The given transfer of 804 million m³/a is based on the 1 in 100 year long-term stochastic firm yield. • The IFR releases from Katse and Mohale Dams are based on the Treaty IFRs. • Transfer to the Eastern Cape through the Orange/Fish tunnel is based on the updated LORMS demands (627 million m³/a urban & irrigation) • Orange/Riet Transfer. The various demands will be modelled in detail, as part of the system. • Orange/Douglas Transfer. All the demands will be modelled in detail as part of the system. • Transfer from the Caledon to Modder from Welbedacht Dam, as well as the Novo Transfer from

Scenario Number	Description
	Knellpoort Dam, will be in place and modeled in detail with all the demands in place, as part of the system. Current existing operating rule will be used. This is, however, not necessarily the optimum operating rule. • Compensation flow from Gariep Dam = 16 m³/s. • Hydropower will be generated in accordance with downstream demands only (no additional releases for hydropower purposes will therefore be made.) • Minimum operating level for Gariep at 1 231.63m. (This is equal to the m.o.l. for Orange/Fish tunnel outlet.) (DSV = 637.25 million m³ and live storage = 4 705.68 million m³) • Minimum operating level for Vanderkloof Dam at 1 147.78m. (This is equal to the m.o.l. for releases into Vanderkloof canals. DSV = 1 014.38 million m³ and live storage = 2 172.69 million m³ • Lower Orange hydrology and spills from the Vaal will be excluded from the base scenario 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 the ORRS' environmental demands, river mouth and IFRs. The River Mouth environmental requirement is the main driver and has a fixed annual requirement of 289 Mm³/a. • 2045 updated/verified sediment levels will be used in dams.

4.2.2 Scenarios for Future Development Levels (Phase 2)

Reference Scenario 1 was used as the basis for the 2015- and 2025-development level scenarios. The projected urban/industrial and mining demands, as obtained for this study (See Water Requirements Report (**PWC; 2004a**)), were used for these analyses. Irrigation demands were constant at year 2000 development level, as already discussed in **Section 4.1**. These two scenarios are briefly discussed hereafter.

Scenario 1a represents the 2015-development level analyses and is as Reference Scenario 1 with the only difference being the 2005-development urban/industrial and mining demands that were replaced by the corresponding projected 2015 demands.

Scenario 1b represents the 2025-development level analyses and is as Reference Scenario 1 with the only difference being the 2005-development urban/industrial and mining demands that were replaced by the corresponding projected 2025 demands.

4.2.3 Scenarios Describing the Sensitivity Analyses, Proposed Development Options and Measures to Improve the Water Supply in the System (Phase 3)

Two possible options to improve the water supply in the system were initially analysed. These are Scenario 1c, which included the utilisation of the low level storage (LLS) in Vanderkloof Dam and Scenarios 1e and f, which utilised the spills from the Vaal River System (See **Table 4.2**). By using real time modelling, it will be possible to utilise spills from the Vaal to a greater extent than what is currently achieved.

Several sensitivity analyses were carried out and are listed in **Table 4.2**. Some background information to those scenarios is given hereafter to provide the reader with a better understanding of the situation and reasons for the sensitivity analyses.

Scenario 1d: For Reference Scenario 1, it was agreed not to use the current m.o.l. related to hydropower generation. In stead, the Orange/Fish tunnel outlet was used as the m.o.l. for Gariep Dam and the outlet from Vanderkloof Dam into the Vanderkloof canals as the m.o.l. for Vanderkloof Dam. The main reason for this approach is that during severe drought conditions, the dams will be drawn down below the hydropower m.o.l., to be able to supply the downstream users. (The downstream users are considered as the primary water users, with hydropower generation as a secondary user). In both cases, the m.o.l. for hydropower generation purposes is slightly higher than the m.o.l. selected for Reference Scenario 1 (See **Figure 4.1** and
Figure 4.2). A sensitivity analysis was carried out to determine the effect of the different m.o.l. on the system yield.

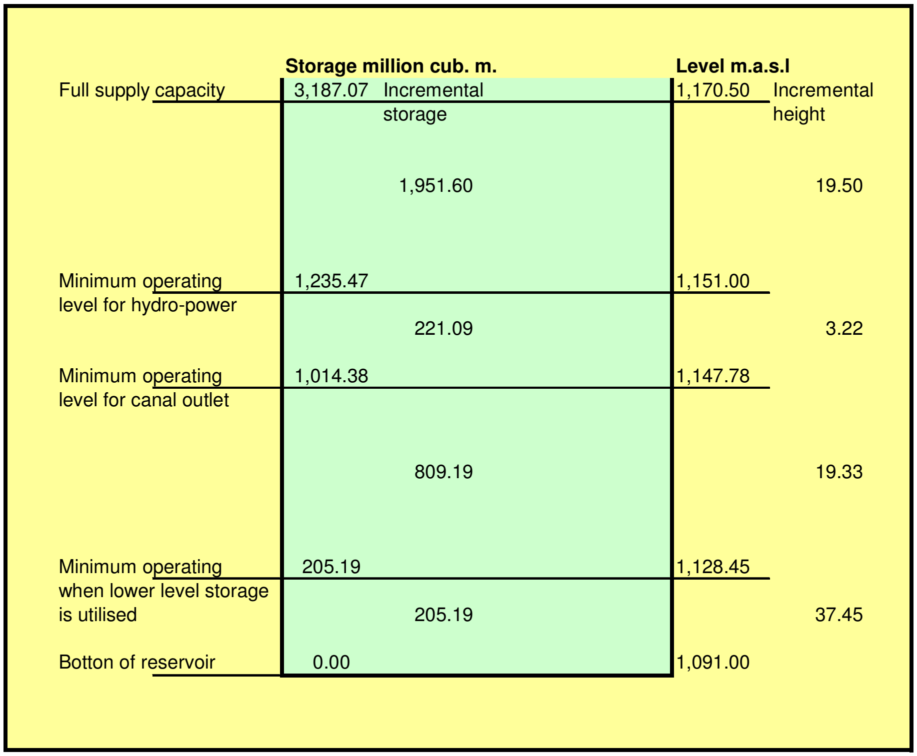

Figure 4.1: Vanderkloof Dam Key Levels and Storage

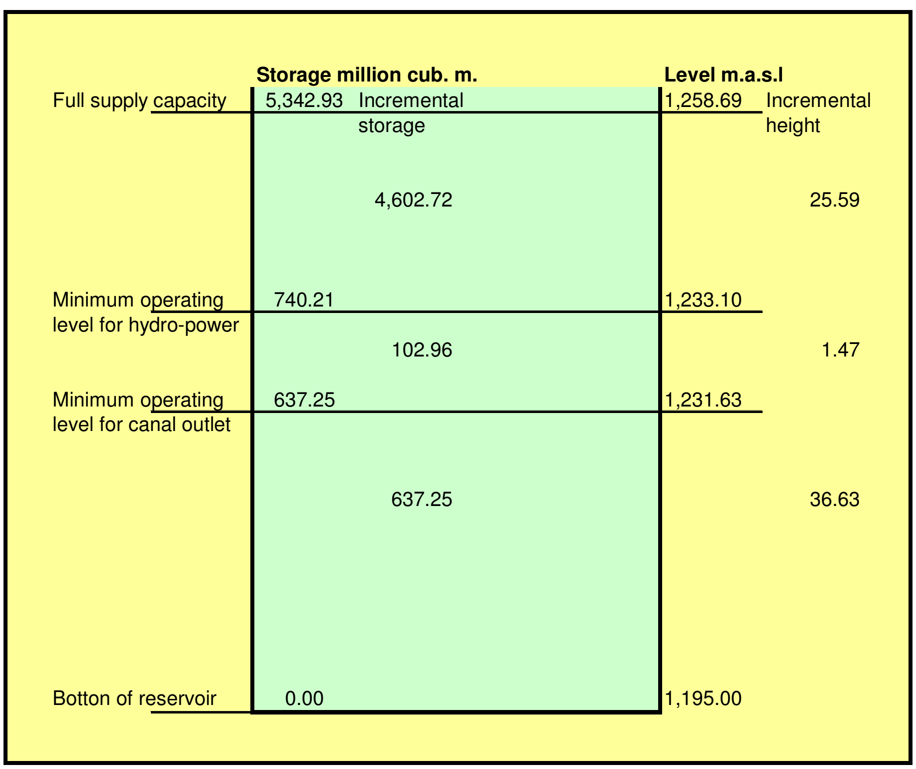

Figure 4.2: Gariep Dam Key Levels and Storage

Scenario 1e & f: The Vaal River System were analysed separately by means of the WRPM to determine the outflow from the Vaal to the Orange River at 2005-development level. The most up to date WRPM configuration for the Vaal River System was used for this purpose, as it already includes all the required return flow and water quality blending components, which is not present in the WRYM configurations. The Vaal River System is not managed to support the Orange River, although normal spills from the Vaal are captured in the Douglas Weir and is partly used to supply in the irrigation requirements of the large irrigation areas around Douglas. Due to the poor quality of the water from the Vaal, water is transferred from Marksdrift in the Orange River, via a canal system to supplement, and to improve the water quality in the Douglas Weir. Spills from the Vaal are therefore to a certain extent utilised from Douglas Weir, but currently not by the users along the Orange River main stem. By means of real time modelling, it will be possible to also utilise spills from the Vaal for users along the Orange River main stem, downstream of the confluence of the two rivers.

From recent Vaal River Sytem water balances, it was found that significant operating losses occurs in the Lower Vaal. The bulk of these losses will most probably flow into the Douglas Weir and can be utilised for irrigation purposes. There are, however, uncertainties with regards to the actual volume of these losses. Two different outflow records from the Vaal were therefore obtained from the WRPM analyses - one with the estimated operating losses included and one without the operating losses. A sensitivity analysis was carried out to determine the effect of the operating losses and Vaal outflows on the surplus yield available in the Orange River System.

Scenario 1h & i: Although the environmental requirements, as obtained from the ORRS, were used for Reference Scenario 1, sensitivity analyses were carried out to determine the effect of planning estimate environmental requirements on the system yield. Planning estimations, using the Desktop method for a C and D class river, were used for this purpose.

A summary of all the above-mentioned scenarios is given in **Table 4.2**.

Table 4.2: Summary of Scenarios Related to Reference Scenario 1

Scenario Number	Description
1	**Reference Scenario 1 related scenarios**
	Purpose: To determine surplus yield available at 2005 development level for possible options that will improve the system yield and to carry out sensitivity analysis to obtain an improved understanding of the system with regards to certain assumptions and uncertainties within the system.
	As Reference Scenario 1 with the following changes:
Scenario 1c	• Using the lower level storage in Vanderkloof Dam to supply downstream requirements and to pump water into the Vanderkloof canals. For this scenario, the m.o.l. for Vanderkloof Dam was reduced from 1 147.78 to 1 128.45 m. The dead storage at the reduced m.o.l. is 205.2 million m^3.
Scenario 1d	• Use m.o.l. related to hydro-power generation for both dams. The m.o.l. in Gariep was for this scenario raised from 1 231.63 to 1 233.10 m and for Vanderkloof Dam from 1 147.78 to 1 151.00 m.
Scenario 1e	• Utilise spills from the Vaal. This scenario excludes the Vaal operating losses from the Vaal spills. For this scenario, it was assumed that these spills can be utilised from Douglas Weir, as well as in the Orange River downstream of Douglas Weir.
Scenario 1f	• Utilise spills from the Vaal. This scenario includes the Vaal operating losses into the Vaal spills. For this scenario it was assumed that these spills can be utilised from Douglas Weir, as well as in the Orange River downstream of Douglas Weir.
Scenario 1g	• Using the lower level storage in Vanderkloof Dam to supply downstream requirements and to pump water into the Vanderkloof canals as for Scenario 1c, but also includes the utilisation of the spills from the Vaal (operating losses included), as described for Scenario 1f.
Scenario 1h	• Replacing ecological requirements as obtained from the ORRS with Desktop estimates for a Class C river. For this scenario, it was assumed that the spills from the Vaal, as well as the runoff generated from the Lower Orange River catchment, can be utilised to supply the ecological requirements. The lower level storage in Vanderkloof Dam was also utilised for this scenario.
Scenario 1i	• Replacing ecological requirements as obtained from the ORRS with Desktop estimates for a Class D river. For this scenario, it was assumed that the spills from the Vaal, as well as the runoff generated from the Lower Orange River catchment, can be utilised to supply the ecological requirements. The lower level storage in Vanderkloof Dam was also utilised for this scenario.

4.3 Description of Reference Scenario 2 and Related Scenarios (Using EFRs from the Desktop Model)

4.3.1 General

Results from Scenarios 1h and 1i (See **Section 4.5.3**) showed a significant reduction in the surplus yield from Gariep and Vanderkloof Dams when the Desktop estimates for the environmental requirements are used in stead of those obtained from the ORRS. After discussions with both clients it was agreed to define a second Reference scenario referred to as **Reference Scenario 2.** This scenario will use the the environmental requirements as obtained from the Desktop Model for a class D river.

4.3.2 Reference Scenario 2 (Phase 2)

At the time when Reference Scenario 2 was discussed as part of the LORMS, updated environmental releases determined by Lesotho for the Lesotho Highlands Water Project (LHWP) became available. These releases are higher than those specified in the treaty between the RSA and Lesotho. Lesotho was already in the process to implement the updated environmental releases and it was decided to replace the Treaty environmental releases in the WRYM data files with the updated EFR releases as part of Reference Scenario 2. A detail description of Reference Scenario 2 is given in **Table 4.3**.

Table 4.3: Description of Reference Scenario 2

Scenario Number	Description
2	**Reference Scenario 2**
	Purpose: To determine surplus yield available at 2005 development level with updated environmental requirements included 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.
	As Reference Scenario 1, but with the following changes: • Desktop Environmental requirements for a Class D river will be used instead of the ORRS environmental requirement. The desktop requirement is not a fixed annual volume, but varies from year to year, depending on the variation of the natural flow at the site. For the historic analysis period, the EFR varied from 758 to 2773 million m^3/a with an average of 1605 million m^3/a. • Spills from the Vaal plus losses from the Vaal, which flow into the Orange River, will be included in the analysis. The spills will only be used to support the environmental requirements and not the irrigation or urban/industrial/mining demands. • The recently updated environmental releases from the LHWP will be used. The effect of the updated EFRs from Lesotho on the transfer rate to the RSA was not available at the time and the transfer rate as given in Reference Scenario 1 was used.

4.3.3 Scenarios Describing the Sensitivity Analyses with regards to Reference Scenario 2 (Phase 3)

As part of the sensitivity analyses, it was decided to determine the effect of the updated environmental releases from the LHWP on the surplus yield from Gariep and Vanderkloof Dams. This scenario is referred to as **Scenario 2a** and is as Reference Scenario 2, but with the updated environmental releases from Katse and Mohale Dams, replaced by the releases as specified in the Treaty. It should be noted that the effect of the updated environmental releases on the transfer to the Upper Vaal has not yet been determined and it was the same transfer rate as used in Reference Scenarios 1 and 2, which was used for Scenario 2a.

It can also be argued that the Vaal River, which is a major tributary of the Orange River, should contribute to satisfy part of the EFR, as determined for the Orange River in stead of supplying the EFR only from the Gariep and Vanderkloof Dams. Technically, all the tributaries should contribute to the EFR, but for the purpose of the sensitivity analysis, it was decided to only focus on the Vaal River. The Desktop Model was used to obtain a planning estimate of the environmental requirement for a Class D river at a site in the Vaal River, just upstream of its confluence with the

Riet River. This requirement was included in the WRPM set up for the Vaal System. A new flow record that represents the outflow from the Vaal System, which includes the environmental requirements, was determined. For this analysis, it was assumed that the environmental requirement in the Lower Vaal will be fully supplied by releases from Bloemhof Dam. The Vaal outflow record was then used as the inflow to the Orange from the Vaal in the Orange River System (WRYM set up), as used for this study. This scenario is referred to **Scenario 2b**.

4.4 Scenarios that include the Top-up Environmental Requirement

4.4.1 General

Results from Reference Scenarios 1 and 2, as well as the related scenarios, showed large differences in the yield available from the Orange River System, depending on the environmental requirement that is imposed on the system (See **Sections 4.5.3** and **4.5.4**). From these results, it was clear that further work is required to determine an EFR, which will be suitable for planning purposes, as part of this study. An additional task was therefore approved to examine the relationship between the current flow regime in the river and the EFR recommended by the Desktop Model. A more feasible EFR was proposed from this task to be used for planning purposes in this study, which is referred to as the Top-up requirement. The Top-up environmental requirement was therefore used in the final set of scenarios to be analysed for this study. Details of the Top-up environmental requirement are given in the report “Additional Environmental Flow Task: Riverine – Supporting Report to Environmental Flow Requirements” (PWC; 2004c). The Top-up environmental requirement basically consists of the Desktop Class D low flow requirements with high flows imposed as a demand on the system only for the month of February. High flows for the other months will not be imposed as a demand on the system, but will still occur from time to time as a result of spills from the major dams or inflows from the tributaries downstream of Vanderkloof Dam.

4.4.2 Reference Scenario 3 (Phase 2)

The scenarios that were selected and analysed, were based on findings and recommendations from the ORRS, but also include Water Conservation and Demand Management (WC&DM)-related scenarios and one or two additional possible options that only came to light after the completion of the ORRS as new information become available. The Reference Scenario used for this set of scenarios was discussed and agreed upon by both Clients. This Reference Scenario represents the current system at 2005-development level, with the "Top-Up" Class D environmental demand included in place of the environmental requirements, as determined in the ORRS. This scenario is referred to as **Reference Scenario 3** and a detail description of Reference Scenario 3 is given in **Table 4.4**.

Table 4.4: Description for Reference Scenario 3

Scenario Number	Description
3	**Reference Scenario 3**
	Purpose: To determine surplus yield available at 2005-development level with revised environmental requirements included 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.
	As Reference Scenario 1, but with the following changes: • EFRs, as determined from the additional LORMS task will be used instead of the ORRS environmental requirement. This EFR is not a fixed annual volume, but varies from year to year, depending on the variation of the natural flow at the site. For the historic analysis period, the EFR varied from 505 to 1 850 million m^3/a with an average of 1062 million m^3/a. The river EFR, as determined for the Augrabies site, was recommended by the Estuary EFR workshop to be used as a river EFR, just upstream of the Estuary. By using this EFR, it will be possible to maintain the Estuary at least at a Class D. • Spills from the Vaal, plus losses from the Vaal, which flow into the Orange River, will be included in the analysis. The spills will only be used to support the environmental requirements and not the irrigation or urban demands. • The recently updated environmental releases from the Lesotho LHWP will be used. • The reduced LHWP Transfer, as result of the updated environmental releases, will be used. The reduced transfer rate from LHWP to the Vaal is 780 million m^3/a for the full Phase 1 of the LHWP. (The 780 million m^3/a was determined by means of a yield analysis and represents the 1 in 50 year long-term stochastic yield. The figure might, however, be revised depending on NAY negotiations.)

4.4.3 Scenarios for Future Development Levels (Phase 2)

Reference Scenario 3 was used as the basis for the 2015- and 2025-development level scenarios. The projected urban/industrial & mining demands, as obtained for this study, were used for these analyses. Irrigation demands were constant at year 2000-development level, as already discussed in **Section 4.1**.

Scenario 3a represents the 2015-development level analyses and is as Reference Scenario 1 with the only difference being the 2005-development urban/industrial and mining demands, which were replaced by the corresponding projected 2015-demands.

Scenario 3b represents the 2025-development level analyses and is as Reference Scenario 1 with the only difference being the 2005-development urban/industrial and mining demands, which were replaced by the corresponding projected 2025 demands.

4.4.4 Scenarios Describing the Proposed Development Options and Measures to Improve the Water Supply in the System (Phase 3)

A total of seven scenarios related to Reference Scenario 3 were selected and agreed upon. The purpose of these scenarios is to determine the effect on the surplus yield at different development levels, as well as for various possible development and WC&DM options. These scenarios are summarised in **Table 4.5**.

Table 4.5: Selected Scenarios which all include the "Top Up" D Environmental Requirement

Scenario Number	Description
	Scenario 3 Related Scenarios
	Purpose: To determine surplus yield available at different development level with revised environmental requirements included as for Reference Scenario 3, but also including various possible development, as well as WC&DM options. These yields will be used to compare with Reference Scenario 3 and related scenarios to determine the increase or decrease in yield.
	As Reference Scenario 3, but with the following changes:
Scenario 3c	• Use surplus from the Vaal, which is in excess of 200 million m³/a in 2005, but will reduce over time to zero between 2015 and 2020. The surplus can be pumped from the Tugela into Sterkfontein Dam and released to flow through the Vaal and Bloemhof Dams into the Orange River. This will have the advantage of improving the water quality in the Lower Vaal although it will have some negative effect on the water quality in the Lower Orange. Another option is to release some of the water from the LHWP Transfer to the Vaal into the upper reaches of the Caledon. Sediment in the Caledon might, however, be a problem. Eskom will benefit from this option, as hydropower can be generated with these releases when flowing through the Gariep and Vanderkloof Dams.
Scenario 3d	• Utilize spills from the Vaal River by means of real time modelling.
Scenario 3e	• Utilize the Lower Level storage in Vanderkloof Dam. Results from a separate study on this option ,with the focus on the effect on hydropower generation, will also be obtained as an input to this
Scenario 3f	

Scenario Number	Description
	scenario.
Scenario 3g	• Large Vioolsdrift Dam (3 sizes) will be analysed to determine the incremental yield. The live storage suggested for the 3 dam sizes are: ▪ 500 million m³ ▪ 1500 million m³ ▪ 2400 million m³ (From initial analysis it seems that the possible maximum future development downstream of Vioolsdrift Dam will not be able to utilize the available yield from a dam larger than this.
Scenario 3h	• Large Boegoeberg Dam (3 sizes) will be analysed to determine the incremental yield. The live storage suggested for the 3 dam sizes are: ▪ 500 million m³ ▪ 1500 million m³ ▪ 2400 million m³ (The ORRS analysis showed that a larger dam will inundate parts of Prieska).
Scenario 3i	• Re-regulating dams at Vioolsdrift and Boegoeberg were analyzed by means of the hydraulic river modeling. The results showed that the required dam sizes are almost the same at both locations (required live storage 110 mcm Vioolsdrift and 103 mcm Boegoeberg), although the savings that can be obtained by the Vioolsdrift Dam is significantly higher (170 mcm/a at Vioolsdrift and 70 mcm/a at Boegoeberg). For the purpose of the system analysis, it is suggested to only include Vioolsdrift Dam as a re-regulation dam. • WC&DM with focus on the area between Gifkloof and the Namibian border as this area is expected to provide the highest returns. By 2005, it is expected that returns from WC&DM will not yet be available. The first returns as result of scheduling, metering and tariffs is expected by 2009 and returns as a result of improved irrigation systems and reduced conveyance losses is expected to be available by 2012.

4.5 Historic Firm Yield Results

4.5.1 General

Base Scenario 20 from the ORRS was used as the basis for the scenarios analysed in the LORMS, as discussed in **Section 4.1**. The surplus yield for Scenario 20, as obtained from the ORRS, is 302 million m³/a. Using this data set and only updating the hydrology with the latest available hydrology, as given in **Section 2.2**, the surplus yield reduced by 69 to 233 million m³/a. By including the updated demands and system changes to represent Reference Scenario 1 of this study, the surplus yield was reduced to 120 million m³/a.

Only the growth in the urban/industrial and mining demands were included in the WRYM as configured for the Orange River System at 2005-, 2015- and 2025-development levels. It will therefore be necessary to compare the surplus yield available at the future development levels with the possible growth scenarios proposed for irrigation in the Orange River System. The irrigation demand projections were obtained from the Water Requirements Report (PWC, 2004a) produced as part of the LORMS and are briefly summarised in **Section 4.6.2**.

4.5.2 Irrigation Demand Projections

The possible irrigation demand projections for the LOR along the common border area, as obtained from the LORMS Water Requirements Report, is shown in **Figure** 4.3 and **Figure 4.4**.

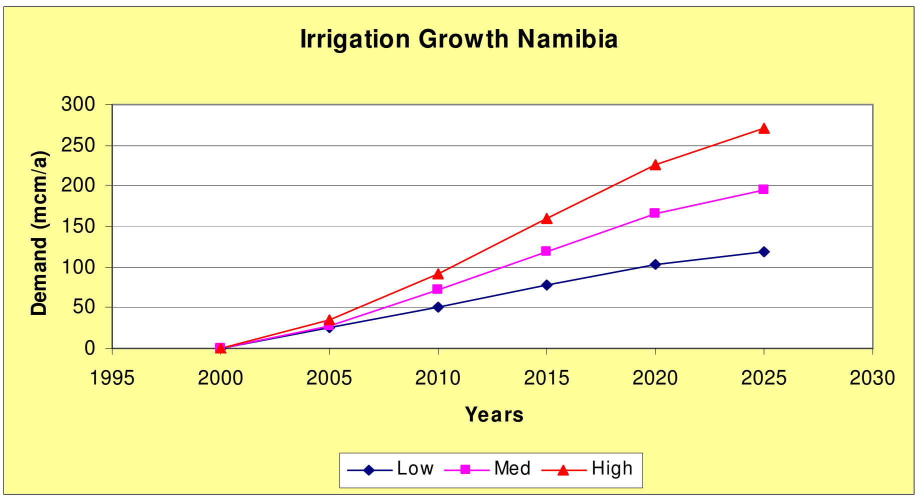

Figure 4.3: Irrigation Growth within Namibia along the Common Border

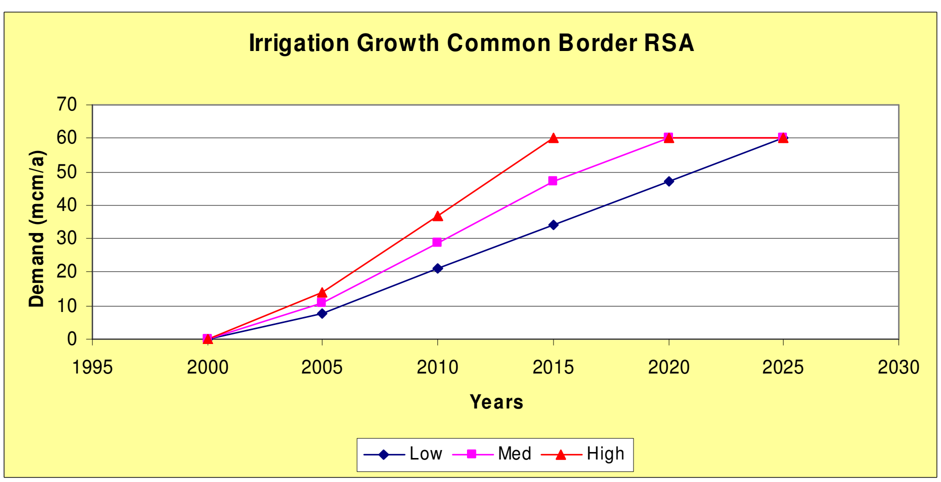

Figure 4.4: Irrigation Growth within RSA along the Common Border

A total of 12 000 ha was earmarked for the development of resource poor farmers of which 4 000 ha was allocated to the Lower Orange Water Management Area (WMA). For the purpose of this study, it was assumed that the latter 4 000 ha will be developed along the common border.

It was agreed by both countries that, for the purpose of the yield analysis, only two scenarios would be considered. A low growth and a most possible growth scenario where the low growth scenario is a combination of the RSA medium growth projection with the Namibian low growth projection. The most probable growth scenario is a combination of the RSA high growth with the Namibian medium growth scenario. It was further assumed that the remaining 8 000 ha on the RSA side will grow at the same rate as predicted for the 4 000 ha in the Lower Orange WMA. The combined growth curves for all the possible irrigation developments are shown on **Figure 4.5**.

To simplify the comparisons of surplus yield with irrigation growth projections, it was decided to add the effect of the urban/industrial and mining growth, as obtained from the yield analysis to the irrigation growth curve presented in **Figure 4.5**. This means that 53 million m^3/a must be added to the 2015 projected demand and 86 million m^3/a to the 2025 projected irrigation demand (See **Table 4.6**). The results from this combination are shown in **Figure 4.6**. It is important to note that no growth in irrigation was included in the WRYM data sets and that the irrigation requirements included in the WRYM represented the year 2000-development. The most probable expected irrigation growth indicated a growth of 61 million m^3/a from 2000 to 2005. For this reason, the most probable demand curv, as shown in **Figure 4.6**, starts at 61 million m^3/a at 2005.

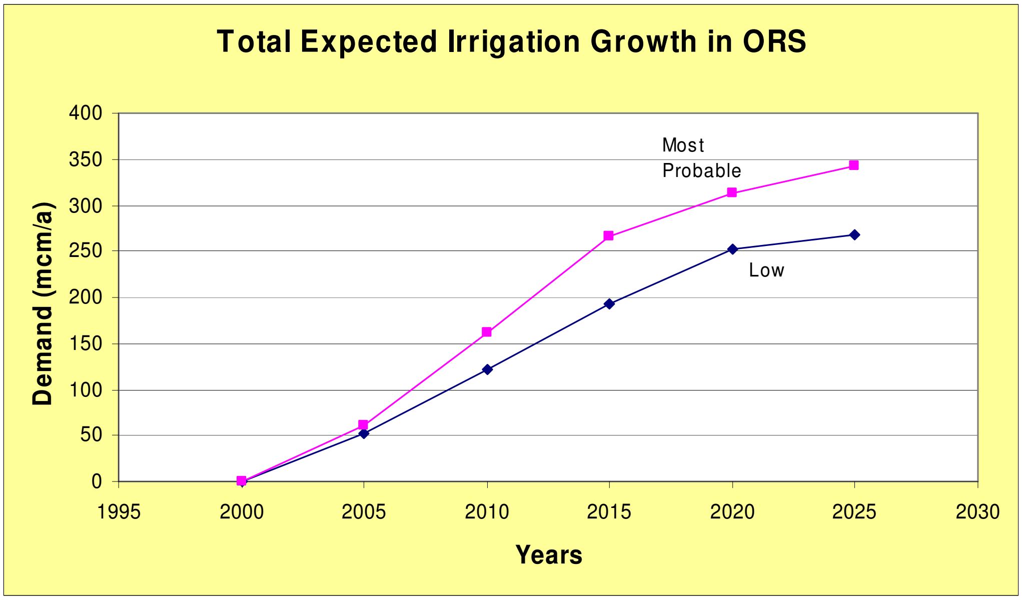

Figure 4.5: Total Irrigation Growth within the Orange River System

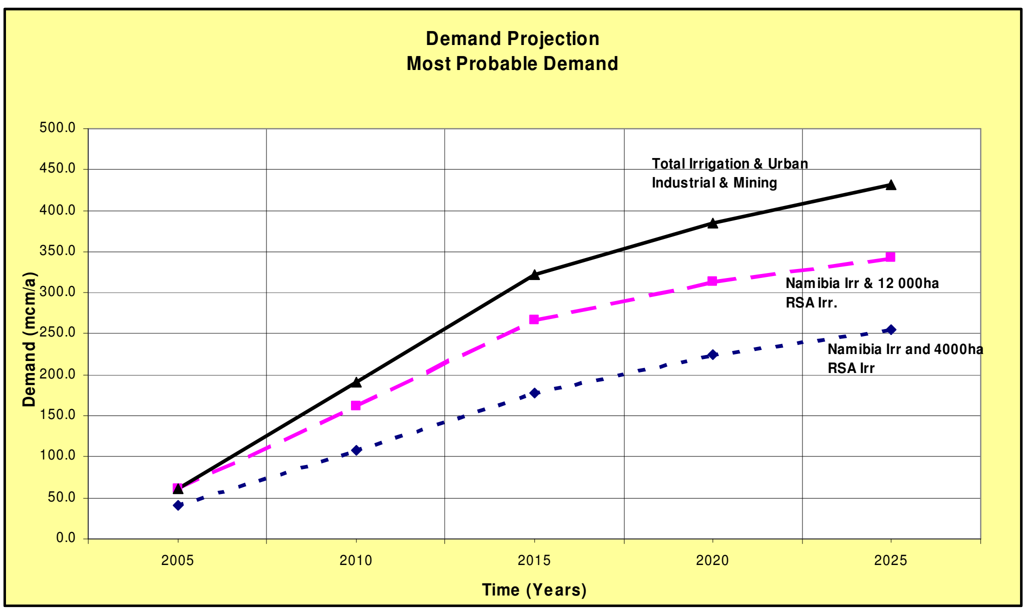

Figure 4.6: Most Probable Irrigation and Urban/Industrial Growth within the Orange River System

4.5.3 Reference Scenario 1 and Related Scenarios

It is important to realise that the yield results given in **Table 4.6** refers to the surplus yield available in the system. This is the surplus available after all the demands were fully supplied. The surplus yield in the system for Reference Scenario 1 is a 120 million m³/a, but the total system yield is 3 251 million m³/a and includes all the demands supplied from the Gariep and Vanderkloof Dams. A summary of the results for all the scenarios analysed, is given in **Table 4.6**. The system schematics are included in **Appendix D** (**Figures D-1** to **D-3** with penalty structures and **D-4** to **D-6** showing the water balance). Results from the analyses show that the system is currently almost in balance as the 120 million m³/a surplus for this large system represents less than 4% of the total system yield.

Table 4.6: Results from Reference Scenario 1 and Related Scenarios

Scenario no.	Description	Units	Surplus/deficit Yield	Increase/ Decrease
1	Reference Scenario 1 (2005-development level)	million m³/a m³/s	120 3.8	0 0
1a	Reference Scenario 1 (2015-development level)	million m³/a m³/s	67 2.1	-53 -1.7
1b	Reference Scenario 1 (2025-development level)	million m³/a m³/s	34 1.1	-86 -2.7
1c	Vanderkloof Lower Level Storage (2005-development level)	million m³/a m³/s	271 8.6	151 4.8
1d	Hydro-power m.o.l. in both dams (2005-development level)	million m³/a m³/s	40 1.3	-80 -2.5
1e	Include Vaal spills operating losses excluded (2005-development level)	million m³/a m³/s	172 5.5	52 1.6
1f	Include Vaal spills operating losses included (2005-development level)	million m³/a m³/s	264 8.4	144 4.6
1g	Vanderkloof lower level storage plus Vaal spills operating losses included (2005-development level)	million m³/a m³/s	483 15.3	363 11.5
1h	Desktop Class C EFR with Vanderkloof Lower Level Storage plus Vaal spills operating losses included (2005-development level)	million m³/a m³/s	-417 -13.2	-537 -17.0
1i	Desktop Class D EFR with Vanderkloof Lower Level Storage plus Vaal spills operating losses included (2005-development level)	million m³/a m³/s	-201 -6.4	-321 -10.2

The growth in urban/industrial and mining components have a relative small impact on the system yield as it reduces the system yield from 2005 to 2025 by only 86 million m³/a.

A similar reduction in yield (80 million m³/a) will occur when the current hydropower m.o.l. is used in stead of those specified for Reference Scenario 1.

Results from Scenarios 1e and 1f show that the surplus yield can be increased by up to 144 million m³/a when the spills from the Vaal are fully utilised by the existing users. In practise, however, it will not be possible to obtain that without additional storage. Some of it can, however, be utilised by means of improved management and operating procedures (See **Section 4.4.5 c** for detail). It is interesting to note that the inclusion of the operating losses from the Vaal River Sytem increases the surplus yield by 92 million m³/a. These losses end up in Douglas Weir and some of it can therefore be utilised by the irrigators. The accuracy of the volume of operating losses is unfortunately not good and further work in this regard is required.

The planning estimates for EFR in the Orange River are significantly different from that given in the ORRS, which are currently being supplied from Vanderkloof Dam. The yield results indicated that deficits in excess of 400 million m³/a could be experienced in the system when the Desktop estimate of the EFR for a Class C river has to be met.

Yield results for some of the scenarios are compared with the most probable demand projection in **Figure 4.7**.

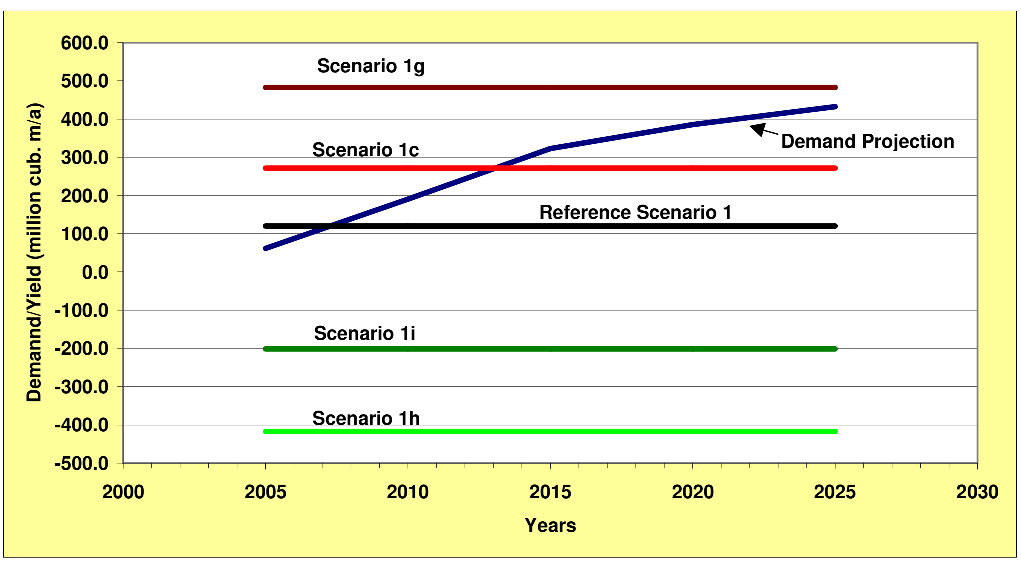

Figure 4.7: Yield Comparison with Most Probable Demand Projection

From the comparison in **Figure 4.7**, it can be seen that the current system will be able to supply the expected growth in demand only until 2007. A development option such as the utilisation of the Vanderkloof LLS will be able to supply the growth in demand up to 2013. A combination of Vanderkloof LLS with the utilisation of the Vaal spills should be sufficient to supply the growth in demands until 2025.

If the EFR planning estimates from the Desktop Model are included in the model, significant deficits already occur at 2005-development level. From these results it is clear that more work is required on the EFR estimations as the EFR from the ORRS and the Desktop Model results in large differences in the available yield from the system.

4.5.4 Reference Scenarios 2 and Related Scenarios

As a result of the major impact on the system yield with the inclusion of the Desktop estimates of the EFR, a new Reference Scenario was defined, as described in **Section 4.3**. Results from Reference Scenario 2 and some sensitivity analyses are summarised in **Table 4.7**. The system schematics are included in **Appendix D** (**Figures D-7** to **D-9** with penalty structures and **D-10** to **D-12**, showing the water balance).

Table 4.7: Results from Reference Scenario 2 and Related Scenarios

Scenario No.	Description	Units	Surplus/Deficit Yield	Increase/ Decrease
2	Reference Scenario 2 (2005-evelopment level)	million m³/a m³/s	-299 -9.5	0 0
2a	Reference Scenario 2 with Treaty releases from LHWP (2005-development level)	million m³/a m³/s	-366 -11.6	-67 -2.1
2b	Reference Scenario 2 with Vaal River EFR contibution (2025-development level)	million m³/a m³/s	-104 -3.3	195 6.2

The main differences between Reference Scenarios 1 and 2 is the inclusion of Desktop EFRs for a Class D river, updated instream flow requirement (IFR) releases from LHWP and the utilisation of Vaal spills and local runoff to supply EFRs in the Orange. Reference Scenario 2 results in a deficit of almost 300 million m³/a in the system and the deficit will further increase by 67 million m³/a when the Treaty IFRs are considered instead of the updated releases. This also means that the updated

IFR releases from the LHWP will increase the Orange River System yield by approximately 70 million m³/a.

When the Vaal River is used to supply it's portion of the EFR in the Orange River, the deficit in the Orange River can be reduced significantly by 195 million m³/a.

4.5.5 Scenarios Using the Top up Environmental Requirement

a) Reference Scenario 3, 3a & 3b

For Reference Scenario 3, it was decided to use the "Top up" environmental demand as determined for Augrabies at the Augrabies site (obtained from the River IFR workshop (PWC; 2004c)) and also as the EFR at the River Mouth (PWC; 2004d). This Reference Scenario resulted in a surplus yield of 14 million m³/a available in the system at 2005-development level. When only the growth in the urban/industrial/mining requirement is allowed in the system, the surplus in the system will become zero between 2007 and 2008 with a deficit of 42 million m³/a in 2015 and a 75 million m³/a deficit in 2025. It should be noted that the irrigation requirement included in the surplus yield calculation, is representing the current 2000-development level, as obtained for this study. Due to the large uncertainties around the possible growth in irrigation, it was decided not to include the possible future irrigation demand in the system used for analysis purposes, but rather compare the surplus yield obtained from the system analysis with different possible projections of the future irrigation requirement. Based on the LORMS irrigation demand projections, it is expected that for the most probable demand projection, the growth in the irrigation demand from 2000 to 2005 will already accumulated to an additional 61 million m³/a. When this possible growth is taken into account, it means that there will already be a deficit of 47 million m³/a in the system at 2005-development level. The system schematics are included in **Appendix D** (**Figures D-13** to **D-15** with penalty structures and **D-16** to **D-18** showing the water balance).

b) Utilize the Vaal Surplus (Scenario 3c)

A revision of the augmentation requirements for the Integrated Vaal River System was carried out in 2001 and the final reports were available in April 2002. This study used the latest updated hydrology from the VRSAU Study, which was commissioned by the Department of Water Affairs and Forestry (DWAF) RSA in 1995. The updated demand projections that were used for the revision of the augmentation requirements, were obtained from a comprehensive study

(MarkData, 2001) initiated by the DWAF to obtain projections for population, economic and socio-economic variables, with the aim of producing countrywide long-term water usage projections. This study incorporated the impact of HIV/AIDS on the projected population figures, expected migration patterns and the anticipated economic growth expected for over 700 Consumption Centers in the country.

Results from the study "Revision of the augmentation requirements for the Integrated Vaal River System" (DWAF; 2002) showed an expected surplus in the Vaal River System of 5 million m³/a for the year 2000, which will increase to a maximum of 238 in 2005 from where it will gradually decrease to zero in 2026. The increasing surplus in the system over the first five years is as result of the LHWP of which Phase 1A was already commissioned and Phase 1B will commence delivery in 2003. The projected support requirements and the available surplus for the Integrated Vaal River System, as obtained from the above-mentioned report, are as shown in **Table 4.8**.

Table 4.8: Projected Support Requirements and Available Surplus for the Integrated Vaal River System.

Balance Components	Years						
	2000	2005	2010	2015	2020	2025	2030
Integrated Vaal River System Yield	1 835	1 835	1 835	1 835	1 835	1 835	1 835
Total System Net Water Requirement	2 321	2 432	2 525	2 564	2 599	2 660	2 707
Support required for the Integrated Vaal River System from the LHWP	486	597	690	729	764	825	872
Yield from LHWP Phases 1A and 1B	491	835	835	835	835	835	835
Surplus (+) or shortfall (-) of the Integrated Vaal River System including Phase 1 of LHWP	5	238	145	106	71	10	-37

The Integrated Vaal River System Demands are being updated on continuous bases to ensure that projections are as close as possible to the actual demands. A more recent demand projection was included in the "Water Requirements" Report (PWC; 2004a), produced as part of this study (LORMS). The yield from LHWP Phases 1A and B has since changed from 835 to 780 million m³/a. This is as a result of the updated environmental requirements that have recently been implemented in Lesotho with regards to the LHWP. These changes will have a significant impact on the available surplus in the Vaal System as shown in **Table 4.9**.

When water is pumped from the Tugela to support the Lower Orange, losses are also expected to occur along this route. The Integrated Vaal River System yield already includes the effect of these losses for the total system down to Bloemhof Dam. Releases currently made from Bloemhof Dam and Vaalharts Weir also take into account the effect of losses. The same approach is followed for the Orange River System with regards to releases from Vanderkloof Dam. The fact that a relative small additional flow will be flowing along the same route will thus not really add substantially to the losses already experienced in the system. It was therefore decided to only include a relative small percentage loss of 10% with regards to the possible additional releases. With the effect of losses taken into account, it can be seen from **Table 4.9** that the maximum Vaal surplus, which can be utilised in the Lower Orange, will be 160 million m³/a in 2003, and it will reduce to 10 million m³/a in 2015.

Table 4.9: Updated Projected Support Requirements and Available Surplus for the Integrated Vaal River System

Balance Components	Years				
	2003	2005	2010	2015	2020
Integrated Vaal River System Yield	1 835	1 835	1 835	1 835	1 835
Total System Net Water Requirement	2 437	2 510	2 584	2 604	2 657
Support required for the Integrated Vaal River System from the LHWP	602	675	749	769	822
Yield from LHWP Phases 1A and 1B	780	780	780	780	780
Surplus (+) or shortfall (-) of the Integrated Vaal River System including Phase 1 of LHWP	178	105	31	11	-42
Reduced surplus when 10% losses are included	160	94	28	10	-
Cost to transfer total volume available based on the full Vaal tariff. (R million/a)	R259.2	R152.9	R45.2	R16.0	

The full Vaal water tariff is applicable to any new water user obtaining water from the Integrated Vaal River System and includes the following:

- Raw water cost R1.421 per cubic m;
- Water Resource Management cost for agriculture of R0.0078 per cubic m; and
- Research cost of R0.0276 per cubic m.

Total cost of R1.4564 per cubic m (All the costs excludes VAT).

c) ***Utilise the Current Spills from the Vaal River System (Scenario 3d)***

Although the Vaal River System is operated to minimize the outflows from the Vaal River System into the Orange River, a substantial volume of water still enters the Orange River from the Vaal. These inflows occur as a result of uncontrolled spills from the major dams upstream of the confluence, local runoff generated in the incremental catchment downstream of the major dams and upstream of the Orange-Vaal confluence, as well as result of operational losses in the Lower Vaal downstream of Bloemhof Dam and Vaalharts Weir. Similar to the situation found in the Orange River System, operational losses occur in the Lower Vaal as it is almost impossible to release the exact volume required by the users along the river downstream of the main storage dam. In an effort to ensure that all the users do receive the required volume of water, more water than the actual requirement is released to overcome the uncertainties with regards to the effect of local runoff, actual abstractions, heat waves, sufficient flow in the river to enable abstraction directly from the river, losses along the river, time for the flow to reach the various users, etc.

Results from the WRYM showed that at 2005-development level, on average, 1 680 million m^3/a enters the Orange River from the Vaal. The monthly flows vary from almost zero to extremely high flows during periods of high runoff when the major dams are spilling. Currently, these flows are not taken into account when releases are made from Vanderkloof Dam to supply downstream requirements.

Real time river modelling will enable the operator at Vanderkloof Dam to reduce releases from Vanderkloof Dam at the required time, to be able to utilise the inflows from the Vaal for users in the Lower Orange. Daily flow volumes, as used for the hydraulic river modelling, were used to determine the relationship between the monthly flow volumes from the Vaal and the portion of the monthly flow volume that can be utilised by the users along the Lower Orange (see **Section 5.6**). This relationship was then used in the WRYM monthly model to determine the effect on the surplus yield available in the Orange River System, when real time modelling is used to utilise the inflows from the Vaal. It is, however, important to know that Reference Scenario 1 was used as the basis for this analysis and not Reference Scenario 3, for specific reasons as explained hereafter.

During periods when Vanderkloof Dam is spilling, there will be no benefit in trying to utilise the spills from the Vaal, as more than sufficient water to satisfy the downstream demands will at such times, be flowing down the Orange River. The Orange River System operating rule was therefore defined in such a way in the WRYM, that the model only allowed support from the Vaal during times when Vanderkloof Dam was not spilling. Results from this analysis indicated that the surplus yield in the system could be increased by 80 million m^3/a. It is important to note that the benefit of 80 million m^3/a is the benefit as applicable for the current system where the ORRS environmental requirements are still imposed on the system. These environmental requirements are constant annual values and are currently supplied by means of releases from Vanderkloof Dam. The most recent methodology available with regards to environmental requirements links the environmental requirement for a specific month to the natural flow generated for that month. When analysing the environmental flow based on this methodology in a system context, it therefore requires that one should take into account the spills available in the system, to partly supply the environmental requirement and only obtain the remaining deficit by means of releases from an upstream storage dam.

The result from Reference Scenario 3 (14 million m^3/a surplus) therefore already takes into account the benefit of utilizing the Vaal spills and so will all the scenarios using Reference Scenario 3 as their base. It is further important to realise that to be able to implement and manage an environmental requirement, based on the latest accepted methodology, it will be necessary to have a real time modelling system in place, which is supported by accurate flow gauging at various selected key points.

The main cost to implement this option will be the upgrading of flow gauging stations along the Orange River, as well as in the Lower Vaal to be able to measure low flows accurately. Existing flow gauges in the Orange River and Lower Vaal River, which are already included in the existing telemetry network, are listed in **Table 4.10** below.

Table 4.10: Existing Flow Gauges included in the Telemetry Network

Station Name	DWAF Gauge Number	Distance from Vanderkloof (km)	Measured Component	Type of Transmission
Vanderkloof Dam	D3H023	0	Flow	Satellite
Doorenkuilen	D3H012	0.7	Stage	Satellite
Marksdrift	D3H008	174	Stage	Satellite/Cellular
Katalani	D7H007	190	Stage	Satellite
Boegoeberg	D7R001	471	Stage	Satellite
Zeekoeibaart	D7H008	473	Stage	Satellite
Neusberg	D6H014	703	Stage	Cellular
Vioolsdrift	D8H003	1 097	Stage	Satellite/Cellular
Brandkaros	D8H007	1 362	Stage	Satellite/Cellular
Vaal River				
Douglas Weir	C9R001	(Vaal River)*	Stage	Cellular

Note * The Vaal River enters the Orange River just downstream of Marksdrift Weir with Douglas Weir located approximately 5km upstream of the confluence in the Vaal River.

To be able to reduce operational losses by means of real time modelling, accurate flow gauging is required at the following sites:

- **Vanderkloof Dam** or a gauging station not far downstream of Vanderkloof Dam. (The stage-discharge relationship for the current gauging station at Doornkuilen is severely affected by the hydropower releases as result of the opening and closing of the turbines and the fact that the station is located to close to Vanderkloof Dam.
- **Marksdrift Weir**, just upstream of the Orange/Vaal confluence. (The accuracy of the existing gauge is currently not sufficient, but it can be upgraded at a relative low cost. This gauge is currently regarded as one of the best gauges in the Lower Orange).
- **Douglas weir** in the Vaal River. (This weir can only gauge very low flows – 7 m^3/s and lower. A new weir will be required close to this site).
- **Boegoeberg or Zeekoebaart**. (The accuracy of these gauges is not good and significant improvements would be required).
- **Neusberg Weir.** (This weir is also regarded as one of the best gauges and can be improved to an acceptable accuracy at a relative low cost).
- **Vioolsdrift Weir**. The accuracy of this gauge is not good at low flows. (This is mainly a flow diversion structure that was built by the Irrigation Boards (IBs) and is also used for flow gauging. A total new structure upstream or downstream of this site would be the best option and could be combined with

the building of a re-regulation dam).

- **Sendelingsdrift** downstream of the Orange Fish confluence, but upstream of the existing gauge at Brand Karos. (DWAF are currently planning for a flow gauge at this site. This gauge is located far enough upstream from the mouth not to be affected by the tides from the ocean, but close enough to the river mouth to monitor the inflows to the mouth for environmental purposes. It is estimated that the cost of the flow gauge will be at least R7 million).

A relative small scoping study or investigation is required to establish the needs for the implementation of real time modelling and the practicalities around the day to day operation, supporting systems, as well as the required training. The cost for such a study is estimated at R250 000.

Changes in the coding of the hydraulic river model are required to accommodate the modules developed for real time modelling as part of a WRC Study. These modules must still be included in the latest ISIS Model before it can be used in a streamlined user-friendly modelling operation. The total cost to include the required changes and to provide the model is estimated to be R180 000.

d) Vanderkloof Lower Level Storage (Scenario 3e)

Reference Scenario 3 was used as the base for this scenario. Results from this scenario showed an increase in the surplus yield of 143 million m^3/a at 2005-development level from 14 to 157 million m^3/a. Due to growth in urban/industrial/mining requirement, this surplus will reduce to 101 million m^3/a by 2015 and to 68 million m^3/a by 2025. With a possible additional growth in irrigation of 61 million m^3/a by 2005 the available surplus in 2005 will reduce to only 96 million m^3/a.

e) Large Vioolsdrift Storage Dam (Scenario 3f)

Three different sizes for a storage dam at Vioolsdrift were analysed. The height of the spillway for each dam was based on the required storage to accommodate the expected 50-year sediment volume, as well as live storages of 500, 1500 and 2 400 million m^3. Initially, just after the completion of the dam, the required dead storage was set at 100 million m^3 for each of the dam sizes. Over a 50-year period, the dam will have captured the estimated 50-year sediment volume so that the dead storage at that time will have increased to 602 million m^3. It is therefore clear that the live storage and the yield benefit of the dam will be significantly more just after the completion of the dam and it will decrease over time due to the sedimentation. Yield analyses were therefore carried out for the three dam sizes, each with a dead storage of 100 million m³ and 602 million m³/a.

The yield results shown in **Figure 4.9** only represent the yield benefit as a result of the water stored in the dam. A large dam will, however, also be used for re-regulating purposes. This means that the total yield benefit of the dam will be that given in **Figure 4.9**, plus the saving in operational losses as given in **Table 4.6**. The storage in the large Vioolsdrift Dam must then be increased by the 110 million m³, as given in **Table 4.6**.

From the results given in **Figure 4.9**, it is clear that the sediment captured over time has a significant effect on the surplus yield available in the system. Part of the reduction in yield is a result of the decrease in the live storage and the increase in the evaporation area at the higher dead storage level. The decrease in the volume is not difficult to model correctly as it is done by simply reducing the live storage in the dam. It is, however, difficult to predict what the future effect of the sediment will be on the evaporation area at various depths and more specificall, at the dead storage level. The dam is operated in such a way that the water available in Vioolsdrift Dam, is used first to supply in the downstream demands and the maximum additional abstraction imposed on the dam (to determine the surplus yield from the dam). Only when the Vioolsdrift Dam has reached its dead storage level, will water be released from Vanderkloof Dam to support the Vioolsdrift Dam. For this reason, it is possible that the Vioolsdrift Dam can be empty for almost five consecutive years. To be able to understand how the dam was modelled with regards to the two different dead storage levels, the reader is referred to **Figure 4.8**. The current area, capacity and height characteristics were used for both scenarios, as we do not have any information of how these characteristics will change over time due to sedimentation, except for the fact that the storage volume will reduce. The dead storage level, just after the completion of the dam, was selected as 100 million m³ and it was assumed to co-inside with the lowest outlet level. The Dead Storage Level 2 was selected at the level where sufficient volume exists below this level to accommodate the expected 50-year sediment volume of 602 million m³ in the case of Vioolsdrift Dam. From **Figure 4.8** it is clear that the evaporation area at Dead Storage Level 2 will be significantly larger than at Dead Storage Level 1, when the existing area, capacity and height curves are used. The bulk of the sediment under normal conditions tends to settle at the tail end of the dam, indicated by location-A in **Figure 4.8**. As previously described, it often happens that Vioolsdrift Dam can be empty for relative long periods as a result of the operating rule followed. This will result in sediment moving to the dam wall – location-B. As a result of the uncertainties with regards to the effect of the sediment on the surface area, specifically at the dead storage levels, a sensitivity analysis was carried out to determine the effect on the surplus yield for different assumptions regarding the surface area at Dead Storage Level 2. The surface area characteristics for Dead Storage Level 2 were then adjusted to be equvalent to that of Dead Storage Level 1, when the dam are in both cases at their corresponding dead storage levels.

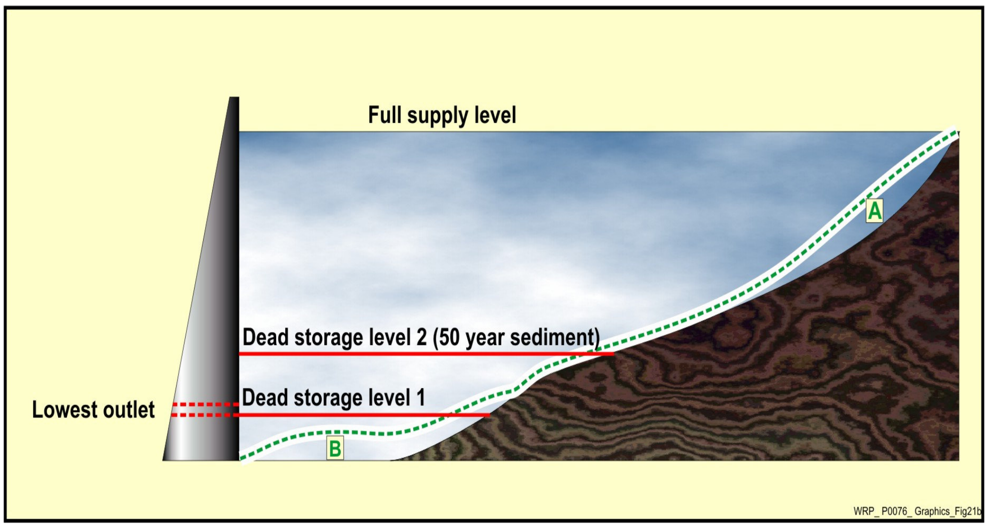

Figure 4.8: Effect of Sediment on Dead Storage Level

The adjusted surface area at Dead Storage Level 2 resulted in a significant increase in the surplus yield of between 60 and 50 million m³/a, depending on the size of the storage dam. The results from this analysis are shown on **Figure 4.8** and are indicated as those from the adjusted curve.

f) Large Boegoeberg Storage Dam (Scenario 3g)

Three different sizes were also analysed for the Boegoeberg storage dam. The height of the spillway for each dam was determined in the same way as for Vioolsdrift Dam. Live storages of 500 million m³, 1500 and 2 000 million m³ were, however, considered. A larger dam than the 2 000 million m³ at Boegoeberg will start to inundate parts of Prieska.

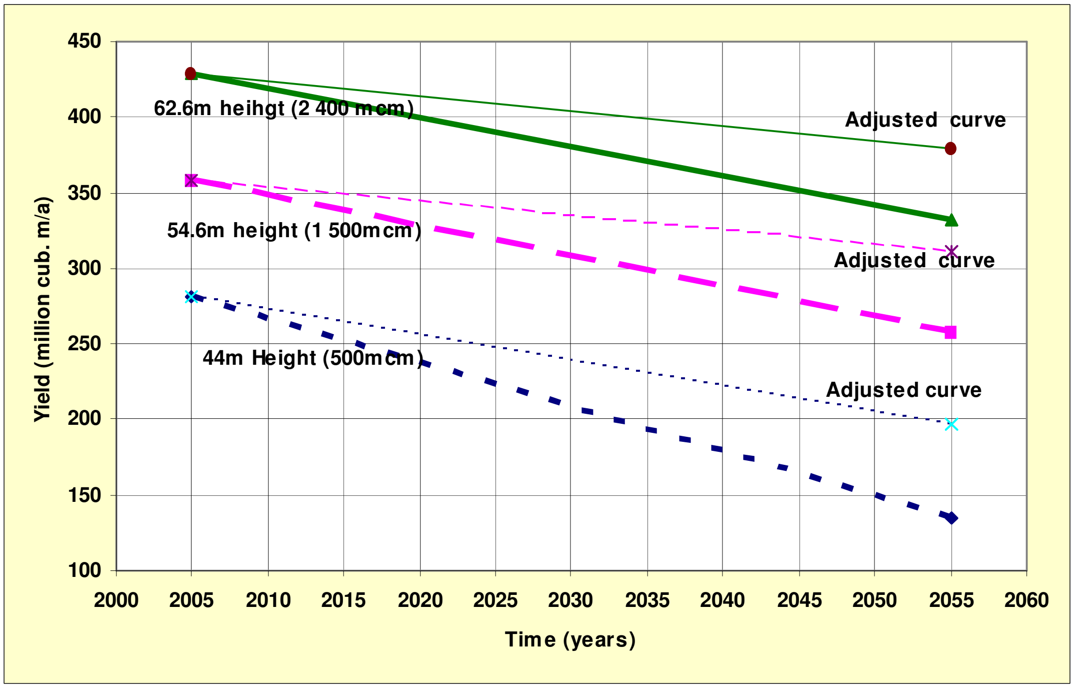

Figure 4.9: Effect of Sediment on Vioolsdrift Dam

Initially just after the completion of the dam, the required dead storage was set at 100 million m³ for each of the dam sizes. Over a 50-year period, the dam will have captured the estimated 50-year sediment volume so that the dead storage at that time will have increased to 711 million m³. It is therefore clear that the live storage and the yield benefit of the dam will be significantly more just after the completion of the dam and it will decrease over time due to the sedimentation. Yield analyses were carried out for the three dam sizes each with a dead storage of 100 million m³ and 711 million m³/a.

Results of the analysis are shown in **Figure 4.10.** A large dam at Boegoeberg will also be used for re-regulation purposes, as described for the large Vioolsdrift Dam. The additional benefit as given in **Table 4.11** can then be added to the yield results given in **Figure 4.10** on the condition that the live storage of the large dam is increased by 90 million m³.

From the results shown in **Figure 4.9** and **Figure 4.10**, it is can be seen that Viooldrift Dam is providing a higher yield for the same live storage and is also less effected by the sediment. The reason for the higher yield benefit is two-fold.

The first and most important reason is the incremental runoff that enters the system between Boegoeberg and Vioolsdrift Dams. On average over the analysis period almost 120 million m³/a enters the Orange River between the two possible dams. Although this only represents approximately 1% of the total runoff generated in the Orange and Vaal catchments, it can only be utilised by Vioolsdrift Dam. For the purpose of the analysis, the system was operated in such a manner that all the demands downstream of Vioolsdrift Dam, as well as the additional yield/demand imposed on the system, is first supplied from the Vioolsdrift Dam and only when Vioolsdrift Dam is at its minimum operating level, will water be released from Vanderkloof to support these demands. As a result of this operating rule, the water level in Vioolsdrift Dam is relatively low for most of the time, so that a significant portion of the incremental runoff can be captured by Vioolsdrift Dam. This incremental runoff contributes to approximately 70% of the difference in yield between Boegoeberg and Vioolsdrift Dams. The difference in yield at the same live storage for Boegoeberg and Vioolsdrift Dams is shown in **Figure 4.11**.

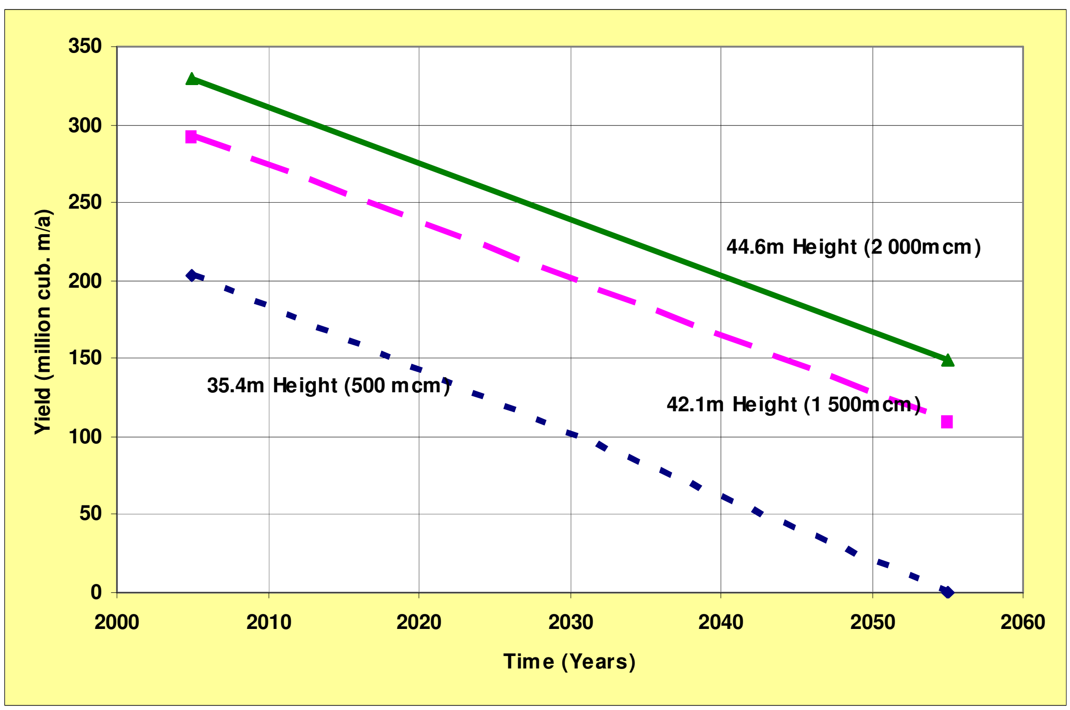

Figure 4.10: Effect of Sediment on the Boegoeberg Dam Yield

The second reason is the significantly higher surface area for Boegoeberg Dam in comparison with that of Vioolsdrift Dam for the same storage. Although the monthly evaporation in mm at Boegoeberg is lower than at Vioolsdrift, the average total annual evaporation from Boegoeberg Dam is significantly higher than that from Vioolsdrift Dam. The difference in the surface area for the two dams can clearly be seen on the area / capacity curves shown in **Figure 4.12**.

g) Re-regulating Dam in the Lower Orange River (Scenario 3h)

Results from the hydraulic river modelling task (see **Section 5.4**) clearly indicated that for the purpose of a re-regulation dam, the Vioolsdrift option provides a significantly higher benefit with regards to the reduction in operational losses than could be obtained by a similar dam at the Boegoeberg or Komsberg sites. The results from the hydraulic river modelling are summarised in **Table 4.11**.

Table 4.11: Results for Re-regulation Dams at Three Different Sites

Scenario Description	Live Storage Required. (million m^3)	Saving in Operational Losses (million m^3/a)	Remaining Operational Losses (million m^3/a)
Current system	0	0	270
Boegoeberg	90	62	208
Komsberg	100	126	144
Vioolsdrift	110	170	100

The live storage required for the Vioolsdrift and Komsberg re-regulating dams is not much higher than that required for the Boegoeberg re-regulating dam. The savings in operational losses, however, are more than double that obtained from a Boegoeberg re-regulation dam. This was expected to a certain extend, as the length of the river that must still be controlled from a dam at Boegoeberg is in excess of 900 km in comparison with only 280 km downstream of the Vioolsdrift Dam site. The demands downstream (193 million m^3/a, excluding river mouth environmental requirement) of the Vioolsdrift re-regulating dam are sufficient to utilise the indicated saving of 170 million m^3/a.

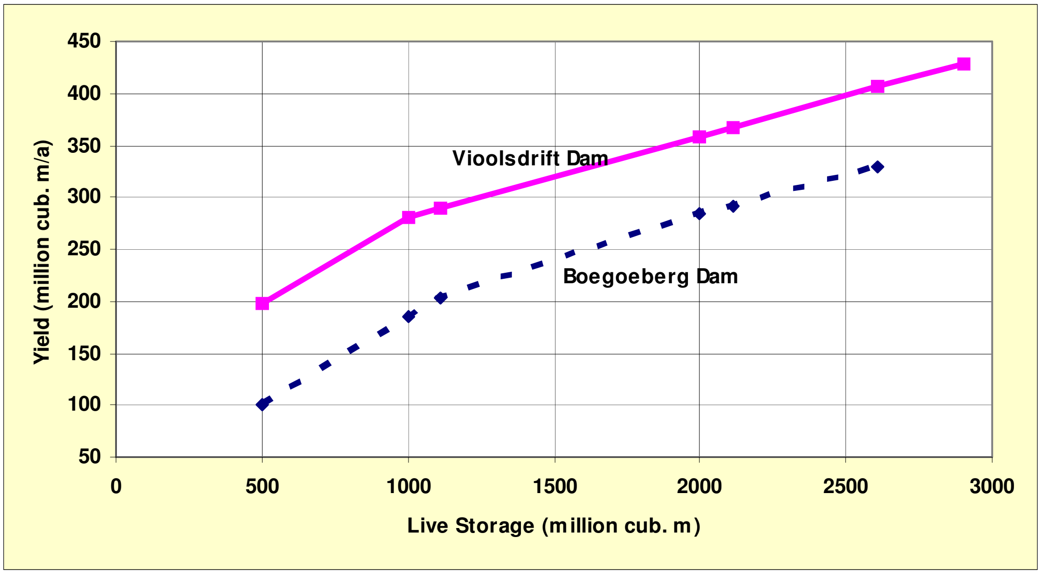

Figure 4.11: Yield Comparison between Boegoeberg and Vioolsdrift Dams

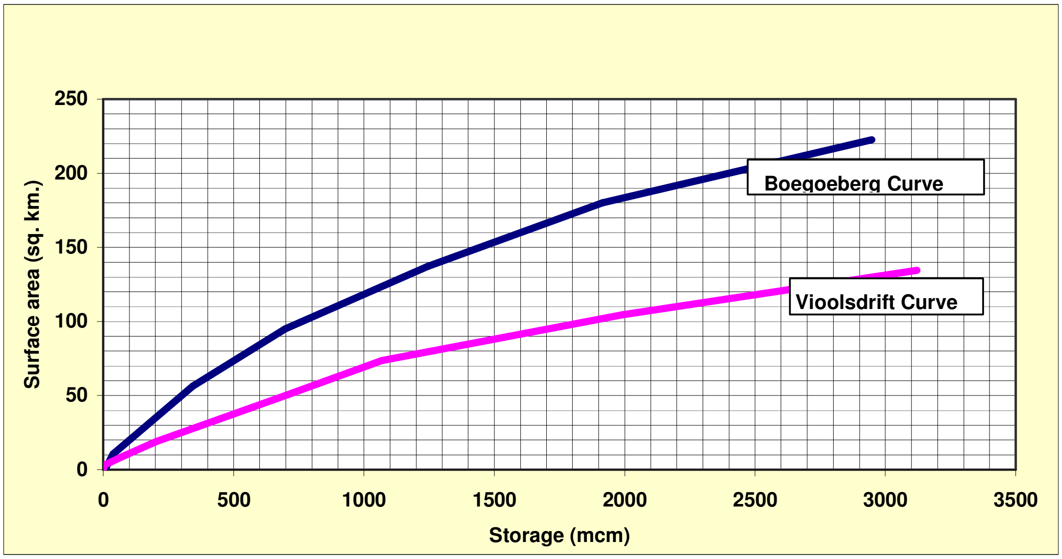

Figure 4.12: Boegoeberg Vioolsdrift Area Capacity Comparison

h) Water Conservation and Demand Management (WC&DM) Option (Scenario i)

In the LORMS Report "Water Conservation" (PWC; 2004b), the Gifkloof–Neusberg area was identified as the area with the highest potential savings at the lowest cost. The main reason for this is the fact that the area is mainly utilised for high value crops and at the same time has the benefit to cover a substantial area (15 564 ha) under irrigation. For this reason, it was decided at the Swakopmund workshop and meeting, that the Gifkloof–Neusberg area should be concentrated on as the pilot area for WC&DM and that the other areas would follow later. For the purpose of this analysis, the Gifkloof–Neusberg area was therefore used as basis for comparison purposes.

A second area that can also be considered for WC&DM purposes is the area between Neusberg to the Namibian Border. This area is fairly similar to the Gifkloof to Neusberg area in the sense that high value crops are also produced in this area, covering a total of 11 572 ha under irrigation.

The benefit from WC&DM will not become available immediately after it has been initiated. It is a long process of getting various support structures in place, providing training and relevant information, implementation of metering and conservation orientated tariffs and improving of the operational efficiency.

The potential savings that have been identified in order of priority are:

- Proper scheduling 7% (after 30% return flows was deducted).
- Metering and pricing 7% on the reduced water demands after scheduling savings were obtained.
- Improvement of irrigation systems 20,13%.
- In the Neusberg Gifkloof area savings through irrigation systems is only 15,1% as a result of more advanced systems.

For the purpose of this scenario, it is accepted that no WC&DM is in place in 2005 and that the effects of scheduling and metering-pricing will only reach its full potential at the beginning of 2009. These will be followed by the effect from improved irrigation systems with the full potential only reached at the start of the year 2012. Results from the WC&DM actions for Gifkloof to Neusberg area are summarised in **Table 4.12** and for Neusberg to Namibian border in **Table 4.13**.

Table 4.12: Summary of Expected Savings through WC&DM Initiatives for the Gifkloof Neusberg Area

Description	% Net Saving	Net Saving (million m³/a)	Net Water Requirement (million m³/a)	Year in which Full Potential Saving become available
Current allocation	-	-	233.45	-
Scheduling net savings	7%	16.34	217.11	2009
Metering-pricing net saving	7%	15.20	201.91	2009
Irrigation systems net saving	20%	40.64	161.27	2012
Total saving	**31%**	**72.18**	**161.27**	**2012**

Table 4.13: Summary of Expected Savings through WC&DM Initiatives for the Neusberg Namibian Border Area

Description	% Net Saving	Net Saving (million m³/a)	Net Water Requirement (million m³/a)	Year in which Full Potential Saving become available
Current allocation	-	-	173.58	-
Scheduling net savings	7%	12.15	161.43	2010
Metering-pricing net saving	7%	11.30	150.13	2010
Irrigation systems net saving	15%	22.67	127.46	2014
Total saving	**26%**	**46.12**	**127.46**	**2014**

4.5.6 Summary of Key Results

Three different reference scenarios were analysed for the LORMS. These three scenarios are briefly described here after:

- **Reference Scenario 1**: (Also referred to as Scenario 1 for the Estuary EFR workshop). This scenario represents the current system with 2005-development demands imposed on the system and the EFR, as obtained from the ORRS, was used in the analysis. Inflows or spills from the Vaal was not utilised to supply any of the downstream demands.
- **Reference Scenario 2**: (Also referred to as Scenario 10 for the Estuary EFR workshop). This scenario represents the current system with 2005-development demands imposed on the system and the EFR, as obtained from the Desktop Model for a Class D river, was used in the analysis. Inflows from the Vaal were used to supply the EFRs and river requirements (evaporation and seepage) as far as possible.

- **Reference Scenario 3**: (Also referred to as Scenario 7 for the Estuary EFR workshop). This scenario represents the current system with 2005-development demands imposed on the system and an adjusted Desktop D EFR (also referred as the Top Up environmental demand) was used for Augrabies and the River Mouth in the analyses. Inflows from the Vaal were used to supply the EFRs and river requirements as far as possible.

Reference Scenario 1 showed a surplus yield of 120 million m^3/a available in the system at 2005-development level. When the full Desktop D demands are imposed on the system (Reference Scenario 2), the surplus yield is non-existent, and there is in fact a deficit of 299 million m^3/a in the system for this scenario. By using an adjusted Desktop D EFR for Augrabies and the River Mouth (Reference Scenario 3) in the place of the full Class D EFR, it was possible to obtain a small surplus yield of 14 million m^3/a at the 2005-development level.

The yield results of all three these scenarios are compared with the expected most probable demand growth (irrigation and urban) in **Figure 4.13**. From this comparison, it is clear that there is a serious water supply problem in the system when the full Class D Desktop EFRs are imposed on the system (Reference Scenario 2). When Reference Scenario 3 is considered, the system will already experience a deficit of (61 – 14 = 47) 47 million m^3/a at 2005-development level. Reference Scenario 1 uses the ORRS EFRs, which is currently also released in practice. This scenario resulted in a surplus yield of 120 million m^3/a for the 2005-development level with the growth of the irrigation demand between 2000 and 2005 included, the surplus reduce to 60 million m^3/a. From the comparison given in **Figure 4.13**, it is evident that under these conditions, the system will be able to supply in the expected demand growth until 2007.

The yield result of a fourth scenario is also shown in **Figure 4.13**. This scenario is as Reference Scenario 3, but with no River Mouth EFR imposed on the system. This scenario is also referred to as Scenario 8 for the Estuary EFR workshop. In this scenario, it was assumed that most of the environmental flow releases made to satisfy the Augrabies environmental site, will reach the river mouth. The environmental flow from Augrabies will only be reduced by the natural river evaporation and seepage losses between Augrabies and the River Mouth. For this scenario, the surplus yield was increased considerably to 248 or 190 million m^3/a when the irrigation growth (2000 to 2005) is included, and the surplus will be sufficient to supply the expected demand growth until 2012. This option will, however, result in a further deterioration of the Estuary to a Class E.

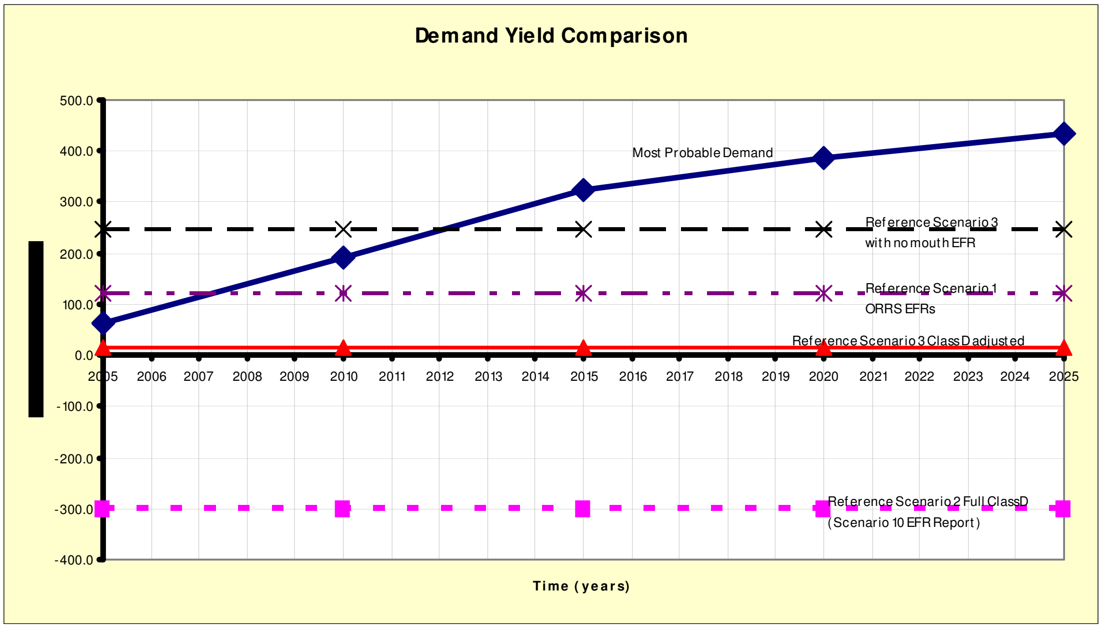

Figure 4.13: Most Probable Demand Projection in Comparison with Different Yield Scenarios

4.6 Long-term Stochastic Yield Analysis

4.6.1 General

For the historic firm yield analyses as described in the previous sections, the surplus yield available from the system was determined in each case, for all the scenarios considered. The main benefit of determining the surplus yield and not the total system yield was that all the demands were located close to their physical location in the system network, which for example, allows users from Douglas Weir to also benefit from irrigation return flows and spills from the Riet/Modder and Vaal Rivers. The effect of a demand that vary from year to year, such as the releases through the Orange/Fish tunnel, could also be simulated in detail. All the demands placed on the system were fully supplied over the analysis period, and therefore has the same assurance of supply as the historic firm yield. A simplified layout of the system, as used for the historic yield analyses, is shown in **Figure 4.14**. From this schematic, one can see the some demands are supplied directly from the Gariep and Vanderkloof Dams and some by means of releases into the river. For this set up, the inflows from the Vaal are not entering the Orange River at the Orange/Vaal confluence. This is to prevent the users along the Orange River to utilise these inflows.

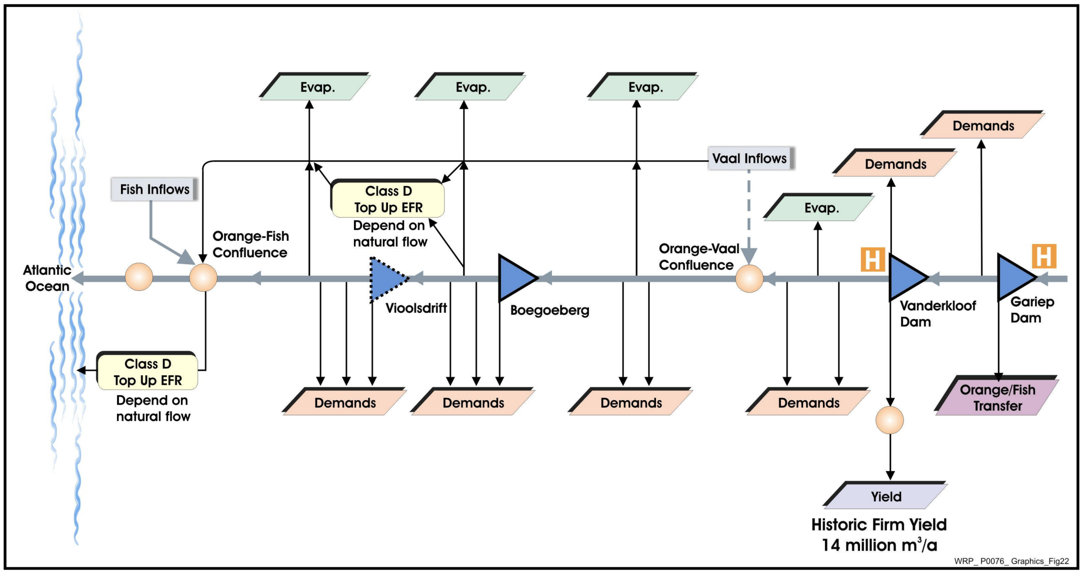

Figure 4.14: Historic Analyses Simplified System Schematic

This is in line with the current operating procedure where inflows from the Vaal are not taken into account. The Vaal inflows are, however, available to supply the river evaporation along the river, as well as environmental requirements at Augrabies and the river mouth. Inflows from the Fish River (Namibia) are only utilised to supply the river mouth environmental requirements. If the Vaal inflows are not sufficient to meet the evaporation and environmental requirements, additional water is released from Vanderkloof Dam to ensure that these requirements are fully met.

The result from the schematic represents Reference Scenario 3. The yield channel on the schematic therefore shows that after all the current demands in the system were fully met; there is still 14 million m^3/a surplus yield available in the system.

The historic firm yield analysis does not provide us with a detail indication of the assurance of supply, only that there were no failures over the 68 years of the analysis period. The stochastic analyses are specifically carried out to determine the yield available at different levels of assurance. For the purpose of the stochastic analysis, the total system yield need to be determined, as the surplus yield, as well as all the existing demands are supplied at different assurance levels, depending on the category of user. A simplified layout of the system as used for the stochastic analyses is shown in **Figure 4.15**.

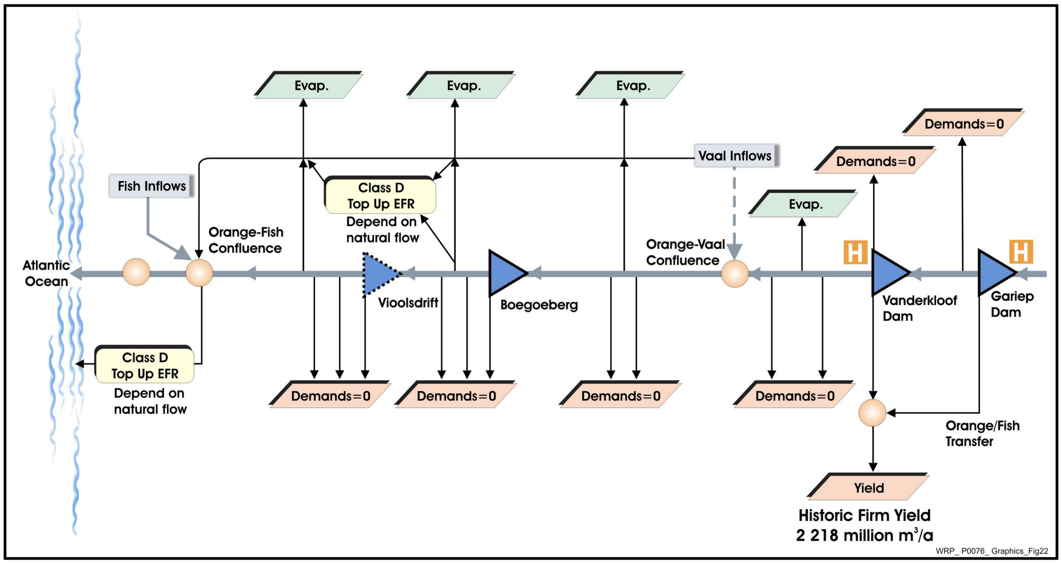

Figure 4.15: Stochastic Analyses Simplified System Schematic

The result from this analysis also represent Reference Scenario 3, with the only difference that all the demands, except for the river evaporation and environmental requirements, were set equal to zero, and the total system yield were therefore determined. For the purpose of this analysis, it was assumed that the evaporation from the river and the environmental requirements can partly be supplied from the Vaal and Fish Rivers spills, as well as from local runoff generated in the Lower Orange. The historic firm yield for this scenario was determined as 2 218 million m^3/a. Based on this system configuration, the stochastic analyses were carried out, and results are discussed in **Section 4.6.2**.

4.6.2 Reference Scenario 3

Reference Scenario 3, configured as shown in **Figure 4.15**, was used as the base or reference scenario for the long-term stochastic analysis. For the purpose of the long-term stochastic analysis, 501 stochastic sequences, each of a 68-year record length, were analysed. Results from this analysis are summarised in **Table 4.14**.

Table 4.14: Reference Scenario 3, Summary of Long-term Stochastic Yield Results

Scenario Description	Historic Firm Yield Recurrence Interval (years)	Long-term Stochastic Firm Yield at Indicated Recurrence Intervals			
		1: 20 year (million m³/a)	1: 50 year (million m³/a)	1: 100 year (million m³/a)	1: 200 year (million m³/a)
Reference Scenario 3	100 (2 218)*	2 825	2 450	2 218	2 000

Note * : Value in brackets refers to the historic firm yield in million m³/a.

The total demand imposed on the system as defined for Reference Scenario 3 is 2 162 million m³/a. This, however, excludes the river evaporation and the environmental requirements. From the stochastic results it can be seen that it is possible to supply the full system demand at a 1: 100 year assurance with almost no surplus left. The recurrence interval for the historic firm yield is also 1 in 100 years, which means that for the historic analyses all the demands were supplied at the same assurance, which is a relative high assurance for irrigation purposes.

If all the demands are supplied at a 1:50-year assurance, the stochastic analysis shows a surplus of 288 million m³/a, which is significantly more than the 14 million m³/a obtained from the historic firm yield analyses. The assurance, at which the demands are supplied, therefore has a significant effect on the surplus available in the system. In practise, however, all the demands are not supplied at the same assurance. Users are grouped into user categories and the categories are classified according to the required priority for water supply. These required assurance levels for the Orange River System were obtained through questionnaires as part of the water demand data collection process and are included in LORMS Water Requirement Report (PWC; 2004a), and are summarised in **Table 4.15** in this report. From **Table 4.15**, it follows that 50% of the total urban requirement needs to be supplied at a high assurance of 1 in 200 years, 31% at a 1 in 100 year assurance and 19% at a low assurance of 1 in 20 years. Most of the irrigation (63%) needs to be supplied at a low assurance, with some allocated to the medium and high assurance classes. Losses are all allocated to the high assurance class, as it is not possible to curtail losses, and losses will remain even during drought periods.

Table 4.15: User Categories and Priority Classifications Obtained from the Water Requirement Report

User Category	Priority Classification & assurance of supply		
	Low 1 in 20 year	Medium 1 in 100 year	High 1 in 200 year
Urban	19%	31%	50%
Industrial	45%	35%	20%
Mining	10%	23%	67%
Irrigation	63%	27%	10%
Losses	0%	0%	100%

During the November 2003 SMC meeting with both Clients, the stochastic yield results from Reference Scenario 3 was discussed and it was decided to slightly adjust and simplify the user categories and priority classifications for the Orange River System. This priority classification will be used as the basis in further stochastic analysis, as well as for the WRPM analysis, and is summarised in **Table 4.16**.

Table 4.16: User Categories and Priority Classifications Suggested for the LORMS

User Category	Priority Classification & Assurance of Supply		
	Low 1 in 20 year	Medium 1 in 100 year	High 1 in 200 year
Urban	20%	30%	50%
Irrigation	60%	30%	10%
Losses	0%	0%	100%

The actual demands as imposed on the Orange River System for Reference Scenario 3 were according to the user categories sub-divided into the priority classes on a volume basis as shown in **Table 4.17**. From **Table 4.17** it follows that 1 074 million m^3/a of the total demand must be supplied at a low assurance, 549 million m^3/a at a medium assurance and 539 million m^3/a at a high assurance. These allocations can then be plotted on the long-term stochastic yield curve as shown in **Figure 4.16** to determine whether the system will be able to supply the system demand at the required assurance levels.

Table 4.17: User Categories and Priority Classifications Suggested for the LORMS

User Category	Priority Classification & Assurance of Supply (million m³/a)			Total (million m³/a)
	Low 1 in 20 year	Medium 1 in 100 year	High 1 in 200 year	
Urban	12	18	30	60
Losses	0	0	332	332
Irrigation	1 062	531	177	1 770
Total	**1 074**	**549**	**539**	**2 162**

Figure 4.16 clearly shows that a maximum target draft of 2 650 million m³/a can be imposed on the system without affecting the required assurance of supply for the demands allocated to the different priority classes. The base yield line representative of the 2 650 million m³/a target draft is shown by the red line on **Figure 4.16**. The demands allocated to the medium and high priority classes, just touches the base yield line, indicating that no surplus is available at these two priority classes. At the low priority class there is still 480 million m³/a surplus available as indicated on **Figure 4.16** This is significantly more than the 14 million m³/a indicated by the historic firm yield analysis. The main reason for the large difference is the fact that the historic firm yield represents an assurance of supply of 1 in 100 years, which means a possibility of not supplying 100% of the demand, only once in 100 years. The stochastic analysis also indicated that there is only a very small surplus of 56 million m³/a available if all the demands are supplied at a 1 in 100 year assurance.

Sensitivity analyses were also carried out to determine the effect of different priority classifications on the available surplus. For this purpose two other priority classifications were used, the Vaal priority classification as currently used for the annual Vaal operating analyses and the priority classification used for the annual hydro-power operational analysis of the Orange River System. These two priority classifications are given in **Table 4.18** and **Table 4.19**.

The main difference between these two priority classifications and the proposed priority classification of the LORMS is that less irrigation is allocated to the low assurance class and more to the medium assurance class.

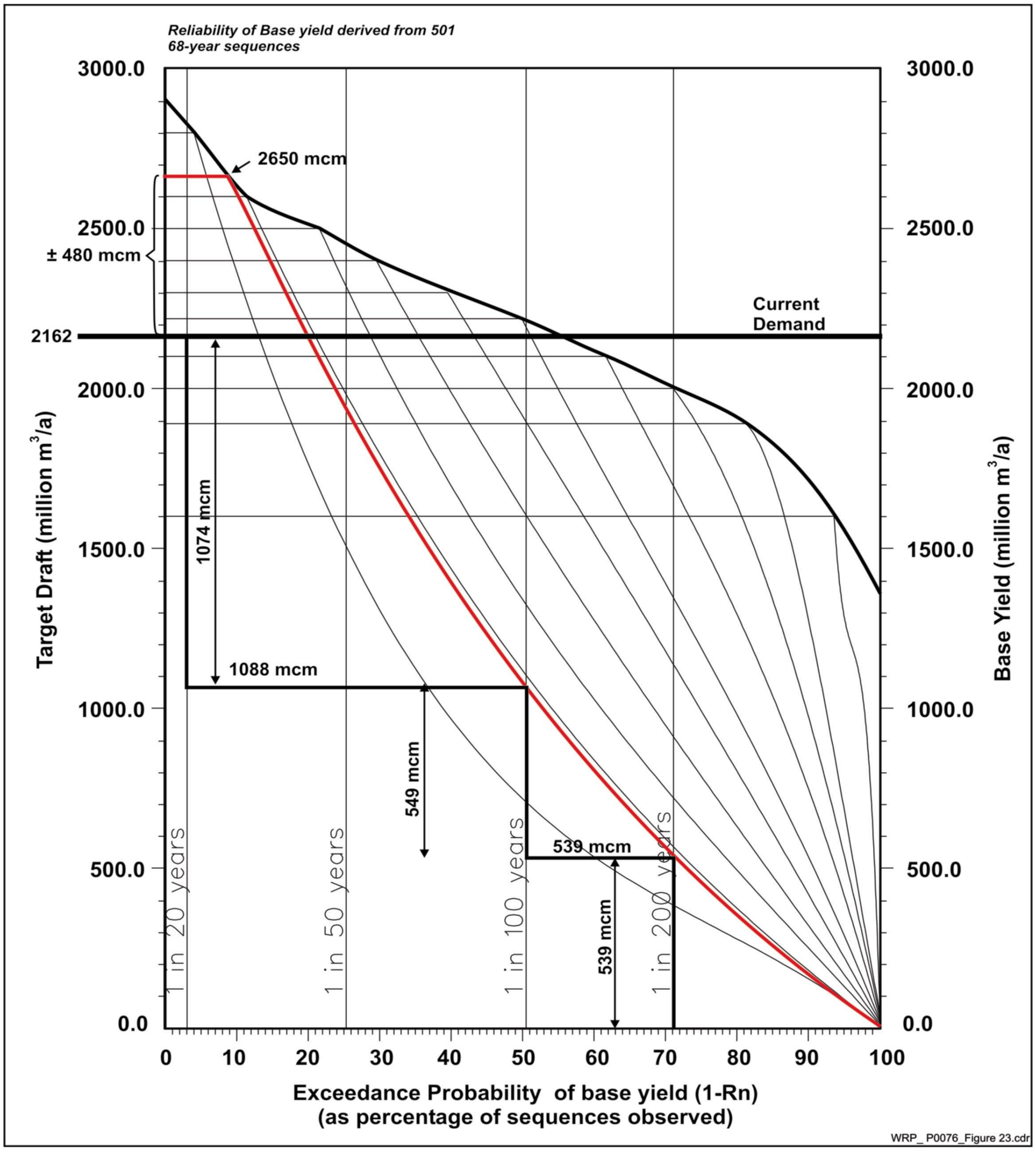

Figure 4.16: Long-Term Stochastic Yield Curve with LORMS Priority Classification and Demands Imposed on the Curve

Table 4.18: User Categories and Priority Classifications used for the Vaal System

User Category	Priority Classification & Assurance of Supply		
	Low **1 in 20 year**	**Medium** **1 in 100 year**	**High** **1 in 200 year**
Urban	22%	24%	54%
Strategic industries	0%	0%	100%
Irrigation	50%	30%	20%
Losses	0%	0%	100%

Table 4.19: User Categories and Priority Classifications used for the Hydropower Operating Analysis in Orange River System

User Category	Priority Classification & Assurance of Supply		
	Low **1 in 20 year**	**Medium** **1 in 100 year**	**High** **1 in 200 year**
Urban	20%	30%	50%
Irrigation	50%	40%	10%
Losses	0%	0%	100%

These two sets of priority classifications were applied to the LORMS demands as defined for Reference Scenario 3. The demands allocated to each of the priority classifications according to the two sets, were then plotted on the long-term stochastic yield curve to determine the surplus available. Results from this sensitivity analyses are summarised in **Table 4.20**.

Results from the sensitivity analysis clearly show the importance of the priority classification selected for a system, as the surplus available vary by as much as 142 million m³/a just between the three different selected priority classifications.

When the stochastic yield results are compared with the most probable demand growth as given in **Figure 4.13** from **Section 4.5.6** a total different perspective is obtained with regards to the required timing for intervention measures to prevent water supply shortages in the system. The results from this comparison are summarised in **Table 4.21**.

Table 4.20: Surplus Available at 2005-Development Level for Different Priority Classifications

Description	Priority Classification & Assurance of Supply (million m³/a)			Surplus at 1 in 20 year (million m³/a)
	Low 1 in 20 year	Medium 1 in 100 year	High 1 in 200 year	
Vaal classification	898	545	718	338
ORS Hydro-power system classification	539	726	897	375
LORMS Proposed classification	1 074	549	539	480

Table 4.21: Surplus/Deficit at Different Development Levels

Development Level	Historic Firm Yield	Stochastic Yield (million m³/a)		
		LORMS Classification	Vaal Classification	ORS Hydropower Classification
2005	-47	480	338	375
2015	-308	90	20	25
2025	-418	-20	-90	-85

From the results in **Table 4.21** it is clear that there are substantial differences in the surplus yield available and therefore also in the resulting time required for intervention. The historic analyses showed that intervention would be required at 2003, while the stochastic analyses indicated the earliest date for intervention to be by 2015.

There are mainly two reasons for these differences:

- The first is the fact that the historic firm yield is representative of a 1 in 100 year recurrence interval. This means that for the historic yield analyses all the demands are supplied at a 1 in 100 year assurance. For the stochastic analyses approximately 50% of the demands are allocated to a 1 in 20 year assurance and the remaining to the 1 in 100 and 1 in 200 year assurances.
- Secondly, the demand growth curve for the Orange River System is relatively flat, so that a small difference in the calculated yield will make a significant difference in the timing required for intervention measures.

It should also be noted that the current surplus in the system is of equal magnitude than the margin of error generally accepted for hydrology purposes. The Orange River System, however, has an extremely high system yield of approximately 3 200 million m^3/a. Although 10% is an acceptable margin of error, it represents 320 million m^3/a, which is a large volume that can still be utilised for various purposes.

The initial task description, as given in the Inception Report, required that historic firm yield analyses be carried out and that these results be used to determine the timing of measures required to improve the management and water supply in the study area. It also stated that stochastic analyses must be carried out for the most promising option. This proposed procedure, to determine the timing of intervention measures, provides results that are in general of sufficient accuracy for most systems, particularly at a pre-feasibility level. From the description given above, it is, however, clear that the Orange River situation is unique, due to the high system yield and specific combination of water users. A different and more accurate approach is clearly required to obtain improved results with regards to the required timing of intervention measures. It was therefore suggested that:

- Some sensitivity analyses be carried out with regards to the long-term stochastic yield. This will also help to set the scene for the short-term stochastic analyses and related assumptions.
- The WRPM should be used to obtain the required timing when intervention will be required.

The WRPM uses the short-term stochastic yield characteristics and the associated operating rule by which curtailments are imposed on the system as required. The results obtained from the historic firm yield analysis tend to edge on the conservative side as it is indirectly assumed that all the demands are supplied at a 1 in 100 year assurance level, which is very high for irrigation purposes.

The long-term stochastic yield analysis did take into account the different assurances at which users should be supplied, depending on their specific requirements. When the long-term stochastic yield is determined, high target drafts are imposed on the system and the reservoirs are then allowed to be drawn down to their m.o.l. Complete failure can therefore occur when trying to meet the target draft. In the day-to-day operation of the Orange River System, the WRPM is currently used on an annual basis to indicate when curtailments will be required. By doing this, the resource and the users are protected against complete failure in supply. Using the WRPM to determine the required intervention time, will therefore result in a more conservative and realistic result than that obtained by means of the long-term stochastic yield analysis.

4.6.3 Long-term Stochastic Sensitivity Analyses

In **Section 4.6.2**, it was explained that losses are all allocated to the high assurance class as it is not possible to curtail losses, and that losses will remain even during drought periods. This will also apply to the evaporation losses from the Orange River. From **Figure 4.14** and **Figure 4.15**, it is, however evident that the river evaporation losses were not included as part of the system yield as these river requirements remained in place and it was allowed to be partly supplied from spills from the Vaal System. The question, however is, what the effect will be on the calculated surplus from the stochastic analysis, if the river evaporation losses were also set to zero in **Figure 4.15** and considered as part of the yield. The river evaporation losses can then be added on to the total demands allocated to the 1 in 200 year assurance level, when the system demands are compared with the long-term stochastic yield characteristics. The result is expected to differ, as it is not sure at which assurance the river losses were supplied, for the stochastic analyses based on the configuration shown in **Figure 4.15**.

It was therefore decided to carry out a stochastic analyses where the river evaporation was included as part of the system yield and to determine the effect of this on the available surplus yield in the system. This scenario is referred to as Scenario 3-1. Results from this analysis are included in **Table 4.22** and shown in **Figure 4.17**. From **Table 4.22**, it can be seen that the total demand allocated to the high assurance class has increased by the 615 million m^3/a due to the river evaporation losses. The surplus yield for this scenario has reduced by 180 to 300 million m^3/a, which indicates that the river evaporation losses were supplied at a lower assurance than the 1 in 200 year assurance as used for Scenario 3-1.

Current investigations with regards to the operating losses experienced in the Lower Vaal River indicated that the operating losses have increased and a significant part of the operating losses could be as result of illegal abstractions along the Lower Vaal River. Final results from this investigation are, however, not yet available. It was then decided to rather use the Vaal inflow record that excludes the effect of the Vaal operating losses, as a large portion the operating losses will most probably not be available for use in the Orange River. Another aspect that should be taken into account, specifically for the generation of the short-term stochastic analyses, is the fact that for the lower starting storages, spills from Bloemhof Dam that enters the Lower Vaal and eventually flow unto the Orange, will most probably be non existent. To test the effect of the Vaal spills on the long-term stochastic yield, it was decided to define another scenario, in which the Vaal operating losses are excluded from the Vaal inflow record as well as the spills from Bloemhof Dam. This scenario is referred to as Scenario 3-2 and can be regarded as a worst-case scenario with very little inflow from the Vaal System into the Orange River (**Table 4.22**). The effect of the adjusted Vaal inflow record is clearly quite significant on the surplus yield obtained from the stochastic analysis as the surplus of 300 million m³/a was reduced to zero million m³/a.

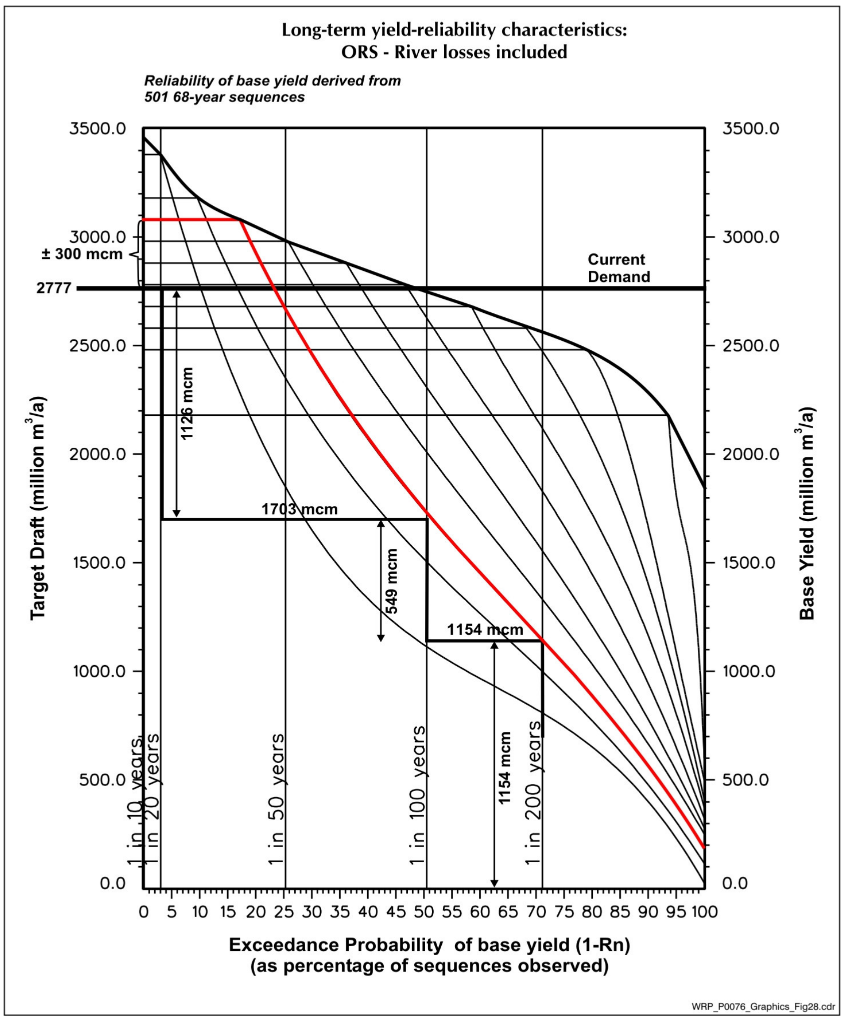

Figure 4.17: Scenario 3-1: Long-term Stochastic Yield Curve with LORMS Priority Classification with River Evaporation Losses included. Demands Including River Evaporation are imposed on the Curve

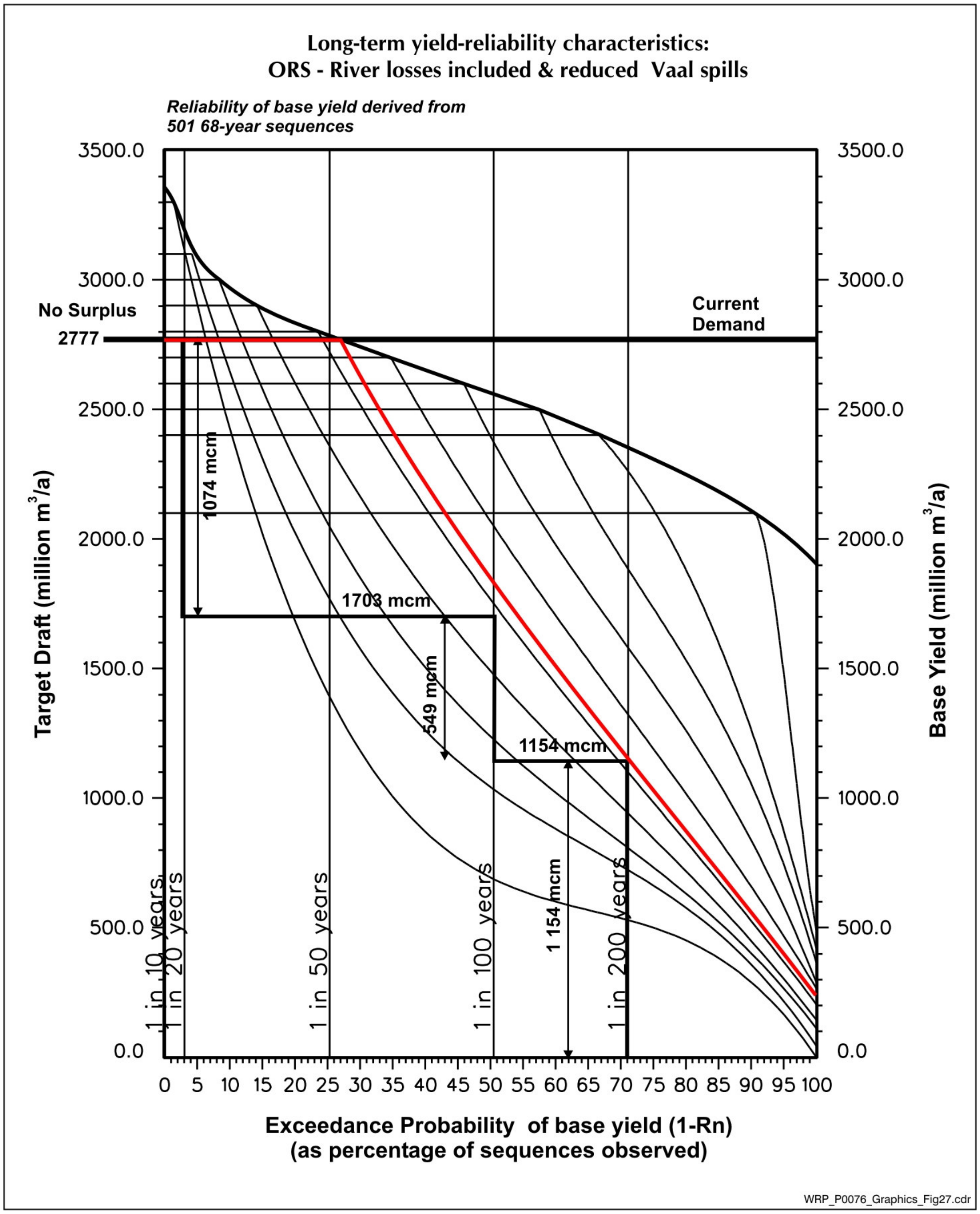

Figure 4.18: Scenario 3-2: Long-term Stochastic Yield Curve with LORMS Priority Classification with River Evaporation Losses Included and Spill from Bloemhof Dam Excluded. Demands Including River Evaporation are imposed on the Curve

From the results obtained for Scenario 3-2, it was clear that the Vaal inflow record as obtained from a WRPM analysis using the historic flow sequences, will not be sufficient for the Orange River Stochastic Analyses. Stochastic analyses will also have to be performed with the WRPM for the Vaal System to obtain a set of 501 stochastic flow sequences representative of the Vaal inflows to the Orange System. Scenario 3-3 was therefore defined and analysed. This scenario used a set of 501 flow sequences representative of the Vaal inflows as input to the Orange River system. For this purpose, the Lower Vaal operating losses was excluded from the WRPM analysis. Results from Scenario 3-3 are shown in **Figure 4.19** and in **Table 4.22**. Scenario 3-3 resulted in a surplus yield of 243 million m^3/a at a 1 in 20 year assurance level (see **Table 4.22**), which is significantly less than the 480 million m^3/a, as obtained for Reference Scenario 3.

Table 4.22: Surplus Available at 2005-development Level for Different Scenarios

Description	Priority Classification & Assurance of Supply (million m^3/a)			Surplus at 1 in 20 Year (million m^3/a)
	Low 1 in 20 Year	Medium 1 in 100 Year	High 1 in 200 Year	
Reference Scenario 3	1 074	549	539	480
Scenario 3-1 (Orange River losses included in yield)	1 074	549	1154	300
Scenario 3-2 (Orange River losses included in yield & reduced Vaal spills)	1 074	549	1154	-77
Scenario 3-3 (Orange River losses included in yield & Vaal spills from Stochastic Analysis)	1 074	549	1154	243

Based on the results of the sensitivity analyses and the fact that much more detailed stochastic analyses are involved in the Scenario 3-3 result, this surplus result is regarded as the most accurate indication of the surplus from a long-term stochastic analysis. The short-term stochastic analyses will therefore be based on Scenario 3- 3. The yield characteristics to be included into the WRPM for the Orange River System will be obtained from these short-term stochastic analyses.

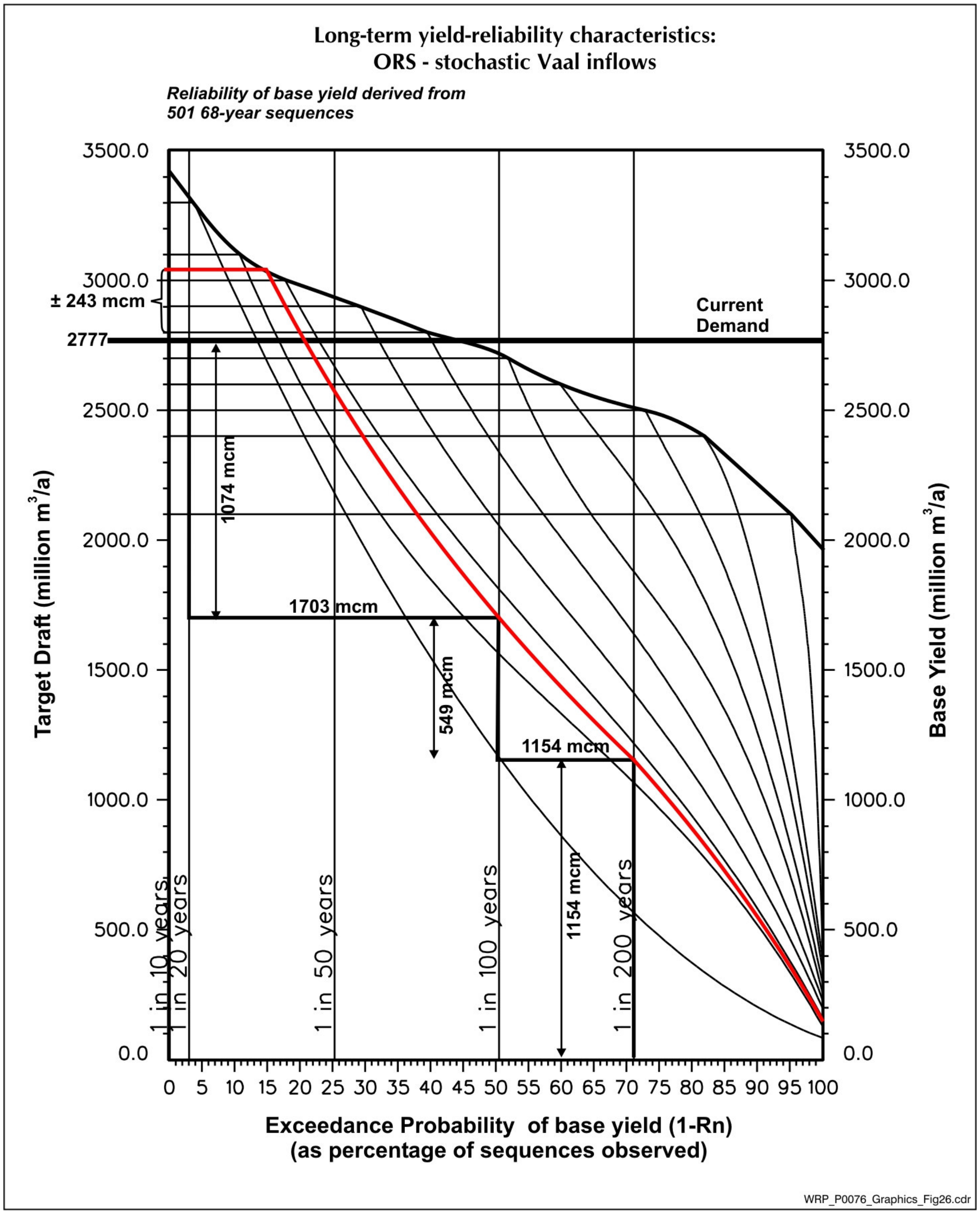

Figure 4.19: Scenario 3-3: Long-term Stochastic Yield Curve with LORMS Priority Classification with River Evaporation Losses Included and Stochastic Vaal Spills Records Used. Demands Including River Evaporation are Imposed on the Curve

4.7 Short-term Stochastic Yield Analyses

Scenario 3-3 as defined in **Section 4.6.3** was used as the basis to determine the short-term stochastic yield characteristics for the Orange River System. 501 Stochastically generated flow sequences, each 5 years in length, were used in the short-term yield analysis. A period of 5 years was used as it generally represents the typical length of the critical period during drought events for most of the sub-systems. The analysis was repeated for a number of different starting volumes as the short-term yield from a system or reservoir is largely dependant on the storage in the reservoirs at the beginning of the analysis period.

The start volumes used were 100%, 80%, 60%, 40%, 20% and 10% of the net full supply capacity of the dam. The corresponding starting storage elevation was determined from the storage-elevation curve and this value was entered in the F06 - WRYM data file. For each starting storage volume analysed, all the reservoirs in the system, including the dummy dams, were set to start each stochastic sequence with the selected percentage of storage volume. To be able to obtain representative inflow records from the Vaal to the Orange, stochastic analyses for the Integrated Vaal River System were also carried out with the WRPM for each of the selected starting storage levels. Due to the operating rule used for the Integrated Vaal River System (see **Section 3.2**), in which the downstream dams such as Bloemhof and Vaal are utilised first and only when they reach specific low storage levels, will water be released from Sterkfontein Dam to support them. This means that when the total Vaal Sytem is at 40% storage, the Vaal and Bloemhof Dams will be at much lower levels than 40% and the Grootdraai and Sterkfontein Dams at higher levels than 40%. Typical levels for each dam were obtained from a historic yield analysis, and years were selected when the total system is at one of the selected starting storage levels. The appropriate levels for each of the selected starting storages were then obtained from an appropriate year and then used in the short-term stochastic analyses for the Integrated Vaal River System.

For each starting storage volume, the yield results were produced for all the period lengths up to and including five years. The firm yield curves for each period length were analysed and compared and the most conservative result was selected. This is most evident at low starting storage conditions where the yield curves for period lengths less than five years produce the most conservative results.

The short-term coefficient data files, which were produced from the short-term stochastic yield curves, were used as input to the WRPM.

Results from the short-term stochastic analyses are summarised in **Table 4.23**. The full details of the short-term yield characteristic curves are presented in **Figures C-1** to **C-7** of **Appendix C**.

Table 4.23: Results of the Short-term Stochastic Analysis for the Orange River System

System Start Volume as % of Live Storage	Firm Yield for the Indicated Recurrence Interval (million m³/annum)			
	1:20 Year	1:50 Year	1:100 Year	1:200 Year
100%	3 860	3 410	3 100	2 895
80%	3 600	3 165	2 900	2 650
60%	3 300	2 790	2 610	2 400
40%	2 875	2 490	1 990	1 700
20%	2 300	1 895	1 625	1 380
10%	1 750	1 430	1 180	1 000

5. HYDRAULIC RIVER MODELLING

5.1 Introduction

5.1.1 Background

Considerable time and effort has been spent over the past 6 years developing a hydraulic model for certain reaches of the Orange River through two WRC-managed studies. The first study (WRC; 1999), has been used to analyse the river losses from the Orange River in an attempt to derive better estimates of the necessary releases from Vanderkloof Dam. The second study (WRC; 2003) focussed on the development of a real time operational model.

The developed hydraulic model can be used to analyse the attenuation of releases from Vanderkloof Dam as the water travels approximately 1 400 km to the river mouth. While the model is relatively coarse and to a large degree based on cross-sections derived from aerial photographs, it has been shown to provide realistic and reliable estimates of the releases as they move downstream. Such a model can assist in various ways, including the analysis of riverine losses, different release patterns from Vanderkloof Dam, as well as the attenuation of specific flood events.

5.1.2 Specific Objectives

The following specific objectives were set for this particular task:

- Optimise the release pattern from Vanderkloof Dam (**Objective 1**);
- Determine the size of the proposed re-regulating dams (**Objective 2**);
- Evaluate the theoretical demands patterns from Vanderkloof Dam to the river mouth (**Objective 3**); and
- Evaluate the possibility of utilising the inflows from the Vaal River (**Objective 4**).

5.1.3 Structure of Section 5

This section has been structured with an introduction that outlines the context, as well the objectives of the hydraulic river modelling task. This is followed by **Section 5.2**, which provides some detail regarding the hydraulic model and demands/releases. **Section 5.3** includes the optimisation of the release patterns from Vanderkloof Dam. **Section 5.4** discusses the sizing of the proposed re-regulating dams. This is followed in **Section 5.5** by the evaluation of the theoretical demand patterns. The next section (**Section 5.6**) provides insight into the evaluation of the possible utilisation of Vaal River inflows, followed by **Sections 5.7** and **5.8,** which complete this task with conclusions and recommendations, respectively.

5.2 Hydraulic Model

5.2.1 General

The flow component of ISIS River and Catchment Modelling software has been used to perform the full hydrodynamic numerical hydraulic modelling.

5.2.2 Model Setup

The model setup that was configured during the latest WRC-managed study (Fair: 2003) was used for this task. The following paragraphs provide some information regarding the setup.

The River Reach Modelled:
The stretch of river modelled starts from Vanderkloof Dam and ends at Brandkaros. The river has been divided into eleven (11) reaches to take into account abstractions and river losses. For a graphical presentation of the extent of the model, the different reaches and the gauging stations with available daily flow records, see **Figure 5.1**.

Cross Sectional Data:
Most of the information used for the cross sections was obtained from contour maps and aerial photographs. Only a few sections were physically surveyed. Due to the data sources, the shape of the river below the normal operating water surface had to be interpolated using visible properties from the aerial photographs. The channel properties were then calibrated by comparing the width of the water surface of the simulated flows to those shown in the aerial photographs which were taken during similar flow conditions.

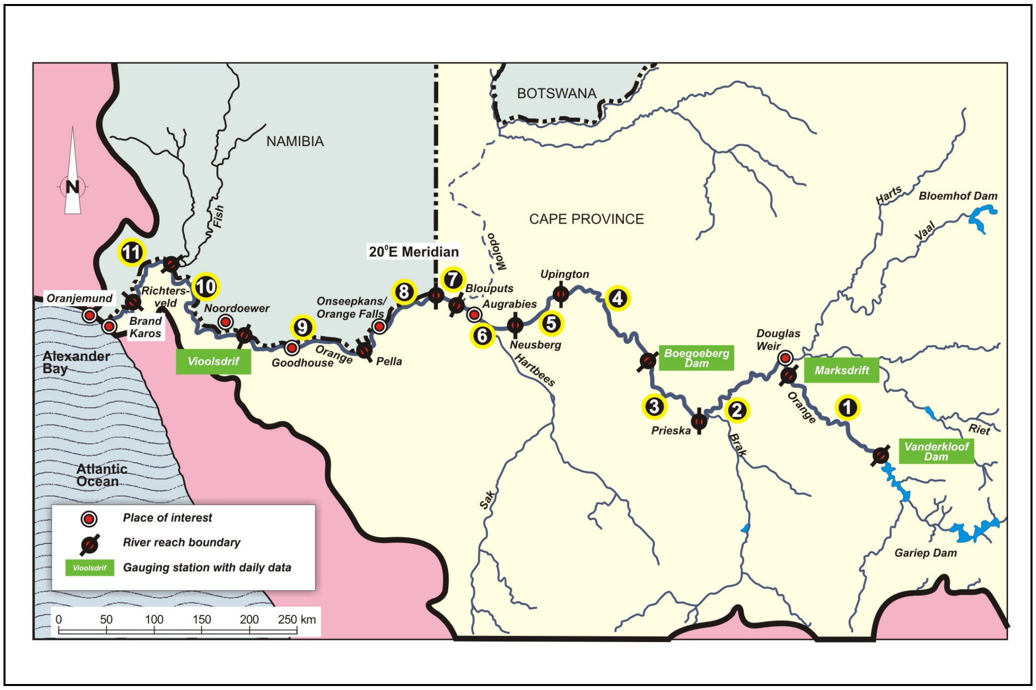

Figure 5.1: River Reach Modelled

Channel Roughness:

In the WRC Study, the model setup was calibrated by estimating the channel roughness from photographs and site visits, and then calibrating it against measured flows.

5.2.3 Demands and Other Releases

The releases from Vanderkloof Dam used in the modelling are made up of the following:

- EFRs (289 million m^3/a);
- River requirements (615 million m^3/a);
- Demands (1 004 million m^3/a);
- Operating releases (270 million m^3/a); and
- Additional hydropower releases from the surplus available in the system (60 million m^3/a).

The environmental requirements referred to above, are only those requirements at the mouth of the river, as the other environmental requirements were not known at the time. Presently the remaining environmental requirements are not taken into account when determining the releases from Vanderkloof Dam as they are deemed to be satisfied by the other release components.

The river requirements have previously been called river losses. The results from the Orange River Losses Study (WRC: 1999), as adjusted by Fair (WRC: 2003), have been used in this regard. The river requirements were modelled as discrete demands abstracted from the lower ends of the river reaches.

The demands are made up of irrigation demands (by far the biggest demand) and other demands that include domestic, industrial and mining demands (see **Figure 5.2**) for the location of the major irrigation schemes and other major consumers in relation to the river sections).

These theoretical demands patterns were updated as part of this study. These updated demands patterns were used for all the sub-tasks (to be referred to as the *2003-demands* in the rest of the document). In the sub-task that evaluated the theoretical demand patterns, the demand patterns determined during the ORRS (McKenzie & Maré: 1997) (to be referred to as the *ORRS-demands* in the rest of the document) and used in the annual operating analysis were also used.

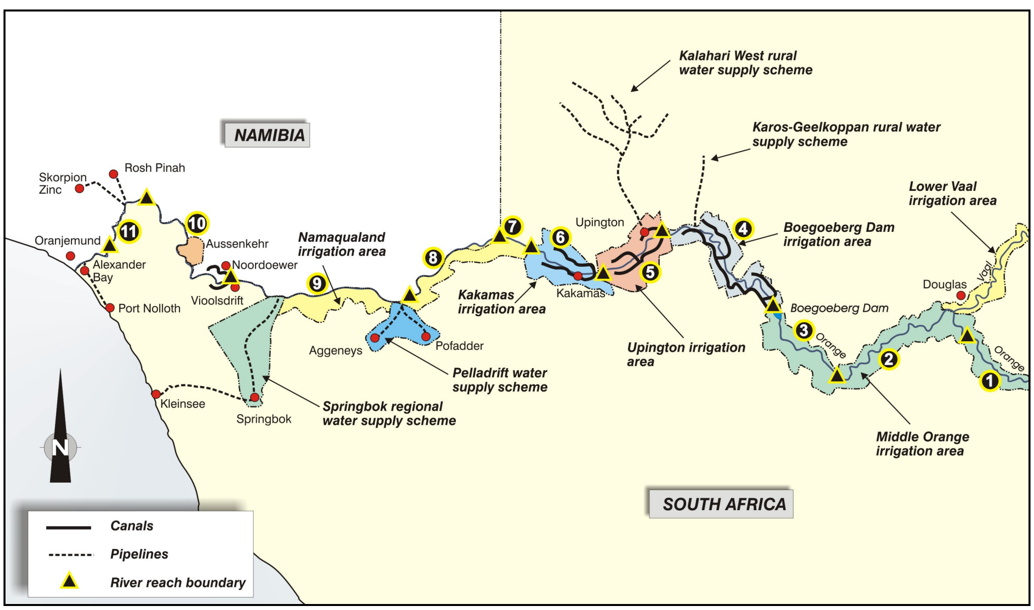

Figure 5.2: Location of Major Demands

The operating releases can be described as a safety factor to ensure that all demands could still be supplied notwithstanding fluctuating climatic and water use patterns. In practice 210 million m^3/a of the 270 million m^3/a operating losses are released according to a fixed predetermined pattern, while the remaining component is released based on ad hoc decisions by the Regional Ofice of the RSA DWAF.

For the purpose of the comparison of the LORMS and ORRS demand patterns, the additional hydropower releases were not included. These releases mainly occur during the winter months when the power demand is high and the timing for these releases is determined by Eskom. All the releases from Gariep and Vanderkloof Dams into the river, to meet downstream requirements, are also used to generate hydropower.

The demands and river requirements represent the consumptive water use. When analysing the 2003 demand patterns, it is interesting to note that the demands from Vanderkloof to Boegoeberg indicate two peak consumption periods (October and another in January), whereas the rest of the reaches only have one peak period (January). The lowest consumption is determined to take place during May in all the reaches. For a graphical presentation see **Figure 5.3**.

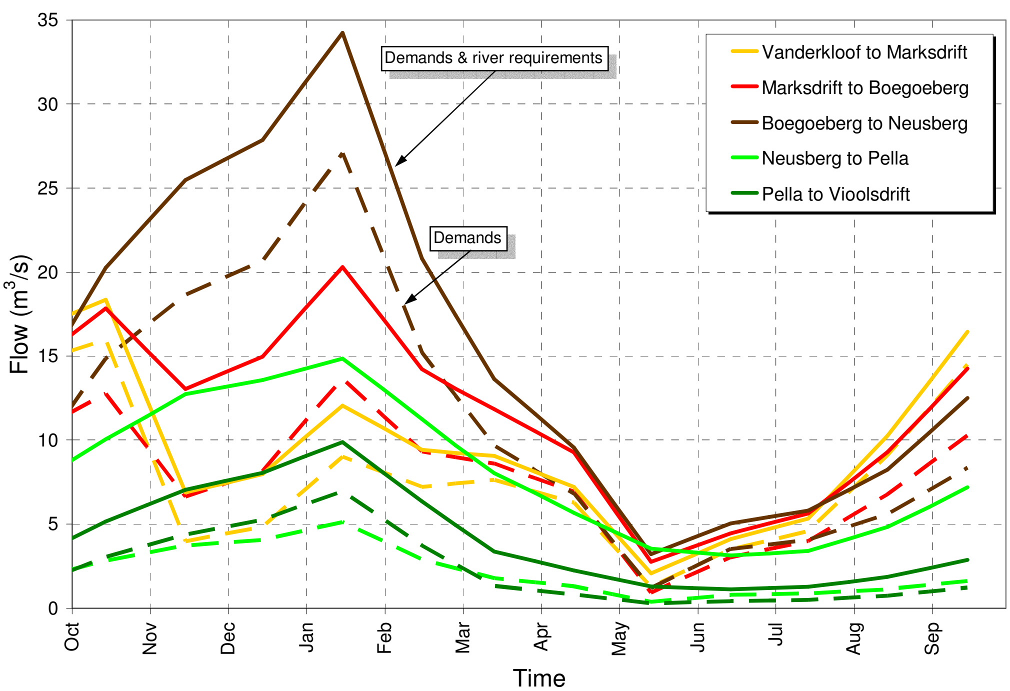

Figure 5.3: 2003 (LORMS) Demands and River Requirements

When analysing the ORRS demand patterns, it is evident that the peak consumption is from November through to January. However, there is an exception of the reach from Vanderkloof to Boegoeberg where there is reduction in use during December. With regard to the lowest consumption, June is indicated as such. For a graphical presentation see **Figure 5.4**.

Figure 5.5 graphically highlights the major differences between the 2003 and ORRS demand patterns. It is obvious that the peak demands determined by ORRS are higher for the following reaches: from Vanderkloof to Boegoeberg and Neusberg to Pella. However, it is lower for Pella to Vioolsdrift, and both higher (October to December) and lower (January) for Boegoeberg to Neusberg. With regards to the low consumption periods, it is only the Vanderkloof to Marksdrift reach, which indicate a significant difference (2003 higher).

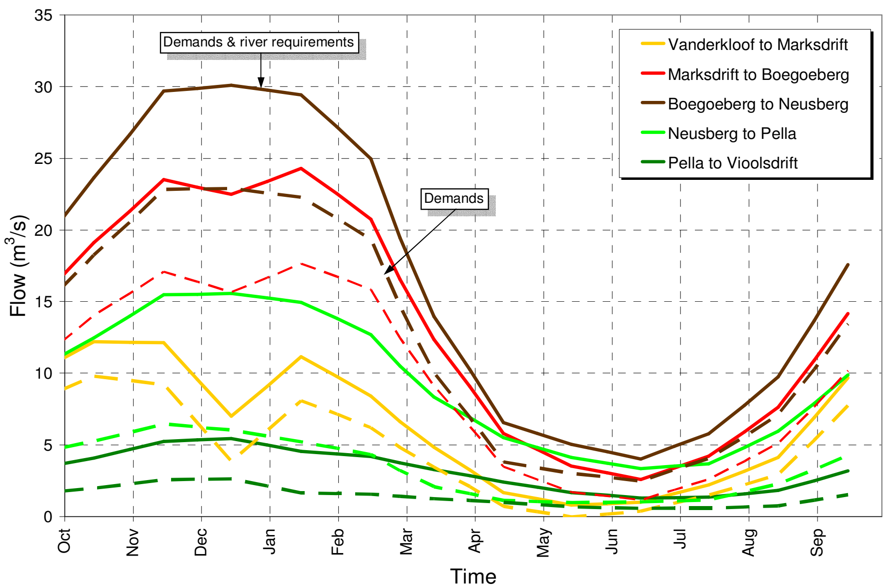

Figure 5.4: ORRS Demands and River Requirements

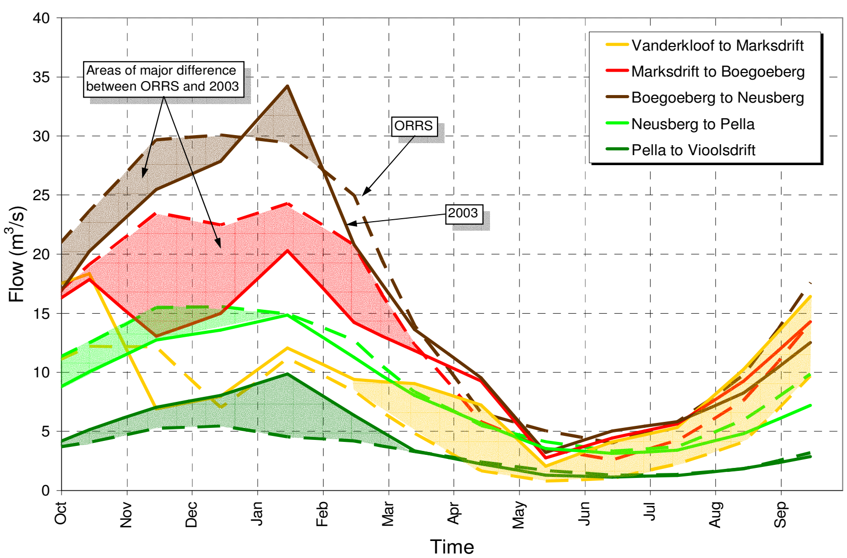

Figure 5.5: Comparison of 2003 (LORMS) and ORRS Demands and River Requirements

5.3 Optimisation of Release Pattern from Vanderkloof Dam

The release pattern from Vanderkloof Dam, currently in use, was determined using a 60/40 principle, whereby all the reach requirements for a particular month are summed and then shifted using the 60/40 principle to take into account the time lag for releases to reach their destinations.

Running the hydraulic model with these release patterns indicated some problems, especially during the October to November and January to March periods. To overcome this problem, a methodology was developed whereby hydraulic modelling was used through an iterative process, in order to optimise the release patterns from Vanderkloof Dam.

The following assumptions were made:

- The 2003 (LORMS) demand and river requirement patterns were used; and
- The additional hydropower releases by Eskom and the 60 million m^3/a operating releases managed by the Regional Office of DWAF, were not taken into consideration as there is no set pattern for these releases.

The methodology involved the following (for the results of the methodology, see **Figure 5.6**):

- The first hydraulic modelling run was conducted with a constant release of 110 m^3/s from Vanderkloof Dam.
- Using the results, the difference between:
  - the modelled flow at Brandkaros; and
  - the sum of the EFR downstream of Brandkaros and the total operating releases was determined.
- The constant release was then changed by the adjusted difference (20 days to take into account time lag).
- This adjusted release pattern was then used in the next hydraulic modelling run (first iteration).
- The iteration process of adjusting the release pattern at Vanderkloof Dam was repeated once more. This was done by using the difference between the modelled results and the sum of the EFR and the operating releases.

- This adjusted release pattern was used again in the next hydraulic modelling run (second iteration).
- The final iteration involved the graphical evaluation of the results of the second iteration and fine tuning the release patterns using human judgement.

From **Figure 5.6**, it is clear that the methodology used resulted in a substantially different release patterns during the problem periods (October to November and January to March). When using this new release pattern, the hydraulic modelling runs resulted in meeting the downstream requirements at Brandkaros. It is therefore recommended that this methodology be used in future to determine the release patterns from Vanderkloof Dam.

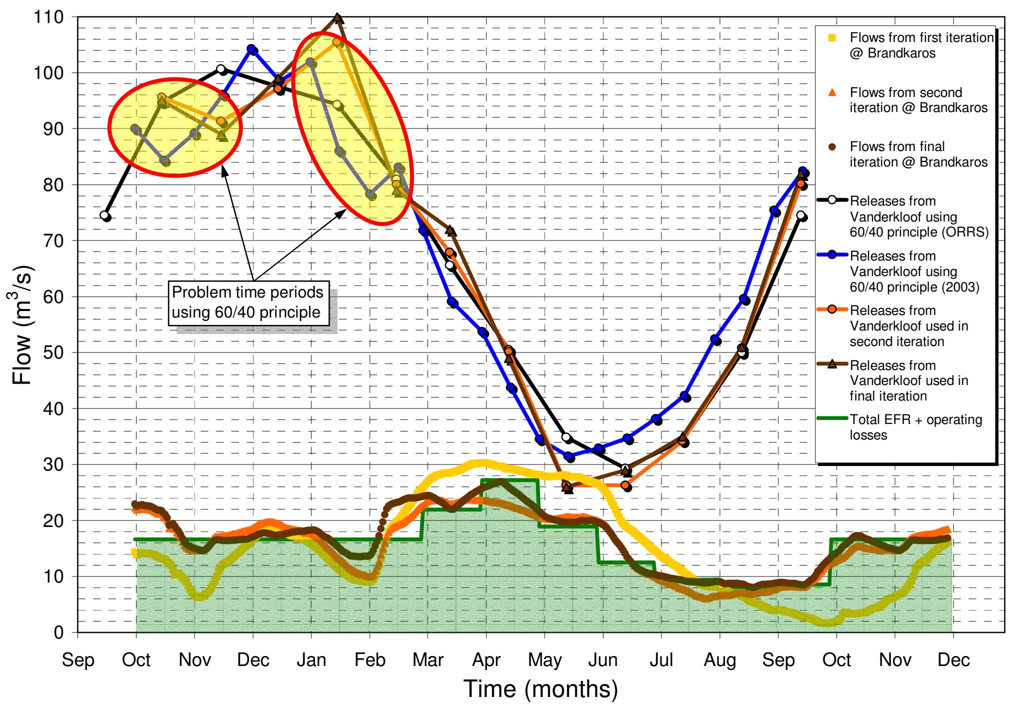

Figure 5.6: Results of Optimisation of Release Patterns at Vanderkloof Dam

5.4 Sizing of Proposed Re-regulating Dams

The purpose of the proposed re-regulating dams would be to re-use the normal operating releases from Vanderkloof Dam.

Basically, the same principles that were used by McKenzie and Maré (1997) in the ORRS have been used to determine the optimal sizes of the proposed re-regulating dams. The major difference is that the results of hydraulic modelling (utilising the optimised release patterns from Vanderkloof Dam), were used instead of the results from yield and system analysis, as was the case in the ORRS.

It is also important to note that no cognisance was taken with regard to the operating releases decided upon by DWAF's Regional Office and the additional hydropower releases made by Eskom.

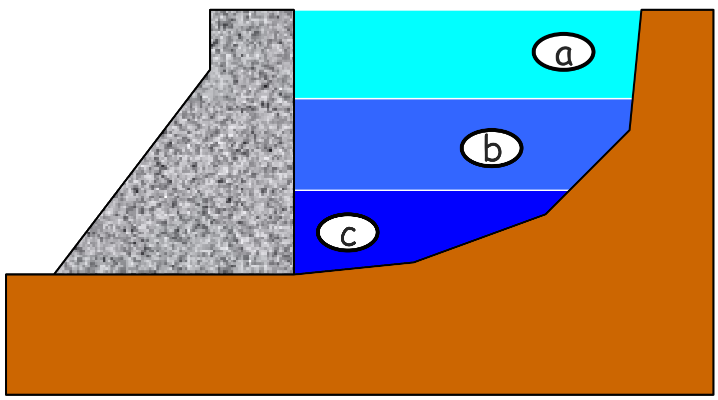

Figure 5.7: Section through Re-regulating Dam Showing Different Theoretical Storages

The typical storage to ensure the optimal use of the operating releases consists of the following (as shown in **Figure 5.7**):

- The upper zone is included as a safety zone and provides some capacity for capturing local inflows, human errors, etc. It is calculated by adjusting the middle zone's volume by using the time lag involved to get water from Vanderkloof Dam to the proposed re-regulating dam (**Zone A**);
- The middle zone is equivalent to the maximum monthly saving in operating losses using the results from the hydraulic modelling, as well as taking into account the downstream requirements for the operating loss (which was calculated using a direct relationship between the downstream requirement and the distance from the river mouth) (**Zone B**); and
- The lower zone is for storage of the downstream requirements for the next month, taking into account the time lag involved to get water from Vanderkloof Dam to the proposed re-regulating dam (**Zone C**).

The total required storage was determined by summing the maximum monthly storage size as determined for each zone, irrespective of whether or not it is in the same period. The maximum saving was calculated by subtracting the evaporation from the monthly saving, as determined in the ORRS (DWAF; 1997).

Three possible sites were considered, namely Boegoeberg, Komsberg and Vioolsdrift. The required sizes and possible savings were determined by using the two different monthly flow distributions patterns, one as obtained from the ORRS and the latest one as obtained as part of the LORMS. The results of the sizing exercise are given in **Table 5.1**. Due to all the assumptions made, inaccuracies with regards to low flows in the river, as well as actual water use and return flows the results provided represents the best estimate than can be made with data currently available. After the evaluation of the results, recommended values to be used in the system analyses were included in **Table 5.1**, based on the results from the analyses, typical trends that were observed and to rather err on the conservative side. Detail information with regards to the sizing for each site is provided in **Appendix B**.

Table 5.1: Sizes of Proposed Re-regulating Dams

	Boegoeberg	Komsberg	Vioolsdrift
Storage required (million m³)			
LORMS distribution	86	74	102
ORRS distribution	91	-	110
Recommended	**90**	**100**	**110**
Net saving (million m³/a)			
LORMS distribution	62	126	212
ORRS distribution	50	-	171
Recommended	**60**	**126**	**170**

From the results it is clear that the Vioolsdrift site will provide the biggest saving.

5.5 Evaluation of Theoretical Demand Patterns

5.5.1 Methodology

In order to evaluate the theoretical demand patterns, especially the irrigation demand patterns, it is necessary to model the LOR reach using historical inflows and to compare the results with the downstream observed flows.

To be able to do this, daily flow records were needed. Enquiries at DWAF lead to the conclusion that daily data is only available for four gauging stations in the LOR reach (see **Figure 5.8**). These stations are located at:

- Doorenkuilen (D3H012), just downstream of Vanderkloof Dam;
- Marksdrift (D3H003);
- Zeekoebaart (D7H008), just downstream of Boegoeberg Dam; and
- Vioolsdrift (D8H003).

Daily flow data in the Vaal River is also available at Douglas (C3R003), which is close to its confluence with the Orange River.

An additional daily data source exists at Vanderkloof Dam, where the Regional Office of DWAF uses release times and turbine openings obtained from Eskom. A comparison of the daily flow data at Doorenkuilen and the Eskom values showed an average annual difference of more than 7 m^3/s (more than 220 x 10^6 m^3/a). Due to the uncertainty with regards to the correct data source at Vanderkloof Dam, it was decided to only model the reach downstream of Marksdrift Weir. This included the inflows from the Vaal River by assuming that the measured values at Douglas are correct. (See **Figure 5.8** for the daily observed flows at Marksdrift and Douglas Weirs, respectively).

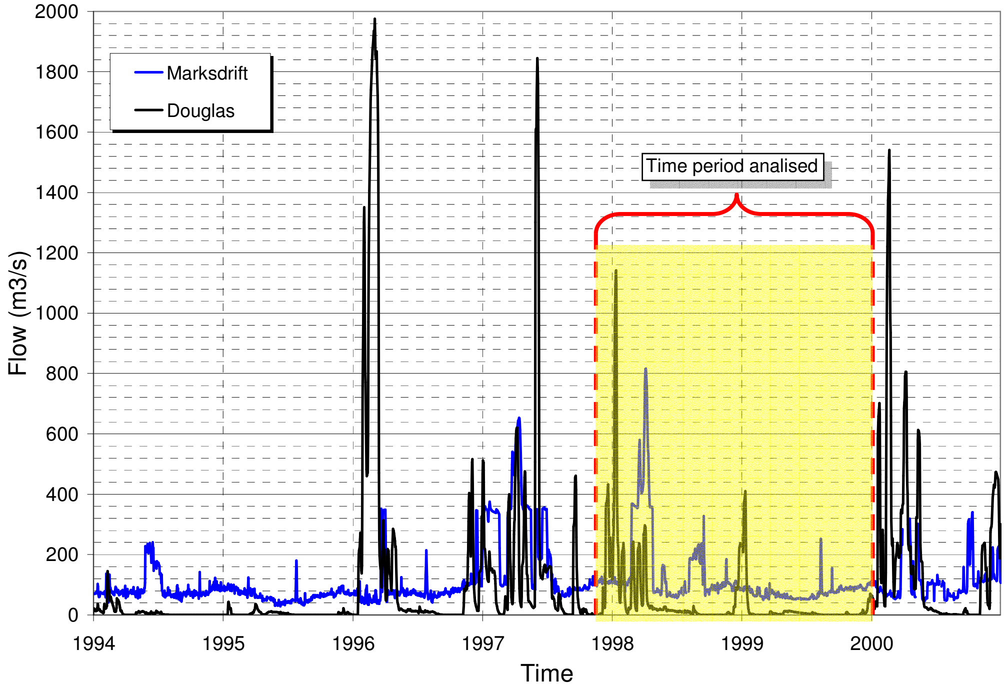

Figure 5.8: Daily Flows at Marksdrift and Douglas Weirs (1994 – 2000)

To decide which historical period should be modelled, the following were considered:

- Daily flow data should exist for all the stations especially for Marksdrift and Douglas;
- Flows during the periods should be (as much as possible) normal releases; and
- The period should not be too far back, in order to enable the use of current theoretical demand patterns.

After careful consideration, it was decided to use the period 1 November 1997 to 31 December 1999 (see **Figure 5.8**) and to split it into two periods:

- 1 November 1997 to 31 December 1998 (**1998 analysis**); and
- 1 November 1998 to 31 December 1999 (**1999 analysis**).

It is important to also note the following:

- No inflows from other downstream tributaries were modelled; and
- Both the 2003 (LORMS) and ORRS demand patterns were used in separate analysis.

5.5.2 Results

A comparison of the modelled flows with the measured flows at Boegoeberg Weir (Zeekoebaart in the case of the measured flows) indicated significant differences at low flows during both periods. Note that the measured flows were lower than the modelled flows (see **Figure 5.9** and **Figure 5.11** for the 1998 and 1999 analysis periods, respectively). The differences between the two demand patterns are also not evident due to the fact that in the period of significant difference (December to February, see

Figure 5.5), high flows occurred in both cases.

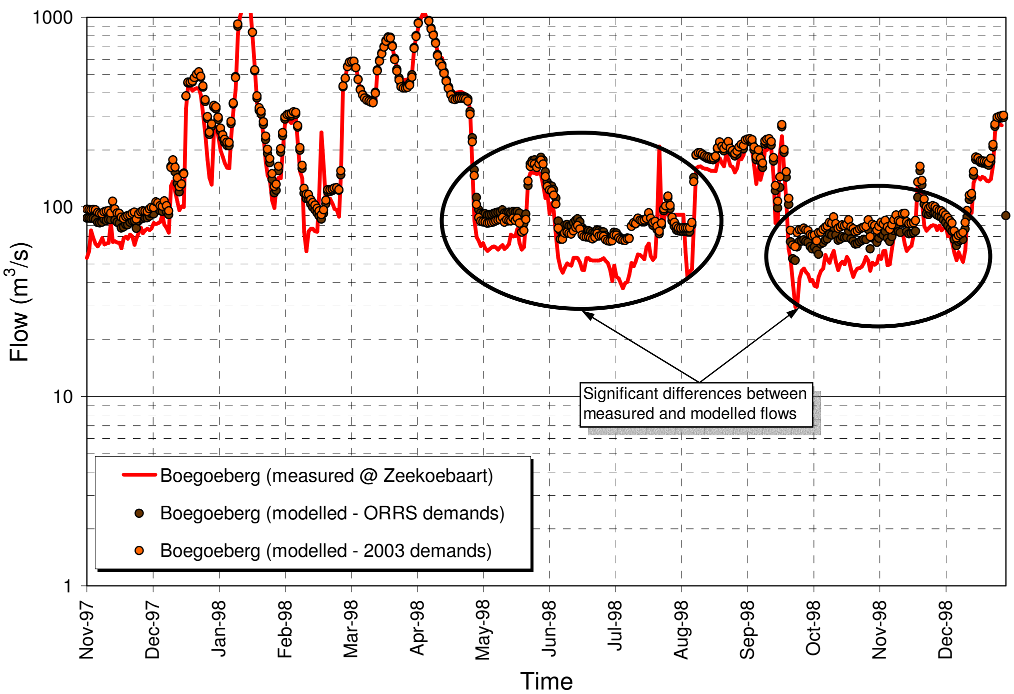

Figure 5.9: Measured Flows versus Modelled Flows at Boegoeberg (1998)

With regard to the Vioolsdrift Weir, the comparison indicated notable differences between the modelled flows and the measured flows using the 2003 (LORMS) demand patterns, as well as a slightly better correlation using the ORRS demand patterns (see **Figure 5.10** and **Figure 5.12** for the 1998 and 1999 analysis periods, respectively). It would therefore seem that the 2003 (LORMS) demands downstream of Boegoeberg are lower than the actual demands in some of the months.

The comparison also indicated possible periods of non-compliance with downstream demands (October to November and February to March). These periods were also highlighted during the first sub-task as possible problem periods using the 60/40 principle to determine the release patterns from Vanderkloof Dam (see **Figure 5.6**).

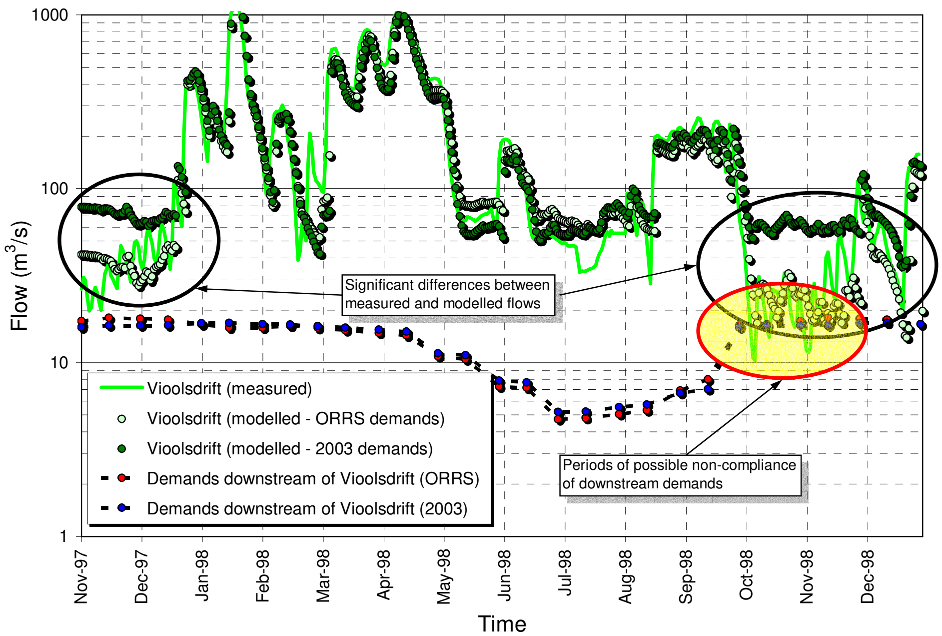

Figure 5.10: Measured Flows versus Modelled Flows at Vioolsdrift (1998)

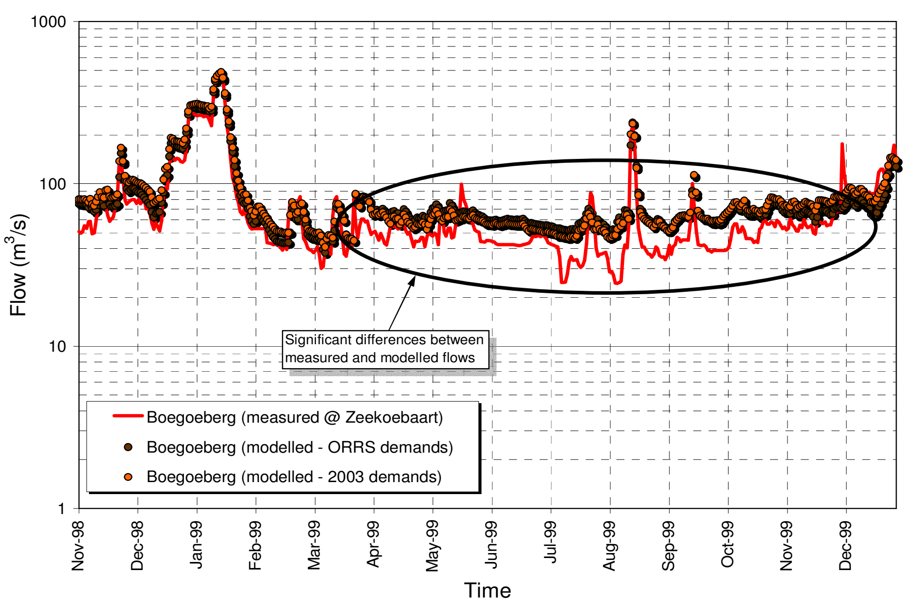

Figure 5.11: Measured Flows versus Modelled Flows at Boegoeberg (1999)

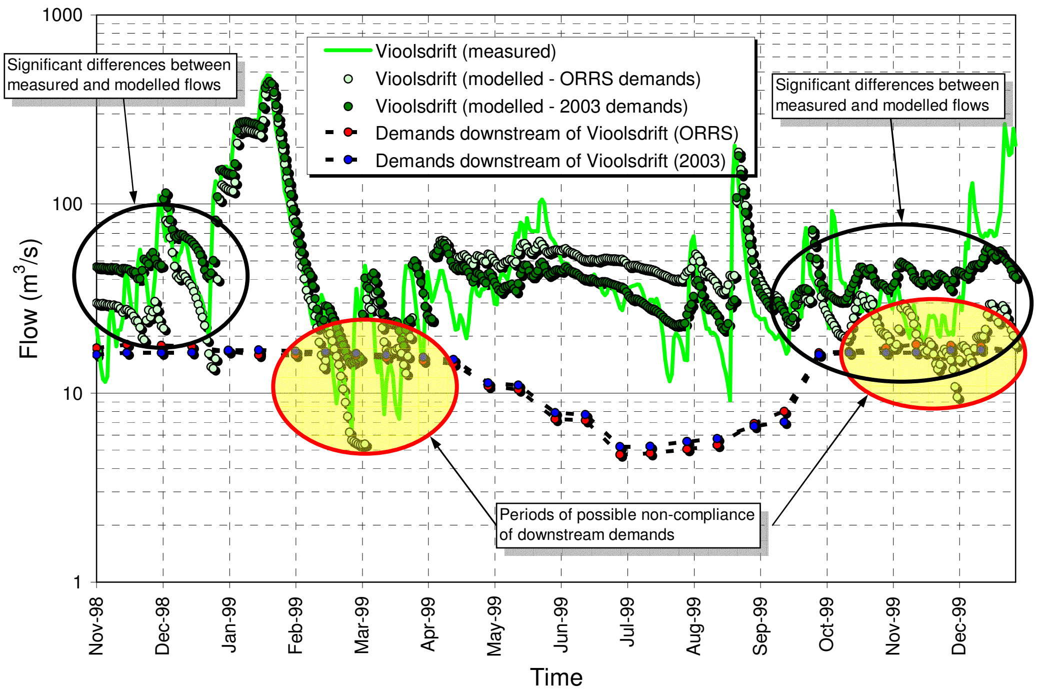

Figure 5.12: Measured Flows versus Modelled Flows at Vioolsdrift (1999)

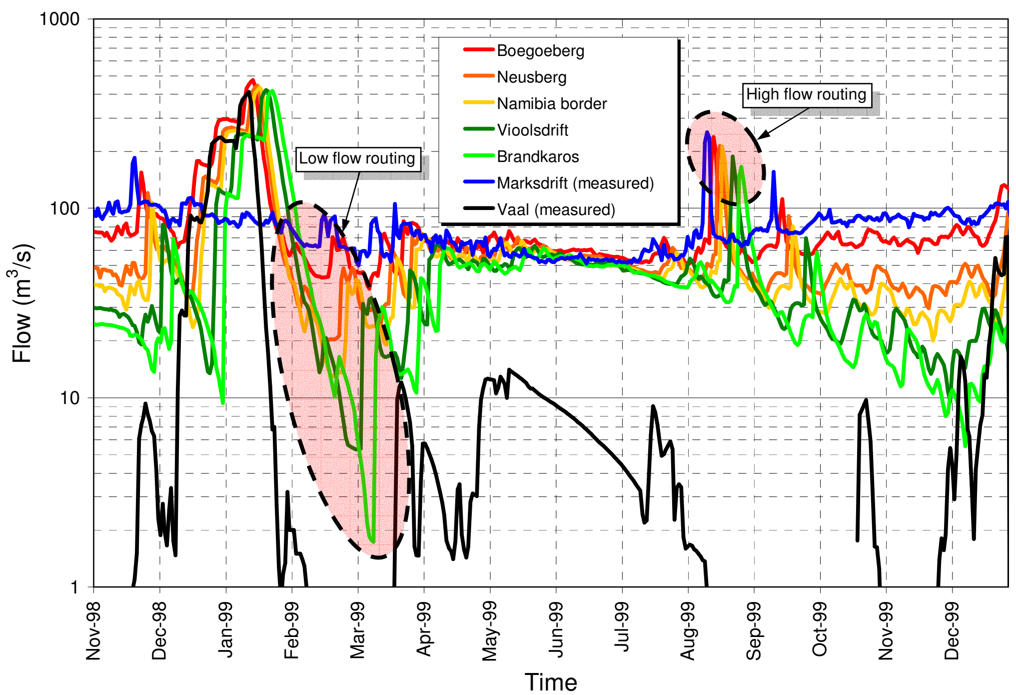

Figure 5.13: Time Lags During High and Low Flows

A point of interest is also the fact that the hydraulic model could be used to provide an indication of the extent of inflows from downstream tributaries (see the differences in modelled and measured flows during May 1999 in **Figure 5.11** and **Figure 5.12**, respectively).

The results of this sub-task were also used to determine the time lag used in the sizing of the proposed re-regulating dams (see **Figure 5.13** for an indication of the different time lags during periods of high and low flows, respectively).

5.6 Evaluation of Possible Utilisation of Vaal River Inflows

The present operation of the LOR System assumes that there are no inflows from the Vaal River and if there are, these inflows are not taken into consideration for downstream use.

The purpose of this sub-task was two-fold:

- The first was to determine the viability of utilising inflows from the Vaal River by analysis of the available daily data (see **Figure 5.14**); and
- The second was if the first proved viable, to derive a monthly relationship for use in the systems modelling.

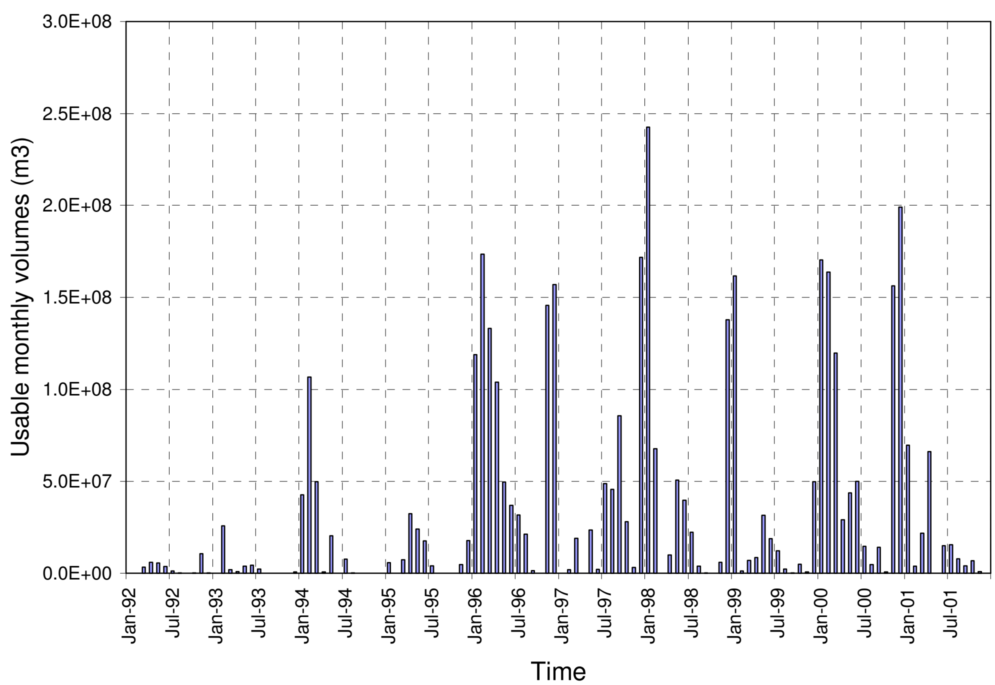

Figure 5.14: Usable Monthly Inflow Volumes from the Vaal River (1992 - 2001)

An analysis of the usable inflows from the Vaal River on a daily basis aggregated to monthly flows showed their significance (see **Figure 5.14**). The main reason why it is not correct to model the effect of the Vaal inflows on a monthly basis in the WRYM, is the fact that when it's analysed on a monthly basis, large flood peaks that occur over a time period shorter than a month, would lead to over optimistic results - as the model assumes that the total volume from the flood peak can be utilised.

After proving the viability of utilising the inflows from the Vaal River, the following assumptions were made in analysing the daily data to derive a monthly relationship:

- Inflows from the Vaal River were not considered usable during periods of spillage of Vanderkloof Dam; and
- The sum of downstream demands, river requirements and EFRs at the river mouth was set as the maximum daily usable flows from the Vaal River. The remainder of the daily inflow was considered as spillage.

Using these assumptions and aggregating the daily flow data to monthly flows, a general relationship was determined (see **Table 5.2** and **Figure 5.15**, respectively).

Table 5.2: Relationship between Total and Usable Monthly Inflows from Vaal River

Total Flows (m^3/month)	Usable Flows (m^3/month)
10 000	10 000
100 000	100 000
1 000 000	1 000 000
10 000 000	10 000 000
50 000 000	50 000 000
100 000 000	75 000 000
300 000 000	120 000 000
1 000 000 000	160 000 000
4 000 000 000	160 000 000

The use of this relationship in the systems model resulted in a saving of 80 x 10^6 m^3/a. It is important to note that a real time monitoring and modelling system would facilitate the utilisation of spills from the Vaal River. The construction of at least a re-regulating dam at Vioolsdrift would also make it possible to utilise inflows from the Fish River.

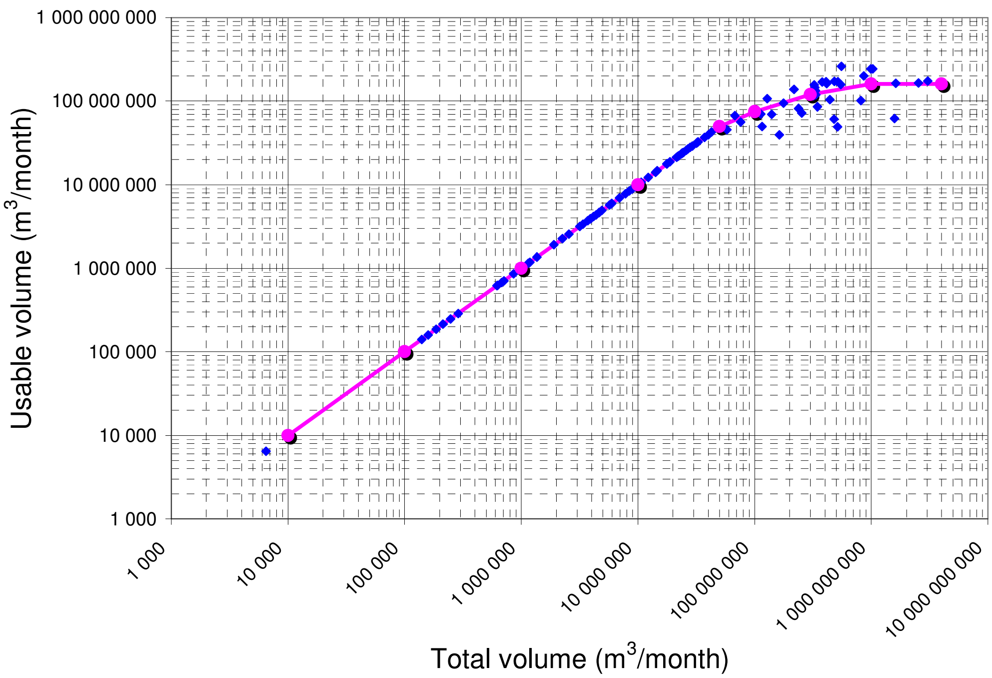

Figure 5.15: Total versus Usable Monthly Inflows from Vaal River

6. REVIEW OF CHANGES IN WATER QUALITY IN THE LOWER ORANGE RIVER

6.1 Introduction

During the Vaal Augmentation Planning Study (DWAF, 1996) the WQT Model was calibrated on Total Dissolved Salts (TDS) data collected prior to 1987. One of the tasks of the LORMS was to determine whether the water quality (TDS) had changed significantly since 1987 and to decide if the WQT Model should be re-calibrated with post 1987 data.

A statistical exercise was undertaken to establish whether the water quality data collected after the calibration periods used in the calibration of the WQT Model in the ORRS differed significantly from that used to calibrate the WQT Model.

Water quality (TDS) output from the WQT Model is presented as flow-weighted monthly averages and strictly speaking it should be the flow-weighted TDS values of the post calibration periods that should be compared to those of the calibration period. For the LOR, however, it is recognized that the flow is much bigger, than for instance the flow in the Upper Berg River and the difference between the flow-weighted values and the raw TDS data should be much smaller.

With this in mind, it was decided that the comparison of the raw data should give a meaningful indication of any significant changes that occurred in the TDS records.

6.2 Approach

To compare the mean of the calibration period to the mean of the post calibration period, the T-test for independent samples was used (Statistica, 2000) as a first approximation. This test, however, can only be applied if the samples are normally distributed and if the variation in the two sample sets is not reliably different. The non-parametric equivalent of this test (Mann-Whitney U test) was employed when the above conditions were not met.

6.3 Results

Statistical comparison of the following stations was undertaken (DWAF, 1996).

- D1H011
- D3H008
- D7H002
- D7R001
- D7H005
- D8H003
- D1H003
- D1H009
- D2R004
- D3R002
- D8H007

The results for each station are discussed in the ensuing sections.

6.3.1 D1H011 (Roodewal)

Calibration period : 1973 – 1987
Post-calibration period : 1988 – 2002

Using the t-test for independent samples, it was shown that the difference in means of the calibration period (170 mg/ℓ) and that of the post-calibration period (194 mg/ℓ) was significant ($p < 0.05$) and not caused by chance. Using the Shapiro-Wilks' W-test for normality, revealed that the data collected during the calibration period (Shapiro-Wilk W=0.98338, p<0.0005), as well as those collected after 1987 (Shapiro-Wilk W=0.78819, p<0.0005), were not normally distributed indicating that non-parametric testing of the difference in means was required.

The non-parametric *Mann-Whitney U-Test* of the same data showed that the difference in means was statistically significant (p = 0.000001).

6.3.2 D3H008 (Marksdrift)

Calibration period : 1972 – 1987
Post-calibration period : 1988 – 2002

T-test analysis of the two sample sets showed that the mean of the calibration period (132 mg/ℓ) and that of the post-calibration period (151 mg/ℓ) was significantly different ($p<0.05$). Using the Shapiro-Wilks' W-test for normality, revealed that the data collected during the calibration period (Shapiro-Wilk W=0.73348, $p<0.0005$), as well as those collected after 1987 (Shapiro-Wilk W=0.39002, $p<0.0005$), were not normally distributed indicating that non-parametric testing of the difference in means was required.

The non-parametric *Mann-Whitney U-Test* of the same data showed that the difference in means was statistically significant ($p < 0.05$).

6.3.3 D7H002 (Prieska)

Calibration period : 1977 – 1987
Post-calibration period : 1988 – 2002

T-test analysis of the two sample sets showed that the mean of the calibration period (158 mg/ℓ) and that of the post-calibration period (176 mg/ℓ) was significantly different (p=000005). Using the Shapiro-Wilks' W-test for normality, revealed that the data collected during the calibration period (Shapiro-Wilk W= 0.69179, $p < 0.0005$), as well as those collected after 1987 (Shapiro-Wilk W= 0.89142, $p< 0.0005$), were not normally distributed indicating that non-parametric testing of the difference in means was required.

The non-parametric *Mann-Whitney U-Test* of the same data showed that the difference in means was statistically significant ($p < 0.05$).

6.3.4 D7R001 (Boegoeberg Dam)

Calibration period : 1976 –1987
Post-calibration period : 1988 – 2002

T-test analysis of the two sample sets showed that the mean of the calibration period (155 mg/ℓ) and that of the post-calibration period (209 mg/ℓ) was significantly different (P =0.000001). Using the Shapiro-Wilks' W-test for normality, revealed that the data collected during the calibration period (Shapiro-Wilk W= 0.88358, $p<0.0005$), as well as those collected after 1987 (Shapiro-Wilk W = 0.69498, p<.0005), were not normally distributed indicating that non-parametric testing of the difference in means was required.

The non-parametric *Mann-Whitney U-Test* of the same data showed that the difference in means was statistically significant (p<0.05).

6.3.5 D7H005 (Upington)

Calibration period : 1976 – 1987
Post-calibration period : 1988 – 2002

T-test analysis of the two sample sets showed that the mean of the calibration period (176 mg/ℓ) and that of the post-calibration period (228 mg/ℓ) was significantly different (p =0.000021). Using the Shapiro-Wilks' W-test for normality, revealed that the data collected during the calibration period (Shapiro-Wilk W= 0.87433, p<0.0030), as well as those collected after 1987 (Shapiro-Wilk W=0.90630, p<0.0005), were not normally distributed indicating that non-parametric testing of the difference in means was required.

The non-parametric *Mann-Whitney U-Test* of the same data showed that the difference in means was statistically significant (p = 0.000001).

6.3.6 D8H003 (Vioolsdrift)

Calibration period : 1976 – 1987
Post-calibration period : 1988 – 2002

T-test analysis of the two sample sets showed that the mean of the calibration period (214 mg/ℓ) and that of the post-calibration period (264 mg/ℓ) was significantly different (p < 0.05). Using the Shapiro-Wilks' W-test for normality, revealed that the data collected during the calibration period (Shapiro-Wilk W=0.95476, p<0.0005), as well as those collected after 1987 (Shapiro-Wilk W=0.93291, p<0.0005), were not normally distributed indicating that non-parametric testing of the difference in means was required.

The non-parametric *Mann Whitney U-Test* of the same data showed that the difference in means was statistically significant (p < 0.05).

6.3.7 D1H003 (Aliwal North)

Calibration period : 1972 – 1987
Post-calibration period : 1988 – 2002

T-test analysis of the two sample sets showed that the mean of the calibration period (125 mg/ℓ) and that of the post-calibration period (150 mg/ℓ) was significantly different ($p < 0.05$). Using the Shapiro-Wilks' W-test for normality, revealed that the data collected during the calibration period (Shapiro-Wilk W=0.90547, $p < 0.0005$), as well as those collected after 1987 (Shapiro-Wilk W=0.96996, $p<0.0005$), were not normally distributed indicating that non-parametric testing of the difference in means was required.

The non-parametric *Mann-Whitney U-Test* of the same data showed that the difference in means was statistically significant ($p < 0.05$).

6.3.8 D1H009 (Oranjedraai)

Calibration period : 1978 – 1987
Post-calibration period : 1988 – 2002

T-test analysis of the two sample sets showed that the mean of the calibration period (115 mg/ℓ) and that of the post-calibration period (136 mg/ℓ) was significantly different ($p < 0.05$). Using the Shapiro-Wilks' W-test for normality revealed that the data collected during the calibration period (Shapiro-Wilk W=0.95381, $p< 0.0005$), as well as those collected after 1987 (Shapiro-Wilk W=0.86673, $p<0.0005$), were not normally distributed indicating that non-parametric testing of the difference in means was required.

The non-parametric *Mann-Whitney U-Test* of the same data showed that the difference in means was statistically significant ($p < 0.05$).

6.3.9 D2R004 (Welbedacht)

Calibration period : 1978 – 1987
Post-calibration period : 1992 – 2002

T-test analysis of the two sample sets showed that the mean of the calibration period (136 mg/ℓ) and that of the post-calibration period (163 mg/ℓ) was significantly different ($p = 0.0014$) Using the Shapiro-Wilks' W-test for normality, revealed that the data collected during the calibration period (Shapiro-Wilk W=0.86682, $p<0.0005$), as well as those collected after 1987 (Shapiro-Wilk W=0.91143, $p<0.0005$), were not normally distributed indicating that non-parametric testing of the difference in means was required.

The non-parametric *Mann-Whitney U-Test* of the same data showed that the difference in means is statistically significant ($p = 0.000436$).

6.3.10 D3R002 (Gariep)

Calibration period : 1978 – 1987
Post-calibration period : 1988 – 2002

T-test analysis of the two sample sets showed that the mean of the calibration period (113 mg/ℓ) and that of the post-calibration period (133 mg/ℓ) was significantly different ($p < 0.05$). Using the Shapiro-Wilks' W-test for normality, revealed that the data collected during the calibration period (Shapiro-Wilk W=0.92284, $p<0.0005$), as well as those collected after 1987 (Shapiro-Wilk W=0.93216, $p<0.0005$), were not normally distributed indicating that non-parametric testing of the difference in means was required.

The non-parametric *Mann-Whitney U-Test,* using the same data, showed that the difference in means was statistically significant ($p < 0.05$).

6.3.11 D8H007 (Brand Karos)

Calibration Period : 1980 – 1987
Post-calibration period : 1988 – 2002

T-test analysis of the two sample sets showed that the mean of the calibration period (243.08 mg/ℓ) and that of the post-calibration period (232.79 mg/ℓ) was not significantly different ($p = 0.32$). Using the Shapiro-Wilks' W-test for normality, revealed that the data collected during the calibration period (Shapiro-Wilk W=0.972184, $p=0.00002$), as well as those collected after 1987 (Shapiro-Wilk W=0.660287, $p<0.0005$), were not normally distributed indicating that non-parametric testing of the difference in means was required.

The non-parametric *Mann-Whitney U-Test,* using the same data, showed that the difference in means was statistically significant (p = 0.03).

6.4 Comparison of Post-calibration Median TDS Values with Median Values Obtained from the WRPM at a 1995-level of Development

Table 6.1 Salt Concentrations at Various Locations along the Orange River

Location	Observed Median TDS Post Calibration Period 1988 – 2002 (mg/l)	WRPM Median TDS (mg/l)	
		1995 Level	2030 Level
Gariep Dam	134	121	142
Vanderkloof Dam	136	132	160
Orange / Vaal confluence (at Prieska)	176	164	201
Boegoeberg Dam	178	182	228
Kakamas	217	306	388
Vioolsdrift	252	311	410
Orange River Mouth	213	326	514

The comparison of the observed mean TDS of the Post calibration period (1988-2002) and the median TDS value as determined from the WRPM at the 1995-level of development is shown in **Table 6.1**.

At Gariep Dam, Vanderkloof Dam, Orange/Vaal confluence and Boegoeberg Dam the predictions for the median TDS value from the WRPM analyses for the 1995-level of development are representative of the observed median values obtained from the observed record.

Downstream of Upington at Kakamas, Vioolsdrift and the Orange River Mouth, however, the median TDS values from the WRPM analyses (1995-level of development) are higher than the values obtained from the observed record. The model predictions for the 1995-level of development were more conservative than what were observed at those points. This could possibly have been caused by more conservative salinity parameters obtained from the WQT calibration for these incremental sub-catchments.

7. WATER RESOURCE PLANNING MODEL ANALYSES

7.1 Introduction

Significant differences were experienced between the historic firm yield and the long-term stochastic yield results (See **Section 4.6.2** & **4.6.3** for details) and more specifically with regards to the time when intervention will be required to ensure that the growing water demand can be met. It was therefore proposed and approved that the WRPM be used to determine more accurate intervention timings for the different water supply options. Using the WRPM to determine the required intervention time will result in a more conservative and realistic result than that obtained by means of the long-term stochastic yield analysis and a more optimistic result than that from the historic firm yield analyses.

The WRPM uses the short-term stochastic yield characteristics and the associated operating rule to impose curtailments on the system, when required. The results from the short-term stochastic analyses are given in **Section 4.7** of this report with the detailed short-term stochastic yield characteristic curves presented in **Appendix**, **C Figures C-1** to **C-7**.

The existing WRPM data sets as used for the annual Integrated Vaal River System (IVRS) analyses were used as the basis for this study and were extended to include the total Orange River and Riet Modder systems. By modelling the combined system (Orange & Vaal) the spills from the Vaal will automatically be available as a required in-flow to the Orange River at the confluence of the two rivers. The only drawback at this stage is that the allocation algorithm can only be used for either the Orange or the Integrated Vaal system and not for both at the same time. For the purpose of this study the allocation algorithm was only used for the Orange River System and it was accepted that no curtailments would then be imposed on the IVRS. This will result in slightly conservative results for the Orange as spills to the Orange from the Vaal are expected to be less when curtailments are not imposed on the Vaal System.

The system schematics for the WRPM analyses are included in **Appendix F**, **Figures F-1** to **F-6**. These figures describe the total Integrated Vaal System, as well as the Orange River System.

7.2 Scenarios Analysed

7.2.1 Reference Scenario P3

Reference Scenario 3 (with refinements) as described for scenario 3-3, was used as the reference scenario for the WRPM analyses. The WRPM Reference Scenario is referred to as **Reference Scenario P3**. This means that the full Phase 1 of the LHWP is included as well as the latest environmental releases from Katse and Mohale Dams. The new adjusted (Top-Up) Class D environmental flow requirements as determined for the LORMS were applied at Augrabies and the River Mouth. Spills from the Vaal and Fish (Namibia) Rivers, as well as local runoff from the Lower Orange were utilised to supply part of the environmental requirements and river evaporation along the Lower Orange. It was assumed that the operating losses in the Lower Vaal would not be available for use in the Orange or in Douglas Weir.

The starting date for the analyses was selected as 1st of May 2004. This date was also used for the WRPM operating analyses for the Vaal System. The operating analyses use the 1st of May each year in most cases as the starting date of the analyses. At that time, the effect of the summer rains on the storage in the main storage reservoirs is evident and the appropriate operational decitions based on the WRPM results can then be put in place for the year ahead. The starting storage of the storage dams in the WRPM data files were set equal to the 1st of May 2004 observed levels.

The urban/industrial/mining growth in the water requirements, as well as the growth in the RSA and Namibian irrigation requirements, was based on the most probable demand projection as determined for the LORMS. The projected irrigation demand allowed 195-million m^3/a growth in demand for Namibia, which will be fully developed by 2025. The projected irrigation demand included for the RSA is 148 million m^3/a (12 000 ha allocated to resource poor farmers) and will be fully developed by 2015.

Results from this analysis indicated that curtailment levels are clearly exceeded from 2006 onwards (see curtailment plot in **Appendix E**, **Figure E-1**). This means that curtailments are being imposed on the system more often than the given risk criteria. Although there is a small exceedance at 2005 with regards to the 1 in 20-

year curtailments, it is relatively small and can be managed.

From the storage projection plot for the combined Gariep and Vanderkloof storage (see **Appendix E**, **Figure E-2**), it is evident that the observed 1 st of May storage level is significantly lower than the long-term median storage level. The storage projection shows that the system storage will increase over time to reach the median storage level by approximately 2010 and then gradually reduce due to the growing demand imposed on the system.

7.2.2 Scenario P3a: Starting Reservoirs Full

Due to the low starting storage, it was decided to carry out a sensitivity analysis on the effect of the starting storage. This scenario is therefore as Reference Scenario P3 with the only difference that the reservoirs are full at the beginning of the analyses period. For this purpose, the starting storage for all the dams in the Orange and Vaal Systems were set equal to their full supply levels. Results from this analysis showed curtailment levels are for this scenario exceeded from 2008 onwards (see curtailment plot in **Appendix E**, **Figure E-3**). This clearly indicated that the starting storage has a notable effect on the time when intervention is required.

7.2.3 Scenario P3b: Limited Irrigation Growth

The purpose of this scenario was to determine whether acceptable curtailment levels could be obtained by limiting the possible growth in irrigation. Reference Scenario P3 was used as the base for this scenario with the following adjustments to the irrigation growth.

The most probable irrigation growth projection was used for the RSA and Namibia only until 2005. From then onwards no further irrigation growth was allowed for either the RSA or Namibia. The growth in the urban/industrial and mining sectors was not changed. For Namibia this means that an additional irrigation demand of 26 million m^3/a is allowed over and above the existing 54 million m^3/a at 2000-development level. Together with the possible future demand of 30 million m^3/a for Haib Mine the total Namibian demand imposed on the Orange System will then be 110 million m^3/a. The growth in irrigation for the RSA from 2000 to 2005 represents a further 35 million m^3/a irrigation demand that will be imposed on the Orange River System.

Results from this analysis are shown on **Figure E-4** of **Appendix E**. From the curtailment level plot, it can be seen that although the curtailment levels are not exceeded to the same extent as for Reference Scenario P3, intervention will still be required by 2006.

7.2.4 Scenario P3c: Vioolsdrift Re-regulating Dam

This scenario is as Reference Scenario P3 with the exception that Vioolsdrift Re-regulation Dam is included as if it is in place from 1 May 2004. Although it is not possible to have Vioolsdrift Dam in place by then, this scenario will provide a good indication of what can be achieved by the proposed re-regulation dam.

Results from this scenario (see **Figure E-5** of **Appendix E**) show a temporary shortage from 2006 to 2009, which is possibly a result of the relatively low starting storage. The curtailment levels are, however, continuously exceeded from 2012 onwards. This indicates that Vioolsdrift Re-regulating can only provide "additional yield" (saving in operating losses) to supply 6 years of possible growth of the demand imposed on the system.

7.2.5 Scenario P3d: Vioolsdrift Re-regulating Dam with Full Starting Storage

To test the effect of the starting storage on the temporary shortages from 2006 to 2009, Scenario P3c was analysed with all the reservoirs at 100% full at the beginning of the analyses period. Results from this analysis clearly showed that the shortages between 2006 and 2009 disappear when the reservoirs are full at the beginning of the analysis period and the curtailment levels are exceeded only from 2012 onwards (See **Figure E-6** of **Appendix E**). These temporary shortages are therefore a result of the low May 2004 observed storage levels.

7.3 Combination of Scenarios

7.3.1 Scenario Description and Background Information

From the results it is clear that action needs to be taken to improve the supply situation in the Orange River System from 2006 onwards, until a Vioolsdrift Re-regulating Dam can be put into place. In practise, it will only be possible to have Vioolsdrift Dam in place, at the earliest, by 2012. Possible actions or options that may be implemented to overcome the expected shortages over this period (2006 to 2012) include:

- Control the growth in demand.
- Change the assurance of supply to users (priority classification)
- Use Vanderkloof LLS (Effect hydro-power generation – Eskom)
- Utilize the temporary surplus in the Vaal System
- Use the EFR from the ORRS for this period until Vioolsdrift Dam needs to be built.
- Use real time modelling in combination with the ORRS EFR to reduce operating losses and to utilise some of the inflows from the Vaal. (Real time modelling is already included in Reference Scenario P3 as it will be required to manage the releases from Vanderkloof Dam for the new EFRs (from LORMS), as well as utilising Vaal and Fish River spills for EFR purposes.)

Decisions on which option to use not purely dependant on economic criteria is using URVs. Political aspects, internal strategic percpectives of the Department of Water Affairs, practical consideratoins, etc. also have a significant effect on the selection of the above-mentioned options. It was therefore considered important to have a discussion with the Client to obtain some guidance towards the options that may be utilised to overcome the projected shortages between 2006 and 2012.

From the discussions the following guidlinenes were provided:

- *Control the growth in demand*: Due to commitments made with regards to the 12 000 ha earmarked for resource poor farmers in the RSA and the accepted growth in irrigation for Namibia, it is unlikely that limited growth in irrigation can be considered as an option. Results from Scenario P3b also indicated that exstreme limitations on the growth will be required to achieve acceptable curtailment levels in future. Furthermore, it is not possible to stop the growth in the demand for the urban, industrial and mining sectors.
- *Change the assurance of supply to users:* The priority classification selected for the Orange River System for the purpose of the LORMS already results in slightly lower assurances than currently used in the IVRS. If these assurances of supply are to be changed, detailed discussions with the users would be required, where the effects of the lower assurances are illustrated, so that an agreement can be obtained from the users in this regard. This will not be possible within the time frame and available budget of the LORMS.

- *Vanderkloof lower level storage:* This is an option that can be utilized before the implementation of the Vioolsdrift Re-regulating Dam. It should, however, not be implemented as early as 2006, but rather a few years later as there are still some uncertainties that need to be clarified, specifically with regards to the effect on Eskom. This option was identified in the ORRS as the option with the lowest URV, although the effect on hydropower generation was not taken into account in the ORRS evaluations.
- *Utilize the temporary surplus in the Vaal System:* This option is not seen as a viable option for the Orange River System as it will be expensive for irrigation purposes due to the high pumping costs for transfers from the Tugela System. In addition, it could only be used for a short period from 2005 as it will reduce to almost zero by 2010. This surplus should be reserved for emergency situations only.
- *Use the EFR from the ORRS and real time modelling:* Currently releases are made for the EFR based on the estimations from the ORRS, although the volume and timing is not what it should be. These releases are expected to continue until a new structure such as a dam, is built in the Orange. According to the Water Act (RSA) it will then be required to determine the Ecological Reserve before the structure can be built. The Resource Directed Measures (RDM) office (RSA) might give the Orange River System a high priority that requires the Reserve to be determined and implemented at an earlier stage. Currently there are other rivers, which are much higher on the priority list and is therefore expected that the Reserve for the Orange River will not be determined in the near future.

It is expected that the ORRS EFR will still be released for a number of years with some improvements over time until such time as the reserve has been determined. The surplus available in the Orange River System is significantly more with the ORRS EFR imposed on the system than with the LORMS EFR.

It seems that the most practical option is to make use of the ORRS EFRs until the Vioolsdrift Dam can be built. The time before the construction of Vioolsdrift Dam should then be used to improve existing gauging structures and to build new ones where required, to be able to measure low flows accurately. This will aid in the implementation of real time modelling, to improve the timing of releases, as well as to avoid high flows in winter months. These actions will improve the supply to the EFR, specifically at the river mouth. The real time modelling will also enable the operators to utilise spills from the Vaal and therefore save on the releases from Vanderkloof to increase the system yield.

Over this period, practical experience will be gained in managing the system with the aid of real time modelling, so that an effective operating system can be put into place, in order to manage the reserve according to the latest techniques and principals.

A combination of the options discussed will be required to enable the system to supply in the growing demand based on the LORMS projection. The following methodology was followed to determine possible combinations of options:

- Use Reference Scenario P3 and replace the LORMS EFR with the ORRS EFR. This also means that spills from the Vaal and Fish Rivers, as well as local runoff cannot be used to supply part of the EFR. Run the WRPM and determine when the curtailment levels are exceeded. (*Scenario P3e*)
- Based on the results from Scenario P3e, decide when real time modelling should be implemented and include this option in the WRPM. Run the WRPM and determine when intervention is required. (*Scenario P3f*)
- At this point, Vanderkloof LLS can be added at the time as obtained from Scenario P3f. This scenario will then include the ORRS EFR with real time modelling from a certain time onwards, and then Vanderkloof LLS, based on the required timing from Scenario P3f. This combined scenario will then be analysed to determine when the Vioolsdrift re-regulating dam is required. *(Scenario P3g)*

7.3.2 Results

Scenario P3e: From the curtailment level plot (See **Figure E-7** in **Appendix E**) for Scenario P3e (existing system with ORRS EFR), it is evident that intervention will be required by 2012. However, the curtailment levels for 1 in 100 and 1 in 200 assurance of supply did indicate some temporary shortages between 2007 and 2009.

Scenario P3f: The full benefit of real time modelling will not be achieved within one year. For the purpose of this analysis, it was assumed that the possible increase in the surplus yield will occur over a four year period, with increments of 20 million m^3/a

starting in 2007, at the time when the first temporary shortages occured. This means that the full benefit of real time modelling will be obtained in 2010, which is still 2 years before intervention is actually required. Results from this analysis indicated that with real time modelling in place the required time for intervention is postponed to 2018 (see **Figure E-8** in **Appendix E**).

Scenario P3g: Utilizing Vanderkloof LLS from 2018 onwards will be more than sufficient to supply the growing demand until 2025, when the ORRS EFR is used. This is illustrated on **Figure E-9** of **Appendix E**. However, it is not acceptable to use Vanderkloof LLS from this time onwards with only the ORRS EFR in place, as the damage to the environment will more than likely be beyond acceptable limits. After discussions with the Client, it was decided that the latest date at which the Reserve should be put into place for the purpose of this study, is 2015. However, it is strongly recommended that the current releases for the EFR be improved upon, with increased knowledge over time, until the Reserve is implemented.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The results from many scenarios were given in the previous sections with regards to the yield available, hydraulic river modelling and water quality review. In this section, the most important conclusions that can be drawn from the results are given.

Reference Scenario 1 – The Existing System with EFR as Currently Released:

Historic Yield Analyses:

This scenario refers to the current system with 2005-development level urban/industrial/mining demands, the ORRS' EFRs as currently released and with the existing operating rule in place. The Orange River System is almost in balance as the surplus yield of 120 million m³/a available under these conditions, only represents approximately 3,5% of the total system yield. Taking into account the most probable growth projection, the system will only be able to support the expected growth until 2007.

If spills from the Vaal system can be fully utilised, the indications are that the system yield can be increased by 50 to 140 million m³/a, depending on assumptions with regards to operating losses in the Lower Vaal System.

Reference Scenario 1 was also used as basis to determine the effect of EFRs on the system yield. Planning estimates of the EFRs were obtained by using the Desktop Model. The effect of these EFRs on the system yield were determined and compared with that originally determined in the ORRS. The comparison indicated significant differences. A deficit in excess of 400 million m³/a was obtained when the Desktop estimate of the EFR for a Class C river has to be met in comparison with the surplus of 120 million m³/a when the ORRS' EFRs are used.

Reference Scenario 2 – The Existing System with Desktop EFR Estimates for a Class D River

Historic Yield Analyses:

From the results obtained from Reference Scenario 1, it was decided and agreed upon by both Clients to use the Desktop EFR estimate for a Class D river in further analyses. At this stage, Lesotho started to implement updated environmental flow releases from Katse and Mohale Dams, which were also included as part of Reference Scenario 2. An important difference in the operating rule between Reference Scenarios 1 and 2 is, that the spills from the Vaal System, as well as local runoff generated in the Lower Orange were used in Reference Scenario 2, to partly supply the EFRs and the river evaporation, while it was not utilised at all in Reference Scenario 1. The yield analysis for Reference Scenario 2 showed a deficit of almost 300 million m^3/a at the 2005-development level.

Sensitivity analyses were also carried out which indicated that the updated Lesotho environmental flow releases contributed to an increase in the system yield of approximately 70 million m^3/a. This additional yield was, however, used to supply the Desktop Class D EFR included for the LOR and Estuary. If the Vaal River System was used to supply it's portion of the Class D Desktop EFR, the deficit in the Orange River System will reduce by almost 200 million m^3/a to approximately 100 million m^3/a. The EFR contribution from Vaal System can therefore have a significant effect on the available surplus in the Orange River System.

The different ERFs resulted in severe differences in the available surplus yield from the Orange River System. Additional work was therefore carried out to determine an EFR that can be used for planning purposes in the LORMS.

Reference Scenario 3 – The Existing System with Adjusted Desktop EFR Estimates for a Class D River

Historic Yield Analyses:

From the additional work carried out to determine acceptable environmental flows as required for the LOR and at the Estuary, an adjusted Desktop D EFR was obtained and used for planning purposes in the LORMS. This EFR was referred to as the Top Up environmental requirement. With the Top Up EFR in place, it will be possible to keep the river and estuary in their current state (Class D) without further deterioration. The updated Lesotho EFRs, as well as the changed operating rule as used for Reference Scenario 2, were also included as part of Reference Scenario 3. No EFR contribution from the Vaal was included for Reference Scenario 3. Reference Scenario 3 was used as the final reference scenario or base to be used in the LORMS to evaluate and compare with possible future development and management options.

Yield results for this scenario indicated a deficit of 47 million m^3/a in the system at 2005-development level, after taking into account the possible irrigation growth from 2000 to 2005. For this scenario, the deficit will increase to 308 million m^3/a by 2015 and to 418 million m^3/a by 2025.

Possible options that were analysed to increase the system yield included:

- Utilising the current surplus in the Vaal.
- Vanderkloof LLS utilization.
- Improve system operation to be able to utilise Vaal Spills.
- Reduce the Orange River operating losses by means of re-regulating dams.
- Increase the system yield by means of additional storage dams.
- WC&DM options.

From the results it was concluded that:

- The Vaal surplus of 94 million m^3/a at 2005 will reduce to almost zero in 2015. This will, however, be an expensive option, as the surplus water needs to be pumped from the Tugela. This option can also only be used in the short-term, and mainly as an emergency resource.
- Relative to Reference Scenario 3, Vanderkloof LLS can provide an additional 143 million m^3/a to the system yield at relatively low cost, but this option will have an impact on hydropower generation. A separate study was carried out in parallel to the LORMS, to determine the effect of this option on the hydropower generation. The incremental yield benefit for this option as quoted in that study was 240 million m^3/a. The reasons for the differences in the incremental yield benefit, is the fact that the LORMS used a lower m.o.l. for the Reference Scenario than was used in the other study, and secondly different EFRs were used in the LORMS for the Orange River System, as well as for the LHWP.

- Without additional storage in the Lower Orange, real time modelling and improved gauging of low flows in the Orange River is required to be able to utilise the spills from the Vaal System. An additional 80 million m³/a can be utilised by means of this option. However, it is important to realise that the Orange River System operation management and infrastructure should, in any case, be upgraded to this level in order to manage the supply of environmental requirements at the Estuary and to monitor whether or not the supply was met. As part of Reference Scenario 3, it was stated that spills from the Vaal, as well as runoff generated locally in the Lower Orange, will be used to partly supply the river evaporation and environmental requirements. This means that the results from Reference Scenario 3 already include the effect of utilising spills from the Vaal.
- Of the three possible dam sites investigated for a re-regulating dam, Vioolsdift Dam was clearly the best option from a yield point of view. A re-regulating dam at Vioolsdrift can reduce the operating losses by approximatelly 170 million m³/a in comparison with the 126 and 62 million m³/a at Komsberg and Boegoeberg Dams, respectively.
- Large storage dams were analysed at the Boegoeberg and Vioolsdrift sites. Vioolsdrift was identified as the best option with an incremental yield of between 270 and 420 million m³/a, depending on the size of the dam (500 to 2 400 million m³ live storage). A larger dam at Vioolsdrift will create an incremental yield in excess of the possible future demands downstream of the dam and it will therefore not be sensible. Sedimentation plays an important role at both dams and will, in the case of Vioolsdrift Dam, reduce the incremental yield over a 50 year period to approximately 120 and 320 million m³/a respectively, for the two live storages as quoted previously. There are, however, a number of uncertainties with regards to the sediment volumes at the two sites, as well as the effect that sedimentation will have on the area capacity characteristics of the dams. Sensitivity analyses showed that different assumptions with regards to the evaporation area of the dams at the m.o.l. (after the 50-year of sedimentation was taken into account), can result in yield differences for the same dam of up to almost 60 million m³/a.
- WC&DM - A pilot area from Gifkloof to the Namibian border was investigated for this purpose. Results indicated possible savings of 55 million m³/a by 2010 and 188 million m³/a by 2014. These are substantial volumes, which can still be utilised. However, the main problem with this option is that a detailed and

accurate monitoring infrastructure and support is required to manage and monitor the actual use and savings. The reliability of this source is also in question and largely depends on the ability of the irrigators to achieve these goals, year after year.

Stochastic Yield Analyses:

The long-term stochastic yield analyses for Reference Scenario 3 indicated a surplus yield available at 2005-development level of 180 million m³/a, which will be able to supply the expected growth in demand until 2012. This is significantly more than the deficit of 47 million m³/a as obtained from the historic firm yield analyses. The reason for this difference is that for the historic analyses all the demands in the system were supplied at an assurance of 1 in a 100-years, as this is the representative recurrence interval for the historic firm yield. For the purpose of the stochastic analyses, the users were supplied at different levels of assurances - some at a 1 in 200-year, some at 1 in 100-year and some at 1 in 20-year assurance level. The bulk of the water use in the Orange River System is for irrigation, of which 60% is supplied at a low assurance (1 in 20-years), and at lower assurances a higher yield is available from the system, resulting in the larger surplus. If, for example, all of the demands in the Orange River System are supplied at a high assurance (1 in 200-years), the long-term stochastic results indicate a shortage in excess of 300 million m³/a at 2005-development level. These results clearly show the importance of stochastic analyses and specifically when different users or user groups need to be supplied at different levels of assurance.

Sensitivity analyses showed that the surplus available based on the long-term stochastic yield results can vary significantly depending on the priority classification and assurance of supply assigned to the various user categories. For example, the available surplus in the system can be reduced by approximately 140 million m³/a if the Vaal priority classification is used for the Orange River System, instead of the priority classification proposed in this study.

Long-term stochastic yield results are also sensitive to assumptions with regards to the spills from the Vaal System. For the worst case scenario where Bloemhof Dam was not spilling and operation losses in the Lower Vaal were set to zero, the surplus in the Orange River System was reduced by more than 240 million m³/a. Currently, some of the operating losses in the Lower Vaal do enter the Orange River and can therefore be utilised in the LOR. There are, however, uncertainties with regards to the actual volume of these operating losses, and how much of these losses do in fact enter the Orange River. The main reason why the long-term stochastic analyses are sensitive to assumptions with respect to the Vaal spills is due to the EFR structure used. This structure requires that during periods of high natural flows, the EFR should also be high. If the Vaal spills are reduced, particularly during periods of high natural flow, the high flows as required by the environment in the Lower Orange will have to be supplied from Gariep and Vanderkloof Dams alone. This will in turn reduce the surplus yield capability of Gariep and Vanderkloof.

The difference in results from the historic and long-term stochastic analyses make it difficult to decide how much additional yield needs to be created and by when, to be able to supply the possible growth in demand. The WRPM was therefore used to obtain a more realistic date when intervention is required. Results from these WRPM analyses still need to be included in this report as the analyses are still in process.

Hydraulic River Modelling:
The hydraulic river modelling was mainly used to support the options and analyses carried out with the WRYM. Support in this regard was specifically required to obtain the sizes required for the re-regulation dams, as well as the possible savings that can be obtained by means of real time modelling. Several other valuable results were also obtained as part of the hydraulic river modelling.

Conclusions drawn from the hydraulic river modelling task include the following:

- The existing 60/40 principle used to determine the current release patterns from Vanderkloof Dam is not one hundred percent effective in successfully meeting the downstream requirements. It has been proven that the release patterns could be optimised by the use of hydraulic modelling through an iterative process.
- The re-regulating dam at Vioolsdrift will by far provide the biggest saving (170 million m^3/a). The Komsberg and Boegoeberg sites will provide significantly smaller savings, mainly due to large downstream demands and the long river reach that still needs to be managed from the latter re-regulating dams.
- There are significant differences between the ORRS and 2003 (LORMS) demand patterns, especially during the peak consumption periods.
- There is a discrepancy between the measured and modelled flows at

Boegoeberg/Zeekoebaart (the measured flows are notably lower in some months than the modelled flows).

- The 2003 (LORMS) demand patterns downstream of Boegoeberg are notably lower than the actual demand patterns.
- Utilising inflows from the Vaal River by means of real time modelling could result in a significant saving (80 x 10^6 m^3/a as given in **Section 4.5.5 c**).

Water Quality Review:

Analysis of the data for the selected gauges as discussed in **Section 6**, showed that the there was a statistically significant difference between the means of the data collected during the calibration period and the means of the data collected after the calibration period at all the selected gauges.

Although the statistical analysis shows that all of the selected stations are statistically different (based on means) for the pre- and post calibration periods, it should be viewed in the context of the WQT Model's ability to simulate TDS at a scale fine enough to depict this change, and whether this statistical significance is relevant in terms of the fitness for use, e.g., does the change in mean TDS move the river reach into a poorer class in terms of its fitness for use? (Change from "fit for use" class to an "acceptable" class).

The WRPM analyses at the 1995-level of development produced TDS concentration that are representative of the post calibration TDS median values or are more conservative than these values, which should be satisfactory for modelling purposes. According to the water quality ranges defined in the Orange River Development Project Replanning Study (DWAF, 1998), the predicted median TDS values (for the 1995-level of development) at all points along the Orange River should fall within the "fit for use" category even with the conservative prediction of the median TDS values. This conclusion is supported by TDS concentrations observed in the river since 1989.

WRPM analyses:

Results from the WRPM analyses indicated that intervention is required by 2006 for the current system, when the updated LORMS EFRs are included (It is important to note that real time modelling is assumed to be in place when LORMS EFRs are used). It was also evident from the results that the current storage in the dams is well below the long-term expected median storage level. If the dams were full at the beginning of the analyses period it will postpone the intervention date by 2 years, to 2008.

For the current system with the ORRS EFRs in place, intervention will only be required by 2012 and this can be extended further until 2018 if real time modelling is also used. Using the ORRS EFR initially will provide sufficient time for the construction of a dam at Vioolsdrift. By implementing real time modelling, additional surplus will be created in the system, which can be utilised to improve the supply to the environment over time, as more data become available. However, the reserve needs to be implemented when new infrastructure, such as a Vioolsdrift Re-regulating Dam is constructed.

As soon as Vioolsdrift re-regulating dam is in place, one will require the re-regulating dam as well as an additional development option, such as Vanderkloof LLS or a Large Vioolsdrift Dam, in order to supply the higher environmental requirements in combination with the growth in demands, up to that time (approximately 2015). This is clearly illustrated on **Figure E-10** in **Appendix E**. It is also evident from **Figure E-10** that the Vioolsdrift re-regulating dam and Vanderkloof LLS will not be sufficient to supply the growing demand until 2025, and that additional live storage of approximately 280 million m^3 is required for this purpose.

Depending on the final results from the parallel Vanderkloof Lower Level Study, it might be possible that the Vanderkloof Dam LLS option could be excluded as a possible future option. This then will require a large storage dam in combination with a re-regulating dam at Vioolsdrift. It should, however, be noted that due to the limited water use downstream of Vioolsdrift Dam, the maximum live storage for a storage dam at Vioolsdrift, is limited to between 1 500 to 2 000 million m^3, depending on where future development will take place (downstream or upstream of Vioolsdift Dam). The maximum downstream use will also be affected by the actual river mouth environmental requirement that will be used in future, as well as the extent to which flows from the Fish River (Namibia) can be utilized to supply the environmental requirements.

8.2 Recommendations

Based on the results from the analyses, the following recommendations are made:

- Different EFRs resulted in significantly different impacts on the available surplus in the system. Although the adjusted Desktop Class D EFR (Top Up EFR) was recommended to be used for planning purposes at this stage, it is of utmost importance that processes should be put in place in time to improve the knowledge-base and understanding of environmental-related requirements and issues. Through these processes, the necessary data could be collected and stored that will enable specialists to make sound recommendations in future, with regards to the actual EFRs needed. The upgrading of current gauging structures to obtain accurate flow values at key points, specifically near the Estuary need to be included as part of this process.
- Contributions to the Lower Orange EFRs from Orange River tributaries, and in particular, from main tributaries such as the Vaal was not included in the EFRs proposed for LORMS planning purposes, as it would require extensive additional work to include the Vaal in such an assessment. However, sensitivity analyses showed that EFR contributions from the Vaal can have a significant impact on the surplus available in the Orange River System. This will also apply to the other tributaries, although to a lesser extent. Therefore, it is recommended to include the Vaal and other major tributaries in future EFR assessments for the Orange River.
- In order to manage and satisfy the water supply and environmental requirements of the Estuary according to the latest techniques developed and used in the RSA, it will be necessary to significantly improve the operational management of the Orange River System. This will require improvements on existing gauging structures to measure flows more accurately (specifically low flows), as well as a gauging structure close to the river mouth. A structure is currently planned by the DWAF RSA at Sendelingsdrift, which can be used effectively for this purpose. Real time modelling will enable operators to manage the system far more accurately and effectively, as the effect of inflows from the Vaal, as well as other local inflows, can be modelled and evaluated to provide guidance to the operator in order to adjust releases accordingly. Results indicated that savings of in the order of 80 million m^3/a can be obtained by using real time modelling in combination with improved gauging facilities. The upgrading of gauging stations

and the implementation of real time modelling is therefore recommended as one of the first options to be implemented and thus improve the operational management of the system and increase the water availability.

- Therefore, there is an urgent need for a more accurate and extensive real time monitoring system. A proposed monitoring system is shown in **Figure 8.1**. This proposed system takes into account the location of the major demands, the demand patterns and river requirements, as well as the possible utilisation of inflows from the Vaal and Fish Rivers.
- The use of the hydraulic model through an integrated approach to include, for example, the determination and implementation of the Reserve, the optimisation of water resources, disaster management (both drought and flood), as well as water quality management.
- To achieve this, the model should be extended to include the lower parts of the Vaal and Fish Rivers. It would also be necessary to extend some of the cross sections so that the model could be used as a flood management tool; and
- There is an urgent need for a single custodian for the hydraulic model to achieve the above-mentioned integration.

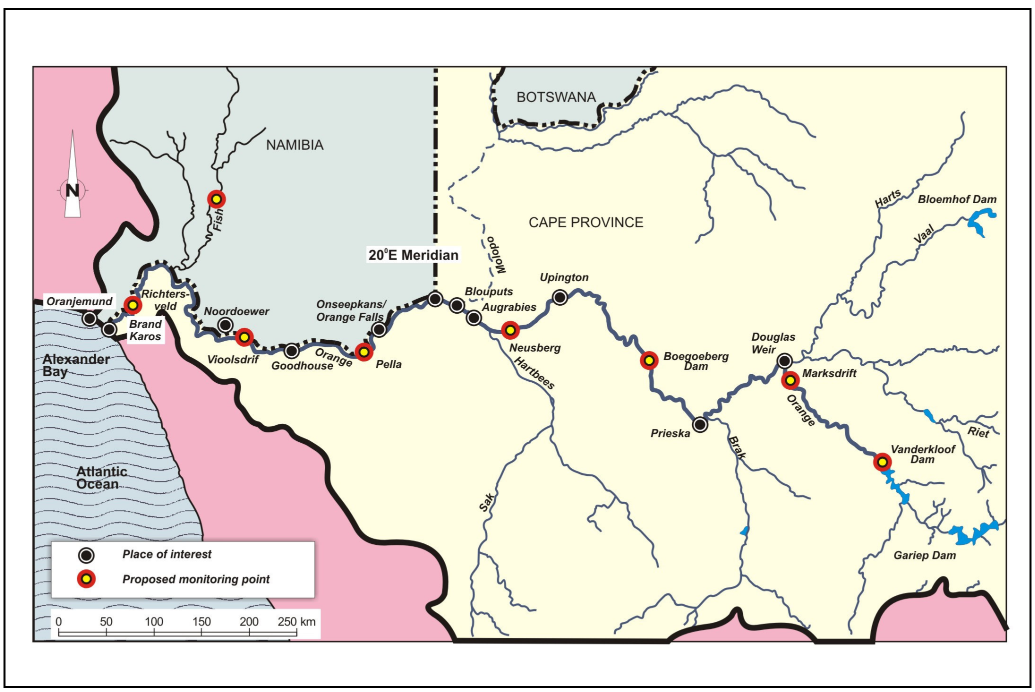

Figure 8.1: Proposed Monitoring System

- It is recommended that economic and financial analyses be carried out for the Vioolsdrift re-regulating and large storage dams, the Vanderkloof LLS option, as well as for the possibility to utilize the current Vaal surplus. Results from the separate study on the impact of Vanderkloof LLS utilisation on hydropower generation should be included in the economic and financial analyses.
- Results from the system analyses clearly show that the surplus yield in the Orange River is sensitive with regards to assumptions of the spills from the Vaal. Therefore, detailed investigations and improved accuracy of low flow monitoring in the Lower Vaal are recommended to obtain improved information on the actual operating losses in the Lower Vaal, as well as for the portion of the losses that is, in fact, reaching the Orange River.
- Sedimentation has a major impact on the yield from dams in the Lower Orange and there is a lack of relevant data for this area. Therefore, the process which store and collect the necessary data in time, should be put into place, in order to enable specialists to make sound recommendations on future sedimentation of proposed dam development options in the Lower Orange, and in particular for the smaller dam options.
- WC&DM should be strongly promoted in this area, as large volumes of water can be made available though the suggested actions. However, it is anticipated that the additional water from WC&DM will mainly be utilised by the irrigators themselves, to enable them to irrigate larger areas with the same volume of water, or to trade some of their allocation.

Water Quality Related Recommendations:

The Water Quality Task was reduced to only include the review of water quality changes in the Lower Orange and to exclude further water quality modelling at this stage. This was motivated from the findings from the water quality review, which indicated that the calibration of the WQT Model could possibly be postponed to a later date. It was therefore recommended to spend the remaining budget on detailed WRPM analyses as recommended in **Section 4.6.**

Further motivation for not doing the originally envisaged water quality modelling using the WRPM, included the following:

- TDS is not the main water quality problem in the Orange. Currently, TDS concentrations in the Orange River, just downstream of its confluence with the Vaal, are in the range of 150 to 160 mg/ℓ. Concentrations of less than 260 mg/ℓ are regarded as ideal for irrigation purposes.

- Results from the LORMS indicated that a re-regulating dam at Vioolsdrift is the most possible future development structure. The impact of such a structure on the TDS is expected to be relatively small.
- Algea blooms/nutrients are currently the main concern in the LOR.

This does not mean that water quality is not a problem in the Lower Orange; it is in fact a serious problem specifically with regards to the algae blooms. It is therefore strongly recommended that a separate study should be commenced to investigate this and other related water quality problems in the Lower Orange. This study should at least also include the Lower Vaal as part of the problems experienced in the Lower Orange, which might be as results of inflows from the Lower Vaal.

WRPM Analyses Related Recommendations:

The following recommendations follow from the WRPM analyses:

- Vioolsdrift Dam re-regulating dam needs to be constructed as soon as possible.
- Use ORRS EFRs and real time modelling in the period before the construction of Vioolsdrift Dam to be able to supply the growing demand, and to improve the supply to the environment.
- Use the results from the Vanderkloof Lower Level Study and resulting URV to decide whether this option should be implemented or not. Results from the WRPM, however, require that this option be implemented somewhere between 2006 and 2015 depending on the combination of demand growth and improved EFRs. The implementation of this option should preferably be done no later than the construction of Vioolsdrift Dam.
- By 2015 a combination of Vanderkloof LLS and the Vioolsdrift Re-regulating Dam is required to supply the needs of the growing demand and improved EFR (LORMS EFR). It is therefore recommended that a combined storage/re-regulating dam be constructed at Vioolsdrift and not a phased option. An additional storage of 280 million m^3 (110 million m^3/a yield) will be required at Vioolsdrift to be able to supply the growing demand and EFR until 2025, in combination with Vanderkloof LLS.
- When Vanderkloof LLS is excluded as a possible future option, a storage dam of at least 830 million m^3 (253 million m^3/a yield) is required in combination with a re-regulation dam at Vioolsdrift to supply the growing

demand until 2025.

- When a large storage dam is considered at Vioolsdrift, the possibility of a large dam such as Bosberg/Boskraai and Mashai should also be evaluated and compared with the large Vioolsdrift option.

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