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DEPARTMENT OF WATER AFFAIRS AND FORESTRY
DIRECTORATE OF OPTIONS ANALYSIS

LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY

APPENDIX 4: SYSTEM YIELD ANALYSIS

FINAL

NINHAM SHAND CONSULTING SERVICES

January 2006

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

DIRECTORATE OF OPTIONS ANALYSIS

LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY

APPENDIX 4

SYSTEM YIELD ANALYSIS

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FINAL

January 2006

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LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY

SYSTEM YIELD ANALYSIS

EXECUTIVE SUMMARY

1. INTRODUCTION

The Lukanji Regional Water Feasibility Supply Study, commissioned by the Department of Water Affairs and Forestry (DWAF), commenced in March 2003. The main aim of the study is to review the findings of earlier studies and, taking cognisance of new developments and priorities that have been identified in the study area, to make a firm recommendation on the next augmentation scheme to be developed for the supply of water to the urban complexes of Queenstown and Sada following the implementation of a suitable water demand management programme. In addition, proposed operating rules will be identified for the existing water supply schemes and the augmentation scheme, to provide for the ecological component of the Reserve and the equitable distribution of water between rural domestic and urban water supplies and irrigators.

In a previous study, the Queenstown Regional Water Supply Study (DWAF, 1997), the Water Resources Yield Model was configured to represent the Upper Kei Basin Water Resources System of which the Lukanji Water Resources System is a component. This document describes the verification and, where necessary, modification of the original model to suit the purposes of the current study. It also describes the use of the modified model to determined the yields of the dams of the Lukanji System and to derive operating rules for the System.

2. VERIFICATION AND MODIFICATION OF THE MODEL

The functioning of the model was checked and the following adjustments were made :

- The surface area/capacity relationships for the dams were adjusted to allow for estimated silt accumulation by the years 2020 and 2045.
- The water requirements for irrigation were adjusted in the light of recent information, which included that obtained through the DWAF process for the registration of water use.
- The streamflow sequences for the catchment of Waterdown Dam were adjusted to compensate for a change in the area of irrigated land.
- The modelling of river channel losses was improved.
- The facility to model releases for environmental instream flow requirements was added.

3. RELEASES FOR ENVIRONMENTAL INSTREAM FLOW REQUIREMENTS

The impacts on the yields of dams of releases to meet environmental instream flow requirements (IFRs) are shown in Table 1 for the various scenarios considered. The negative values indicate a reduction in the yield that would be available if no IFR releases were made. The shortfalls at the IFR sites shown in the table are shortfalls that would occur if no special IFR releases were made from the dams.

TABLE 1 IMPACT OF IFR ON YIELD FOR WATERDOWN, OXKRAAL, XONXA AND LUBISI DAMS

IFR SITE	PERIOD		IFR SHORTFALL : EXPECTED MIN IMPACT ON YIELD					
			IFR SCENARIOS					
			1	2	3	4	5	4
			SHORTFALLS AT IFR SITES (Mm^3/a)					
1	System critical period	1 Sep 44 - 31 Jan 50	-2,8	-3,8	-4,4	-2,4	-1,3	-2,4
2			-2,1	-2,1	-3,5	-1,5	-1,5	-2,4
3			-1,2	-2,3	-5,5	-2	-1	-2,4
4	Sub-system critical period	1 May 78 - 31 Jan 85	-4,3	-6,4	-10,5	-3,5	-1,8	
5			-2,58	-3,8	-6,1	-2,2	-1,2	
Dam	**Supplying the following IFR sites**		**Selecting largest shortfall for the appropriate IFR sites (Mm^3/a)**					
Waterdown	IFR 1 only		-2,8	-3,8	-4,4	-2,4	-1,3	-2,4
Waterdown and Oxkraal	IFR 1, 2 and 3		-2,8	-3,8	-5,5	-2,4	-1,5	-2,4
Xonxa	IFR 5 only		-2,58	-3,8	-6,1	-2,2	-1,2	
Xonxa and Lubisi	IFR 4 and 5		-4,3	-6,4	-10,5	-3,5	-1,8	

4. YIELD ANALYSIS OF DAMS

Historical firm yields and long-term stochastic yields of dams for catchment conditions and dam storage capacities as they are expected to be in 2020 were determined as shown in Table 2. Historical firm yields for conditions in 2005 were also determined.

TABLE 2 HISTORICAL FIRM YIELDS AND LONG-TERM STOCHASTIC YIELDS

DAM NAME	YIELD UNDER 2005 CONDITIONS	YIELDS UNDER 2020 CONDITIONS					
			DIFFERENT ANNUAL PROBABILITIES OF FAILURE, i.e. 1 IN …. YEARS				
	HISTORIC FIRM YIELD (Mm^3)	HISTORIC FIRM YIELD (Mm^3)	1:10 YEAR YIELD (Mm^3)	1:20 YEAR YIELD (Mm^3)	1:50 YEAR YIELD (Mm^3)	1:100 YEAR YIELD (Mm^3)	1:200 YEAR YIELD (Mm^3)
Waterdown Dam	16,81	16,81	24,45	23,26	20,25	18,84	17,56
Oxkraal and Bushmanskrantz Dam (1)	6,67	6,18	8,6	7,96	6,95	6,21	5,67
Bonkolo Dam	0,832	0,695 to 0,9 (2)	1,16	1,1	0,934	0,833	0,736
Xonxa Dam	18,91	20,63	29,6	27,16	22,97	20,74	19
TOTAL	**43,2**	**44,3**	**63,8**	**59,5**	**51,1**	**46,6**	**43,0**

1. Increased by 1,55 x Mm^3/a for Zwelindinga Irrigation Scheme and villages.
2. Larger yield assumes that siltation occurs as a delta where the river enters the dam.
3. The 2005 historical firm yield (HFY) is less than the 2020 HFY because the 2005 analysis assumed the dead storage of 1,22 Mm^3 was inaccessible and would be maintained in the dam. Silt was assumed to fill this dead storage by 2020. The surface area of this dead volume in 2005 is 1,4 km^2 and the evaporation from this surface decreased the yield with regard to the 2020 value. In practice, measures to access this water during droughts, such as pumping from a raft, could increase the yield to the 2020 value.

In addition, the yield of the integrated system was analysed and it was concluded that, because Xonxa Dam is situated in a different hydrological zone to Waterdown, Bushmanskrantz and Oxkraal Dams, it does not always experience droughts when the other dams do. Consequently, the yield of the integrated system can be increased by providing sufficient excess capacity in the pipelines from Waterdown Dam and from Xonxa Dam to allow as much as possible of the full water requirements of Queenstown to be conveyed from either source.

Estimates of the assurances at which water can be provided for irrigation from run-of-river flow have been made. It will be possible to improve the level of confidence in these once sufficient information is available from the new flow gauge on the lower Black Kei River to enable run-of-river flows and river channel losses to be more accurately determined.

5. SYSTEM OPERATING RULES

Operating rules specifying the sequence in which the dams should be drawn down, and the curtailments that should be applied to the quantities of water supplied for urban use or for irrigation use, when storage in the individual dams falls to specified volumes, are provided in the report.

LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY

SYSTEM YIELD ANALYSIS

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ADDENDA

ABBREVIATIONS

/a	per annum
DWAF	Department of Water Affairs and Forestry
EC	Ecological Category
ECA	Environmental Conservation Act
EWR	Environmental Water Requirement
FSC	Full supply capacity
ha	hectare
IFR	Instream flow requirements
kl	kilolitre
km	kilometre
l/s	litres per second
LTCC	long-term characteristic curves
m^3	cubic metres
MAP	mean annual precipitation
MAR	mean annual runoff
Ml/d	megalitres per day
Mm^3/a	million cubic metres per year
NPV	Net Present Value
p.a.	per annum
QRWSFS	Queenstown Regional Water Supply Feasibility Study
REC	Recommended Ecological Category
Sc	Scenario
$t/km^2/a$	tons per square kilometre per annum
t/m^3	tons per cubic metre
UKBS	Upper Kei Basin Study
URV	Unit Reference Value
V_t	volume after t years
V_{50}	volume after 50 years
WARMS	Water Use and Authorisation Management System
WRSA	Water Resources Situation Assessment
WRYM	Water Resources Yield Model

LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY

SYSTEM YIELD ANALYSIS

1. INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The Lukanji Regional Water Feasibility Supply Study, commissioned by the Department of Water Affairs and Forestry (DWAF), commenced in March 2003. The main aim of the study is to review the findings of earlier studies and, taking cognisance of new developments and priorities that have been identified in the study area, to make a firm recommendation on the next augmentation scheme to be developed for the supply of water to the urban complexes of Queenstown and Sada following the implementation of a suitable water demand management programme. In addition, proposed operating rules will be identified for the existing water supply schemes and the augmentation scheme to provide for the ecological component of the Reserve and the equitable distribution of water between rural domestic and urban water supplies and irrigators.

In a previous study, the Queenstown Regional Water Supply Feasibility Study (QRWSFS) (DWAF, 1997), several alternative phased schemes were identified to meet the predicted water requirements of Queenstown and Sada/Whittlesea to the year 2045. The future water requirements were projected from recorded water use to 1995, and the schemes were compared on the basis of their calculated Net Present Values (NPVs). The scheme with the lowest NPV was found to be one for which the proposed first phase was the construction of a pipeline from Xonxa Dam to Queenstown.

The actual growth in water requirements since 1995 has been significantly lower than predicted and the unutilised Oxkraal Dam has become available to augment the supply to existing users. In view of this, it was not certain that a scheme that would entail the construction of the Xonxa Pipeline as its first phase would still be the most advantageous. Consequently, a number of alternative schemes were again investigated with the results presented in this report.

The current study includes the determination of environmental flow requirements, and updating predictions of irrigation and urban water requirements. The results of these investigations have been used in the Water Resources Yield Model (WRYM) to update the previous estimates of the quantities of water available from surface water resources for the supply to Queenstown and to determine operating rules for the Lukanji Water Resources System. Factors such as the likely impacts of the implementation of the Reserve on the yields of dams, and expected future irrigation water requirements, have been taken into account in determining the quantities of water available from the various sources.

The WRYM was originally configured to represent the Upper Kei Basin Water Resources System as part of the QRWSFS. This original system model was modified for the present study. This document describes the changes made to the model and the analyses that were carried out by means of the modified version.

1.2 THE SYSTEM MODEL

The original configuration of the WRYM to represent the Upper Kei Basin was based on information that was available in 1995. A shortcoming of the model was that the effect on the assurance of supply to irrigators of supplying more urban water out of the system could not be adequately assessed. One of the objectives of the system analysis carried out under the present study was, therefore, to check and adjust the configuration, if necessary, of the WRYM produced for the QRWSFS to suit the requirements of the present study. The development of the current system model was originally worked on by DWAF but was handed over to Ninham Shand Consulting Services for completion. The current model, designated the WRYM QUEE20, has been configured to be representative of the Upper Kei Basin Catchment for the year 2020.

To verify the accuracy of the model in terms of meeting the requirements of the present study, comparisons were made between the modelled domestic and agricultural demands on the system and projected demands for the years 2020 and 2045. Particular attention was given to the irrigation schemes in the study area, some of which are no longer fully utilised. In addition, the modelled net storage capacities of the Upper Kei basin reservoirs were compared to projected values based on recorded measurements of sediment accumulation and the likely future impact of sedimentation. Finally, the hydrology for the system was checked by comparing the cumulative flows in the current system model to the naturalised mean annual runoff (MAR) values as determined from the QRWSFS model. The relationship between the unit runoff and mean annual precipitation (MAP) for each sub-catchment was also checked.

For the current system model, the original model was adjusted to include instream flow requirements (IFR). Five IFR sites were identified in the Upper Kei Basin for which the requirements, shortfalls and impact on yields were determined. These analyses are discussed in detail in this report.

Once the model had been checked and updated, it was used to perform a system yield analysis to establish the historical firm yield of the individual dams, run-of-river yield and the yield of the integrated system. Based on the results of that analysis, operating rule scenarios for the bulk water supply system were determined. A stochastic analysis was also carried out for the selected operating scenarios in order to attach probabilities to the system yields.

2. INFRASTRUCTURE REASSESSMENT

2.1 DAMS

2.1.1 Available Data

The existing reservoirs in the Upper Kei Basin that were included in the current system analysis study are listed in Table 2.1 below, together with their respective characteristics (DWAF, 1993a). Two possibilities for augmenting the water supply to Queenstown, namely Stitchel and Waklyn Dams, were also included in the system model. Shiloh Dam, which has a low capacity of 0,89 Mm^3, was not included in the model as it is not currently in use and has a very small yield. The agricultural demands on the latter dam were, however, included in the system analysis model by compounding them with those of Oxkraal Dam.

TABLE 2.1 PHYSICAL CHARACTERISTICS OF EXISTING AND PROPOSED RESERVOIRS IN THE UPPER KEI BASIN (DWAF 1993A)

RESERVOIR	DATE OF CONSTRUCTION	TOTAL CATCHMENT AREA (A) (1) km^2	MAR	FULL SUPPLY HEIGHT (1) m above msl	FULL SUPPLY AREA (1) km^2	FULL SUPPLY CAPACITY Mm^3	DEAD STORAGE Mm^3	REFERENCE
Waterdown	1958	606	38	1170.64	2.61	38.61	1.34	DWAF, 1993a
				1170.64	2.61	38.39	1.08	1988 basin survey
Oxkraal	1989	314.6	15	1127	2.2	17.8	0	DWAF, 1993a
				1127	2.13	15.68	0	1989 basin survey
Xonxa	1974	1460	42	931.5	13.17	157.6	-	DWAF, 1993a
				931.48	12.88	121.1	5.24	2002 basin survey
Bonkolo	1908, raised 1.2 m in 1935	102	2.5	1137.82(1)	1.1	7.19, 8.25	0	DWAF, 1993a
				1137.82	1.394	6.95	0	1994 basin survey
Doring River	1969	295	9	1252.7	3.67	23.44	-	DWAF, 1993a
				1252.68	3.59	17.93	0	1998 basin survey
Bushmanskrantz	1983	75.8	-	1310	0.55	4.72	0	DWAF, 1993a
Thrift	1974	131	-	-	-	2.9	0	DWAF, 1993a
Limietskloof	1975	42	-	1375	0.225	0.877	-	DWAF, 1993a
Thibet Park (proposed)		-	-	-	-	-	0	DWAF, 1993a
Lubisi	1968	1009	41	1017.4	11	157	-	DWAF, 1993a
				1017.42	11.29	158.23	0.23	1965/8 basin survey
Stitchel (proposed)	-	-	-	982	10.75	140	0	DWAF, 1993a
Waklyn (proposed)	-	-	-	1012	12.25	164	0	DWAF, 1993a

1. From the 1994 Dam Basin Survey. The value of 1113.7 m in DWAF 1993a was assumed incorrect.

2.1.2 Reassessing Net Capacities

To check the net storage capacities of the Upper Kei Basin reservoirs used in the current system model, the net storage capacities were recalculated by subtracting the dead storage and sediment volume from the reservoir's original full supply capacity. The values of dead storage and full supply capacity were taken from the DWAF 1993a report. The projected values of the sediment volume for each dam, however, was calculated.

The method adopted to calculate the projected sediment volume in a dam was that developed by A Rooseboom and documented in the 1975 Department of Water Affairs and Forestry report, *Sedimentneerlating in Damkomme*. This method is based on the calculation of the sediment volume averaged over 50 years (V_{50}) and takes into account the trap efficiency of the reservoir and silt consolidation. The value of sediment yield ($t/km^2/a$) selected for each dam was taken from Rooseboom's estimated average sediment yield (Table 16.3 of DWAF 1993a report). These values of sediment yield were checked and validated by Ninham Shand using observed data (provided by DWAF) for Waterdown, Xonxa and Doring River Dams.

An example of the method used for the calculation of the sediment volume (for 2020) is given below for Waterdown Dam.

Waterdown Dam characteristics

Original full supply capacity : FSC	=	38,61 Mm^3
Dead storage : DS	=	1,34 Mm^3
Total catchment area : A	=	606 km^2
Mean annual runoff : MAR	=	38 Mm^3/a
Date of construction	=	1958

Sediment properties

Assumed sediment density (Rooseboom) : ρ	=	1,35 t/m^3 (DWAF, 1999)
Estimated sediment yield (Rooseboom : SY	=	50 $t/km^2/a$ (DWAF, 1993b)

Calculation procedure

The first step is to calculate the sediment volume averaged over 50 years (V_{50}) using the following equation :

$$V_{50} = (SY*A*50\ yrs)/(\rho*10^6) = 1{,}12\ Mm^3$$

To take into account the consolidation of silt in the reservoir, Figure 2.1 (from Rooseboom, 1975) is used. By knowing the consolidation period (t), the ratio of Volume at (t) years to V_{50} (V_t/V_{50}) can be read off the y-axis of the graph using the "gemiddelde kurwe" envelope curve.

Consolidation period : t	=	2020 - 1958 = 62 years
V_t/V_{50}	=	1,07

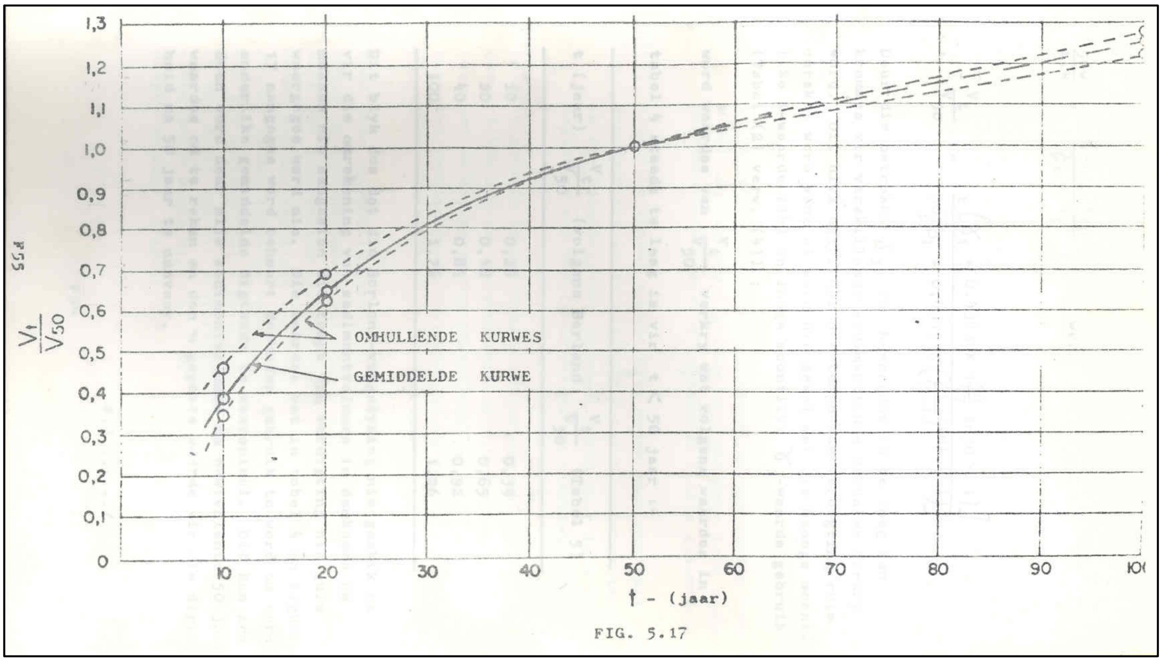


Figure 2.1 Sediment consolidation curve (Rooseboom, 1975)

To determine the trap efficiency of the reservoir, Figure 14 of the Rooseboom 1975 report is used (Figure 2.2. Here the ratio of FSC to the MAR of the reservoir (x-axis) is required to determine the "Brune Factor" (y-axis), which refers to the percentage of sediment trapped by the reservoir. The value can be read off the graph using the "Mediaan-kurwe (Brune)" envelope curve.

FSC/MAR	=	38,61/38	= 1,02
% sediment trapped	=	100% (Brune factor = 1,00)	

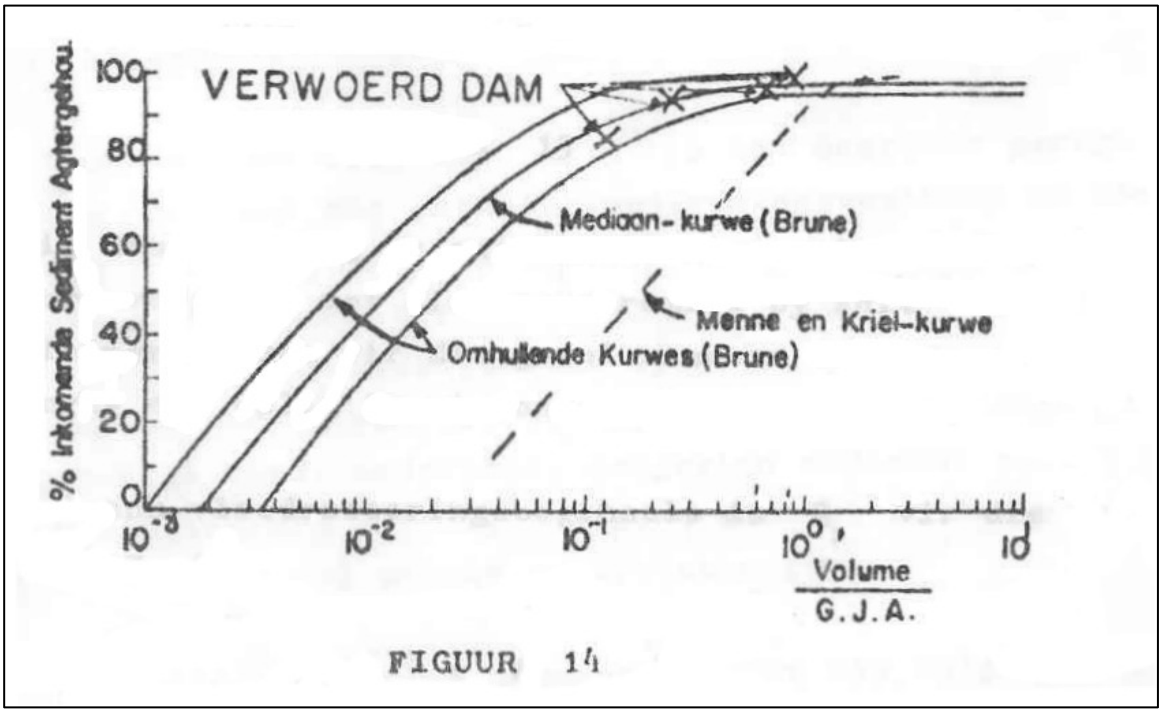


Figure 2.2 Trap efficiency curve to determine the Brune Factor (Rooseboom, 1975)

The volume of sediment for 2020 including the effects of consolidation and trap efficiency of the reservoir can now be calculated using the equation below :

$V_{2020} = V_{50}*(V_t/V_{50})*\text{Brune factor} = 1.12*1.07*1.00 = 1.14\ 10^6 m^3$

Therefore,

Net full supply capacity = FSC - DS - V_{2020} = 38.61 - 1.34 - 1.14 = 36.07 $10^6 m^3$

The estimated values of sediment volume and net storage capacity for the Upper Kei Basin reservoirs for years 1992, 2010, 2020 and 2045 are shown in Table 2.2. It should be noted that the net full supply capacities for Bushmanskrantz, Thrift, Limietskloof and Thibet Park Dams could not be calculated because insufficient information was available for these dams. Also, the impact of sedimentation was not considered for the farm dams in the system because any sedimentation or loss of capacity will increase spillage into the rest of the system.

TABLE 2.2 TABLE COMPARING SEDIMENT VOLUME

DAM	MEASURED SEDIMENT YIELD	ESTIMATED AVERAGE SEDIMENT YIELD	V_{50}	TRAP EFFICIENCY (BRUNE FACTOR)	1992				2010				2020				2045			
					SILTATION PERIOD	(V_t/V_{50})	SILT VOLUME	NET STORAGE	SILTATION PERIOD	(V_t/V_{50})	SILT VOLUME	NET STORAGE	SILTATION PERIOD	(V_t/V_{50})	SILT VOLUME	NET STORAGE	SILTATION PERIOD	(V_t/V_{50})	SILT VOLUME	NET STORAGE
	$t/km^2/a$	$t/km^2/a$	10^2m^3		years		10^2m^3	10^2m^3	years		10^2m^3	10^2m^3	years		10^2m^3	10^2m^3	years		10^2m^3	10^2m^3
Waterdown	12..	50..	1,12..	1,0	34	0,88	1,0	36,3	52	1,0	1,1	36,1	62	1,07	1,2	36,1	87	1,19	1,3	35,9
Oxkraal	-	500..	5,83..	1,0	3	-	-	-	21	0,7	3,8	14,0	31	0,82	4,8	13,0	56	1,03	6,0	11,8
Xonxa	881..	900..	48,67..	1,0	18	0,62	30,2	127,4	36	0,9	43,3	114,3	46	0,97	47,2	110,4	71	1,11	53,9	103,7
Bonkolo	-	800..	3,02..	1,0	84	1,178	3,6	4,7	102	1,3	3,8	4,4	112	1,32	4,0	4,3	137	1,43	4,3	3,9
Doring River	646..	700..	7,65..	1,0	23	0,7	5,4	18,1	41	0,9	7,0	16,4	51	1,02	7,8	15,6	76	1,13	8,6	14,8
Bushmans-krantz	-	100..	0,28..	1,0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thrift	-	100..	0,49..	1,0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Limietskloof	-	100..	0,16..	1,0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Thibet Park weir	-	-		1,0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lubisi	776..	800..	29,9..	1,0	24	0,72	21,5	135,5	42	0,9	28,1	128,9	52	1,03	30,6	126,4	77	1,14	33,9	123,1

For Bonkolo Dam, a different approach to that of Rooseboom was used for the calculation of sediment volume. The reason was that the first basin survey was undertaken at Bonkolo Dam in 1994 and gave a surveyed full supply capacity of 6,95 Mm^3. Using Rooseboom's method of calculating sediment yield (Rooseboom, 1975; DWAF, 1993a), i.e. taking into account sediment consolidation and the trap efficiency of the reservoir, a sediment yield could be calculated based on the documented initial 1908 value of reservoir storage and the surveyed 1994 value. The new value of sediment yield between 1908 and 1994 was found to be 300 $t/km^2/a$. This differs quite substantially from Rooseboom's suggested value of 800 $t/km^2/a$ (DWAF, 1993a). The original 800 $t/km^2/a$ would result in a loss of storage due to sedimentation by 1992 of 3.6 million m^3 (see Table 2.2) much more than the actual loss of storage to 1994 of about 1,3 million m^3 (obtained from deducting 6,95 from 8,25 in Table 2.1). A reduced sediment yield of 300 – 600 $t/km^2/a$ is used in later tables such as Table 2.5 and explained in the following sections.

In the report on the sedimentation studies carried out for the Upper Kei Basin Study (DWAF, 1993a), the vegetation cover around Bonkolo Dam is described as "good" in comparison to that around the relatively nearby Xonxa and Doring River Dams, where the vegetation is described as "degraded". The two latter dams were described by Rooseboom to have relatively high sediment yields of 900 $t/km^2/a$ and 700 $t/km^2/a$, respectively, which would be expected for areas that are degraded. The value of 300 $t/km^2/a$ for Bonkolo therefore seems reasonable seeing that the land is not yet as degraded as for the other two dams. The sediment volume for Bonkolo Dam was therefore determined by calculating the volume of sediment obtained for a 300 $t/km^2/a$ sediment yield from the construction date of 1908 and an original full supply capacity of 8,25 Mm^3 (DWAF, 1993b).

Based on Figure 2.3, however, it appears possible that for future scenarios the area around Bonkolo Dam could further degrade. Also, a geological survey of the area shows a large amount of alluvium surrounding the dam. To be conservative, therefore, it was decided to increase the total sediment yield from 1994 onwards, starting from the surveyed full supply capacity of 6,95 Mm^3/a, by an additional 300 $t/km^2/a$, thus giving a total sediment yield of 600 t/km^2. This value sits approximately midway between the earlier calculated value of 300 t/km^2 and Rooseboom's estimated value of 800 t/km^2. It is important to note that a single sediment yield of 600 t/km^2 starting from the surveyed full supply capacity was not the approach taken to determine the future sediment volumes for 2010, 2020 and 2045, as this approach does not allow for further consolidation of the sediment that has been building up in the dam at a rate of 300 t/km^2 since its construction in 1908. Instead, two sediment volumes increasing at the same rate of 300 t/km^2 but at different stages of consolidation were added together to determine the total volume of sediment accumulated in Bonkolo Dam for the projected years. These cumulated values are shown in Table 2.3.

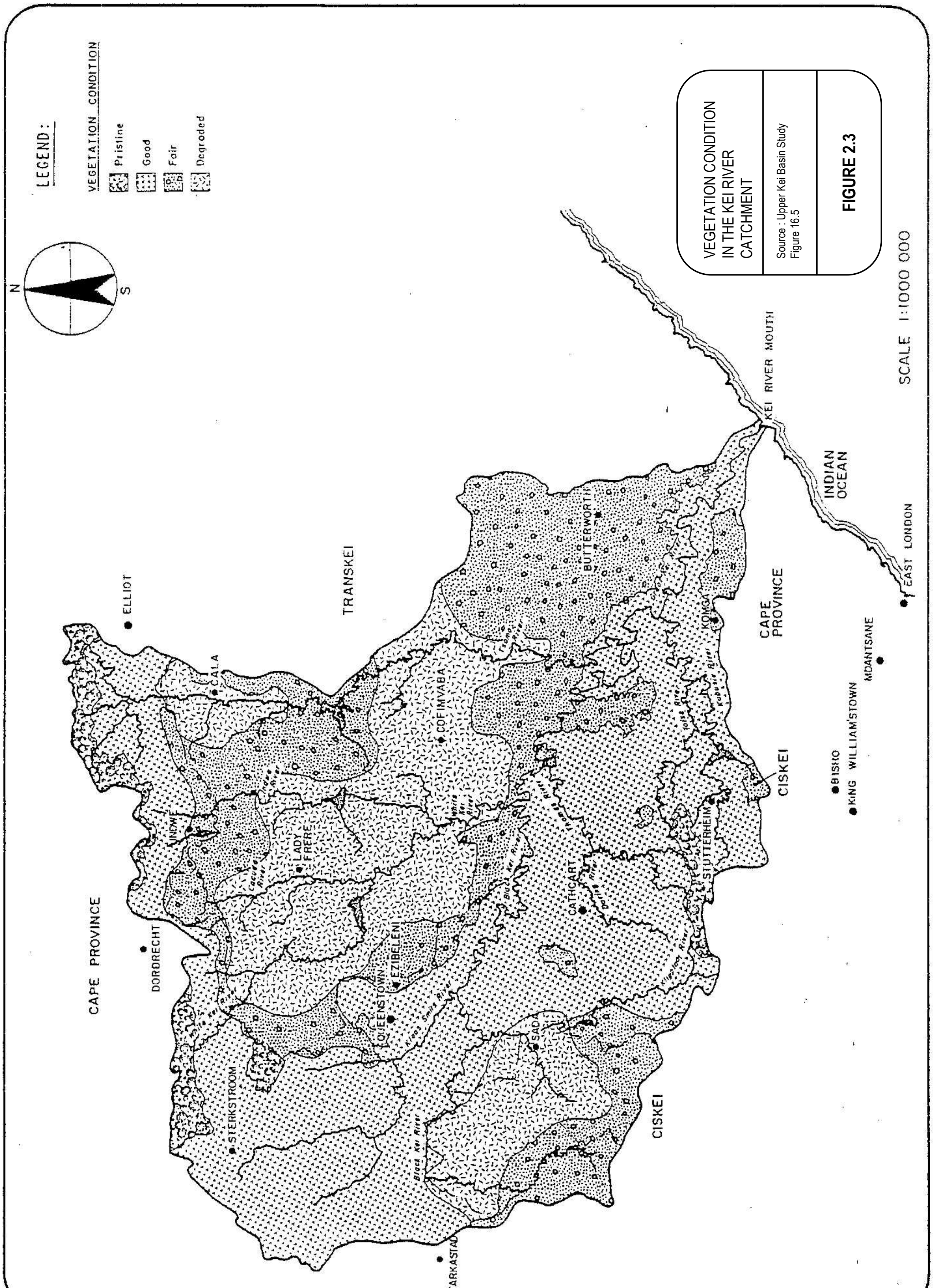

VEGETATION CONDITION IN THE KEI RIVER CATCHMENT
Source : Upper Kei Basin Study Figure 16.5
FIGURE 2.3
LEGEND:
VEGETATION CONDITION
Pristine
Good
Fair
Degraded
N
S
SCALE 1:1000 000
KEI RIVER MOUTH
INDIAN OCEAN
EAST LONDON
CAPE PROVINCE
TRANSKEI
CISKEI
ELLIOT
CALA
BUTTERWORTH
COFIMVABA
LADY FRERE
INDWE
DORDRECHT
CATHCART
EZIBELENI
QUEENSTOWN
STERKSTROOM
TARKASTAD
STUTTERHEIM
KOMGA
MDANTSANE
KING WILLIAMSTOWN
BISHO
SADA

TABLE 2.3 TABLE COMPARING SEDIMENT VOLUME DERIVED IN THE CURRENT STUDY WITH THOSE DERIVED IN PREVIOUS STUDIES

RESERVOIR	COMPARISON OF SEDIMENT VOLUME FOR 2010		COMPARISON OF SEDIMENT VOLUME FOR 2020		COMPARISON OF SEDIMENT VOLUME FOR 2045	
	CALCULATED (ROOSEBOOM METHOD)	ROOSEBOOM (DWAF, 1993A)	CALCULATED (ROOSEBOOM METHOD)	QRWSFS (INTERPOLATED)	CALCULATED (ROOSEBOOM METHOD)	QRWSFS
	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3
Waterdown	1,14	1,2	1,2	1,21	1,33	1,36
Oxkraal	3,85	4,0	4,78	5,88	5,97	7,54
Xonxa	43,31	45,2	47,21	44,27	53,92	55,1
Bonkolo	2,07 (1)	4,7	2,34		2,77	-
Doring River	7,04	7,3	7,8	7,68	8,6	8,85
Bushmanskrantz	-	0,23	-	0,24	-	0,3
Thrift	-	0,44	-	0,47	-	0,55
Limietskloof	-	0,14	-	-	-	-
Lubisi	28,1	28,7	30,64	39,07	33,93	44,9

1. Sediment volume for Bonkolo Dam was calculated using a sediment yield of 300 t/km^2 from 1908 to 1994 and 600 t/km^2 from 1994 to 2010, 2020 and 2045. This differs from Rooseboom's method that uses a sediment yield of 800 t/km^2.

2.1.3 Comparison with Earlier Net Storage Volumes

The net storage capacities of the Upper Kei Basin reservoirs were recalculated to include the effect of future sedimentation on storage. Rooseboom's method for the calculation of the sediment volume was adopted and applied to years 2010, 2020 and 2045. To check the validity of Rooseboom's method, the calculated values of sediment volume were compared to Rooseboom's published values of sediment volume for 2010 (DWAF, 1993a), and to those used in the Queenstown Regional Water Supply Feasibility Study (QRWSFS) (DWAF, 1996a) for 2020 and 2045. These values can be viewed in Table 2.3.

The calculated values of sediment volume compare well with those of Rooseboom (DWAF, 1993a) with the exception of Bonkolo Dam. As explained under Section 2.1.2, the sediment volume for Bonkolo Dam was calculated using a lower sediment yield (300 t/km^2 from 1908 to 1994 and 600 t/km^2 from 1994 to 2010, 2020 and 2045) than that suggested by Rooseboom (800 t/km^2). For years 2020 and 2045, the calculated values of sediment volume compare well with those used previously with the exception of Lubisi Dam, which is shown to have a 20 - 25% higher sediment volume in the previous calculations. It is thought that this discrepancy may have occurred as a result of a total catchment area of 1 304 km^2 being used in the previous calculations in comparison to the effective catchment area of only 1 009 km^2 used in the current study.

The recalculated values of net storage capacity were checked against the net storage capacities used in the current system model (WRYM QUEE20), which were originally inputted by DWAF.

From Table 2.4 below, it can be seen that the projected net storage values obtained from Waterdown, Oxkraal, Xonxa and Bonkolo Dams compare favourably to the modelled values. The only exception is Lubisi Dam, which has a higher modelled net storage value than the recalculated value. This is because for the running of the model, the impact of sedimentation was not considered for Lubisi Dam as it was not seen to affect the yield of the system supplying Queenstown.

TABLE 2.4 COMPARISON OF MODELLED (WRYM QUEE20) AND PROJECTED NET STORAGE CAPACITIES

RESERVOIR	MODELLED (WRYM QUEE20) FOR 2020					PROJECTED VALUES FOR 2020 (ROOSEBOOM 1975 METHOD)
	FULL SUPPLY HEIGHT m amsl	FULL SUPPLY AREA km^2	FULL SUPPLY CAPACITY Mm^3	DEAD STORAGE Mm^3	NET STORAGE Mm^3	NET STORAGE Mm^3
Waterdown	1 170,64	2,61	37,31	0	37,31	36,07
Oxkraal	1 127	2,13	15,68	2,42	13,26	13,02
Xonxa	931,48	12,88	115,86	7,66	108,20	110,39
Bonkolo	1 137,82	1,39	6,95	0,94	6,01	5,91
Doring River	1 252,68	3,59	17,93	0	17,93	15,64
Bushmanskrantz	1 310	0,51	4,70	0	4,70	-
Thrift	8	0,77	2,6	0	2,6	-
Limietskloof	1 375	0,23	0,88	0	0,88	-
Lubisi	1 017,42	11,29	157,89	0	157,89 (1)	126,36
Stitchel	982	10,75	140	0	140	-
Waklyn	1 012	12,25	164	0	164	-

1. The effect of sedimentation on the net storage of Lubisi Dam was not evaluated because it did not affect the yield of the system supplying Queenstown.

2.2 FULL SUPPLY CAPACITIES ADOPTED FOR THE 2020 AND 2045 ANALYSES

The storage capacities of many of the dams in the Lukanji study area are being reduced significantly by siltation. For this reason, the latest available gross storages determined from basin surveys were used in preference to the original dam survey information. It was assumed that all the siltation subsequent to the basin survey occurred near the bottom of the dam, rather than higher up in the dam basin. The net available storage was calculated using:

- the full supply capacities given in Table 2.1.
- deducting the inaccessible ("dead") storage below the drawoff of the lowest supply pipe.
- deducting an estimate of the silt likely to have accumulated since the last survey, based on linear interpolation of the values in Table 2.3.

In the WRYM the latest dam basin survey details specifying the storage and surface area for different contour levels were used (see Annexure B) and the reduction in storage from gross to net was simulated by introducing a zone of water at the bottom of the dam that was inaccessible to all consumers. The upper boundary of this "dead + siltation" zone for 2005, 2010, 2020 and 2045 is specified in the last four columns of Table 2.5, just to the right of the full supply level.

TABLE 2.5 DAM STORAGES (GROSS AND NET) AND LEVEL USED FOR THE WRYM ANALYSES

DAM	GROSS Mm^3	DEAD Mm^3	SURVEY DATE	SILTATION SINCE SURVEY (TABLE 2.2)				DEAD STORAGE PLUS SILTATION (Mm^3)				LEVELS (mamsl)				
												FULL	DEAD + SILTATION			
				2005	2010	2020	2045	2005	2010	2020	2045		2005	2010	2020	2045
Waterdown	38,39	1,08	1988	0,16	0,21	0,24	0,37	1,08 (1)	1,08	1,08	1,45	1 170,64	1 142,67	1 142	1 142,67	1 144,13
Oxkraal	15,68	0,00	1989	2,93	3,85	4,78	5,97	2,93	3,85	4,78	5,97	1 127,00	1 117,61	1 118	1 119,78	1 120
Xonxa 1	121,10	5,24	2002	0,00	5,84	9,74	16,45	5,24	11,08	14,98	21,69	931,48	914,33	916	917,73	919,14
Xonxa 2												931,48	N/A (2)			
Bonkolo	6,95	0,00	1992	0,53	0,74	1,01	1,44	0,53	0,74	1,01	1,44	1 137,82	1 129,48	1 130	1 130,89	1 131,75
Doring River	17,93	0,00	1998	0,66	1,13	1,89	2,69	0,66	1,13	1,89	2,69	1 252,68	used 2020 values			1 246,34
Lubisi	158,23	0,23	1968	24,75	28,10	30,64	33,93	24,98	28,33	30,87	34,16	1 017,42	used 2020 values			1 000,48

1. The estimated increase in siltation from 1988 is 0,2 Mm^3. Historically the siltation accumulated below the dead storage and the future siltation was also assumed to merely deplete the dead storage zone and not reduce the net storage.
2. Storage elevation curve adjusted instead - see Annexure B3. In 2020 these curves gives a gross storage of 112,34 Mm^3 and a dead storage below the outlet level of 1,21 Mm^3.

2.3 PIPELINES

Two pipelines are currently in place to provide a water supply to Queenstown, one from Waterdown Dam and the other from Bonkolo Dam. The Waterdown-Queenstown pipeline also supplies water via an offtake to Sada and the villages. The current capacity of the Waterdown-Queenstown pipeline is 11 Ml/d (5 Mm^3/a), but could be increased to as much as 23 - 25 Ml/d if an additional booster station is constructed to supply Sada. With this in place the pump station supplying Queenstown, which is located downstream of the Sada offtake, will be able to operate at full capacity instead of having to be throttled back to increase pressure in the pipeline supplying Sada.

The current capacity of the Bonkolo-Queenstown pipeline is 7,8 Mm^3/a.

3. URBAN AND RURAL DOMESTIC WATER DEMAND PROJECTIONS

Table 3.1 below shows the projected urban and rural domestic water requirements for the Lukanji region over a 55 year period. The source of the historical data and the derivation of the estimates of future water requirements are described in Appendix 1 to the Main Report of this study.

TABLE 3.1 PROJECTED WATER REQUIREMENTS FOR QUEENSTOWN AND RURAL VILLAGES

AREA	WATER REQUIREMENTS (Mm^3/a)						
	1990	**1995**	**2003**	**2005**	**2010**	**2020**	**2045**
Queenstown complex	5,58	7,60	7,60	7,85	8,10	8,80	10,30
Sada and rural villages	1,23	1,40	2,40	2,41	2,44	2,50	3,00
Ilinge and Macibini villages	0,54	0,64	2,18	2,20	2,20	2,20	2,20
Totals	**7,35**	**9,64**	**12,18**	**12,46**	**12,74**	**13,50**	**15,50**

The modelled water requirements obtained from the WRYM QUEE20 (2020) and QUEE45 (2045) scenarios are listed in Table 3.2 together with those calculated from previous studies. The modelled water requirements can be seen to be almost exactly correlate with the estimated values, thus validating the domestic demands used in the model. The growth rates were based on the predicted rates in the National Water Resources Strategy (NWRS).

TABLE 3.2 COMPARISON OF PROJECTED AND MODELLED URBAN AND RURAL DOMESTIC WATER REQUIREMENTS

AREA	PROJECTED WATER REQUIREMENTS (Mm^3/a)		MODELLED WATER REQUIREMENTS (Mm^3/a)		
	2020	**2045**	CHANNEL NO.	QUEE20 SCENARIO	QUEE45 SCENARIO
Queenstown complex	8,80	10,30	77	8,79	10,30
Sada and rural villages	2,50	3,00	71	2,49	3,00
Ilinge and Macibini villages	2,20	2,20	323	2,20	2,20
Totals	**13,50**	**15,50**	**-**	**13,48**	**15,50**

4. AGRICULTURAL DEMAND RE-ASSESSMENT

4.1 EXISTING IRRIGATION SCHEMES OF THE UPPER KEI BASIN

Crops grown under irrigation in the Upper Kei Basin include lucerne, maize, pasture, and small areas of other crops, mostly vegetables. Irrigation in this region, which is generally by sprinkler, can be classified as either "scheduled" or "opportunistic". "Scheduled" irrigation refers to the scheduled areas under irrigation that form part of formally recognised irrigation schemes, and "opportunistic" irrigation refers to the irrigation of opportunistic areas that will only take place when water is available. Described below are the nine river reaches in the Upper Kei Basin along which irrigation occurs. Where formal irrigation schemes exist, these are mentioned. The irrigation along each reach has been allocated a name for simplification purposes. These names are consistent with those used in the Upper Kei Basin Study (DWAF, 1993d) and Queenstown Regional Water Supply Feasibility Study (DWAF, 1996c).

- **Upper Klipplaat Irrigation Scheme**

This scheme provides irrigation to opportunistic areas upstream of Waterdown Dam along the upper reaches of the Klipplaat River.

- **Klipplaat River Government Water Scheme**

The Klipplaat River Government Water Scheme is probably the most important scheme in the Upper Kei Basin, with Waterdown Dam as its main source of water (DWAF, 1993b). This scheme supplies water for domestic use to the urban complexes of Queenstown/ Mlungisi/eZibeleni (augmented by Bonkolo Dam) and Sada/Whittlesea. The Klipplaat River Government Water Scheme also forms part of a formal irrigation scheme that supplies water to scheduled areas along the Klipplaat River to its confluence with the Black Kei River and along the Black Kei River to its confluence with the White Kei River. Opportunistic irrigation also occurs along this reach where water is extracted directly from the river channel.

- **Doorn River Government Water Scheme**

The Doorn River Government Water Scheme supplies water for domestic use to the town of Indwe, with the Doorn River Dam as its main water source. This scheme also supports a formal irrigation scheme that supplies water from the dam to scheduled areas located along the downstream reaches of the Doorn River. Opportunistic irrigation also takes place where water is extracted directly from the Doorn River.

- **Klaas Smits River Irrigation Scheme**

This scheme supplies water for opportunistic irrigation only, in other words, there is no formal irrigation scheme in place. The opportunistic areas that receive irrigation are located along the Klaas Smits River downstream of Bonkolo Dam up to its confluence with the Black Kei River and along the Bonkolo River upstream of Bonkolo Dam.

- **Zweledinga Irrigation Scheme**

The Zweledinga Irrigation Scheme is a formal irrigation scheme that supplies water to scheduled areas located along the Oxkraal River upstream of Oxkraal Dam. Water for this scheme is supplied from Bushmanskrantz Dam via a piped distribution system (DWAF, 1993b). There is no opportunistic irrigation.

- **Oxkraal Irrigation Scheme**

The Oxkraal Irrigation Scheme is a planned formal scheme that will utilise water from Oxkraal and Shiloh Dams to irrigate scheduled areas along the Oxkraal River downstream of Oxkraal Dam to its confluence with the Klipplaat River. There is no opportunistic irrigation.

- **Ntabethemba Irrigation Scheme**

This scheme provides irrigation to scheduled areas along the Black River upstream of its confluence with the Klipplaat River. Water for irrigation was originally supplied from the Tentergate, Mitford and Glenbrock Dams. More recently, the Thrift and Limietskloof Dams were included in the scheme.

- **Qamata Irrigation Scheme**

The Qamata Irrigation Scheme is a formal irrigation scheme that utilises Lubisi Dam to supply scheduled areas with irrigation along the Indwe River downstream of the dam.

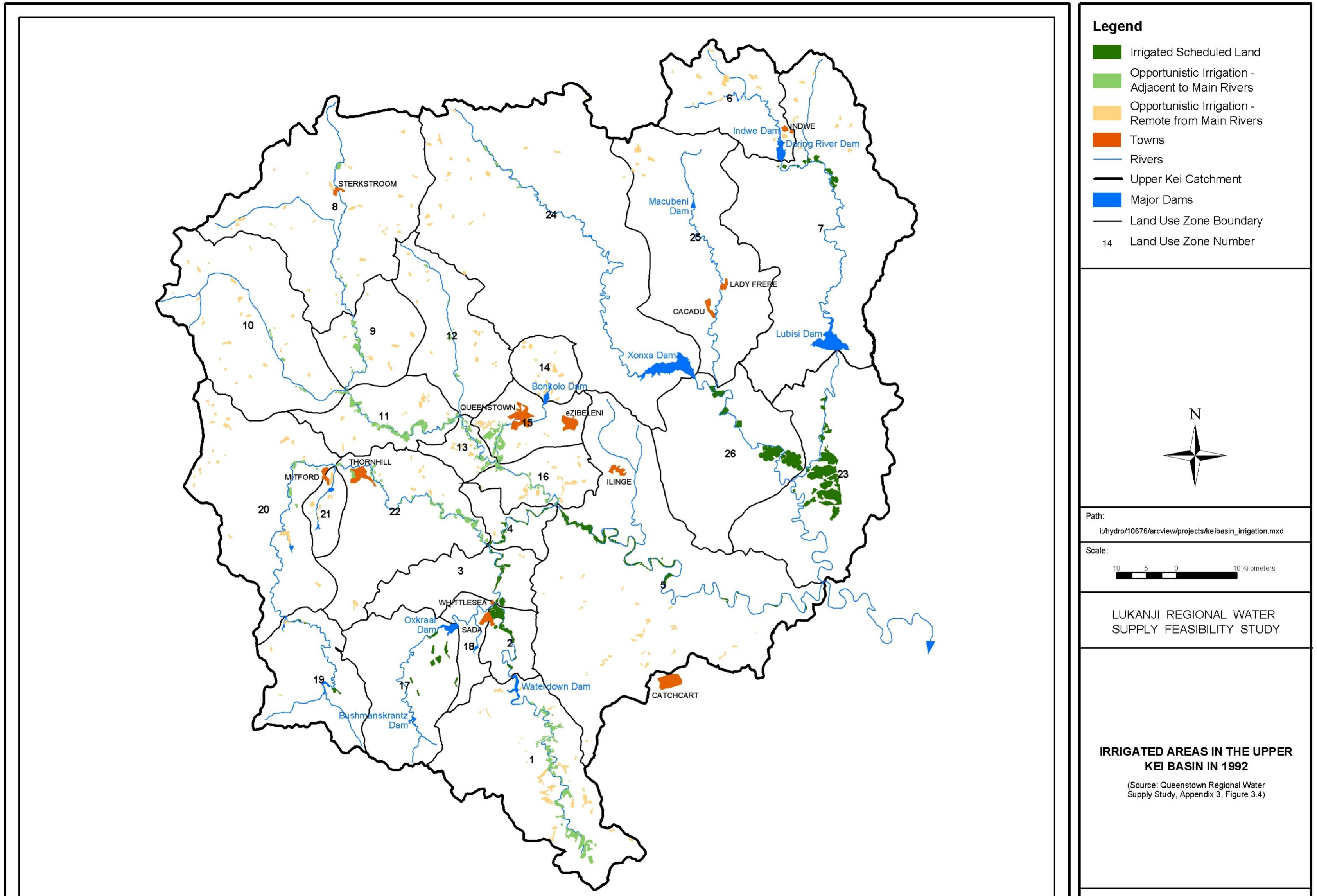
- **Xonxa Irrigation Scheme**

The Xonxa Irrigation Scheme supplies water for scheduled irrigation. Water is supplied from Xonxa Dam and is used by areas along the White Kei River downstream of the dam to its confluence with the Indwe River.

4.2 AVAILABLE SOURCES OF INFORMATION

To verify the accuracy of the model in terms of the agricultural demands in the Upper Kei Basin, the modelled values of irrigation in the DWAF configuration of the model were compared to values obtained from a number of sources. These sources are listed below.

- *The Queenstown Regional Water Supply Feasibility Study – Water Requirements* Report compiled for the Department of Water Affairs and Forestry by the Kei Basin Consulting Engineers (HKS and Ninham Shand). This report forms part of the original study to determine operations in the Upper Kei Basin from which the current study continues. In this report, the current values of scheduled and opportunistic irrigation are summarised by land use zone (see Figure 4.1) and are based on 1985 orthophotos of the Upper Kei Basin that were verified or updated by limited field trips during the first half of 1992. Projected irrigation values are also available in this report for 2045.



Legend
Irrigated Scheduled Land
Opportunistic Irrigation - Adjacent to Main Rivers
Opportunistic Irrigation - Remote from Main Rivers
Towns
Rivers
Upper Kei Catchment
Major Dams
Land Use Zone Boundary
14 Land Use Zone Number
N
Path:
i:/hydro/10676/arcview/projects/keibasin_irrigation.mxd
Scale:
10 5 0 10 Kilometers
LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY
IRRIGATED AREAS IN THE UPPER KEI BASIN IN 1992
(Source: Queenstown Regional Water Supply Study, Appendix 3, Figure 3.4)
STERKSTROOM
INDWE
Indwe Dam
Doring River Dam
Macubeni Dam
LADY FRERE
CACADU
Lubisi Dam
Xonxa Dam
Bonkolo Dam
QUEENSTOWN
eZIBELENI
THORNHILL
MITFORD
ILINGE
WHITTLESEA
Oxkraal Dam
SADA
Waterdown Dam
CATCHCART
Bushmanskrantz Dam
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
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Figure 4.1

It is to be noted that the Queenstown Regional Water Supply Feasibility Study is a follow-on study from the Upper Kei Basin Study that was undertaken for the Department of Water Affairs and Forestry by the Kei Basin Consulting Engineers (HKS and Ninham Shand). The "current" and "future" values of scheduled and opportunistic irrigation presented in the Upper Kei Basin "Water Requirements" report (DWAF, 1993d) are the same as those presented in the *Queenstown Regional Water Supply Feasibility Study* report.

- *The Mzimvubu to Keiskamma Water Management Area - Water Resources Situation Assessment* Report (DWAF, 2001a) compiled by Ninham Shand. This report is based on a desktop or reconnaissance level assessment of the available water resources and water requirements that existing during 1995 in the Mzimvubu to Keiskamma Water Management Area. This report does not address the water requirements beyond 1995 but does provide estimates of the utilisable potential of the water resources after the full development of these resources. The irrigation information is presented as total irrigation per quaternary catchment and is provided in Volume 2 (Appendix F.4) of the report.

- *Lukanji Regional Water Supply Feasibility Study, Appendix 1 : Water Requirements*. This document t was compiled for the current study and presents scheduled irrigation values for Klipplaat River Irrigation Scheme, Oxkraal Irrigation Scheme and Xonxa Irrigation Scheme obtained from discussions with the Department of Agriculture and Chris Hani District Municipality (see Appendix A, Table A.2).

For convenience, the Queenstown Regional Water Supply Feasibility Study (DWAF, 1996) will be referred to as QRWSFS, the Upper Kei Basin Study will be referred to as UKBS, and the *Mzimvubu to Keiskamma Water Management Area - Water Resources Situation Assessment* Report will be referred to as WRSA from this point onwards.

4.3 IRRIGATION POTENTIAL

The "Irrigation Potential" of the soil, as used in the UKBS, describes the potential of the soil to be irrigated in terms of its composition and location relative to the water source. The four classes of irrigation potential are "highly recommended", "recommended", "marginal" and "undefined", with a "highly recommended" soil being that of a good soil located close to the water source. The irrigation potential is a useful indicator of the extent to which an irrigation scheme has been developed and the potential for further development. The values of irrigation potential for the Upper Kei Basin irrigation schemes are shown in Table 4.1. It should be noted that "highly recommended" and "recommended" have been combined together as "recommended and above" for simplification purposes.

TABLE 4.1 IRRIGATION POTENTIAL OF SOILS FOR UPPER KEI BASIN IRRIGATION SCHEMES (UKBS VALUES)

IRRIGATION SCHEME	TOTAL IRRIGATION (ha)	IRRIGATION POTENTIAL (ha)			% IRRIGATION OF "RECOMMENDED +" SOIL
		RECOMMENDED AND ABOVE	MARGINAL	UNDEFINED POTENTIAL	
Upper Klipplaat Irrigation Scheme	496		-	2 900	
Klipplaat River Government Water Scheme	2 376	10 685	5 530	16 215	22,2
Doorn River Government Water Scheme	1 131	-	858	1 425	-
Klaas smits River Irrigation Scheme	5 252	7 374	18 998	16 198	71,2
Zweledinga Irrigation Scheme (near Bushmanskrantz Dam)	259	2 375	2 375	-	10,9
Oxkraal Irrigation Scheme	566	1 375	1 375	-	41,2
Ntabethemba Irrigation Scheme (Upper Black Kei)	?	13 945	21 857	4 037	?
Qamata Irrigation Scheme (downstream of Lubisi Dam)	1 959	1 748	1 748	-	112,1
Xonxa Irrigation Scheme	1 745	1 631	8 669	-	107,0

4.4 REASSESSMENT OF IRRIGATION DEMANDS

Table 4.2 presents the scheduled, opportunistic and total irrigation values for each irrigation scheme in the Upper Kei Basin according to the various sources. The DWAF model values are also included in the table for comparison purposes. The revised model values, in other words, those selected to be used in the current system analysis based on the available information, are presented together with the source from which the value was acquired. The rationale behind the selection of this revised irrigation value for each of the Upper Kei irrigation schemes is presented in the discussion below.

TABLE 4.2 SCHEDULED, OPPORTUNISTIC AND TOTAL IRRIGATION WATER REQUIREMENTS

IRRIGATION SCHEME	SCHEDULED OPPORTUNISTIC IRRIGATION (Mm^3/a) (A)	QRWSFS (1992) (Mm^3/a) (B)	QRWSFS (2020) (Mm^3/a) (C)	WRSA (1995) (Mm^3/a) (D)	APPENDIX 1 (Mm^3/a) (E)	WARMS (Mm^3/a) (F)	QUEE20 INHERITED MODEL VALUES (2020) (Mm^3/a) (G)	REVISED MODEL VALUES (2020) (Mm^3/a)	SOURCE OF REVISED MODEL VALUES
Upper Klipplaat	Scheduled	-	-	5,02	-	5,089	-	-	
	Opportunistic	10,93	10,93		-		10,552	5,086	**(F)**
	Total	**10,93**	**10,93**		**-**		**10,552**	**5,086**	
Klipplaat River Government Water Scheme	Scheduled	13,89	13,89	18,39	14,68	-	14,598	14,68	**(E)**
	Opportunistic	2,45	2,45		-		5,318	2,449	**(C)**
	Total	**16,34**	**16,34**		**14,68**		**19,916**	**17,129**	
Doorn River Government Water Scheme	Scheduled	1,35	1,35	6,41	-	-	1,359	3,812	
	Opportunistic	2,9	2,9		-		2,015	2,899	**(C)**
	Total	**4,25**	**4,25**		**-**		**3 374**	**6,711**	
Klaas Smits River	Scheduled	-	-	32,36	-	-	-	-	
	Opportunistic	29,61	29,61		-		24,833	28,198	**(C)**
	Total	**29,61**	**29,61**		**-**		**24,833**	**28,198**	
Zweledinga (near Bushmanskrantz Dam)	Scheduled	1,5	1,5	0	-	-	1,703	1,703	**(G)**
	Opportunistic	-	-		-		0,14	0	
	Total	**1,5**	**1,5**		**-**		**1,843**	**1,703**	
Oxkraal	Scheduled	-	3,24	0	4,32	-	4,265	4,32	**(E)**
	Opportunistic	-	-		-		0,331	0	
	Total	**0**	**3,24**		**4,32**		**4,596**	**4,32**	
Ntabethemba (Upper Black Kei)	Scheduled	-	3,93	2,11	-	1,657	-	-	
	Opportunistic	12,93	10,93		-		13,291	13,291	**(G)**
	Total	**12,93**	**14,68**		**-**		**13,291**	**13,291**	
Qamata (d/s Lubisi Dam)	Scheduled	16,69	16,69	2,75	-	-	16,701	16,701	**(G)**
	Opportunistic	-	-		-		-	-	
	Total	**16,69**	**16,69**		**-**		**16,701**	**16,701**	
Xonxa	Scheduled	14,84	14,84	5,22	11,25	-	11,295	11,25	**(E)**
	Opportunistic	3,71	3,71		-		3,315	3,71	**(C)**
	Total	**18,55**	**18,55**		**11,25**		**14,61**	**14,96**	

4.4.1 Upper Klipplaat Irrigation Scheme

For this scheme the total QRWSFS irrigation value of 10,93 Mm^3/a, on which the DWAF model value is based, is about double the value of total irrigation taken from the WRSA report (5,02 Mm^3/a). To check this discrepancy, the total irrigation value for this scheme was checked against that obtained from the WARMS database, which showed a close correlation with the WRSA value. The revised model value used for the current system analysis was therefore obtained by adjusting the inherited model value downwards to be representative of the WARMS value, in other words, a value of 5,09 Mm^3/a was selected.

4.4.2 Klipplaat River Government Water Scheme

The Klipplaat River Government Water Scheme was completed in 1957 and originally enabled the irrigation of 2 300 ha of land (DWAF, 1993b). In 1995, 1 905 ha of land was reported to be scheduled for irrigation, of which 1 820 ha was being irrigated (DWAF, 2001a). According to the QRWSFS (DWAF, 1996c), this scheme is not expected to be increased beyond its current requirements in the future.

This scheme provides both scheduled and opportunistic irrigation. The revised model value for total scheduled irrigation to be used in the current system was obtained by the upward adjustment of the DWAF model value to the Appendix 1, in other words 14,68 Mm^3/a. The Appendix 1 values are seen to take preference over other source values of scheduled irrigation, as they are the most recently approved.

For opportunistic irrigation, the DWAF model values were adjusted downward to be representative of the QRWSFS future opportunistic irrigation value of 2,45 Mm^3/a. The total value of irrigation for the Klipplaat River Government Water Scheme to be used in the current system analysis is therefore 17,13 Mm^3/a.

4.4.3 Doorn River Government Water Scheme

The Doorn River Government Water Scheme has both scheduled and opportunistic irrigation and is one of the few irrigation schemes that has been proposed for future development. It was reported in the Upper Kei Basin Study (DWAF, 1993b) that at the time of the report, 513 ha of land was scheduled to be irrigated, of which only 182 ha was in fact being irrigated. This latter value was confirmed by the WRSA Report which stated that only 180 ha was being irrigated by 1995. It is also reported in the Upper Kei Basin Study that after Transkei's independence from South Africa in 1974, Transkei took over a large portion (331 ha) of the scheduled area below Doorn River Dam. This land was never irrigated, which accounts for the small area of land irrigated in comparison to the original scheduled area.

According to the QRWSFS, the scheduled irrigation for this scheme is expected to increase to 3,81 Mm^3/a by 2010, with opportunistic irrigation remaining constant at 2,9 Mm^3/a. These future values were considered to be the most realistic and the DWAF model values were factored upward accordingly to be representative of the current system. The total irrigation value for the Doorn River Irrigation Scheme for the current system analysis is therefore 6,71 Mm^3/a.

It should be noted that this scheme is outside of the study area and is not crucial to the operation of the system.

4.4.4 Klaas Smits River Irrigation Scheme

The Klaas Smits Irrigation Scheme consists of opportunistic irrigation only where water is abstracted from the river reach upstream (Bonkolo River) and downstream (Klaas Smits River) of Bonkolo Dam.

The total value of opportunistic irrigation as given in the Upper Kei Basin Study (DWAF, 1993d) and the QRWSFS (DWAF, 1996c) is 29,61 Mm^3/a, with no prospect of future increase. The WRSA study reported a total value of 32,36 Mm^3/a, which could be seen as an over-estimate, given that the irrigated areas were derived from satellite photographs and may have included cultivated land that is not irrigated. The DWAF model value for this scheme was 24,83 Mm^3/a, which appears to be an under-estimate in comparison to the two other sources. The modelled values were therefore adjusted upward according to those reported in the QRWSFS, with the exception of the irrigation demand upstream of Bonkolo Dam (Land Use Zone 14) which was left as the DWAF value.

In the QRWSFS, the opportunistic irrigation demand upstream of Bonkolo Dam and remote from the river was assumed to be 2,09 Mm^3/a, which differs quite significantly from the DWAF model value of 0,675 Mm^3/a. When checking this demand with data from the earlier "Hydrological Data and Sequences" UKBS report (DWAF, 1993c), the DWAF model value appeared to be similar to the UKBS irrigation demand of 0,6 Mm^3/a. To further check this, the WRSA irrigation value for Land Use Zone 14 (forms part of Quaternary S31F) was calculated and found to be 0,96 Mm^3/a (see Annexure A), which can be viewed as an over-estimate for reasons as mentioned above. Based on this information, it was therefore decided that the DWAF model value of 0,675 Mm^3/a should not be changed. This accounts for the small difference in total irrigation between the revised model value of 28,20 Mm^3/a and the QRWSFS value of 29,61 Mm^3/a.

The percentage of "Recommended and Above" soil that is irrigated by this scheme is 71%. This is a reasonable percentage for a developed scheme used for commercial farming.

4.4.5 Zweledinga Irrigation Scheme

The Zwelendinga Scheme is a formal irrigation scheme that was reported in the mid-1990s as irrigating 259 ha in the upper Oxkraal River Valley, with a water requirement of 1,5 Mm^3/a (DWAF, 1993b, DWAF, 2001a). In the DWAF model, this scheme was shown to have both scheduled (1,703 Mm^3/a) and opportunistic irrigation (0,14 Mm^3/a) with a total irrigation value of 1,843 Mm^3/a. The DWAF model value was seen to be too high and was therefore adjusted downward by changing the opportunistic irrigation value to zero (this scheme has scheduled irrigation only) and the scheduled irrigation value to 1,5 Mm^3/a.

The percentage of "Recommended and Above" soil that is irrigated is only 11%.

4.4.6 Oxkraal Irrigation Scheme

The Oxkraal Irrigation Scheme only involves scheduled irrigation and was constructed with the intention of irrigating 556 ha of land for small scale farmers. At the time of the QRWSFS (1996) and the WRSA (2001), however, the lands had not yet been developed, thus explaining the above results of zero irrigation shown in Table 4.2.

According to the QRWSFS (DWAF 1996c), the water requirement for this scheme is expected to increase to a maximum value of 3,24 Mm^3/a by 2010. Appendix 1 shows this future value to be 4,32 Mm^3/a. This latter value is preferable to the QRWSFS value seeing that the values have been most recently agreed by the Chris Hani District Municipality and the Department of Agriculture.

In the DWAF model, the value for total irrigation supplied by the Oxkraal Irrigation Scheme is 4,60 Mm^3/a, with 4,27 Mm^3/a being allocated for scheduled irrigation and 0,331 Mm^3/a being allocated for opportunistic irrigation. To determine the revised model values, the opportunistic irrigation value was changed to zero (this scheme has scheduled irrigation only) and the scheduled irrigation value was adjusted upward in order to correspond with the preferred value of 4,32 Mm^3/a.

The percentage of Recommended and Above soils irrigated is 41%.

4.4.7 Ntabethemba Irrigation Scheme (Upper Black Kei)

Around the time at which the Ciskei gained independence from South Africa (1981), the South African Government constructed the Ntabethemba Irrigation Scheme to irrigate 500 ha of land in the Ntabethemba region with the possibility of developing 900 ha if found to be justifiable (DWAF, 1993b). By 1993, 305 ha of the land had been developed with water being supplied by the Tentergate and Mitford Dams. A further 104 ha was also developed with water supplied from Glenbrock Dam. It was reported in the Upper Kei Basin Study, that although 409 ha of land had been developed in the Ntabethemba region, the dams have only been able to yield enough water to supply 89 ha of land with the optimum quantity of water needed for irrigation (DWAF, 1993b).

Ntabethemba is one of the few irrigation schemes that have been considered for future development. The QRWSFS (DWAF 1996c) indicates that the total irrigation water requirement will increase from the scheduled irrigation value of 12,93 Mm^3/a in 1992 to 14,86 Mm^3/a (of which 10,93 Mm^3/a is scheduled irrigation and 3,93 Mm^3/a is opportunistic irrigation) in 2010.

The DWAF model value for total irrigation for the Ntabethemba Irrigation Scheme is 13,29 Mm^3/a. This value was adopted as the revised model value, as it lies between the "present" (1992) and fully developed "future" (2010) irrigation values as indicated by the QRWSFS.

An area of 1 200 ha of land had been developed for irrigation but about 480 ha of this which was for small scale farmers, has subsequently fallen into disuse.

4.4.8 Qamata Irrigation Scheme (Downstream of Lubisi Dam)

The Qamata Irrigation Scheme is a formal irrigation scheme that supplies scheduled irrigation to small scale farmers downstream of the Lubisi Dam. At the time of the construction of Lubisi Dam in 1966, the original planning for this scheme involved the development of 3 574 ha of land, of which only 2 600 was actually developed. In 1974, the Republic of Transkei gained independence from South Africa and with that, assumed responsibility for the utilisation of Lubisi Dam. Since independence, only 25% (650 ha) of the area has been cropped and the infrastructure fell into a state of ill repair (DWAF, 2001a).

It is reported that DWAF and the Department of Agriculture and Land Affairs are presently rehabilitating the infrastructure (DWAF, 2001a), and a water user association is soon to be created to improve management of the scheme. The QRWSFS reports that the total irrigation supplied by this scheme in 1995 was 16,69 Mm^3/a, with no further increase of supply expected in the future. This value correlates with the DWAF model value of 16,701 Mm^3/a. In view of the plans in the making to develop this scheme to its full potential, it was decided to adopt the DWAF model value for the current system.

When considering the Irrigation Potential for this scheme, all of the Recommended and Above soil is irrigated with 12% of Marginal soil being irrigated as well.

4.4.9 Xonxa Irrigation Scheme

Xonxa Dam was originally constructed in 1974 to supply water for irrigation to about 4 900 ha of land along the White Kei River (DWAF, 2001a). Since construction, however, much of the land was found to be unsuitable for irrigation and only 1 634 ha of land was developed. By 1995, only 60 ha of land was reported to be irrigated (DWAF, 2001a). This low area of irrigated land could be due to difficulties experienced within the scheme with the maintenance of the pumps and because the cost of pumping was not financially sustainable (DWAF, 2001a).

In Appendix 1, the maximum future potential irrigation water requirement for the Xonxa Irrigation Scheme was reported as 11,25 Mm^3/a. This value was most recently approved by the Chris Hani District Municipality and the Department of Agriculture as being correct in terms of current thinking and is therefore the preferred value for scheduled irrigation water requirements for this scheme. The value was therefore adopted for the current system model. In terms of opportunistic irrigation, the QRWSFS (DWAF, 1996c) reported a current and future value of 3,17 Mm^3/a, which compares well with the DWAF model value of 3,315 Mm^3/a. To be consistent, the DWAF model value was adjusted downward to the QRWSFS value of 3,17 Mm^3/a.

When considering the Irrigation Potential for this scheme, all of the Recommended and Above soil is irrigated with 7% of Marginal soil also being irrigated. It is believed that the Marginal soil is being irrigated due to a lack of suitable soil for irrigation in the area. It would therefore not be feasible to further extend the irrigated areas for this scheme.

5. HYDROLOGY ASSESSMENT

5.1 NATURAL STREAMFLOWS

For the validation of the hydrology used in the current system model (WRYM QUEE20), the cumulated modelled incremental flow values for the river reaches were compared with the naturalised MAR values determined in the original 1997 study (DWAF, 1995). From Table 5.1 it can be seen that for all the river reaches considered, the cumulated modelled streamflow values compared favourably with the previous MAR values, thus validating the hydrology used in the current model.

TABLE 5.1 COMPARISON BETWEEN MODELLED SYSTEM HYDROLOGY (WRYM QUEE20) AND QRWSFS HYDROLOGY

RIVER REACH	SITE	MODELLED VALUES (WRYM QUEE20)				QRWSFS
		NODE NO.	INCREMENTAL INFLOW FILE NAME	INCREMENTAL FLOW VALUE (Mm^3/a)	CUMULATIVE FLOW (Mm^3/a)	NATURALISED MAR (1) (Mm^3/a)
Klipplaat until confluence with Black Kei	Bushmanskrantz Dam	7	320a1994	4,91	4,91	
	Oxkraal Dam	8	320b1994	13,02	17,92	
		9	320c1994	1,84	19,77	
	Waterdown Dam	11	3301994	51,11	51,11	
		12	331a1994	3,15	54,26	
		13	331b1994	2,83	**76,85**	**80**
Black Kei until confluence with Klaas Smits	Thrift Dam	1	3011994	4,29	4,29	
		2	3011994	5,03	9,32	
	Limietskloof Dam	60	302a1994	1,46	10,78	
	Thibet Park Weir	3	302a1994	0,00	10,78	
		4	302b1994	15,75	26,53	
		6	3031994	0,39	26,91	
	Bushmanskrantz Dam	7	320a1994	4,91	4,91	
	Oxkraal Dam	8	320b1994	13,02	17,92	
		9	320c1994	1,84	19,77	
	Waterdown Dam	11	3301994	51,11	51,11	
		12	331a1994	3,15	54,26	
		13	331b1994	2,83	76,85	
		14	331c1994	3,37	107,14	
		15	3041994	1,33	108,47	
	Waklyn Dam (proposed)	16	3041994	0,00	108,47	
		17	3041994	0,53	**109,00**	**109**
Klaas Smits until confluence with Black Kei		41	3101994	21,71	21,71	
		42	3111994	27,79	49,51	
		38	312a1994	3,20	52,71	
		43	312c1994	1,06	53,76	
		39	312b1994	3,44	57,20	
		44	312d1994	3,16	**60,37**	**61**
White Kei until confluence with Black Kei	Doring River Dam	22	2101994	10,80	10,80	
		65	2111994	40,62	51,42	
	Lubisi Dam	23	2111994	0,00	51,42	
		24	20041994	13,23	64,65	
		64	20011994	47,87	47,87	
	Xonxa Dam	26	20011994	0,00	47,87	
		27	20021994	22,16	70,03	
		29	20031994	12,02	82,06	
		25	20051994	1,58	148,28	
		104	20051994	4,32	**152,60**	**153**

1. The cumulated modelled streamflows were compared to the values of MAR from the DWAF 1995 report (*Hydrology - First Draft*) and not with the values from the DWAF 1996 report (*System Modelling - Final Report*). This is because the latter report gave the incorrect MAR values for the river reaches. The UKBS (Upper Kei Basin Study) values were reported instead of the QRWSFS (Queenstown Regional Water Supply Feasibility Study) values.

Figure 5.1 shows the relationship between the naturalised unit runoff and MAP, as determined from the QRWSFS, for the individual sub-catchments of the Upper Kei Basin. The only outlier appears to be for sub-catchment 330, which provided inflows into Waterdown Dam. The naturalised unit runoff is based on a natural inflow of 51,1 Mm^3/a which was determined by adding the flow sequence representing the estimated consumption by irrigation upstream of the Waterdown Dam (about 10 Mm^3/a) to the observed inflow into the dam.

The observed inflow was analysed in detail in the first draft of the QRWSFS report titled *Appendix 4 : Hydrology*, which compared various rating curves determined by DWAF and Professor Rooseboom, to determine an acceptable curve to be used for the hydrological calibration. The various rating curves produced observed inflows for the period from 1979 to 1988 varying from 32 to 38 Mm^3/a and the selected rating curve had an inflow of 35 Mm^3/a.

The remaining uncertainty in the estimate of the natural streamflow upstream of Waterdown Dam is the estimate of the irrigation consumption upstream of the dam. The WRSA report and the WARMS database indicate that the irrigation value may be closer to 5 Mm^3/a instead of 10 Mm^3/a (see Section 4.4.1). Accordingly, the irrigation consumption was halved and the same reductions that were applied to the monthly irrigation demand requirements were also applied to the natural streamflow upstream of Waterdown Dam. Both the irrigation and the natural streamflow were reduced by 5 Mm^3/a on average to keep the modelled inflow into Waterdown Dam unchanged because it was based on the observed inflow sequence. The reduced unit runoff upstream of Waterdown Dam is represented by the green triangle in Figure 5.1, slightly down from the black diamond. This value is still almost double the other catchments in the Black Kei. However, the Klipplaat River feeding the Waterdown Dam is located in the mountains just north of Hogsback and the rainfall in this area is higher than that in the rest of the catchment. For interest, the unit runoff for the Kubusi River upstream of Hammerhead (S6H002), which drains to the south east of the same mountain range has been plotted on the graph (red dot) and indicates that the mountain range does affect the runoff characteristics.

The unit runoff upstream of the Xonxa (#2001) and Bonkolo (#312) Dams is slightly lower than the other catchments, which may compensate slightly for its uncertainty. The catchment upstream of the Bushmanskrantz and Oxkraal Dams (#320) is adjacent to Waterdown Dam which might explain why its unit runoff plots above the catchments of the Xonxa and Bonkolo Dams.

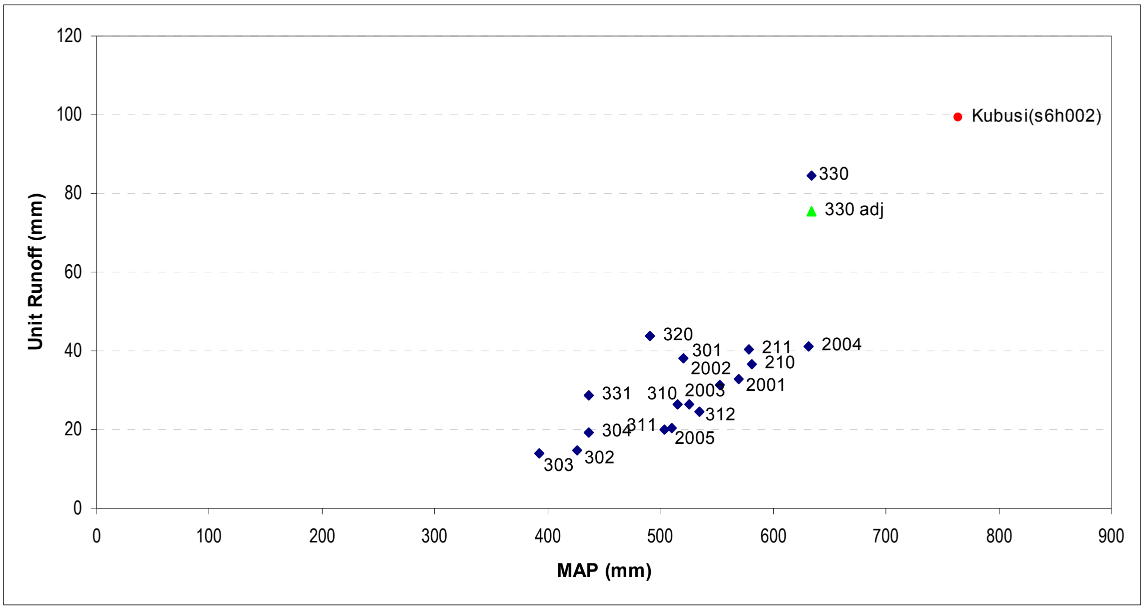

Figure 5.1 QRWSFS values of naturalised unit runoff (mm) vs MAP (mm) for sub-catchments of the Upper Kei Basin

5.2 SYSTEM TRANSMISSION/EVAPOTRANSPIRATION LOSSES

The QRWSFS estimated losses from selected reaches in the study area by modelling a dummy evaporation dam which lost water through evaporation from its surface and would need topping up before water could flow further downstream. The reach length and the width of the river (including a band of riparian vegetation on either side) were used to obtain an evaporation area. The storage of the reach was estimated using a subjective evaluation of the volume of the pools along the river. The study did not determine losses for the reaches downstream of the Xonxa and Lubisi Dams. Depending on whether these losses have the characteristics of the reach on the Black Kei between the Klipplaat and Klaas Smits or the reach on the Black Kei between the Klaas Smits River and the White Kei, the losses on the reach from Xonxa Dam to the Indwe River can vary from 0,7 to 5,4 Mm^3/a. The river downstream of the Xonxa Dam is relatively inaccessible and there is less irrigation alongside the river tanks.

TABLE 5.2 ESTIMATED EVAPOTRANSPIRATION LOSSES

RIVER	REACH	CHANNEL LENGTH (km)	DUMMY DAM AREA (km^2)	DUMMY DAM VOLUME (Mm^3)	AVERAGE LOSS (Mm^3/a)	AVERAGE LOSS/KM ($Mm^3/a/km$)
Klipplaat	Waterdown to Oxkraal	9	0,4	0,3	0,3	0,04
Oxkraal	Oxkraal Dam to Klipplaat confluence	7	0,1	0,1	0,1	0,02
Klipplaat	Oxkraal confluence to Black Kei	10	0,4	0,3	0,4	0,04
Black Kei	Klipplaat to Klaas Smits	24	0,5	0,6	0,6	0,02
Black Kei	Klaas Smits to White Kei	14	1,6	1,9	1,6	0,11
		16	3,4	3,6	3,4	0,22
Sub-total		**80,0**	**6,4**	**6,8**	**6,4**	**0,08**
Estimate based on Black Kei : Klipplaat to Klaas Smits						
White Kei	Xonxa to Indwe	32	0,6	0,8	0,7	0,02
Indwe	Lubisi to White Kei confluence	24	0,5	0,6	0,6	0,02
White Kei	Indwe confluence to Black Kei confluence	30	0,6	0,7	0,7	0,02
Sub-total		**86,2**	**1,7**	**2,0**	**2,0**	**0,02**
Estimate based on Black Kei : Klaas Smits to White Kei						
White Kei	Xonxa to Indwe	32	5,3	5,9	5,4	0,17
Indwe	Lubisi to White Kei confluence	24	4,1	4,5	4,1	0,17
White Kei	Indwe confluence to Black Kei confluence	30	5,0	5,5	5,1	0,17
Sub-total		**86,2**	**14,4**	**16,0**	**14,6**	**0,17**

6. EFFECT OF IFR ON YIELD IN THE LUKANJI SYSTEM

6.1 MODIFICATIONS MADE TO 1997 WRYM

The following modifications were made to the original WRYM to represent the current system model :

The following modifications were made to the original WRYM to represent the current system model:

- Modified Operating Rule so that Oxkraal Dam was used in preference to Waterdown Dam for IFR releases and agricultural demands. This leaves more water in Waterdown for Queenstown.
- In the previous study additional losses on releases were modelled using "Loss Dams", the evaporation of which was based on evapotranspiration along the river channel. For the current model these dams were modified to intercept flow and not make releases to agriculture.
- Inflows into "Loss Dams" were removed except for the Lower Black Kei. Transmission losses were also not "naturalised" for the current study and the natural inflows were not increased to offset the increased losses.

6.2 IFR SITES AND SCENARIOS

Based on environmental consideration, five IFR Sites were identified to be included in the current system model. These five sites were included at the following locations:

- IFR 1: Just downstream of Waterdown Dam (Channel 205). Can only be supplied by unregulated streamflows augmented by releases from Waterdown Dam.
- IFR 2: Just downstream of the confluence of the Black Kei River with the Klaas Smits River (Channel 206). Supplied preferentially from unregulated streamflows augmented by releases from Oxkraal Dam. Possibly supplemented from Waterdown Dam.
- IFR 3: Just upstream of the confluence of the Black Kei River with the White Kei River (Channel 207). Supplied preferentially from unregulated streamflows augmented by releases from Oxkraal Dam. Possibly supplemented from Waterdown Dam.
- IFR 4: Just downstream of the confluence of the White Kei River and Indwe River (Channel 208). Can be augmented by releases from Xonxa and Lubisi Dam.
- IFR 5: Just upstream of the confluence of the White Kei River and Indwe River (Channel 260). Can only be supplied by unregulated streamflows augmented by releases from Xonxa Dam.

It is to be noted that to determine the instream flow requirements at Site 5, the inflows and releases at Site 4 were factored by the ratio of the cumulated incremental flows (naturalised MAR) upstream of IFR 4 over the cumulated incremental flows (naturalised MAR) upstream of IFR 5, in other words, 0.55.

Five IFR scenarios were initially considered under the current modelling system (see Table 6.3 for clarification), namely:

- Scenario 1 : Achieves an Ecological Category (EC) lower than the Recommended Ecological Category (REC). This scenario maintains the environmental class D in the river and there are no supply constraints imposed on the reservoirs.

- Scenario 2 : Achieves and EC equal to the REC. This scenario maintains various environmental classes and there are no supply constraints imposed on the reservoirs.

- Scenario 3 : Achieves an EC higher than the REC. This scenario maintains the highest environmental classes in the river where there are no supply constraints imposed on the system reservoirs.

- Scenario 4 : Same as Scenario 2, except that the releases from the reservoirs are capped by the existing capacity of the outlet structure, i.e. there is an imposed supply constraint on the reservoir (see Table 6.1 for maximum releases from the reservoirs).

- Scenario 5 : Same as Scenario 1, except that the releases from the reservoirs are capped by the existing capacity of the outlet structures.

TABLE 6.1 OUTLET CAPACITIES

DAM	OUTLET CAPACITY (m^3/s) (DAM FULL	OUTFLOW WHEN DAM LEVEL IS REDUCED		REMARK
		PERCENT CAPACITY	OUTFLOW	
Waterdown	5	25%	3,5	4 outlet levels
Oxkraal	11	25%	7	4 outlet levels
Bonkolo				
Xonxa	10	40%	7	5 outlet levels with 42 inch sleeve valve

The five IFR scenarios were evaluated (see Appendix 2 to the Main Report) at a workshop attended by DWAF representatives, environmentalists and water resource engineers. It was decided that Scenario 4 would be adopted for further evaluations of the yield. Although Scenario 4 was chosen as the preferred scenario for further modelling, the results for all five IFR scenarios are presented below as they were initially modelled.

6.3 IFR REQUIREMENTS

Table 6.2 indicates the flow requirements for the different IFR scenarios by comparing the total spare yield of the system when there are no implicit releases from the reservoirs to the total Spare Yield when releases, as determined by the requirements of the IFR scenario, are allowed. (The Spare Yield is defined as the yields of the reservoirs that are available for use for other purposes after the required IFR releases have been made.).

TABLE 6.2 IFR IMPACT ON SPARE YIELD FOR SCENARIOS 1 - 5

IFR SCENARIO	DATASET	SADA	QUEENSTOWN	WATERDOWN SPARE YIELD	WATERDOWN SUB-TOTAL	OXKRAAL SPARE YIELD	BONKOLO SPARE YIELD	XONXA SPARE YIELD	DORING SPARE YIELD	LUBISI SPARE YIELD	TOTAL	DECREASE
		Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a
No explicit releases	p_s	1.6	7.3	2.4	11.3	0.0	0.7	14.4	1.9	7.8	36.1	0.0
1	p1s	1.6	5.7	0.0	7.3	0.0	0.6	10.4	1.9	5.5	25.7	-10.4
2	p2s	1.6	4.5	0.0	6.1	0.0	0.5	9.0	1.9	4.6	22.1	-14.0
3	p3s	1.6	3.5	0.0	5.1	0.0	0.0	6.1	1.9	2.6	15.7	-20.4
4	p4s	1.6	6.1	0.0	7.7	0.0	0.6	11.3	1.9	6.6	28.1	-8.0
5	p5s	1.6	7.3	0.0	8.9	0.0	0.6	12.6	1.9	7.2	31.2	-4.9
4 @ Waterdown	p4sW	1.6	7.3	0.6	9.5	0.0	0.4	14.4	1.9	7.8	34.0	-2.1

In Table 6.3, the IFR requirements for the IFR sites are given for the cases of "Maintenance Year", Drought Year and the "Long-term Average". The Long-Term Average requirements are then repeated in Table 6.4 where they are shown for the various scenarios. In the latter table, the Long-term Average requirements are compared to the IFR requirements during the sub-system critical periods.

It should be noted that for Tables 6.2 and 6.3, IFR Site 5 has been excluded as it was simply factored from the IFR Site 4 flow requirements (described under 6.2).

TABLE 6.3 IFR REQUIREMENTS FOR MAINTENANCE YEAR, DROUGHT YEAR AND THE LONG-TERM AVERAGE

IFR SITE	CLASS	CAPPED TO DAM OUTLETS	MAR	MAINTENANCE YEAR			DROUGHT YEAR			LONG-TERM AVERAGE		
				HIGH	LOW	TOTAL	HIGH	LOW	TOTAL	REQUIRED	% MAR	SUPPLIED (1)
				Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a			
1	BC		51,1	6,9	8,0	14,9	unavail	0,0	unavail	12,1	24%	12,1
	C		51,1	6,9	5,8	12,7	unavail	0,0	unavail	11,0	21%	11,0
	C	Y	51,1	3,6	5,8	9,4	unavail	0.0	unavail	7,8	15%	7,8
	D		51,1	6,4	2,6	8,9	unavail	0,0	unavail	8,9	17%	8,9
	D	Y	51,1	3,1	2,6	5,7	unavail	0,0	unavail	5,7	11%	5,7
2	C		173,4	9,5	16,0	25,5	unavail	0,0	unavail	19,3	11%	19,3
	D		173,4	9,1	6,9	16,0	unavail	0,0	unavail	14,0	8%	14,0
	D	Y	173,4	4,4	6,9	11,2	unavail	0,0	unavail	9,7	6%	9,7
3	BC		228,1	10,0	35,9	45,8	unavail	0,3	unavail	32,9	14%	32,9
	CD		228,1	9,2	16,3	25,5	unavail	0,3	unavail	21,2	9%	21,2
	CD	Y	228,1	1,9	16,3	18,2	unavail	0,3	unavail	14,7	6%	14,7
	D		228,1	9,1	8,7	17,8	unavail	0,3	unavail	16,3	7%	16,3
	D	Y	228,1	1,8	8,7	10,5	unavail	0,3	unavail	9,6	4%	9,6
4	BC		148,4	15,5	29,6	45,1	unavail	1,7	unavail	35,3	24%	35,3
	CD		148,4	15,2	15,4	30,7	unavail	1,7	unavail	27,5	19%	27,5
	CD	Y	148,4	8,1	15,4	23,5	unavail	1,7	unavail	20,1	14%	20,1
	D		148,4	15,0	8,8	23,7	unavail	1,7	unavail	23,0	15%	23,0
	D	Y	148,4	7,8	8,8	16,6	unavail	0,0	unavail	15,5	10%	15,5

1. This column exists as a check for the WRYM that the required IFR is being supplied.

TABLE 6.4 IFR REQUIREMENTS (Mm^3/a) FOR LONG-TERM AND CRITICAL PERIODS

IFR SITE	CLASS	CAPPED TO DAM OUTLETS	MAR	LONG-TERM AVERAGES					SYSTEM CRITICAL PERIODS [1]					SUB-SYSTEM DRITICAL PERIODS						RATIO - CRITICAL PERIOD TO LONG-TERM IFR				
				SCENARIO					SCENARIO					PERIOD	SCENARIO					SCENARIO				
				1	2	3	4	5	1	2	3	4	5		1	2	3	4	5	1	2	3	4	5
1	BC		51,1			12,1					7,4			Sep 1944 - Jan 1950			7,4					61%		
	C		51,1		11,0					6,5				Sep 1944 - Jan 1950		6,5					59%			
	C	Y	51,1				7,8					4,8		Sep 1944 - Jan 1950				4,8					62%	
	D		51,1	8,9					5,1					Sep 1944 - Jan 1950	5,1					57%				
	D	Y	51,1					5,7					3,3	Sep 1944 - Jan 1950					3,3					59%
2	C		173,4			19,3					10,4			Sep 1944 - Jan 1950			10,4					54%		
	D		173,4	14,0	14,0				7,2	7,2				Sep 1944 - Jan 1950	7,2	7,2				51%	51%			
	D	Y	173,4				9,7	9,7				5,5	5,5	Sep 1944 - Jan 1950				5,5	5,5				57%	57%
3	BC		228,1			32,9					19,1			Sep 1944 - Jan 1950			19,1					58%		
	CD		228,1		21,2					11,7				Sep 1944 - Jan 1950		11,7					55%			
	CD	Y	228,1				14,7					9,1		Sep 1944 - Jan 1950				9,1					62%	
	D		228,1	16,3					8,5					Sep 1944 - Jan 1950	8,5					52%				
	D	Y	228,1					9,6					5,8	Sep 1944 - Jan 1950					5,8					60%
4	BC		148,4			35,3					27,8			Dec 1976 - Jan 1985			22,1					63%		
	CD		148,4		27,5					21,7				Dec 1976 - Jan 1985		16,6					60%			
	CD	Y	148,4				20,1					15,3		Dec 1976 - Jan 1985				13,2					66%	
	D		148,4	23,0					21,3					Dec 1976 - Jan 1985	13,0					57%				
	D		148,4					15,5					11,8	Dec 1976 - Jan 1985					9,7					63%

1. For all sites in the system assume critical period from 1 September 1944 (11th month of hydro year 1943/44) to 31 January 1950 (4 of 49/50). Additionally, consider the period from 1 December 1976 to 31 January 1985 for Xonxa and Lubisi Dams.

6.4 IFR SHORTFALLS

In Table 6.5, the actual "IFR requirements" for the different scenarios were determined by allowing additional flows into the system such that all the ecological demand would be met.

The "IFR Supplied Implicitly" values represent how much flow can be released to the IFR sites under the current operation of the system. In this case, "IFR Supplied Implicitly" values were based on the original operation of the system as specified in the original model, with only a few updated demands added such as at Xonxa and Oxkraal Dams. To obtain the "IFR Supplied Implicitly" values, the model is configured such that the IFR exerts a low pull that is insufficient to pull water out of the dams. Only when the dam spills or releases water for other uses such as irrigation further downstream, will the IFR zones receive flow.

By comparing the actual requirements of the IFR sites and the flow that can be provided based on the present day demands for the current system, the IFR shortfall can be determined. This shortfall, shown in Table 6.5 , represents the expected minimum impact that the IFRs will have on the yield in the system. It should be noted that Table 6.5 considers the yield shortfalls at the individual sites without being influenced by releases from upstream dams.

TABLE 6.5 TABLE SHOWING THE IFR SHORTFALLS FOR SCENARIOS 1 - 5

IFR SITE	PERIOD		IFR REQUIREMENTS					IFR SUPPLIED IMPLICITLY					IFR SHORTFALLO : EXPECTED MIN IMPACT ON YIELD					
			IFR SCENARIOS					IFR SCENARIOS					IFR SCENARIOS					
			1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	4
			1Inf	2Inf	3Inf	4Inf	5Inf	p_s1	p_s2	p_s3	p_s4	p_s5	p1s	p2s	p3s	p4s	p5s	p4sW
1	System critical period	1 Sep 1944 to 31 Jan 1950	4,8	6,2	6,9	4,6	3,2	2,0	2,4	2,5	2,2	1,9	-2,8	-3,8	-4,4	-2,4	-1,3	-2,4
2			6,4	6,4	9,5	5,1	5,1	4,3	4,3	6,0	3,6	3,6	-2,1	-2,1	-3,5	-1,5	-1,5	-2,4
3			7,5	10,7	17,9	9,1	5,8	6,3	8,4	12,4	7,1	4,8	-1,2	-2,3	-5,5	-2	-1	-2,4
4			17,5	21,2	27,2	15,2	11,5	11,0	12,5	13,9	11,8	9,9	-6,5	-8,7	-13	-3,4	-1,6	
5			9,7	11,7	15,0	8,4	6,4	5,8	6,5	7,1	6,2	5,2	-3,9	-5,2	-7,9	-2,2	-1,2	
1	Sub-system critical period	1 Sep 1944 to 31 Jan 1950	4,8	6,2	6,9	4,6	3,2	2,0	2,4	2,5	2,2	1,9	-2,8	-3,8	-4,4	-2,4	-1,3	
2			6,4	6,4	9,5	5,1	5,1	4,3	4,3	6,0	3,6	3,6	-2,1	-2,1	-3,5	-1,5	-1,5	
3			7,5	10,7	17,9	9,1	5,8	6,3	8,4	12,4	7,1	4,8	-1,2	-2,3	-5,5	-2	-1	
4		1 May 1978 to 31 Jan 1985	13,0	16,6	22,1	13,2	9,7	8,7	10,2	11,6	9,7	7,9	-4,3	-6,4	-11	-3,5	-1,8	
5			7,3	9,2	12,2	7,3	5,4	4,7	5,4	6,1	5,1	4,2	-2,6	-3,8	-6,1	-2,2	-1,2	

6.5 IFR IMPACT ON YIELD

Table 6.6 presents a summary of the minimum impact that the various IFR scenarios will have on the yield associated with the selected IFR sites, but this time relating these IFR sites to the dams that are responsible for supplying them with water.

As can be seen in the table, the current system yield model was set up so that IFR Site 1 is only supplied by flows from Waterdown Dam, whereas IFR Sites 2 and 3 are supplied preferentially from Oxkraal but also possibly supplemented by Waterdown Dam. Oxkraal was preferred so that there would be more water in Waterdown Dam to supply Queenstown (one of the modifications made to the original model). To achieve this, the IFR release from Waterdown Dam was co-ordinated so that this water would be fully used at IFR Sites 2 and 3. Of course this operation would only be effective if the release of water from Waterdown Dam was in fact required at the downstream IFR sites, otherwise the upstream release would not be used at all the sites or, for example, for irrigation, and would simply be lost to the system. The impact that IFR will have on the annual yield of a system will therefore be larger if in some months the release from an upstream dam is only required for one IFR site. An example of when a release from Waterdown is only used for IFR Site 1 can be seen in Figure 6.1 for April 1948.

For IFR Site 5 the model was set up so that it would only be supplied by Xonxa Dam, whereas IFR Site 4 would be supplied by both Xonxa and Lubisi Dams. The IFR release from Xonxa Dam was configured so that the water released would be fully used by IFR 4 further downstream.

TABLE 6.6 IMPACT OF IFR ON YIELD FOR WATERDOWN, OXKRAAL, XONXA AND LUBISI DAMS

IFR SITE	PERIOD		IFR SHORTFALL : EXPECTED MIN IMPACT ON YIELD					
			IFR SCENARIOS					
			1	2	3	4	5	4
			P1S	P2S	P3S	P4S	P5S	P4SW
			SHORTFALLS AT IFR SITES (Mm^3/a)					
1	System critical period	1 Sep 44 - 31 Jan 50	-2,8	-3,8	-4,4	-2,4	-1,3	-2,4
2			-2,1	-2,1	-3,5	-1,5	-1,5	-2,4
3			-1,2	-2,3	-5,5	-2	-1	-2,4
4	Sub-system critical period	1 May 78 - 31 Jan 85	-4,3	-6,4	-10,5	-3,5	-1,8	
5			-2,58	-3,8	-6,1	-2,2	-1,2	
Dam	**Supplying the following IFR sites**		**Selecting largest shortfall for the appropriate IFR sites (Mm^3/a)**					
Waterdown	IFR 1 only		-2,8	-3,8	-4,4	-2,4	-1,3	-2,4
Waterdown and Oxkraal	IFR 1, 2 and 3		-2,8	-3,8	-5,5	-2,4	-1,5	-2,4
Xonxa	IFR 5 only		-2,58	-3,8	-6,1	-2,2	-1,2	
Xonxa and Lubisi	IFR 4 and 5		-4,3	-6,4	-10,5	-3,5	-1,8	

Table 6.7 shows the comparison between the actual and minimum impacts on the yield at the various dam sites. The actual impacts on yield were obtained by running the model with the IFR demands in place. If one considers Scenario 4 (p4s) for IFR sites 1, 2 and 3 in Table 6.7, it can be seen that the actual impact on yield at IFR 1 is 3,6 Mm^3/a (impact on Waterdown Dam) and only 3,7 Mm^3/a at IFR 2 and 3 (impact on both Waterdown and Oxkraal Dams). With the assumption that releases from Waterdown Dam are fully used at Sites 2 and 3, it can therefore be deduced that Waterdown Dam is supplying the majority of water required for the ecological Reserve, with Oxkraal only releasing 0,1 Mm^3 of water. The reason for this is that although Oxkraal is favoured, it has a high imposed irrigation demand from downstream users (13,8 Mm^3/a) and therefore very little or no spare yield. Waterdown Dam on the other hand has a spare yield of 2,4 Mm^3/a and so will be favoured by the model for releasing more flow. A

consideration for further modelling might be to determine the impact on yield for Waterdown Dam by reducing the irrigation demand on Oxkraal Dam.

Scenario p4sW in Table 6.7 assumes that IFR Sites 2 and 3 do not exist. For this case it can be seen that Oxkraal actually yields a higher volume of water (0,3 Mm^3/a) than when the sites are in place (0,1 Mm^3/a). This is because less water is coming from the IFR sites to supply water for irrigation further downstream, thus necessitating a larger release of water from Oxkraal Dam to meet these demands.

When considering IFR Sites 4 and 5 for Scenario 4, it can be seen that the actual impact on the yield at IFR Site 5 is 3,1 Mm^3/a (impact on Xonxa Dam) and 4,3 Mm^3/a at IFR 4 and 5 (impact on both Xonxa and Lubisi Dams). Lubisi Dam therefore supplies an additional 1,2 Mm^3/a.

The mismatch evident in Table 6.7 between the actual and minimum impacts on yield could be attributed to the fact that releases from the dams are not all perfectly synchronised and there will be times where the upstream dam releases are not fully used by the IFR sites further downstream. These mismatches are also shown in Figure 6.1.

TABLE 6.7 MINIMUM AND ACTUAL IMPACT OF IFR ON YIELD (Mm^3)

DAM	SUPPLYING THE FOLLOWING IFR SITES	COMBINING SHORTFALLS TO DETERMINE MINIMUM IMPACT ON YIELDS FROM DAMS						ACTUAL IMPACT ON YIELD						ACTUAL LESS MIN IMPACT					
		IFR SCENARIOS						IFR SCENARIOS						IFR SCENARIOS					
		1	2	3	4	5	4	1	2	3	4	5	4	1	2	3	4	5	4
		p1s	p2s	p3s	p4s	p5s	p4sW	p1s	p2s	p3s	p4s	p5s	p4sW	p1s	p2s	p3s	p4s	p5s	p4sW
		Shortfalls at IFR sites																	
Waterdown	IFR 1 only	-2,8	-3,8	-4,4	-2,4	-1,3	-2,4	-4,0	-5,2	-6,2	-3,6	-2,3	-1,8	-1,2	-1,4	-1,8	-1,2	-1,0	0,6
Waterdown & Oxkraal	IFR 1, 2 and 3	-2,8	-3,8	-5,5	-2,4	-1,5	-2,4	-4,1	-5,4	-6,9	-3,7	-2,4	-2,1	-1,3	-1,6	-1,4	-1,3	-0,9	0,3
Xonxa	IFR 5 only	-2,6	-3,8	-6,1	-2,2	-1,2		-4,0	-5,4	-8,3	-3,1	-1,8	0,0	-1,4	-1,6	-2,2	-0,9	-0,6	
Xonxa & Lubisi	IFR 4 and 5	-4,3	-6,4	-11	-3,5	-1,8		-6,3	-8,6	-13,5	-4,3	-2,4	0,0	-2,0	-2,2	-3,0	-0,8	-0,6	

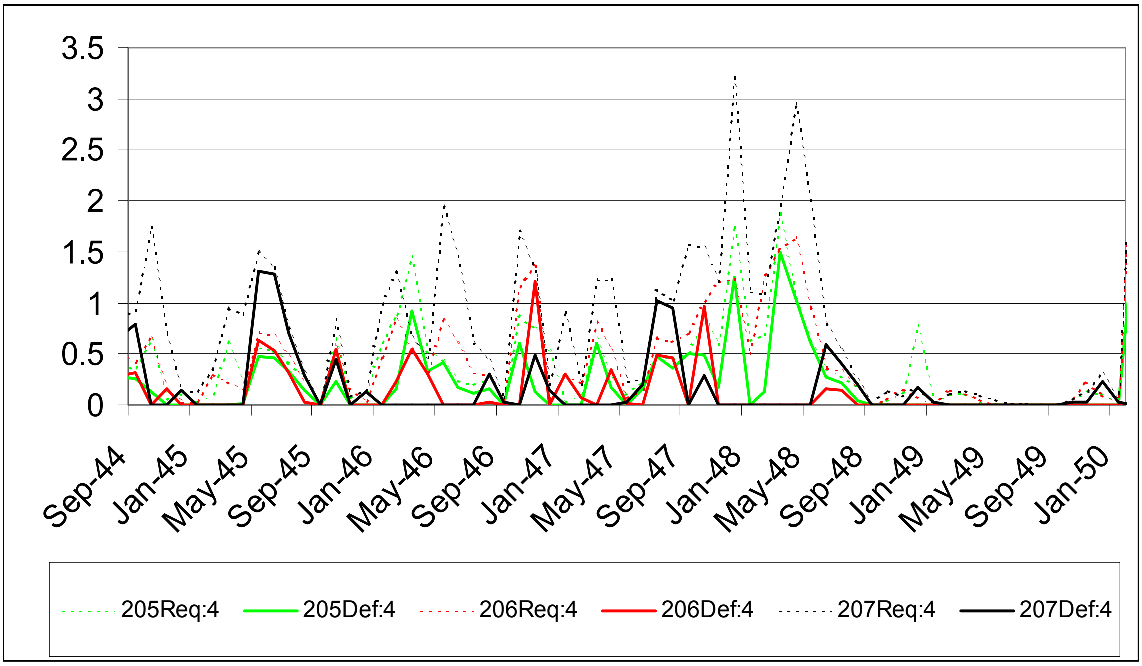

Figure 6.1 Mismatching shortfalls (Mm^3/month) for Scenario 4

7. YIELD ANALYSIS OF INDIVIDUAL DAM SYSTEMS

7.1 INTRODUCTION

Because the contribution of accruals to the agricultural and environmental requirements downstream of the major dams is uncertain, the historical firm yield for the Lukanji sub-systems (Waterdown, Oxkraal/Bushmanskrantz, Bonkolo and Xonxa) was determined assuming no releases were made. The latest estimates of the releases for agricultural and environmental requirements should be deducted from the yield of the dams to obtain the residual available for the urban consumers.

For most of the analysis the estimated conditions in the year 2020 were used.

This means that the estimated available storage needed to be reduced to take additional sedimentation into account. The accumulation of sediment with time has been estimated in Table 2.2. The location where the sediment accumulates in the dam basin can affect the yield.

In the case of Waterdown Dam the sediment volume was small and it was assumed to accumulate in the dead storage zone below the lowest offtake point. This would not affect the active storage and hence the yield was unchanged.

In the case of Oxkraal, Bushmanskrantz, Bonkolo and Xonxa Dams the silt was assumed to accumulate just above the lowest offtake point. The volumes of the dead storage and silt were lumped together and the new volume was treated as inaccessible storage at the bottom of the dam. If the actual silt is deposited as a delta where the incoming stream enters the dam then this approach will over-estimate the evaporation losses.

Sufficient dam basin survey data was available in Xonxa Dam to determine the historical deposition pattern of the silt and to estimate the possible future deposition pattern. The yield of Xonxa Dam was also of special interest because of the proposed bulk supply pipeline from Xonxa to Queenstown, so further analyses were performed on a revised dam basin.

The dead storage and characteristics of the dam basins used in the analyses are summarised in Table 2.5. The determination of the historical firm yields for each sub-system is discussed in more detail in the following sections. The results of the historical firm yield and the long-term stochastic yield analyses are summarised in Table 7.1. The results of the short-term stochastic analyses are summarised in Table 7.2. Additional details, such as the system diagrams and the short-term characteristic curves are included in Annexure C.

TABLE 7.1 HISTORICAL FIRM YIELDS AND LONG-TERM STOCHASTIC YIELDS

DAM NAME	YIELD UNDER 2005 CONDITIONS	YIELDS UNDER 2020 CONDITIONS						ukbs yields under 2010 conditions (Mm^3/a) (see DWAF, 1993b)
			DIFFERENT ANNUAL PROBABILITIES OF FAILURE, i.e. 1 IN …. YEARS					
	HISTORIC FIRM YIELD (Mm^3)	HISTORIC FIRM YIELD (Mm^3)	1:10 YEAR YIELD (Mm^3)	1:20 YEAR YIELD (Mm^3)	1:50 YEAR YIELD (Mm^3)	1:100 YEAR YIELD (Mm^3)	1:200 YEAR YIELD (Mm^3)	HISTORICAL FIRM YIELD
Waterdown Dam	16,81	16,81	24,45	23,26	20,25	18,84	17,56	17,63
Oxkraal and Bushmanskrantz Dam (1)	6,67	6,18	8,6	7,96	6,95	6,21	5,67	7,27 (1)
Bonkolo Dam	0,832	0,695 to 0,9 (2)	1,16	1,1	0,934	0,833	0,736	0,61
Xonxa Dam	18,91	20,63	29,6	27,16	22,97	20,74	19	26,47
TOTAL	**43,2**	**44,3**	**63,8**	**59,5**	**51,1**	**46,6**	**43,0**	52,0

4. Increased by 1,55 x Mm^3/a for Zwelindinga Irrigation Scheme and villages.
5. Larger yield assumes that siltation occurs as a delta where the river enters the dam.
6. The 2005 historical firm yield (HFY) is less than the 2020 HFY because the 2005 analysis assumed the dead storage of 1,22 Mm^3 was inaccessible and would be maintained in the dam. Silt was assumed to fill this dead storage by 2020. The surface area of this dead volume in 2005 is 1,4 km^2 and the evaporation from this surface decreased the yield with regard to the 2020 value. In practice, measures to access this water during droughts, such as pumping from a raft, could increase the yield to the 2020 value.

TABLE 7.2 SHORT-TERM STOCHASTIC YIELDS (SEE ANNEXURE 4.3)

DAM NAME	% FSC	PERIOD LENGTH (YEARS)	STOCHASTIC SHORT-TERM YIELDS UNDER 2020 CONDITIONS (Mm^3)				
			1:10	1:20	1:50	1:100	1:200
Waterdown Dam	100	5	28,83	24,99	22,17	19,95	18,37
	80	5	27,3	24,09	21,1	19,07	17,5
	60	5	25,48	22,68	19,07	17,13	16,23
	40	2	21,58	18,5	15,23	13,13	12,19
	20	2	15,65	12,91	9,9	8,62	7,82
Oxkraal Dam	100	5	10,54	9,11	7,74	6,95	6,07
	80	5	10,07	8,58	7,34	6,47	5,68
	60	4	9,25	7,83	6,32	5,75	5,1
	40	2	7,52	5,75	4,62	4,19	3,83
	20	1	4,89	3,65	2,79	2,5	2,15
Bonkolo Dam	100	5	1,854	1,578	1,284	1,2	1,046
	80	5	1,709	1,427	1,123	1,031	0,902
	60	5	1,542	1,251	0,942	0,835	0,689
	40	5	1,267	1,008	0,744	0,574	0,689
	20	4	0,82	0,571	0,392	0,288	0,237
Xonxa Dam	100	5	41,51	36,27	30,65	28,58	27,31
	80	5	38,48	33,34	27,25	24,9	23,61
	60	5	33,96	29,13	23,2	20,78	19,28
	40	5	28,88	23,72	19,03	16,56	15,46
	20	3	19,66	16,21	13,68	11,85	9,5
Total short-term yields for % FSC	100	5	82,734	71,948	61,844	56,68	52,796
	80	5	77,559	67,437	56,813	51,471	47,692
	60	4 - 5	70,232	60,891	49,532	44,495	41,299
	40	2 - 5	59,247	48,978	39,624	34,454	32,169
	20	1 - 4	41,02	33,341	26,762	23,258	19,707

7.2 WATERDOWN DAM SUB-SYSTEM

The yield obtained in the current analysis of 16,8 Mm^3/a is slightly less than the yield of 17,6 Mm^3/a determined during the UKBS (see Table 7.1). This may be because the UKBS hydrology was revised during the QRWFS Study. Table 5.1 shows that the estimated natural inflows for the stretch from the Kliplaat River to the confluence with the Black Kei River decreased from 80 Mm^3/a (UKBS) to 76,8 Mm^3/a (WRWFS) and this decrease might have reduced Waterdown Dam's yield slightly. In this study the natural inflow and demands upstream of Waterdown Dam were both reduced so that the net inflow to Waterdown remained unchanged (see Section 5.1). The bottom pane of Figure 7.1 shows the drawdown of Waterdown Dam and the critical period from August 1944 to January 1950.

Figure 7.1 Yield flow and dam storage characteristics for Waterdown Dam

7.3 OXKRAAL/BUSHMANSKRANTZ DAMS SUB-SYSTEM

The yields from the Oxkraal/Bushmanskrantz sub-system assume that no water is supplied to the Zweledinga Irrigation Scheme and villages. These requirements are 1,5 and 0,057 Mm^3/a and, should they be supplied, the water available for other consumers would reduce by 1,55 Mm^3/a.

The historical firm yields obtained for the estimated reduction in storage through siltation in 2005 and 2020 were 6,67 Mm^3/a and 6,18 Mm^3/a, respectively. These yields are slightly less than the

7,27 Mm^3/a obtained in the UKBS. Table 5.1 shows that the estimated natural inflows for the stretch from the Klipplaat River to the confluence with the Black Kei decreased from 80 Mm^3/a (UKBS) to 76,8 Mm^3/a (QRWS) and this decrease might have reduced the yield of the Oxkraal/Bushmanskrantz system slightly.

The bottom pane of Figure 7.2 shows the drawdown of Oxkraal and Bushmanskrantz Dams and the critical period from August 1944 to January 1950.

Figure 7.2 Yield flow and dam storage characteristics for Oxkraal Dam

7.4 BONKOLO DAM SUB-SYSTEM

The historical firm yield of Bonkolo Dam is affected by :

- the assumed level of development upstream and
- the degree of degradation upstream of the dam which in turn determines the rate of siltation in the dam.

In the QRWSFS (DWAF, 1996c), the opportunistic irrigation demand upstream of the dam and remote from the river was assumed to be 2,09 Mm^3/a. However, in the earlier UKBS (DWAF, 1993d) the diffuse irrigation demand was estimated to be 0,6 Mm^3/a (Appendix 14.13.2(B)), although the irrigated area was given as 3,9 km^2. More recently, the WRSA provided a combined demand for the Bonkolo Catchment (land-use zone 14) and the downstream land-use zone 15, which together make up Quaternary S31F. The quaternary demand was allocated to land-use zones 14 and 15 according to the ratio of the surveyed demands used in the QRWSFS/UKBS, which gave a demand of 0,96 Mm^3/a above Bonkolo Dam (land-use zone 14) and 1,95 Mm^3/a (land-use zone 15).

The WARMS database, which has not yet been fully verified and is, therefore, of unknown reliability, shows irrigation water use of 0,68 Mm^3/a from surface water and 0,5 Mm^3/a from groundwater. On the assumption that the groundwater abstractions have a negligible effect on streamflow, the original UKBS demand of 0,6 Mm^3/a was adopted for the system analysis.

Bonkolo Dam was last surveyed in 1994 and regular surveys of the dam basin are required to monitor the siltation. The estimated siltation between 1994 and the year 2020, of approximately 1,01 Mm^3, was assumed to accumulate at the bottom of the dam and was modelled in the WRYM by making the lower 1,01 Mm^3 of storage inaccessible to all consumers (see Table 2.5). This is equivalent to a reduction in the original storage volume of the dam of 2,34 Mm^3.

Under 2020 conditions, a historical firm yield of 0,695 Mm^3/a was obtained which is similar to the 0,61 Mm^3/a (2010) obtained in the UKBS (DWAF, 1993b – Executive Summary). The UKBS analysis assumed a larger silt volume of 4,7 Mm^3 silt (see Table 2.3) which was offset by an approximately 30% larger natural inflow (deduced because the current flows are the same as the QRWSFS flows (Table 5.1) and the UKBS values for sub-catchment 312 (15,5) exceed the QRWSFS (11,7) in the Executive Summary of DWAF, 1995b). If the siltation is assumed to occur as a delta at the inlet of the dam, the yield of the dam increases from 0,695 Mm^3/a to about 0,9 Mm^3/a. The yield of the Bonkolo Dam should be re-evaluated with an accurate estimate of the demands upstream and the current siltation level.

The historical firm yield under present day (2005) conditions was 0,832 Mm^3/a, about 20% higher (0,137 Mm^3) than the 2020 historical firm yield. The decrease in yield between 2005 and 2020 is due to a 20% increase in sediment volume in the dam between 2005 (1,864 Mm^3) and 2020 (2,34 Mm^3).

The bottom pane of Figure 7.3 shows the drawdown of the Bonkolo Dam over the critical period from January 1964 to November 1970, when the dam emptied down to its siltation level of 1 Mm^3.

Figure 7.3 Yield flow and dam storage characteristics for Bonkolo Dam

7.5 XONXA DAM SUB-SYSTEM

Initially, the historical firm yield for Xonxa Dam was determined using the following assumptions in the WRYM :

- the hydrology from the QRWSFS (DWAF, 1996), and
- the lower 14,98 Mm^3 was inaccessible. The 14,98 Mm^3 was obtained by adding all the sediment since the last basin survey in 2002 till 2020 (9,74 Mm^3) to the dead storage below the outlet level of 5,24 Mm^3 with the assumption that all the sediment was deposited just above the outlet level of RL 914,48 m.

A yield of 17,12 Mm^3/a was obtained initially. This is significantly less yield than that obtained from the Upper Kei Basin Study (DWAF, 1993b) of 26,47 Mm^3/a for the 2010 siltation level. The difference was primarily because the hydrology was revised in the QRWSFS and the naturalised MAR into Xonxa Dam reduced from 61,3 to 47,9 Mm^3/a (Executive Summary of DWAF, 1995b) as the assumed level of silt in both cases was similar. [The UKBS siltation in 2010 was 45,2 Mm^3 and for the present 2020 analysis was 47,21 Mm^3/a (see Table 2.3)].

A detailed analysis of the behaviour of the dam during the critical drawdown period identified that evaporation was a significant loss. Because of the manner in which the dead storage was modelled in the WRYM the surface area for evaporation was never less than 1,93 km^2, even if the dam was "empty", i.e. when the dam is drawn down to its dead storage level. New storage elevation curves were developed to give a more realistic approximation of the evaporation from the dam and used for further analyses (see Annexure B3). The historical firm yield obtained using these curves was 20,63 Mm^3/a (see Table 7.1).

Interestingly, the historical firm yield of 18,91 Mm^3/a (Table 7.1) obtained under present day conditions was actually less than that obtained under 2020 conditions. The present day analysis assumed that the dead storage volume of 5,24 Mm^3 was inaccessible and would be maintained in the dam (Table 2.5). The surface area of this dead storage volume is 1,86 km^2 (Table B.2, Appendix B) and the evaporation from this surface was about 3,4 Mm^3/a. In practice, emergency measures might be implemented to pump a portion of this dead storage volume out of the dam. These could increase the yield of the system to the 2020 value of 20,63 Mm^3/a (Table 7.1).

Figure 7.4 Yield flow and dam storage characteristics for Xonxa Dam

8. YIELD ANALYSIS OF INTEGRATED DAM SYSTEM UNDER 2020 DEVELOPMENT CONDITIONS

8.1 INTRODUCTION

The yield of the current system and of the system with an additional pipeline supplying water from Xonxa to Bonkolo Dam/Queenstown was determined for number of scenarios (see Table 8.2). Three broad sets of historical firm yield analyses were undertaken :

- the existing system without augmentation from Xonxa Dam,
- the integrated unconstrained system
- the constrained integrated system

In these sets following parameters were varied :

- Bulk supply line capacities from Waterdown and Xonxa Dams (columns b and c in Table 8.2)
- Environmental Water Requirements (EWR) downstream of Waterdown Dam (columns d to h)
- Transmission losses. In most scenarios the losses of the last reach on Black Kei River upstream of the White Kei confluence (column I) were ignored because the losses are high (about 3 Mm^3/a) and are about 10 times the irrigation demand along that reach. By reducing the irrigation slightly the losses could be avoided.
- Irrigation reaches supplied. The supply in the following reaches was varied:

  – Black Kei River upstream of the Klipplaat confluence (column l)
  – Black Kei River downstream of the Klipplaat confluence (column m)
  – Klipplaat River downstream of the Oxkraal confluence (column n)
  – Klipplaat River upstream of the Oxkraal confluence (column o)
  – Irrigation on White Kei River downstream of Xonxa Dam (column p)

- System operation. Local failures were experienced in the supply from Waterdown/Oxkraal to the downstream irrigators when modelling the unconstrained system under a constant draft. These failures were not registered at the yield channel because the yield channel could also obtain additional yield from Xonxa Dam. The system yields were reduced to account for this shortfall (column w and x). However, to reduce the magnitude of the shortfall an artificial link was introduced from Xonxa Dam and Waterdown Dam to the irrigators to help to supply their shortfall in supply (columns q and r). When the constraints in the system infrastructure were modelled these artificial links were disabled.

The historical firm yield relative to the 2020 requirement for the 1920-93 period is reported in column y, while the greater yields for the shorter 1920-39 period is reported in column z.

8.2 PRESENT SYSTEM WITHOUT XONXA DAM

The requirements of the 2020 demands exceed the historical firm yield of the present day infrastructure by about 12 Mm^3/a (Case P1). The requirements of Queenstown could only be supplied from the system without curtailment for the period from 1920-1993 if other demands were omitted (see Scenario P4) :

- irrigators on the Black Kei River downstream of the Klipplaat confluence
- Environmental water requirements downstream of Waterdown Dam (EWR sites 1, 2 and 3)
- Evapotranspiration losses

8.3 WATER AVAILABILITY FROM INTEGRATED UNCONSTRAINED SYSTEM

If the capacity of the bulk water supply pipelines from Xonxa and Waterdown Dams are unconstrained (unlimited) then the yield of the integrated system exceeds the 2020 system requirements by about 5 Mm^3/a (Scenario U1). Various unconstrained scenarios in Table 8.2 were used to investigate the impact of environmental requirements, irrigation demands and evapotranspiration losses on the system yield and the results are summarised in Table 8.1.

TABLE 8.1 IMPACT OF EWR, IRRIGATION AND LOSSES ON THE YIELDS

DESCRIPTION	MAGNITUDE	SCENARIOS USED TO CALCULATE IMPACT (SEE TABLE 8.2)	
		IDENTIFIER	CASE NAME
Waterdown/Oxkraal to confluence with White Kei River			
Evapotranspiration losses in lower 20 km of Black Kei River upstream of White Kei River	2,40	U2-U1	WuXu - WuXuL
Evapotranspiration losses along Klipplaat/Oxkraal/ Black Kei Rivers downstream of Waterdown and Oxkraal Dams (including lower 20 km of Black Kei upstream of White Kei River)	4,90	U3-U1	UxL - WuXuL
Ecological water releases	3,80	U5-U3	UxLE - UxL
Supplementary irrigation releases in Kei River downstream of Klipplaat River	4,60	U6-U3	Ux:LK - UxL
Ecological and irrigation releases	7,40	U7-U3	UxLKE - UxL
Xonxa to confluence with Indwe River			
Supplementary irrigation releases in White Kei River	6,20	U11-U3	UxLEX - UxL
Ecological water releases	5,50	U12-U3	UxLIX - UxL
Ecological and irrigation releases	11,30	U13-U3	UxLRX - UxL

TABLE 8.2 HISTORICAL FIRM YIELDS ASSUMING A 2020 DEVELOPMENT LEVEL

	Bulk supply capacities (m3/s)		EWRs					Transmission/Evapotranspiration losses			Irrigation supplied					Operatn		Supply			'20 - '93 analysis					'20 - 39 analysis					Filenames	
Identifier	Waterdown (ch72)	Xonxa (ch322)	Site 1 (d/s Waterdown)	Site 2 (on B Kei d/s Klaas Smits)	Site 3 (on B Kei u/s W Kei)	Site 7 Klipplaat u/s B Kei	Sites 4 - 6 (Xonxa / Lubisi)	Last reach u/s W Kei	Other reaches	Irrig access pools?	B Kei irrig u/s Klipplaat	B Kei irrig d/s Klipplaat	Klipplaat d/s Oxkraal	Klipplaat u/s Oxkraal	Xonxa Irrig	Artificial link from Xonxa to d/s Oxkraal	Artificial link from Wdown to d/s Oxkraal	Qtown + Sada + Illinge	Supply to Xonxa villages	Bushmankrantz	Yield (Excl Bmanskz Irr, Xonxa villages)	Shortfall to EWR & irrig d/s Wdown/Oxkl	Shortfall d/s Xonxa	HFY yields wrt 2020 (1)(2)		Yield ('25-'39)	Shortfall to EWR & irrig d/s Wdown/Oxkl	Shortfall d/s Xonxa	HFY for '25-'39 period wrt 2020 (1)(2)		Directory \hydro\10676\ym\..	Case names
a	b	C	d	e	F	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	Y = s+t+u+v+w+x-13.5		z	aa	ab	ac = s+t+u+z+aa+ab-13.5		ad	ae
No Xonxa - Present system																																
P1	999	0	Y	Y	Y	N	Y	Y	Y	N	100%	100%	100%	100%	Y	N	Y	0.00	na	1.88	1.30	-1.77	na		-12.09						i9	WuX0L
P2	0.158	0	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	Y	0.00	na	1.88	1.60	-0.53	na		-10.55						i9	P
P3	0.158	0	Y	Y	Y	N	Y	N	N	N	100%	100%	100%	100%	Y	N	Y	0.00	na	1.88	3.60	0.00	na		-8.02						i9	PxL
P4	999	0	N	N	N	N	Y	N	N	N	100%	0%	100%	100%	Y	N	Y	0.00	na	1.88	11.00	0.00	na		-0.62						i9	WxLKE
Water availability from integrated unconstrained system and the impact of environmental and irrigation demands on the urban yield																																
U1	999	999	Y	Y	Y	N	Y	Y	Y	N	100%	100%	100%	100%	Y	Y	N	2.50	0.95	1.88	13.90				5.73						i9	WuXuL
U2	999	999	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	Y	N	2.50	0.95	1.88	16.30				8.13						i9	WuXu
U3	999	999	Y	Y	Y	N	Y	N	N	N	100%	100%	100%	100%	Y	Y	N	2.50	0.95	1.88	18.80				10.63						i9	UxL
U4	999	999	N	Y	Y	N	Y	N	N	N	100%	100%	100%	100%	Y	Y	N	2.50	0.95	1.88	20.00				11.83						i9	UxLE1
U5	999	999	N	N	N	N	Y	N	N	N	100%	100%	100%	100%	Y	Y	N	2.50	0.95	1.88	22.60				14.43						i9	UxLE
U6	999	999	Y	Y	Y	N	Y	N	N	N	100%	0%	100%	100%	Y	Y	N	2.50	0.95	1.88	23.40				15.23						i9	UxLK
U7	999	999	N	N	N	N	Y	N	N	N	100%	0%	100%	100%	Y	Y	N	2.50	0.95	1.88	26.20				18.03						i9	UxLKE
U8	999	999	Y	Y	Y	N	Y	N	N	N	100%	0%	0%	0%	Y	Y	N	2.50	0.95	1.88	26.50				18.33						i9	UxLI
U9	999	999	N	N	N	N	Y	N	N	N	100%	0%	0%	0%	Y	Y	N	2.50	0.95	1.88	31.90				23.73						i9	UxLIE
U10	999	999	Y	Y	Y	N	Y	N	N	N	25%	0%	100%	100%	Y	Y	N	2.50	0.95	1.88	19.10				10.93						i9	UxLUK
U11	999	999	Y	Y	Y	N	N	N	N	N	100%	100%	100%	100%	Y	Y	N	2.50	0.95	1.88	24.30				16.13						i9	UxLEX
U12	999	999	Y	Y	Y	N	Y	N	N	N	100%	100%	100%	100%	N	Y	N	2.50	0.95	1.88	25.00				16.83						i9	UxLIX
U13	999	999	Y	Y	Y	N	N	N	N	N	100%	100%	100%	100%	N	Y	N	2.50	0.95	1.88	30.10				21.93						i9	UxLRX
Yield considering capacity constraints																																
C1a	0.158	0.00	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	0.00	0.00	0.00	3.6	-2.1	0.0	-12.02	-12.02	na	na	na	na	na	id	P-5
C1b	0.158	0.00	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	na	na	na	na	na	6.2	-0.3	0	-5.1	-5.1	id-45	P-5
C2	0.158	0.209	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	10.5	-2.3	0.0	-2.80	-2.80	12.8	-0.1	0.0	1.7	1.7	id & id-45	P0-5
C3	0.158	0.278	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	12.6	-2.3	0.0	-0.70	-0.70	15.0	-0.1	0.0	3.9	3.9	id & id-45	P1-5
C4	0.158	0.40	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	16.3	-2.3	0.0	3.00	3.00	16.3	0.0	0.0	5.3	5.3	id & id-45	P2-5
C5	0.158	0.475	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	16.1	-1.8	0.0	3.33	3.33	16.1	0.0	0.0	5.1	5.3	id & id-45	P3-5
C6	0.158	999	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	16.1	-1.2	0.0	3.86	3.86	15.0	0.0	0.0	4.0	5.3	id & id-45	PU-5
C7a	0.278	0.00	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	0.00	0.00	0.00	3.6	-2.1	0.0	-12.02	-12.02	na	na	na	na	na	id	B-5
C7b	0.278	0.00	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	na	na	na	na	na	7.7	-0.5	0.0	-3.8	-3.8	id-45	B-5
	0.278	0.21																							-2.80						Use result for id C2	
C8	0.278	0.278	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	12.4	-2.7	0.0	-1.25	-0.70	16.2	-0.7	0.0	4.5	4.5	id & id-45	B1-5
C9	0.278	0.396	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	16.0	-2.7	0.0	2.35	3.00	20.0	-0.7	0.0	8.3	8.3	id & id-45	B2-5
C10	0.278	0.475	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	18.0	-2.1	0.0	4.88	4.88	19.6	-0.2	0.0	8.4	8.4	id & id-45	B3-5
C11	0.278	999	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	18.9	-2.7	0.0	5.25	5.25	17.5	0.0	0.0	6.5	8.4	id & id-45	BU-5
C12	0.475	0.40	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	15.9	-2.7	0.0	2.25	3.00	20.0	-0.5	0.0	8.5	8.5	id & id-45	M2-5
C13	0.475	0.475	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	N	N	2.50	0.00	0.00	18.0	-2.7	0.0	4.35	4.88	22.4	-2.0	0.0	9.4	9.4	id & id-45	M3-5
C14	999	999	Y	Y	Y	N	Y	N	Y	N	100%	100%	100%	100%	Y	Y	Y	2.50	0.00	0.00	19.7	-2.8	0.0	5.87	5.87	37.5	0.0	0.0	26.5	26.5	id & id-45	U-5

(1) Assuming Bushmanskrantz Irrigation for Klipplaat and Xonxa villages for Queenstown

(2) In some cases the yields of the system with larger pipe capacities were less than those with smaller pipe capacities because the smaller capacities forced the system to operate in a certain way (ie draw more on Xonxa). The yields of the systems with larger capacities were increased to those of the system with smaller capacities in these cases.

8.4 YIELD CONSIDERING CAPACITY CONSTRAINTS

If the Xonxa system supplies water to Queenstown then the historical firm yield is sufficient for the demand, though the yield is affected by the relative capacities of the bulk water pipelines supplying Queenstown/Illinge and Macibini. The yield of the system (with respect to the 2020 requirement) for different capacities has been summarised in Figure 8.1. This figure indicates that there is no benefit to increasing the capacity of the pipeline from Waterdown Dam to Queenstown, a pipeline of 0,3 m^3/s from Xonxa Dam is required to meet the 2020 demand and a pipeline of 0,37 m^3/s would supply the extra 2 Mm^3/a required for the 2045 demand.

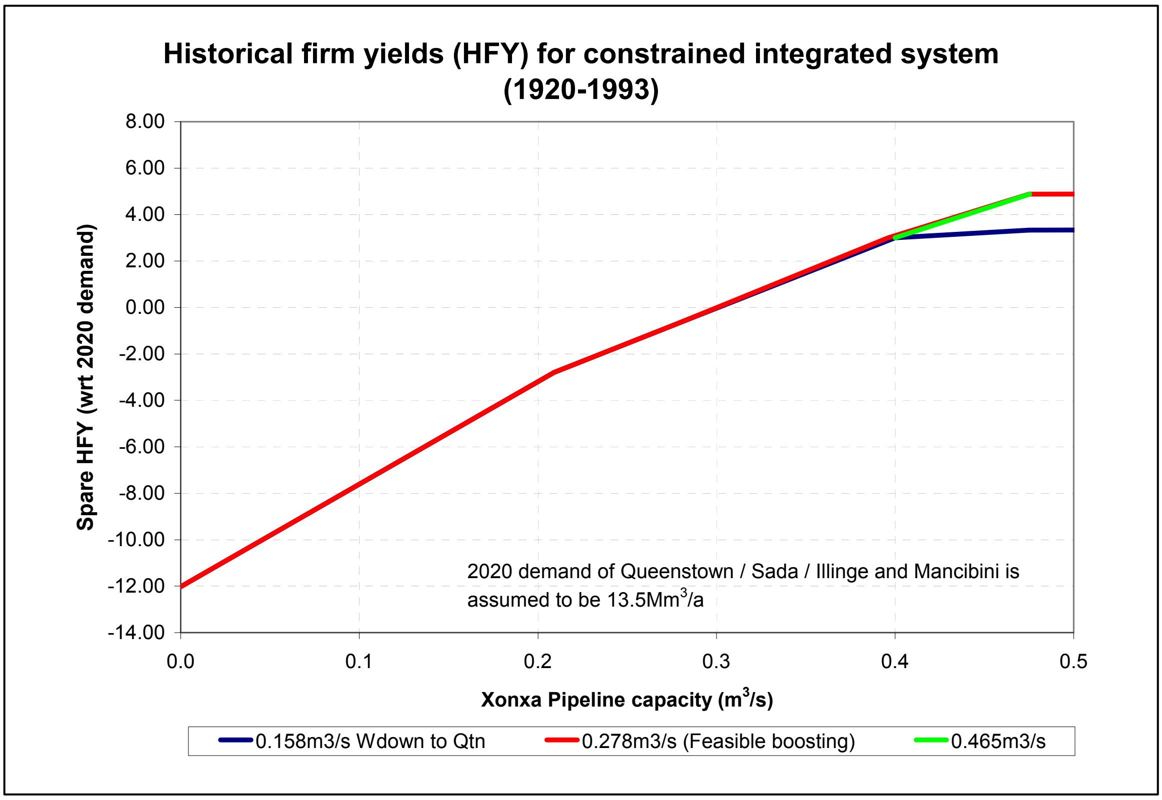

Figure 8.1 Historical firm yield for constrained integrated system (1920 - 1993)

Figure 8.2 illustrates the drawdown of the Waterdown Dam (red) and Xonxa Dam (blue) from 1927 to 1953 and helps to explain why increasing the pipeline capacity from Xonxa Dam increases the historical firm yield while increasing the capacity from Waterdown Dam has no impact.

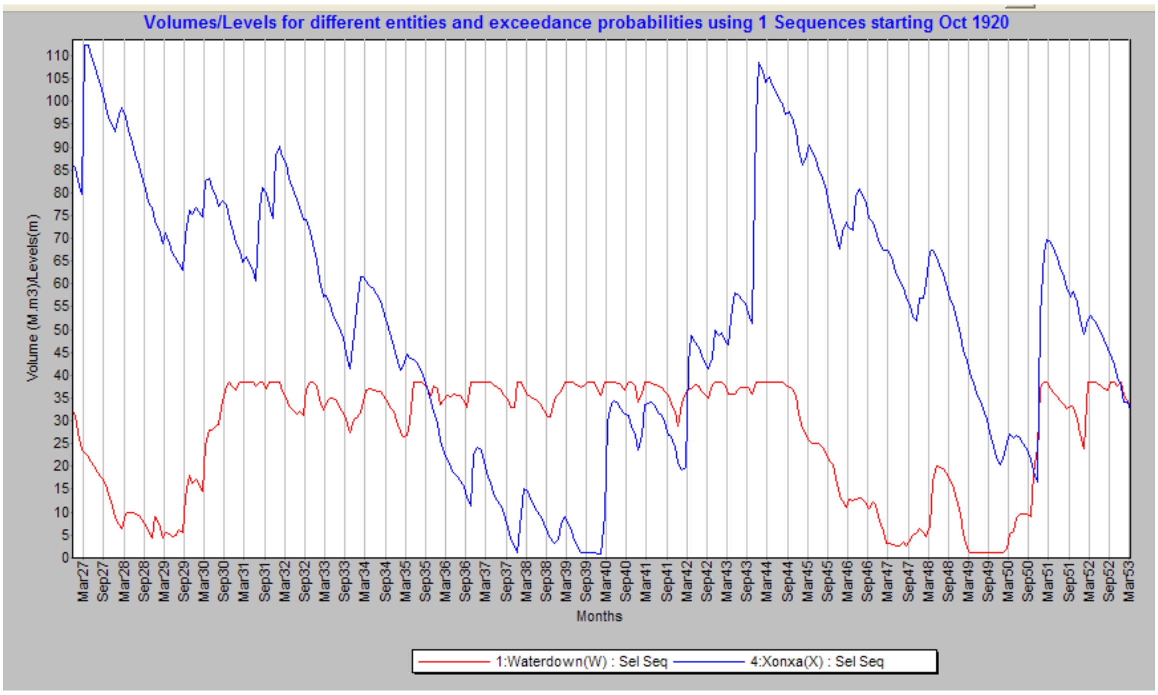

Figure 8.2 Drawdown of Xonxa Dam (blue) and Waterdown Dam (red) (Scenario C4)

In the late 1940s the supply to Queenstown fails because Waterdown and Bonkolo Dams are both empty and the transfer capacity from Xonxa Dam is insufficient to meet the full demand of Queenstown. Obviously, increasing the transfer capacity from Xonxa Dam will increase the supply available to Queenstown until the spare storage in Xonxa Dam is depleted.

In the late 1930s the situation is almost reversed, in that Xonxa Dam is emptied while Waterdown Dam appears to have surplus water. Were the drought in Xonxa Dam a little more severe, this period would be the critical period. Increasing the supply capacity from Waterdown Dam would help to support Xonxa Dam and would increase the yield of the system. Increasing the supply capacity from Waterdown Dam may have more benefit than is indicated in the historical firm yield results for the 1920-1993 period. During the late 1930s additional supply capacity from Waterdown Dam would have increased the abstraction from Waterdown Dam, reducing spillage, and simultaneously reduced the demands on Xonxa Dam enabling the dam to conserve some storage.

Figure 8.3 illustrates the increase in yield for the shorter period from 1920 - 1943 if the supply capacity from Waterdown Dam to Queenstown is increased. For instance, for a transfer capacity from Xonxa Dam of 0,4 m^3/s boosting the capacity from Waterdown Dam to Queenstown from 0,152 to 0,278 m^3/s will increase the system yield by about 3 Mm^3/a (from about 5 to 8 in Figure 8.3).

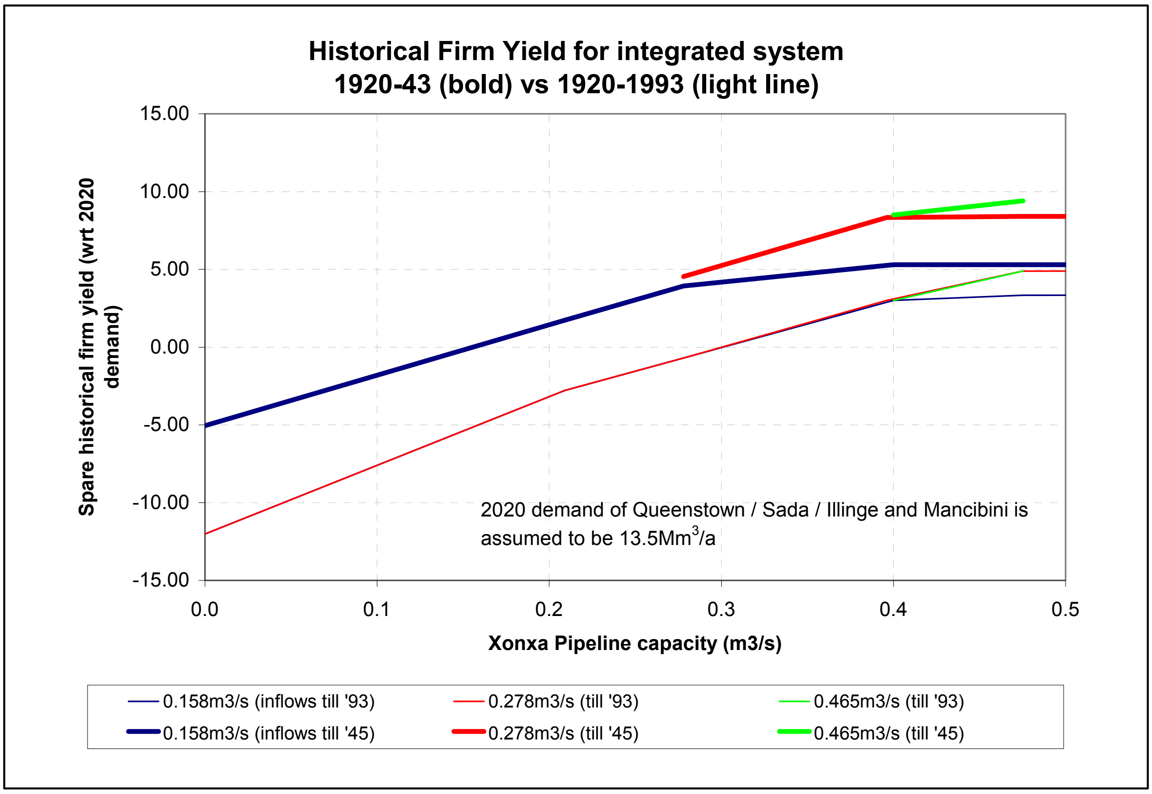

Figure 8.3 Comparison of firm yields of the constrained integrated system for the 1920 - 1943 and 1920 - 1993 periods

9. OPERATION OF THE INTEGRATED SYSTEM

9.1 CONSIDERATIONS

The earlier hydrological analyses have identified a number of uncertainties in the hydrology which necessitate a conservative approach to the development of operating rules:

9.1.1 Xonxa Hydrology

In the Upper Kei Basin Study and the Queenstown Regional Water Supply Study the levels manually recorded at gauge S2H003 were considered unreliable and could not be used because a rating table was not available. Hence the inflow to Xonxa Dam is based on simulated rather than observed records and is less reliable than the inflows to Waterdown Dam (see Section 5.1

9.1.2 Sedimentation and Evaporation considering the Increased Abstraction from Xonxa Dam

The dams in the area, with the exception of Waterdown Dam, are subject to high siltation rates. If Xonxa and Bonkolo Dams are relied on to supply high assurance water to urban consumers during droughts it is important to know how much siltation has reduced the available water, particularly when the dams are drawn down.

9.1.3 Evaporation Losses from Dams

The Waterdown Dam basin has a significantly smaller evaporative surface area for a given storage than the other dams in the system (see Figure 9.1). In addition, the annual evaporation at that dam is lower than the other dams (Table 9.1).

Note that in Figure 9.1 the net storage in 2020 was obtained from the gross storage from the latest available dam basin survey by deducting both the "dead storage" below the minimum supply level and an estimate of the additional silt volume accumulating since the last basin survey. This calculation assumes, conservatively, that siltation will occur just above the minimum supply level. For this reason, even if the modelled net storage available to consumers is zero, evaporation losses still occur.

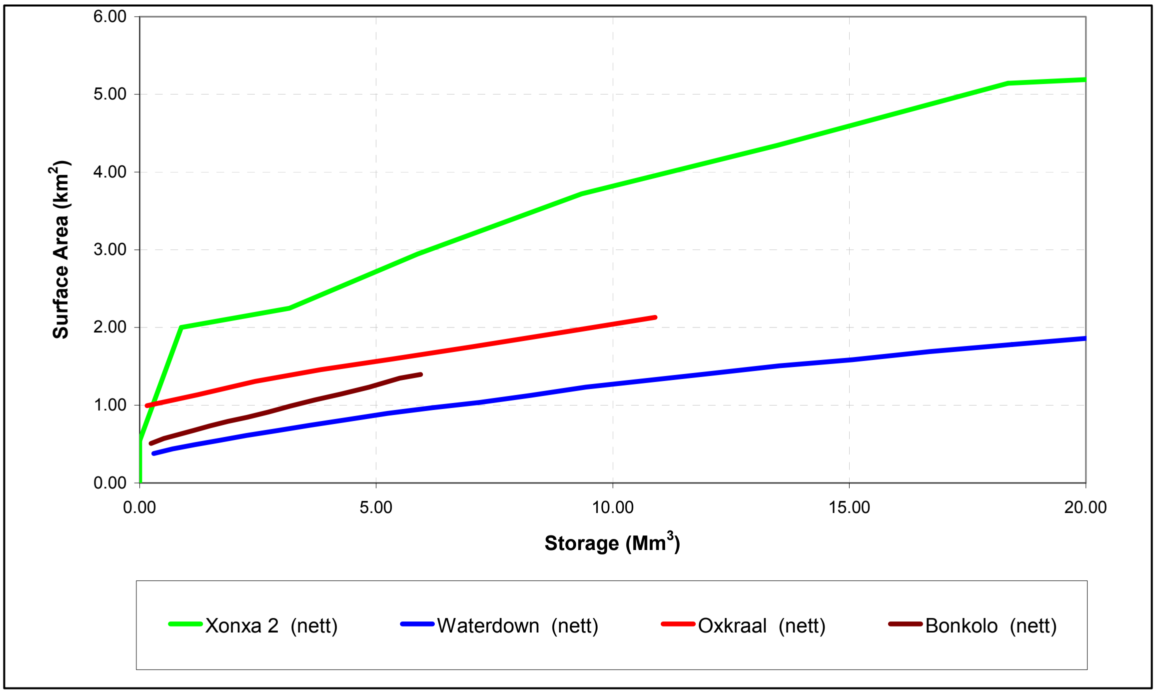

Figure 9.1 Relationship of surface area to net storage for the major dams of the Upper Kei River

TABLE 9.1 EVAPORATION FROM THE MAJOR DAMS

DAM	ANNUAL EVAPORATION (mm)
Bushmanskrantz Dam	1 526
Oxkraal Dam	1 526
Waterdown Dam	1 400
Bonkolo Dam	1 519
Lubisi Dam	1 647
Xonxa Dam	1 823

In the case of Xonxa Dam this would have meant that the surface area of the dam corresponding to zero net storage would have been about 4 km^2 and the evaporation losses would have been over-estimated. Additional dam basin survey data indicating at what level siltation occurred was available for Xonxa Dam and this was used to estimate that dam's future basin characteristics. The surface area corresponding to a net storage of 0 reduced from 4 km^2 to 0.8 km^2 though it does increase rapidly to 2 km^2 for a net storage of less than 1 Mm^3 (see also Annexure B).

9.1.4 Dam Spillage Risks

The capacities of the Xonxa and Bonkolo Dams are more than double their mean annual runoff (MAR), whereas the remaining dams (Waterdown, Oxkraal and Bushmanskrantz) are approximately equal to their MAR. This means that Xonxa and Bonkolo Dams need only be drawn down to 10% to have the same risk of spillage as the other dams when they are drawn down by 20%.

TABLE 9.2 RATIO OF STORAGE TO MAR

DAM	GROSS STORAGE	DEAD STORAGE	NET STORAGE	PRESENT DAY INFLOW (MAR)	RATIO OF NET STORAGE TO MAR
Xonxa	112,3	1,22	111,1	42,8	260%
Waterdown	38,39	1,08	37,31	38,6	97%
Oxkraal	15,68	4,78	10,9	15,3	71%
Bonkolo	6,95	1,01	5,94	2,57	231%
Bushmanskrantz	4,72	0	4,72	4,69	101%

9.1.5 Supply of Water Requirements Downstream of the Major Dams

The assumed releases required from the dams will need to be reviewed as better information becomes available.

The assumptions used for the current model have been documented in Annexure H and some of the major issues are summarised below. The modelled releases have also been summarised in Section 9.1.6.

The contribution from streamflows downstream of the major dams to the demands is uncertain because the actual streamflows were not gauged until about 2003. Furthermore, how much of the streamflows can actually be used by irrigators depends on both the variability of the flows and on whether pools in the river will help to store water for later pumping. In addition, the Upper Kei Basin Study mentions that a temporary arrangement was made to increase the releases by about 5,81 Mm^3/a to allow for losses. The EWR requirement is also not fixed and increases during wet periods and decreases during dry periods.

9.1.6 Irrigation Demands

Table 9.3 compares the dam allocations proposed in the main report with the modelled demands during different periods. In the system's critical period the modelled irrigation releases from Oxkraal and Waterdown Dams are about 0,4 Mm^3/a more than the allocated releases (compare columns f and b). The modelled releases from Xonxa Dam are 2,3 Mm^3/a less than the allocation from Xonxa Dam because the modelling assumes more contribution from accruals. See Section H.8 in Annexure H for a more detailed analysis.

TABLE 9.3 COMPARISON OF ALLOCATED AND MODELLED RELEASES OVER DIFFERENT PERIODS

REACH	RELEASES									
	ALLOCATED (1)	MODELLED								
		AVERAGE (OCT 1920 - SEP 1994)			SYSTEM CRITICAL PERIOD (AUG 1944 - JAN 1950)			DRY PORTION OF CRITICAL PERIOD (JUN 1948 - JAN 1950)		
	IRRIGATION	IRRIGATION	EWR	TOTAL	IRRIGATION	EWR	TOTAL	IRRIGATION	EWR	TOTAL
	(Mm^3/a)	(Mm^3/a)	(Mm^3/a)	(Mm^3/a)	(Mm^3/a)	(Mm^3/a)	(Mm^3/a)	(Mm^3/a)	(Mm^3/a)	(Mm^3/a)
A	B	C	D	E	F	G	H	I	J	K
Oxkraal/Waterdown	19,0	15,4	6,1	21,5	19,4	3,2	22,6	25,8	0,8	26,6
Xonxa	11,3	5,0	5,9	10,9	9,0	1,1	10,1	5,8	4,3	10,1
Total	30,24	20,40	12,00	32,40	28,40	4,30	32,70	31,60	5,10	36,70

(1) Based on releases from dams - column e in Table H.16

On average, the modelled releases (column c) are significantly less than the allocated releases (column b) because of the assumed high abstraction efficiency modelled for accruals, as discussed in Section H.1. For the analysis in Section 10 the releases from the dams were forced to be equal to the allocation to minimise the impact of the accruals.

9.1.7 Available Yield

Table 9.4 shows the long-term yields available from the dams. By deducting the anticipated demands in 2020 the reliability of supply can be estimated.

The 2020 demands were assumed to comprise :

- urban abstractions and
- irrigation and EWR abstractions from the dams during the critical period (column h in Table 9.3).

TABLE 9.4 USING LTCC TO ESTIMATE THE AVAILABLE YIELD

DAM NAME	YIELDS UNDER 2020 CONDITIONS (Mm^3/a)					
	HISTORIC FIRM YIELD	1:10 YEAR	1:20 YEAR	1:50 YEAR	1:100 YEAR	1:200 YEAR
Waterdown Dam	16,8	24,5	23,3	20,3	18,8	17,6
Oxkraal Dam	6,2	8,6	8,0	7,0	6,2	5,7
Bonkolo Dam	0,7	1,2	1,1	0,9	0,8	0,7
Existing system (no Xonxa)	23,7	34,2	32,3	28,1	25,9	24,0
Less 2020 demands on existing system						
Queenstown	-13,5	-13,5	-13,5	-13,5	-13,5	-13,5
Irrigation and EWR releases (1)	-22,6	-22,6	-22,6	-22,6	-22,6	-22,6
Spare supply from existing system	-12,4	-1,9	-3,8	-8,0	-10,2	-12,1
Xonxa Dam	20,6	29,6	27,2	23,0	20,7	19,0
Less 2020 demands on existing system						
Queenstown	0,0	0,0	0,0	0,0	0,0	0,0
Irrigation and EWR releases (1)	-10,1	-10,1	-10,1	-10,1	-10,1	-10,1
Spare supply from Xonxa	10,5	19,5	17,1	12,9	10,6	8,9
Spare supply from integrated system	-1,9	17,6	13,3	4,9	0,4	-3,2

If the full urban demand is imposed onto Waterdown Dam then the spare yield at the 1 in 10 year risk of failure is –1,9 Mm^3, so that failures can be expected at a frequency of more than 1 in 10 years unless support is obtained from Xonxa Dam. If the spare yield from Xonxa Dam is fully used, there is a small surplus of 0,4 Mm^3 at the 1 in 100 years risk of failure (bottom row of Table 9.4). The yield from Xonxa Dam that can be utilised will depend on the capacity of the pipeline from Xonxa Dam to Queenstown.

Table 9.5 shows that if the supply from Xonxa Dam to the urban consumers is increased to 10 Mm^3/a then both the Xonxa and Waterdown systems are close to supplying the demands with a 1 in 50 year risk of failure.

TABLE 9.5 USING LTCC TO ESTIMATE THE AVAILABLE YIELD, ASSUMING THAT 10 Mm^3/a IS SUPPLIED FROM XONXA DAM

DAM NAME	YIELDS UNDER 2020 CONDITIONS (Mm^3/a)					
	HISTORIC FIRM YIELD	1:10 YEAR	1:20 YEAR	1:50 YEAR	1:100 YEAR	1:200 YEAR
Waterdown Dam	16,8	24,5	23,3	20,3	18,8	17,6
Oxkraal Dam	6,2	8,6	8,0	7,0	6,2	5,7
Bonkolo Dam	0,7	1,2	1,1	0,9	0,8	0,7
Existing system (no Xonxa)	23,7	34,2	32,3	28,1	25,9	24,0
Less 2020 demands on existing system						
Queenstown	-3,5	-3,5	-3,5	-3,5	-3,5	-3,5
Irrigation and EWR releases (1)	-22,6	-22,6	-22,6	-22,6	-22,6	-22,6
Spare supply from existing system	-2,4	8,1	6,2	2,0	-0,2	-2,1
Xonxa Dam	20,6	29,6	27,2	23,0	20,7	19,0
Less 2020 demands on existing system						
Queenstown	-10,0	-10,0	-10,0	-10,0	-10,0	-10,0
Irrigation and EWR releases (1)	-10,1	-10,1	-10,1	-10,1	-10,1	-10,1
Spare supply from Xonxa	0,5	9,5	7,1	2,9	0,6	-1,1
Spare supply from integrated system	-1,9	17,6	13,3	4,9	0,4	-3,2

9.1.8 Desired Supply Reliability to Urban Consumers and to the Irrigators

Curtailment rules from previous studies have been summarised in Annexure E. Curtailment rules for irrigation from the UKBS suggest that no water would be released for irrigation at a frequency of about 1 in 10 years (Table 9.6). This is reasonable because the crops being irrigated are annual cash crops as opposed to established orchards. In one operating rule the urban supply was restricted to about 7 Mm^3/a when the Waterdown Dam's storage dropped to 19% (see Figure 9.2) while in another operating rule the supply to Sada/Whittlesea dropped to 45% when the storage dropped to 10% (see Table E.1). These operating rules were developed prior to the need for making ecological water releases.

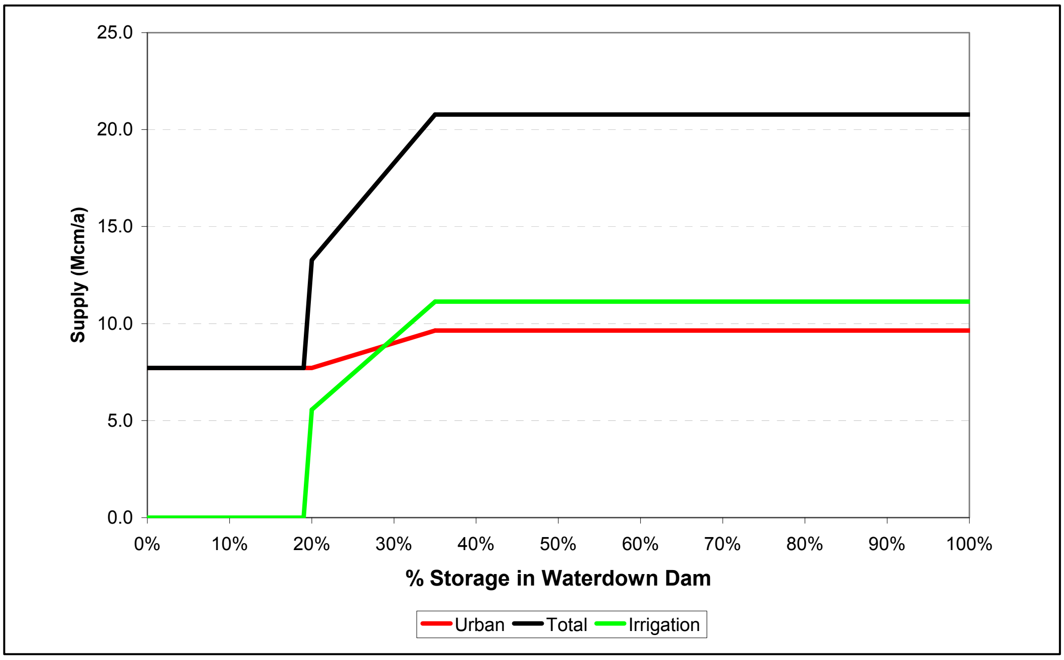

Figure 9.2 Curtailment of supply from Waterdown Dam described in the UKBS Study (see Annexure E.1)

TABLE 9.6 RELIABILITY OF SUPPLY DESCRIBED IN THE UKBS (See Table E.3) in Annexure E.3)

RESTRICTION	RETURN PERIOD (YEARS)	PERCENTAGE REDUCTION (%)
Partial restriction	1:5	0 - 50 (progressive)
Full restriction	1:10	100

The consumption statistics provided by the Lukanji Engineering Department have been used to estimate acceptable levels of curtailment (Annexure D). These are primarily based on capping the domestic monthly consumption to 20, 13, 10 and 5 m^3/month for "light", "medium", "heavy" and "crisis" restrictions and applying some curtailment to the commercial and industrial consumers to reduce gardening and wastage in toilets (see Table 9.7). It was assumed that one third of the unaccounted-for water could not be restricted and that the other two thirds would be reduced with the reduction in demand. The resultant reductions in demand for light, medium, heavy and crisis restrictions were 93%, 75%, 62% and 40% (see Table 9.7), which could be rounded to 90%, 75%, 60% and 40%.

TABLE 9.7 RESTRICTION LEVELS APPLIED TO DOMESTIC, COMMERCIAL AND INDUSTRIAL CONSUMERS

		RESTRICTION LEVEL			
CODE	CATEGORY	LIGHT	INTERMEDIATE	EXTREME	CRISIS
D	Domestic (m^3/month)	20	13	10	5
C	Commercial (% supply)	90%	80%	70%	50%
I	Industrial (% supply)	95%	90%	85%	80%
		93%	75%	62%	40%

The irrigation releases will be curtailed more frequently than the urban supply (Table 9.8) and 1 in 10 years no irrigation releases may be made.

Consider also what EWR flood releases should be made under the following scenario. The dams are 15% full and the urban consumers are being restricted to say 6% of their prevailing requirement. Some inflows raise the dam storage to 25%. Should a large EWR flood release be made or should water be retained to increase the system storage ?

Another consideration is that the flows downstream of Waterdown and Xonxa Dams are modified by the summer irrigation releases. These releases occur in the correct season though they would be made in dry months, whereas the EWR releases would be made in wetter months. However, they may contribute toward the ecological requirements downstream of Waterdown Dam and reduce the releases required in the dry months. Environmentalists should be approached to see if it is feasible to construct an ecological release sequence taking into consideration the modified flow regime introduced by the irrigation releases.

TABLE 9.8 PERCENTAGE OF NORMAL WATER REQUIREMENT SUPPLIED DURING RESTRICTIONS OF VARYING SEVERITY

WATER REQUIREMENT CATEGORY	CRISIS	LEVEL 4	LEVEL 3	LEVEL 2	LEVEL 1
		1 in 200 years	1 in 100 years	1 in 10 years	1 in 5 years
Urban	40%	60%	75%	90%	90%
Irrigation	0%	0%	0%	0%	50%
EWR baseflows	Reduced?	100%	100%	100%	100%
EWR flood releases	Reduced ?	Reduced ?	Reduced ?		

The irrigation releases will be curtailed more frequently than the urban supply (Table 9.8) and 1 in 10 years the no irrigation releases may be made.

TABLE 9.9 PERCENTAGE OF NORMAL WATER REQUIREMENT SUPPLIED DURING RESTRICTIONS OF VARYING SEVERITY

WATER REQUIREMENT CATEGORY	CRISIS	LEVEL 4	LEVEL 3	LEVEL 2	LEVEL 1
		1 IN 200	1 IN 100	1 IN 10	1 IN 5 YEARS
Urban	40%	60%	75%	90%	90%
Irrigation	0%	0%	0%	0%	50%
EWR baseflows	Reduced?	100%	100%	100%	100%
EWR flood releases	Reduced?	Reduced?	Reduced?		

9.1.9 Ecological Water Releases

Environmentalists should be approached to see if it is feasible to construct an ecological release sequence taking advantage of the modified flow regime introduced by the irrigation releases, possibly optimising both the irrigation and EWR release regimes. Historically the irrigation releases were made as a slug of water with a higher initial release rate over a period of 9 to 10 days and this may also help to simulate flood releases (see Annexure E).

Figure 9.3 shows the average monthly distribution of the natural inflows (solid red line), the EWR requirements (dashed blue line) and the irrigation requirements (dashed yellow line). Because some of the requirements are supplied from inflows downstream of the dam the EWR and irrigation releases from the dam are less than the requirements but follow the same pattern (solid yellow and solid blue line respectively). What is interesting is that the average EWR releases and irrigation releases occur in the same season and there might be an advantage if environmentalists and irrigators consider the symbiotic nature of environmental and irrigation releases. In practice the EWR releases may occur in "wetter" months in the summer while the irrigation releases would occur in the "drier" months interspersed between the wetter months but they may both contribute to the same ecological processes.

Figure 9.4 shows releases made solely for EWR (blue area) and solely for irrigation (yellow area) and those EWR releases that could be used by irrigation (green area). The areas are stacked so the sum of the areas is the total release made for EWR and irrigation. For interest the EWR requirements at Site 1 downstream of Waterdown Dam have also been shown (solid red line).

The EWR releases are based on the natural inflow into the system so that if the inflows are small the resultant EWR releases are automatically reduced. The EWR releases at Site 1 (red line) are rather sporadic because of the sporadic inflows. Minimal EWR streamflows are required between September 1948 and January 1950. In the other years, except possibly for the 1947/48 summer, the EWR streamflows occur in early or late summer, rather than during summer itself.

It seems likely that the summer irrigation releases would also contribute to the summer ecological requirements and environmentalists should be approached to integrate the contribution of irrigation releases into the environmental requirement. If one focuses on the releases made during the critical period the following could be addressed :

- What is the benefit of the unseasonal release in June 1945 ?
- To what extent can the irrigation releases in Jan 1946 reduce the EWR requirements in Feb 1946 ? Could the environmental releases in October 1945 be held over to November 2005 when irrigation releases were scheduled ?
- Similarly in 1946/47, would the summer irrigation releases reduce the EWR requirements in October 1946 and March 1947 ? i.e. would the irrigation releases in November 1946 and February 1947 fulfil the same requirement ? Could the irrigation releases be made earlier or the environmental releases be made later ?
- The wetter summer of 1947/48 coincides with a period when the dams are drawn down – could the flood component of the EWR releases be reduced or possibly be integrated into the irrigation releases ?
- In the period from September 1948 and January 1950, very few EWR releases are made. Would some minimum irrigation releases be beneficial to the ecology, bearing in mind that the irrigation releases would probably be stopped during this period to conserve water ?
- In February and March 1950 the dams are almost empty and a freshet helps to lift the dam storage by almost 15%. A significant flood release made at this time, when the urban

supplies were curtailed to 40% and no irrigation releases were being made, might have a very adverse effect on the urban supply. Therefore, it is likely that the need for an EWR release in these circumstances would be very carefully assessed.

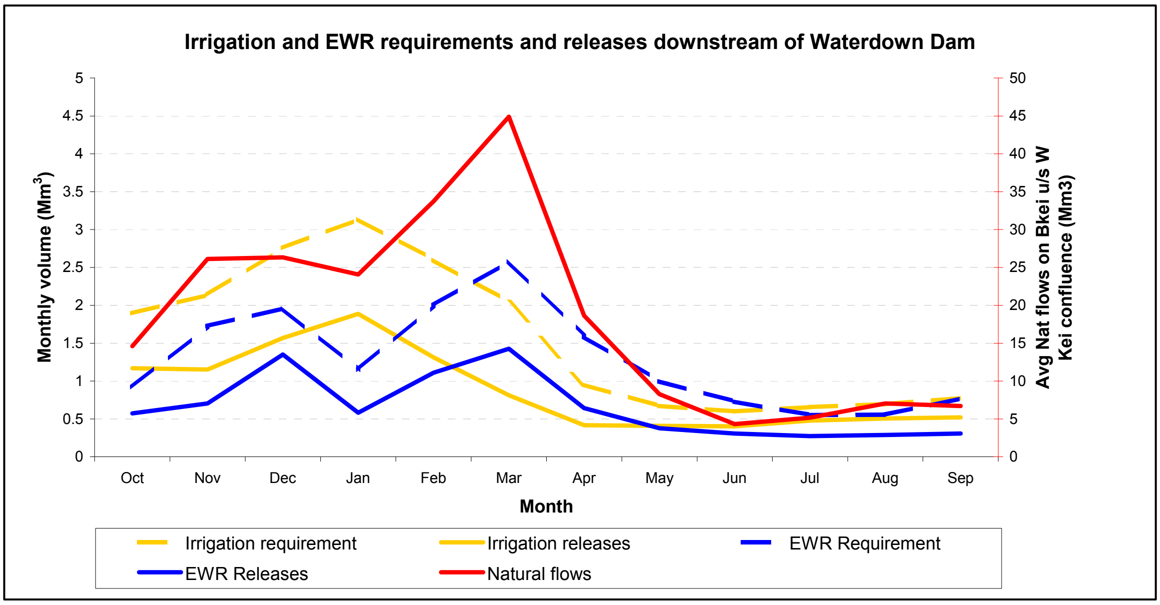

Figure 9.3 Average EWR and irrigation requirements downstream of Waterdown and Oxkraal Dams

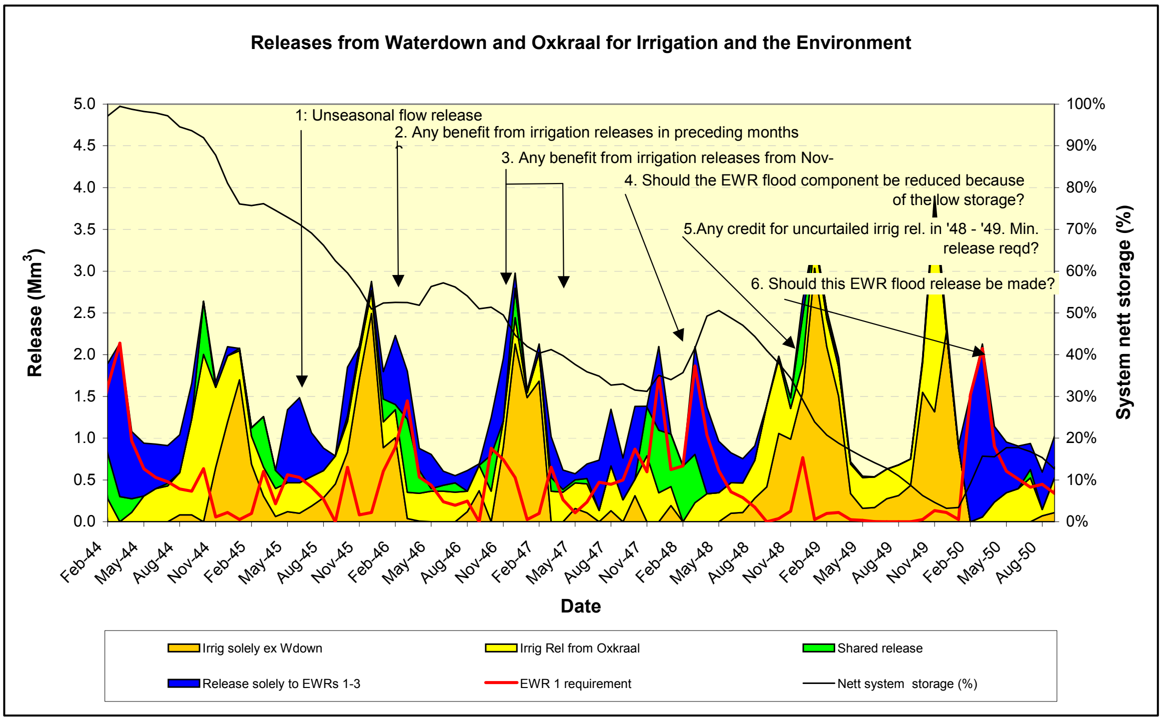

Figure 9.4 Comparison of EWR requirements at Site 1 with releases for EWR and irrigators

9.1.10 High Proportion of Supply to Irrigators

During the critical drawdown period about 60% of the water requirements were for irrigation. If these demands are curtailed too late, the system could easily be over-stressed, resulting in severe curtailment of the urban supply.

9.1.11 Integrated Operation of Waterdown and Oxkraal Sub-systems

It was assumed that the Oxkraal and Waterdown systems would be operated in an integrated manner, but this would have to be discussed with the parties concerned with a view to creating an integrated water user association. At present, the EWR releases for the Klipplaat Dam are made from the Waterdown Dam which is contributing to the deficit of that sub-system. If the Oxkraal system were operated independently, its contribution to the EWR requirements would have to be quantified.

9.2 OPERATING RULES

9.2.1 Idealistic Operation

Ideally, the Lukanji system should be operated in an integrated manner to draw down the dams in a systematic manner, minimising spill and increasing the security of supply to the consumers. An integrated operation would have the following features :

1. When the dams are at a risk of the spilling dams with a smaller ratio of storage to MAR, (Waterdown and Oxkraal) would be drawn down relatively more than the dams with a larger ratio (Xonxa and Bonkolo).
2. As the system is drawn down and the risk of spillage decreases, the demands are switched onto Xonxa Dam to reduce the evaporation losses. If the pipeline capacity from Xonxa Dam to Bonkolo Dam is insufficient to provide the peak water requirement of Queenstown, Illinge and Macibini, then additional water required for the summer peak can be kept in Bonkolo Dam. If Bonkolo Dam is maintained below half full, the risk of spillage is minimal, particularly as the demand on the dam is relatively large compared to its capacity.
3. When the system is drawn down below 50%, the supply to irrigators and urban consumers is curtailed in step-wise increments, initially to 70% and 90% of the median requirements (blue and teal lines)
4. When the system is drawn down to 30%, the supply to the irrigators would be reduced to 50% of the median release, and the supply to the urban consumers would be reduced to 75%.
5. When the system is drawn below 20%, the supply to the irrigators would be completely curtailed and the supply to the urban consumers would be reduced to 60%.
6. In the worst case, the urban demands might be reduced to 40% of the normal demand and the inflows might be minimal for a period of 18 months to two years. To bridge this event, a minimum volume of about 23% is required in Waterdown Dam. The water required by the urban sector can be kept in Waterdown Dam to minimise evaporation, and because there is less likelihood of over-estimating the available water through under-estimating the

siltation. In a crisis Bonkolo and Xonxa Dams can be drawn down completely, possibly using the water in dead storage, to minimise evaporation.

The integrated operation is dependent on the ability to shift demands from one dam to another. In the Lukanji, the only demand that can be switched from the Xonxa/Bonkolo system to the Waterdown/Oxkraal system is the urban demand of Queenstown, Illinge and Macibini. This demand is not sufficient to enable fully integrated operation of the system and ensure a balanced drawdown of the system as was seen in Figure 9.3.

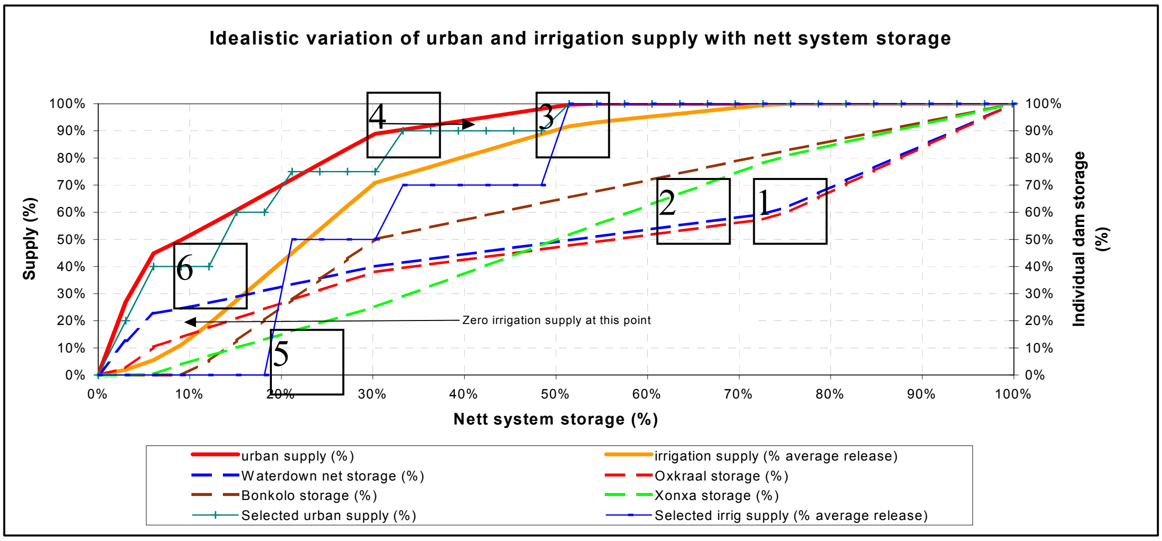

Figure 9.5 Idealised integrated operation of the Lukanji system

9.2.2 Semi-integrated Operating Rule

Because it is not possible to operate the dams in a fully integrated manner, a semi integrated operating rule was adopted.

To determine the curtailment of the urban supply the system was broken up into two sub-systems; the Waterdown sub-system and the Xonxa/Bonkolo sub-system. The Queenstown complex (including Illinge and Macibini) can obtain water from both sub-systems and each of the systems was managed to provide a portion of the urban requirements. The exact proportion from each sub-system can vary if one sub-system has a surplus relative to the other system, and if this surplus can be used to support the sub-system with a shortfall, the curtailments can be relaxed.

The curtailment of irrigation was determined by the state of the appropriate dam, be it Waterdown, Oxkraal or the Xonxa/Bonkolo system, as is illustrated in Figures 9.4, 9.5 and 9.6.

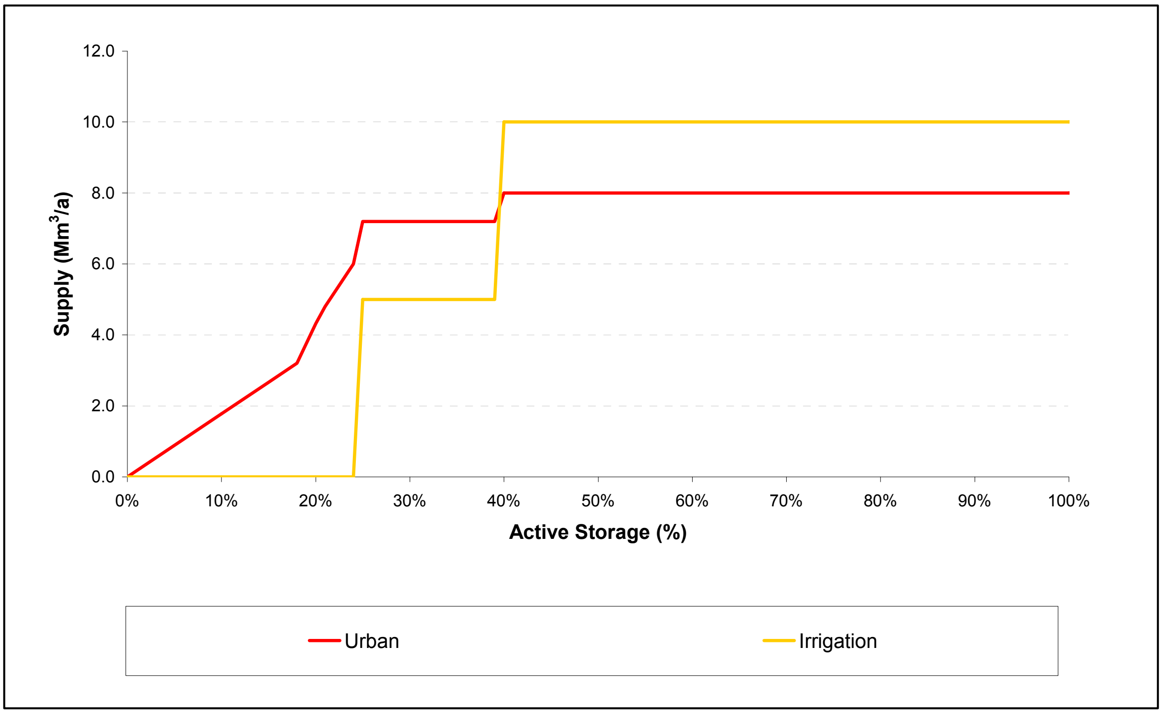

Figure 9.6 Curtailment of supply from Waterdown as a function of active storage

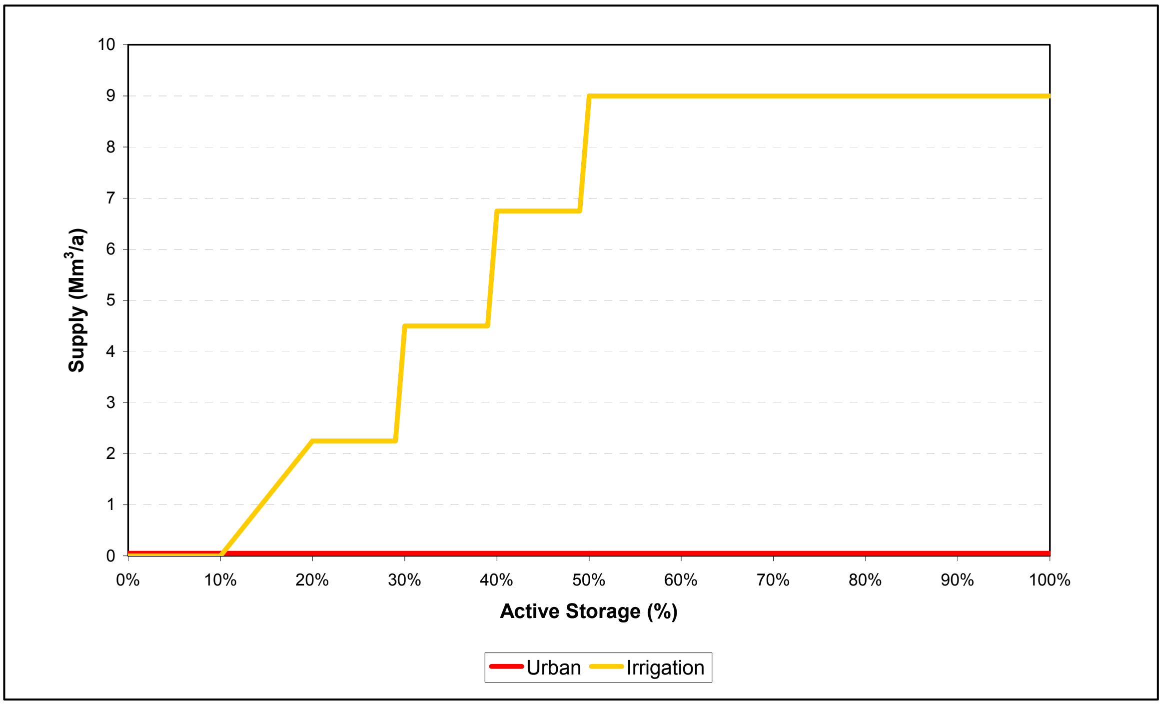

Figure 9.7 Curtailment of supply from Oxkraal Dam as a function of active storage

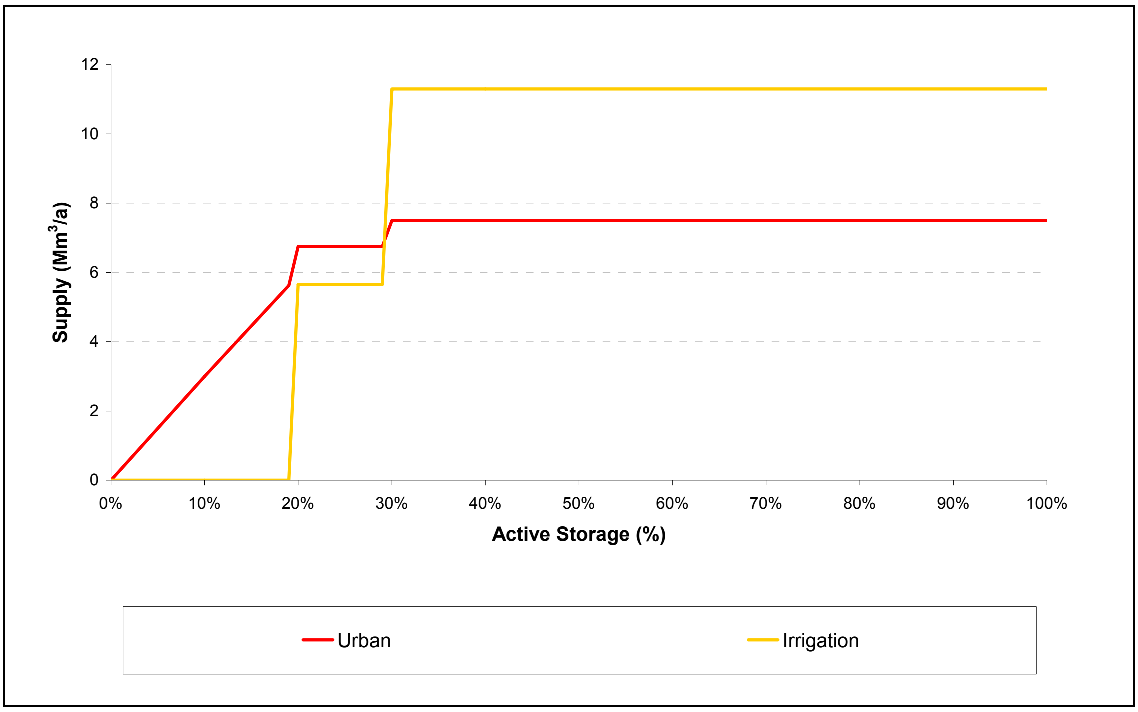

Figure 9.8 Curtailment of supply from Xonxa Dam as a function of active storage

10. IMPACT OF THE CAPACITY OF THE XONXA PIPELINE ON THE RELIABILITY OF SUPPLY

10.1 HISTORICAL ANALYSIS

According to Table 9.5, if about 10 Mm^3/a is supplied from Xonxa Dam, then both the Waterdown Dam and Xonxa Dam sub-systems will have a similar risk of failing under 2020 demand levels.

In practice, however, the systems are not operated with fixed demands on each sub-system.

Firstly, the droughts and wet periods in the two sub-systems do not necessarily coincide so that the abstraction may switch from sub-system to sub-system depending on which has the greater surplus (see Figure 8.2). The larger the bulk-supply lines from Waterdown Dam and Xonxa Dam, the greater the ability to switch supply from sub-system to sub-system to minimise the spill from the system.

Secondly, the demands are progressively curtailed as the dam levels are drawn down to ensure that a portion of the urban supply is provided at a high reliability.

The system was modelled to incorporate different bulk water supply line capacities and a curtailment rule that reduced the supply as the storage in the system reduced. The cases and the results are summarised in Table 10.1..

In all cases :

- The target demand supplied to Sada and Queenstown was equal to the estimated 2045 demand of 15.5 Mm^3.
- The irrigation releases supplied from the dams equalled the allocations summarised in column b of Table 9.3, i.e. 19 Mm^3 supplied from Waterdown and Oxkraal and 11.2 Mm^3 from Xonxa.
- The full EWR requirements downstream of the dams were supplied.
- Pools were used to simulate transmission losses downstream of Waterdown and Oxkraal Dams. However, it was assumed that the 3 Mm^3/a losses incurred in the last 15-20 km upstream of the White Kei confluence (Table 5.2) would be avoided by stopping the 0,3 Mm^3/a irrigation water supplied along that reach.

Figures 10.1, 10.2 and 10.3 show the curtailment in supply with decreasing active storage for the Waterdown, Xonxa/Bonkolo and the Oxkraal systems. Figures 10.4, 10.5 and 10.6 present the same information slightly differently, giving the percentage supply (instead of the Mm^3/a) from the Waterdown, Xonxa/Bonkolo and Oxkraal/Bushmanskrantz systems, respectively. The supply to consumers was adjusted in March and September and kept constant in the intervening months.

If the urban supply from Waterdown (Figure 10.1) plus Xonxa/Bonkolo (Figure 10.2) exceeds the required demand, then the surplus may be supplied from either Waterdown or Xonxa/Bonkolo.

For a given system storage, Figure 10.7 shows the theoretical optimum relative storages of the individual dams such as Waterdown, Xonxa and Bonkolo. The surplus should be provided from the dam that is furthest above its theoretical optimum storage. As discussed in Section 9.2, it is difficult to maintain this relative drawdown of the dams.

The percentage of the irrigation allocation supplied from Waterdown/Oxkraal decreased from about 92% through 87% to 79% as the urban demand on Waterdown Dam increased from 3 through 7.5 to 15.5 Mm^3/a (column m in Table 10.1).

Figure 10.9 shows the reliability of irrigation releases from Waterdown Dam for the various scenarios. Note how slight curtailments can be expected more than 50% of the time. About 20% of the time the supply reduced from the desired 19 Mm^3/a to 16, 14 and 11 Mm^3/a as the supply to the urban consumers from Waterdown Dam increased from 3 through 8 to 15 Mm^3/a, respectively.

As the supply from Waterdown Dam increased so the supply from Xonxa Dam decreased and the water available to irrigation decreased. If Waterdown Dam attempts to supply all the urban requirements, then the 100% of the irrigation supply from Xonxa Dam can be met. This reduces to 95% if the urban demand on Waterdown Dam decreases to 8 Mm^3/a and 81% if only 3 Mm^3/a is supplied from Waterdown Dam.

The reliability of the urban supply increases when water is obtained from both Waterdown and Xonxa Dams. If only 3 Mm^3/a is supplied form Waterdown (i.e. to Sada/Whittlesea) or no water is supplied from Xonxa, then the minimum annual supply to the urban consumers is less than 60% in both cases (see column s of Table 10.1). If water is supplied from both systems, then the minimum annual supply rises to above 80% and on average above 98% of the urban demand is supplied (see column q of Table 10.1).

During droughts the releases to irrigation are curtailed and very little water may be available for extended periods. This is illustrated in Figure 10.11 where the releases from Waterdown Dam do not exceed half of the allocation for the seven year period from 1932 to 1937 and in two years in this period almost no releases are made. Because the system cannot be operated in an integrated manner, Xonxa irrigation releases are not curtailed in this period but in an earlier period.

TABLE 10.1 IMPACT OF THE CAPACITY OF THE XONXA PIPELINE ON THE RELIABILITY OF SUPPLY

Scenario: Identifier	Scenario: Description	Pipeline capacities: Waterdown to Qtown (m³/s)	Pipeline capacities: Xonxa to Bonkolo (m³/s)	Pipeline capacities: Wdown to Qtown *plus* Sada (Mm³/a)	Pipeline capacities: Xonxa to Bonkolo (Mm³/a)	Demands: 15.5Mcm/a to Sada Qtown	Demands: Irrig allocations (inc 25% losses)	Demands: Supply all EWRs	Demands: Losses : last 20km of BKei u/s WKei	Demands: Losses : remaining d/s Wdown/Oxkraal	Factored White Kei inflows	Supply: Irrigation: Waterdown: Irrig Supply %	Supply: Irrigation: Waterdown: years with shortfalls %	Supply: Irrigation: Xonxa: Irrig Supply %	Supply: Irrigation: Xonxa: years with shortfalls %	Supply: Urban: Xonxa: Urban supply %	Supply: Urban: Xonxa: years with shortfalls %	Supply: Urban: Xonxa: Minimum annual supply %	Case in \hydro\10676\ym\ih directory
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t
R1	No urban supply from Xonxa	999	0.00	999	0.0	Y	Y	Y	N	Y	na	79	50	100	0	92	27	39	15x0
R2	Only Sada supplied from Waterdown	Na	0.40	3	15.0	Y	Y	Y	N	Y	100	92	39	81	36	96	31	57	3X15
R3	Existing Waterdown plus up to 7.5 Mm³/a from Xonxa	0.16	0.24	8	7.5	Y	Y	Y	N	Y	100	87	44	95	15	98	27	82	8X7
R4	Existing Waterdown plus up to 15.5 Mm₃/a from Xonxa	0.16	0.40	8	15.0	Y	Y	Y	N	Y	100	88	43	91	27	100	4	97	8X15
R5	Existing Waterdown plus up to 7.5 Mm³/a from Xonxa; White Kei inflows reduced by 20%	0.16	0.24	8	7.5	Y	Y	Y	N	Y	80	87	44	82	30	96	41	69	8X7b
R6	Existing Waterdown plus up to 10 Mm³/a from Xonxa	0.16	0.32	8	10	Y	Y	Y	N	Y	100	87	44	95	14	99	9	82	8X10

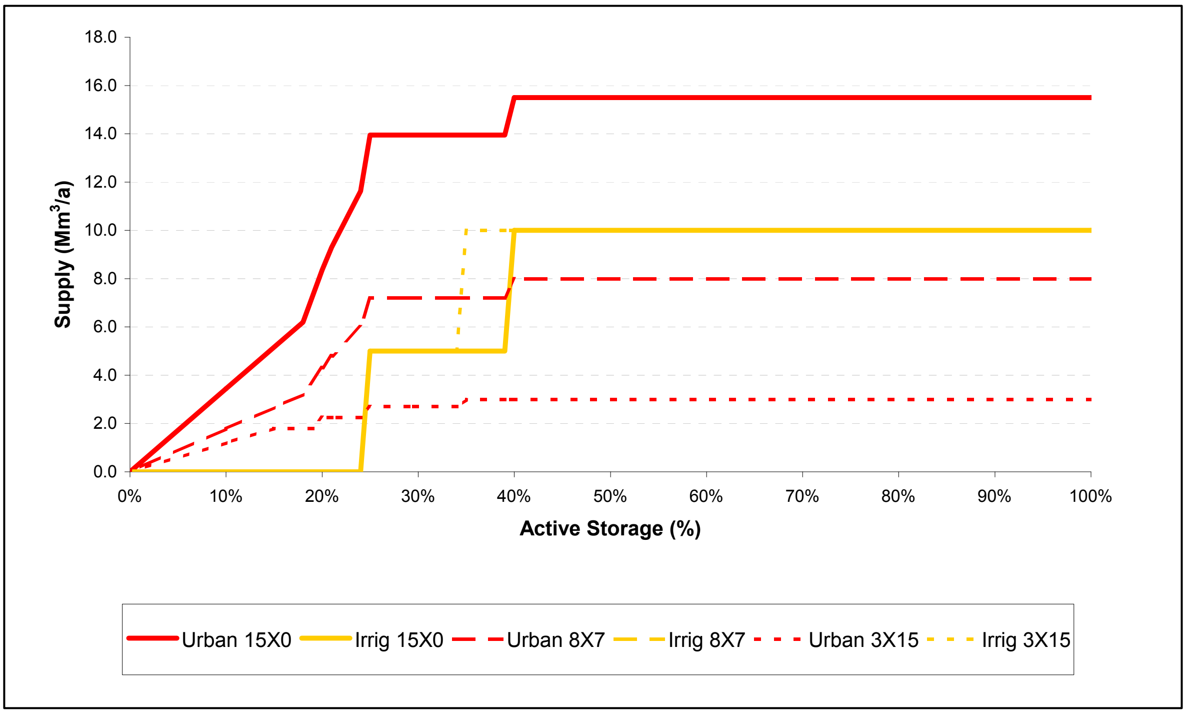

Figure 10.1 Curtailment of supply from Waterdown Dam

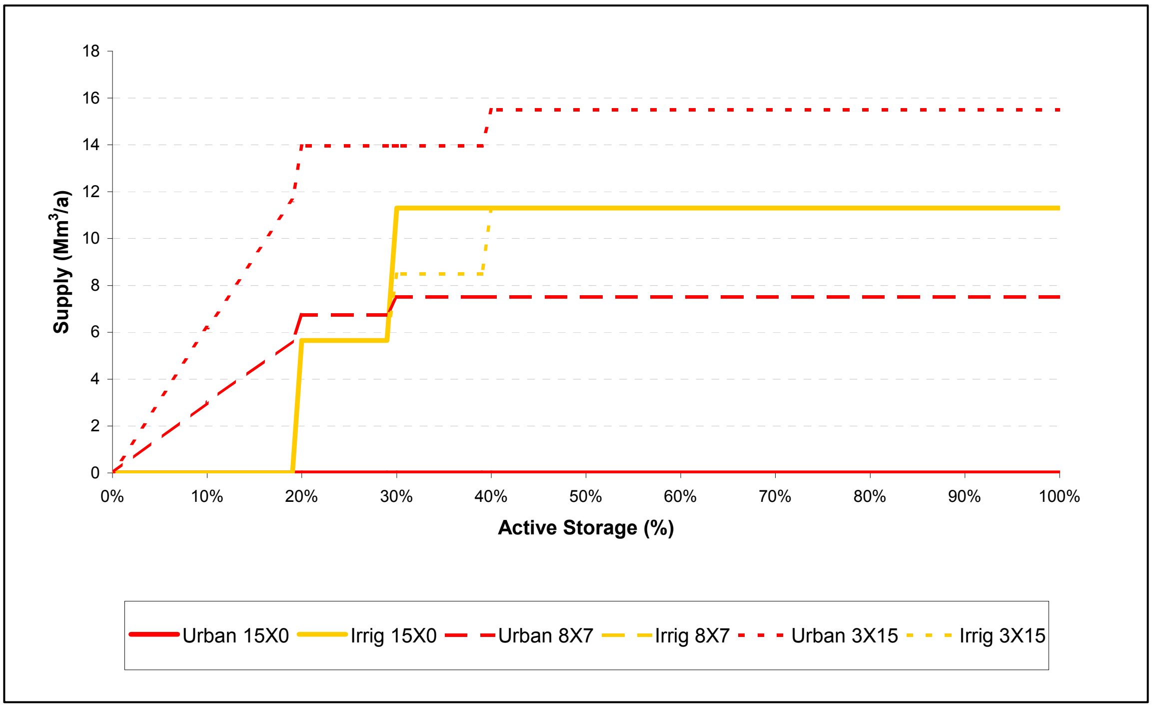

Figure 10.2 Curtailment of supply from Xonxa and Bonkolo Dams

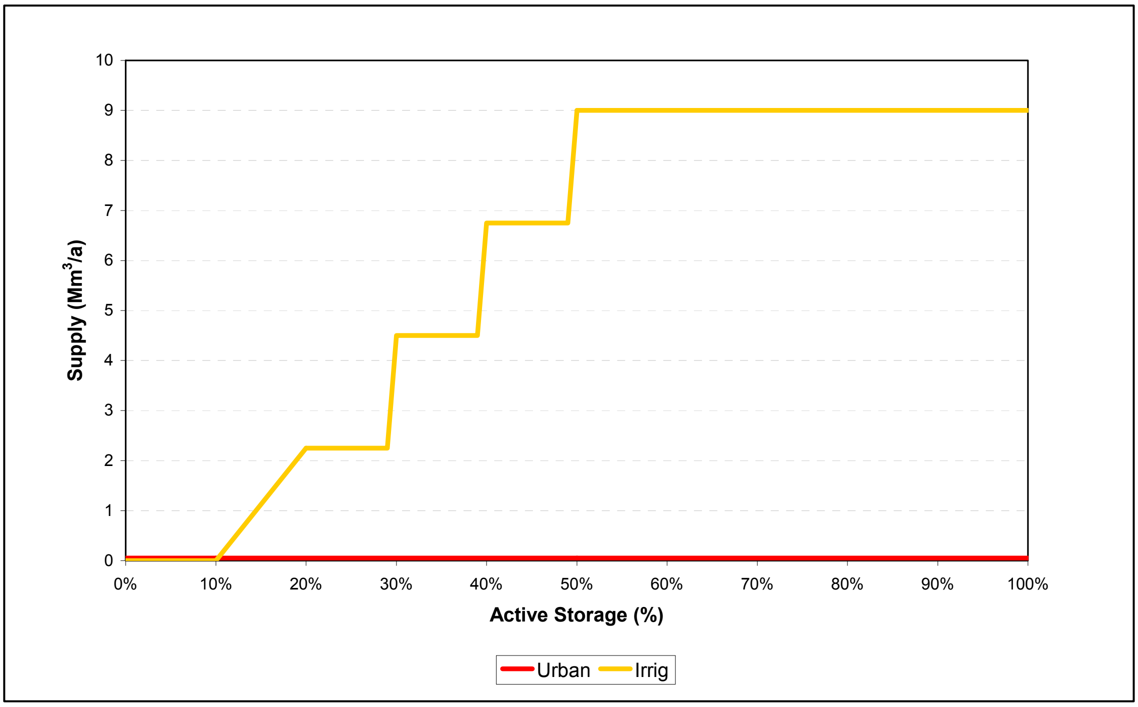

Figure 10.3 Curtailment of supply from Oxkraal/Bushmanskrantz

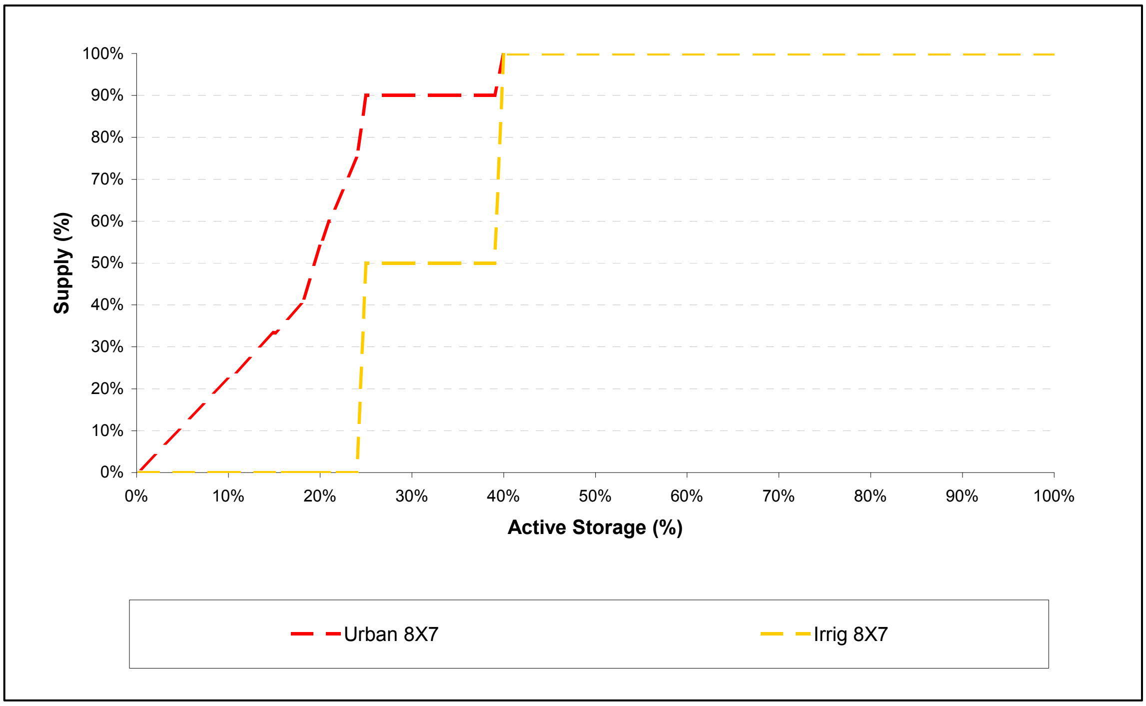

Figure 10.4 Curtailment of supply from Waterdown Dam (% of normal supply)

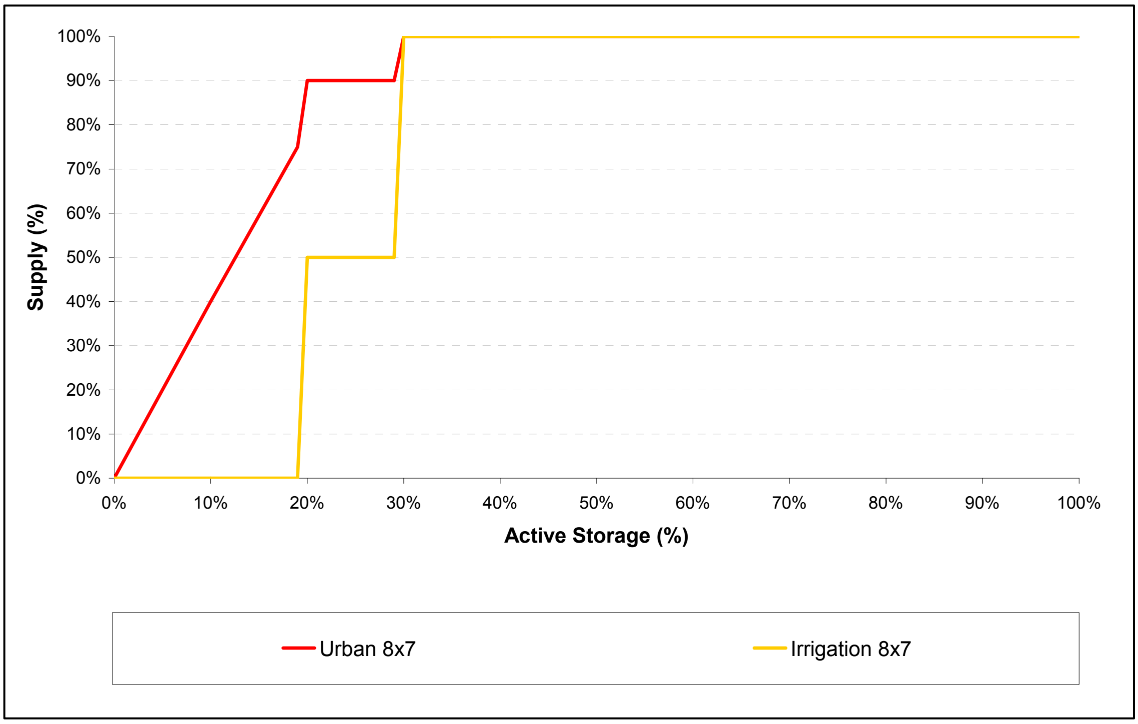

Figure 10.5 Curtailment of supply from Xonxa and Bonkolo Dams (% of normal supply)

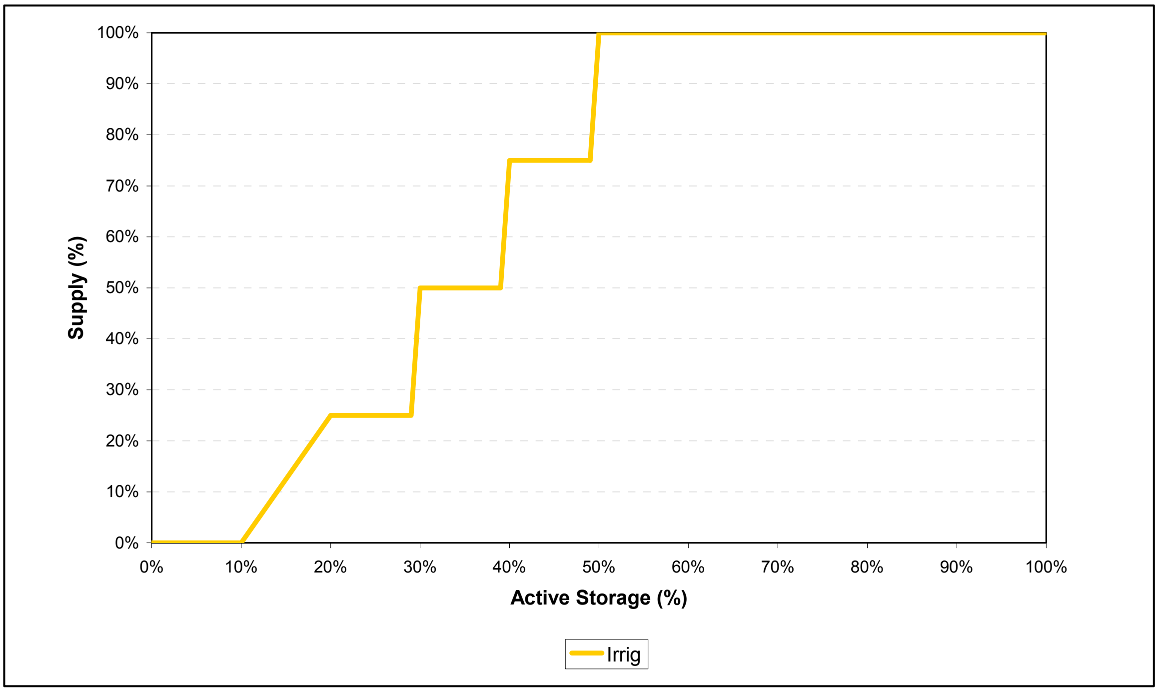

Figure 10.6 Curtailment of supply from Oxkraal/Bushmanskrantz (% of normal supply)

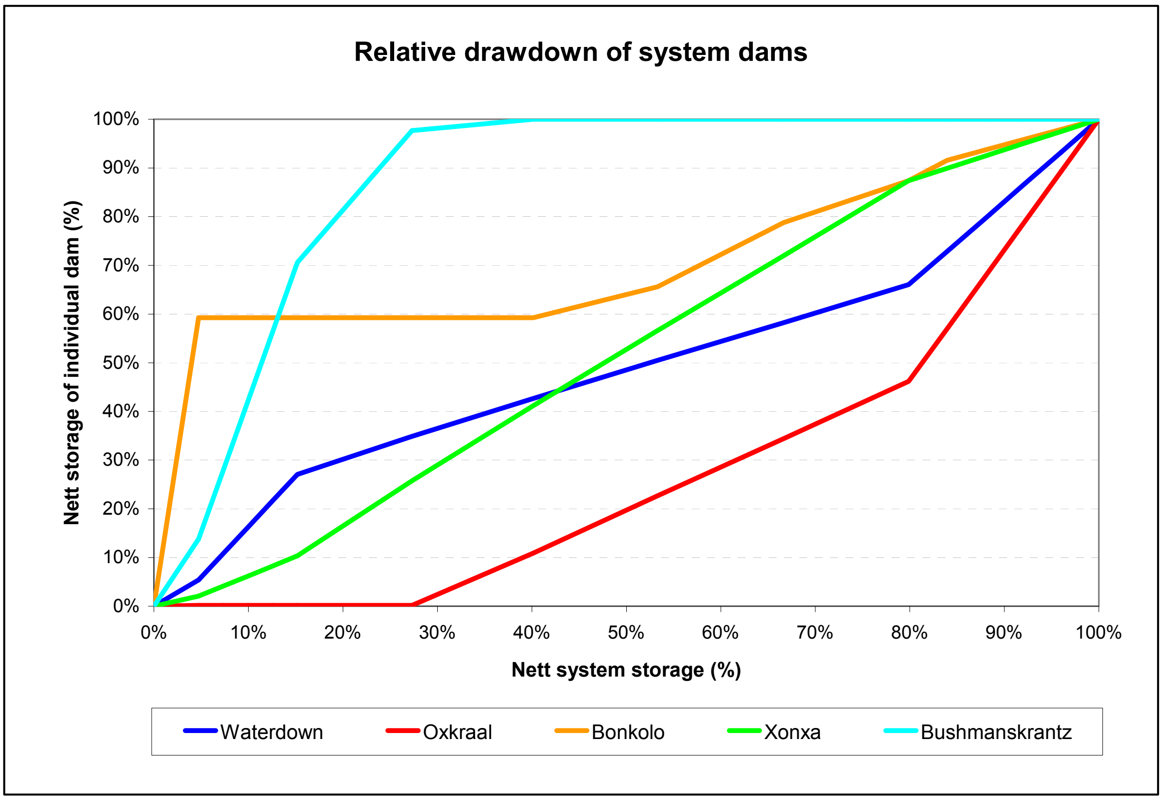

Figure 10.7 Approximate relative drawdown of the system dams

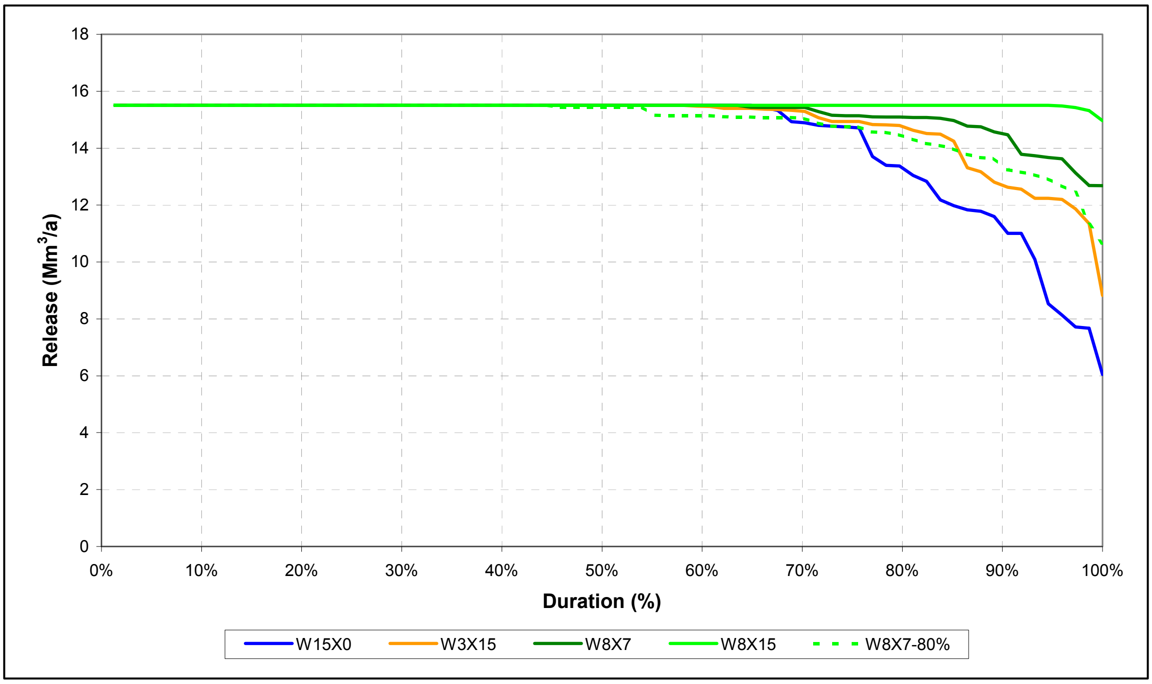

Figure 10.8 Reliability of urban supply

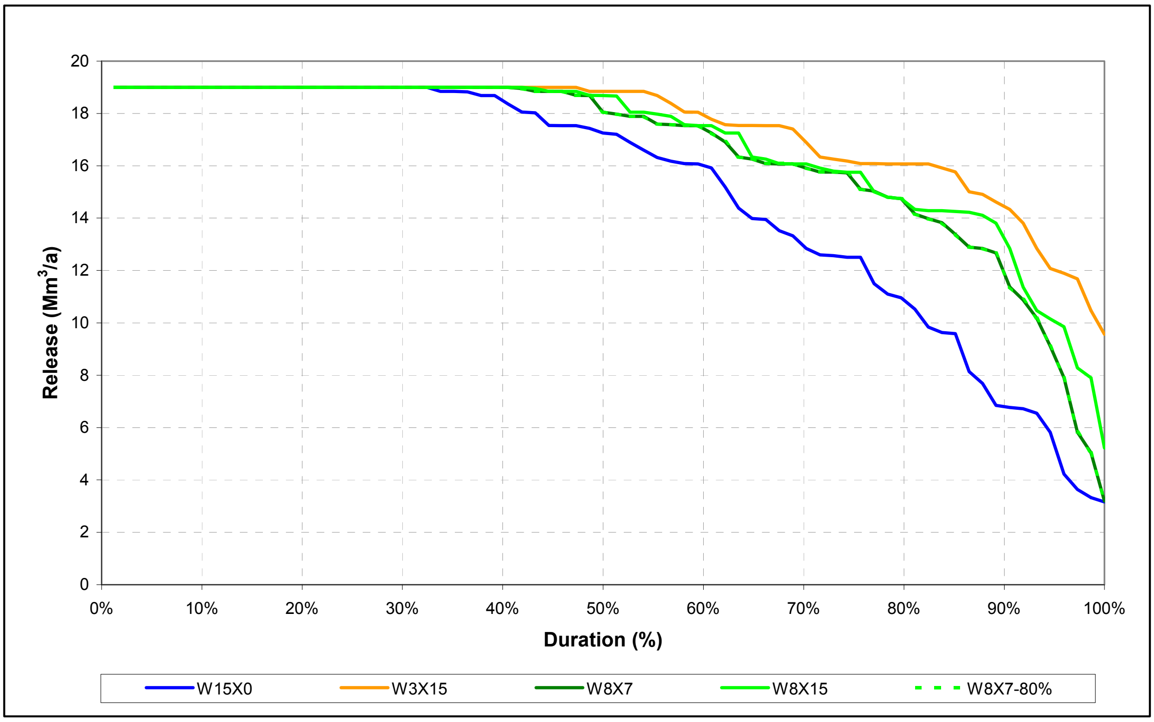

Figure 10.9 Reliability of irrigation releases from Waterdown/Oxkraal

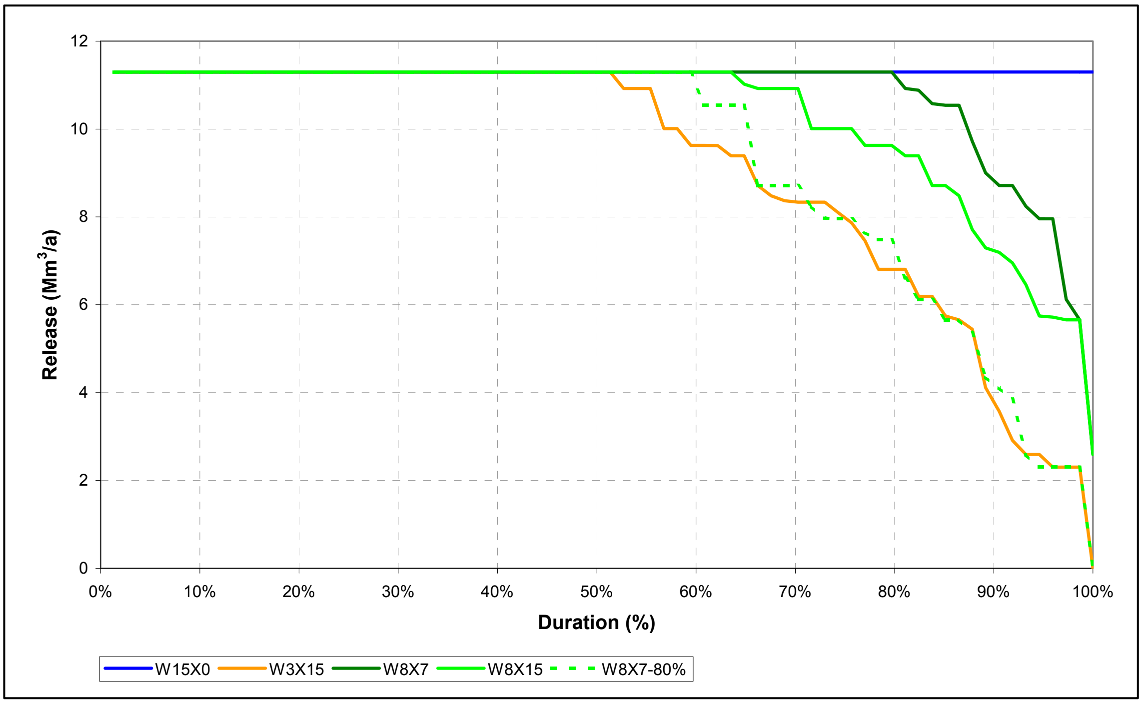

Figure 10.10 Reliability of irrigation releases from Xonxa

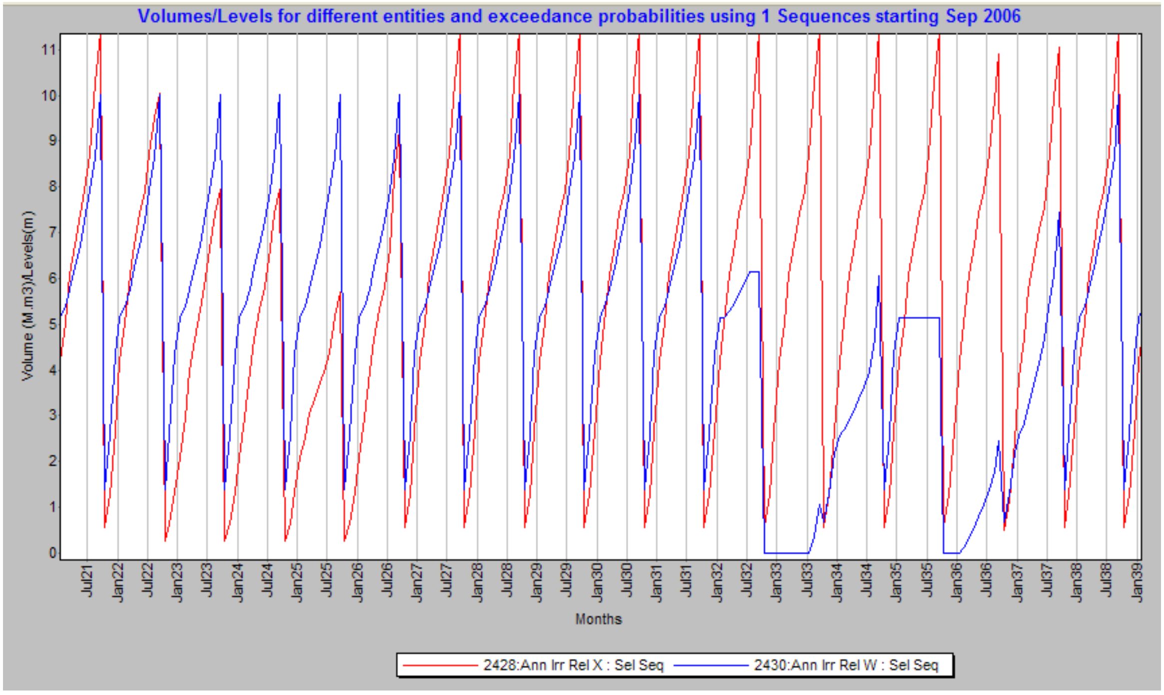

Figure 10.11 Supply to irrigation from Xonxa and Waterdown from 1920 - 1930

10.2 FURTHER REFINEMENTS TO THE OPERATING RULES

The preceding analysis was performed using the historical inflow sequence. The behaviour of the system was also checked under a number of alternative stochastic inflow sequences with the same statistical characteristics as the historical inflow sequence. The system was started at an initial storage of 40% to identify the worst case supply to the urban consumers. The green triangles in Figure 10.12 show how much of the annual demand of 15.5 Mm^3/a was supplied each year to urban consumers over the analysis period. For the year ending August 1913, about 5 Mm^3 was supplied which is approximately 30% of the required demand, which is less than the crisis limit of 40%.

However, the minimum storage in the system at this time was about 11 Mm^3 and an additional 1 Mm^3/a could have been supplied to increase the supply to the crisis limit of 40% of the target draft.

The black triangles show the lowest combined storage modelled in the Xonxa, Waterdown and Bonkolo Dams for the 400 stochastic sequences. The red triangles show the lowest storages modelled in Waterdown while the blue triangles are the lowest storages in Xonxa. These mimima did not occur at the same sequence. Note that although the minimum storage in the combined storage is 11 Mm^3 there are still localised failures in Waterdown Dam. In this sequence, although the storage in Waterdown Dam is drawn down to less than 2 Mm^3 the storage in the other dams would have to be at least 9 Mm^3 for the combined storage to remain above 11 Mm^3. Similarly, at times Xonxa Dam is drawn down to about 4 Mm^3 and at least 7 Mm^3 would need to be stored in the Waterdown and Bonkolo Dams for the combined storage to exceed 11 Mm^3.

Annexure F shows that the drawdown strategy affects the volume of water required to bridge a severe drought and there is an advantage in drawing down the high evaporation dams of Bonkolo and Xonxa as much as possible before using the water from Waterdown Dam. If this strategy is followed, then the pipeline from Waterdown Dam to Queenstown should be sufficient to supply the full curtailed requirement of the Queenstown complex, about 60% of the normal requirement (i.e. about 0,4 m^3/s or 60% of the 12,5 Mm^3/a requirement of Queenstown, Macibini and Illinge - see Table 3.1). At this time the supply to Sada will also be curtailed by 60% (i.e. about 0,08 m^3/s or 60% of the 3 Mm^3/a requirement - see Table 3.1).

If the infrastructure permitted the optimum drawdown strategy to be adopted during the drought and preference could be given to drawing down Xonxa and Bonkolo Dams, then it should be possible to maintain a minimum supply of 40% in a 1 in 400 year drought. Figure 10.13 shows the reliability of supply to the urban centres. The initial two years are distorted by the initial 40% starting condition but thereafter about 9 Mm^3/a (60% prevailing unrestricted demand) is supplied at a 1 in 100 year risk of failure and about 11 Mm^3/a (70% prevailing unrestricted demand) is supplied at a 1 in 50 year risk of failure.

The reliability of the urban supply can be increased by curtailing the irrigation demands slightly earlier. For instance if the irrigation releases from Waterdown Dam are stopped when the dam is 30% full (instead of 25% full - Figure 10.16) and the irrigation releases from Xonxa Dam are stopped when the dam is 25% full (instead of 20% full - Figure 10.17) then the reliability of supply during an extreme drought increases. The modelled minimum supply to the urban consumers increases by about 1 Mm^3/a (see Figure 10.13) and the storage available in the Waterdown, Bonkolo and Xonxa Dams increases from 11 to 16 Mm^3 (see Figure 10.15).

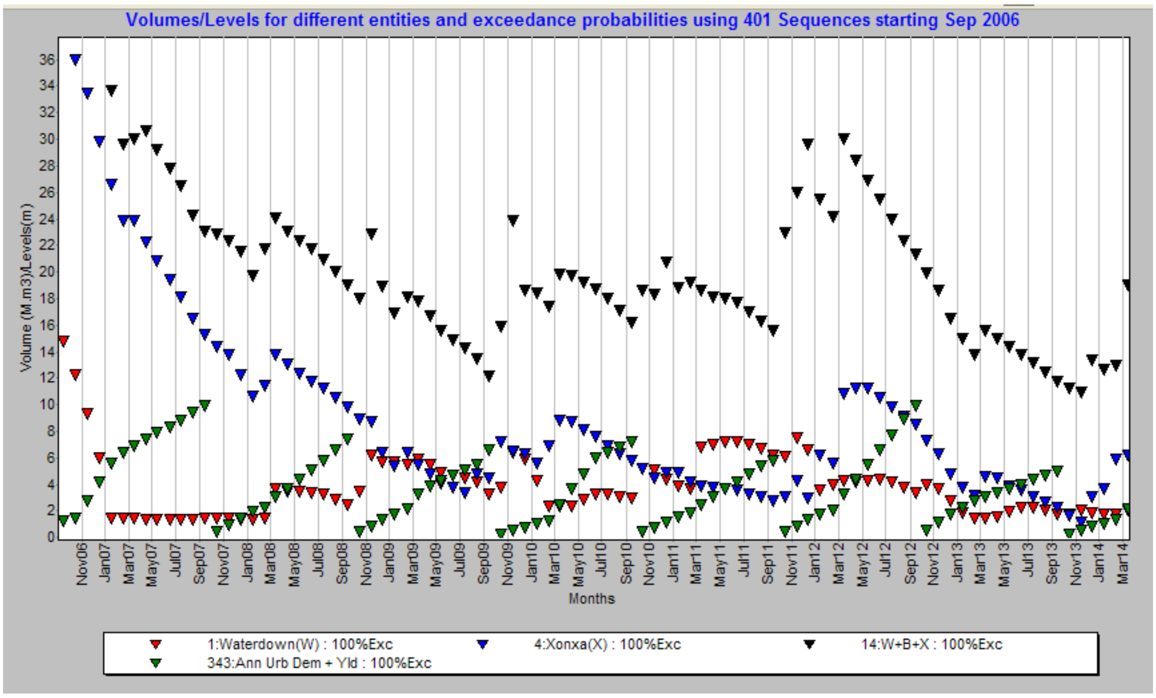

Figure 10.12 System drawdown and urban supply

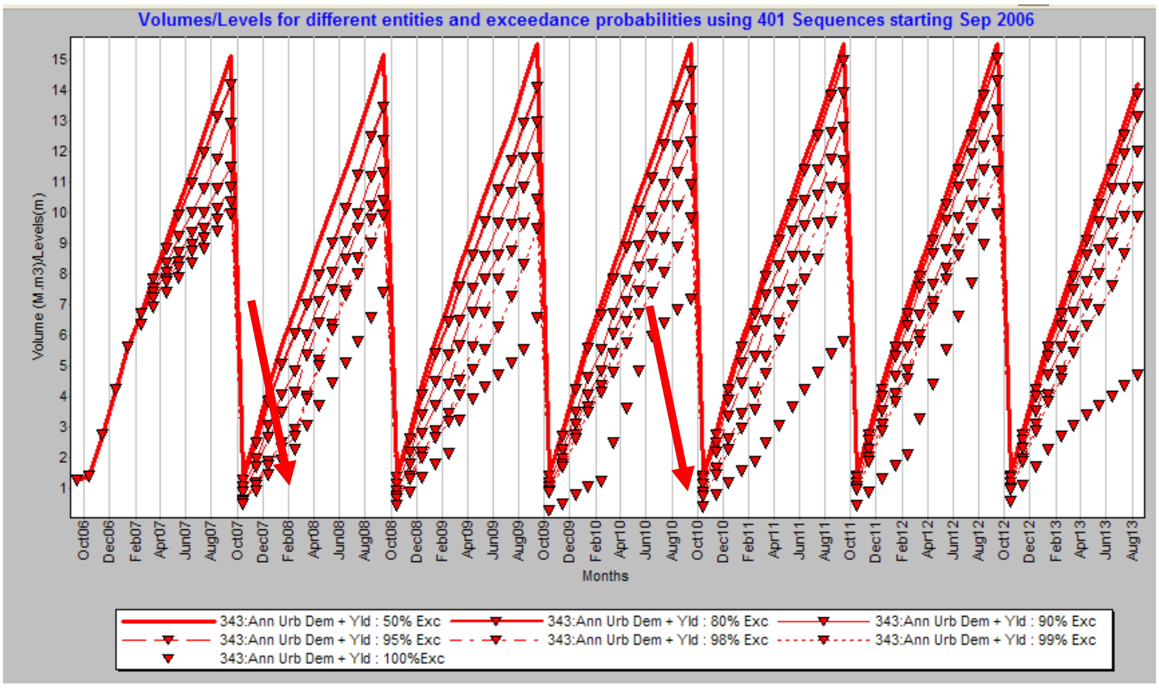

Figure 10.13 Reliability of urban supply

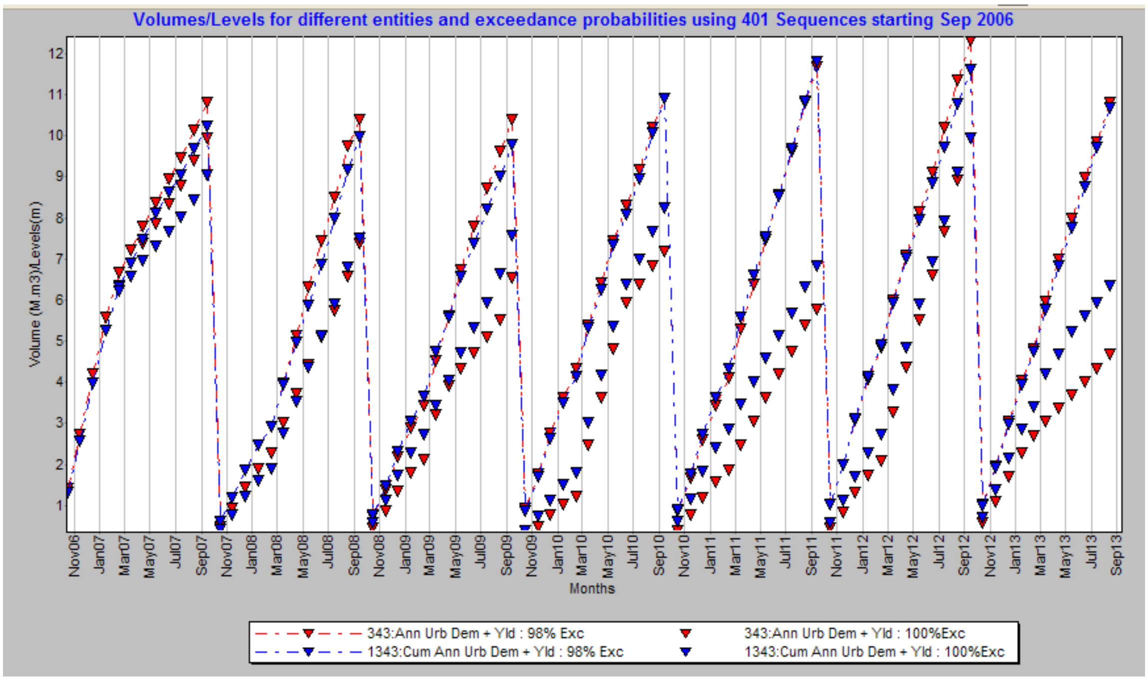

Figure 10.14 Reliability of urban supply

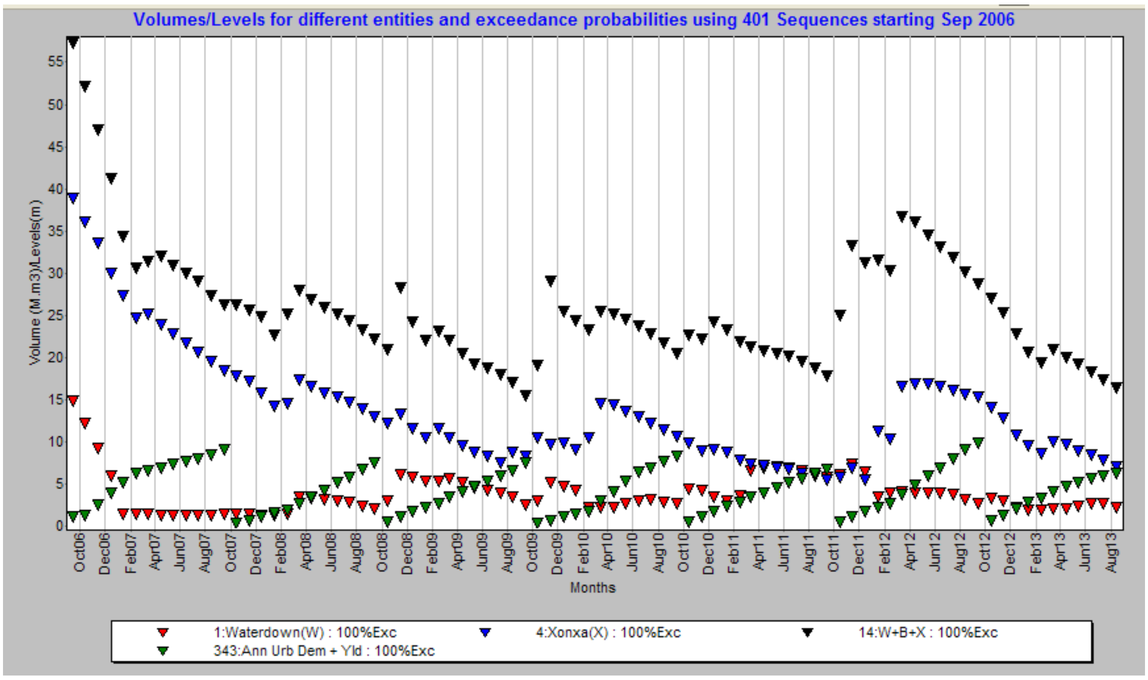

Figure 10.15 Increased urban supply and increased available storage under more conservative operating rule

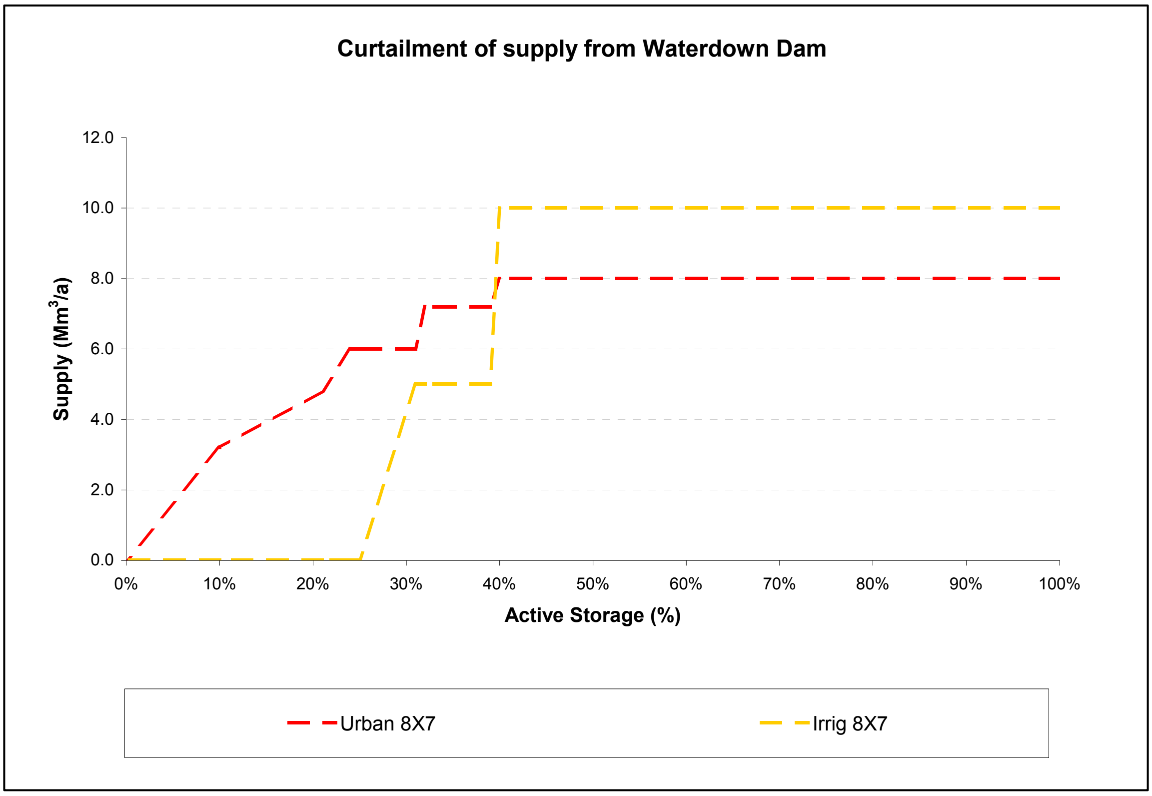

Figure 10.16 Curtailment of supply from Waterdown Dam

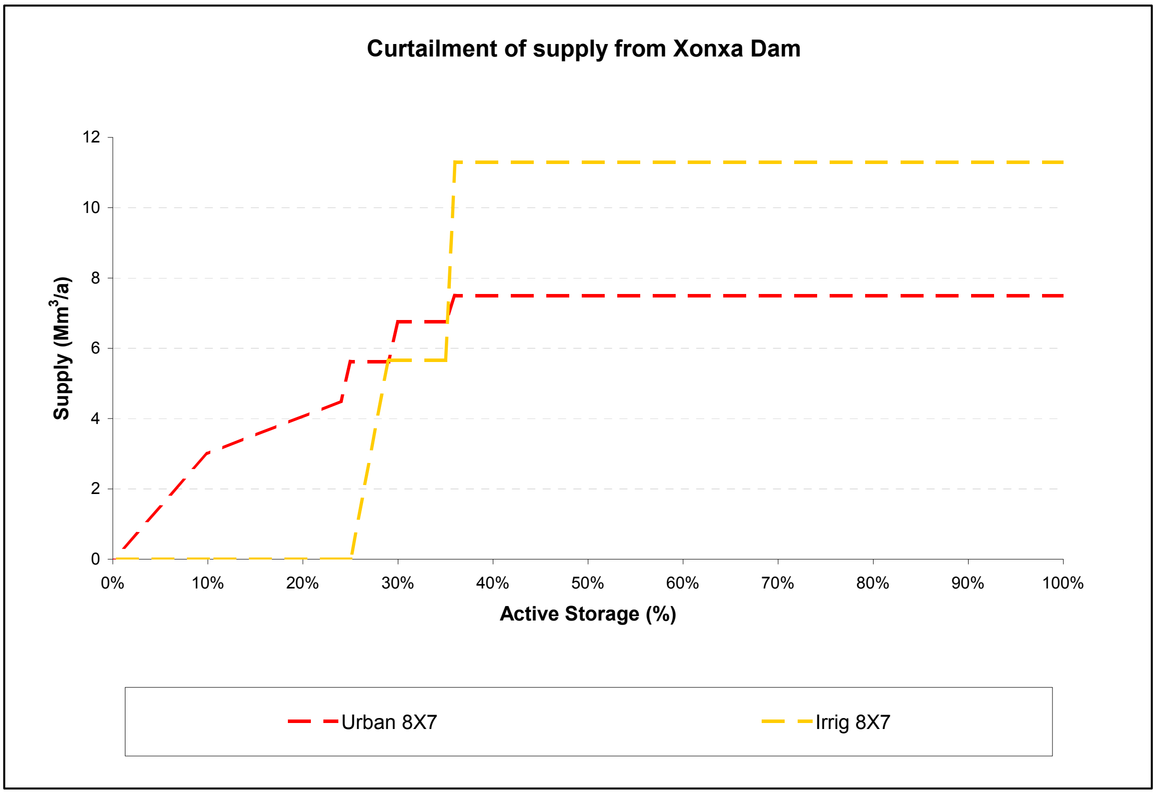

Figure 10.17 Curtailment of supply from Xonxa and Bonkolo Dams

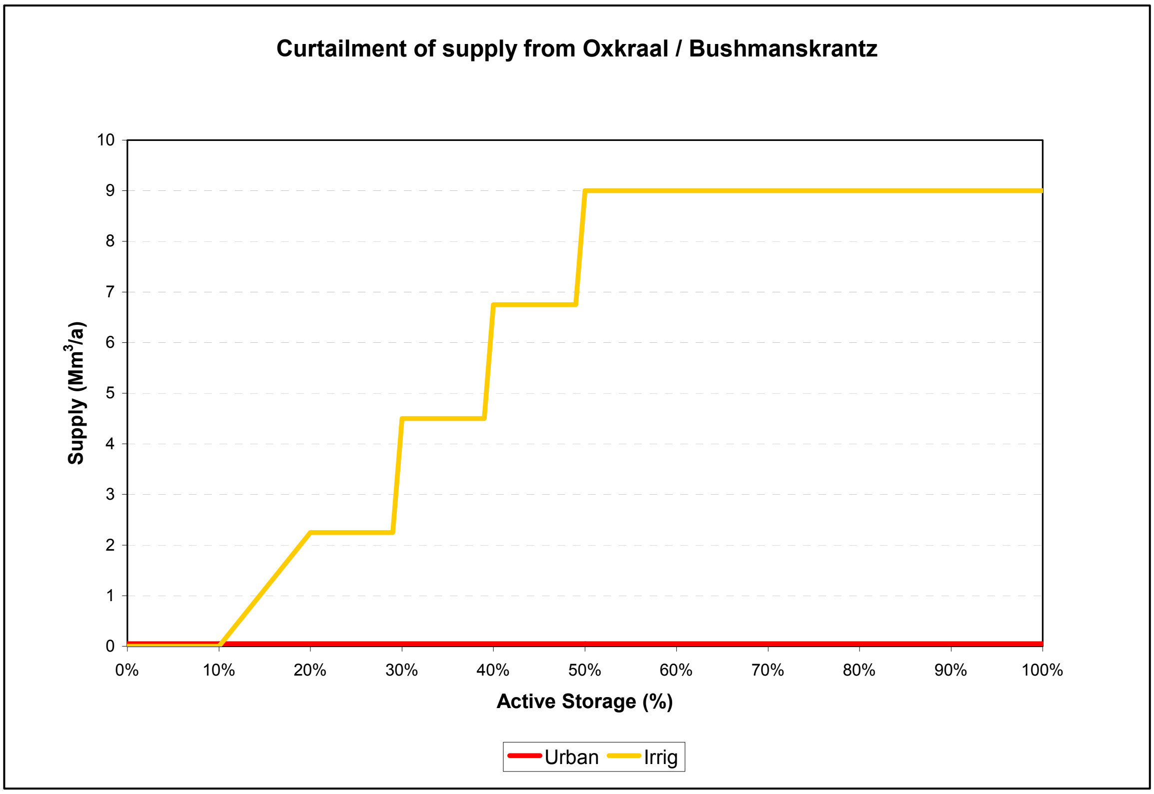

Figure 10.18 Curtailment of supply from Oxkraal and Busmanskrantz Dams

11. SUMMARY AND CONCLUSIONS

11.1 ASSUMPTIONS

The irrigation demands, which comprise about half of the demands on the system have not yet stabilised. To obtain an estimate of the future irrigation demands it was assumed that the Klipplaat, Oxkraal and Xonxa irrigation schemes would be developed to defined limits, and the Zwelindinga and Ntabethemba schemes would not be further developed. This does not mean that the schemes to be implemented have been finalised. However, were the Zwelindinga Scheme to proceed, some reduction in the supply to the other schemes would be necessary.

The EWR requirements meeting the recommended ecological categories but capped by the outlet capacities of the dams (Scenario 4), were applied in the analysis. If it is possible to integrate the summer EWR and irrigation releases then more water may be available (see Section 9.1.9).

The impact of accruals (run-of-river flows) and losses downstream of the dams on the required releases for irrigation and EWR is uncertain. Flows measured at the new gauge on the Black Kei just upstream of its confluence with the White Kei, and experience gained during the operation of the system, should be used to refine the estimate of the supply from accruals summarised in Annexure H. Table 11.1 summarises the releases supplied from the dams. Because of this uncertainty the initial analysis of the individual systems (Chapter 7) determined the yields available from the dams, ignoring the contribution from the streamflows downstream of the dam. When determining firm yields from an integrated system (Chapter 7), the abstractions act along the river channel are supplied by both inflows from tributaries downstream of the dam and by releases from the dams. These "modelled" releases are summarised in Table 11.1. In the later analyses, which modelled the curtailment of the integrated system (Chapter 10), the irrigation requirements were modelled as allocated releases from the dams that were independent of accruals downstream. When the allocated releases were initially determined an allowance was made for the accruals downstream but on average the modelled contribution from accruals is greater than the allocated benefit (compare columns b and h in Table 11.1). Also the overall releases required during the critical period increased by almost 2 Mm^3/a (compare columns e and k), though in practice curtailment would reduce the supply in the critical period.

TABLE 11.1 ALLOCATED AND MODELLED RELEASES FOR EWR AND IRRIGATION (FROM TABLE 9.3)

REACH	RELEASES											
	MODELLED						ALLOCATED					
	AVERAGE (OCT 1920 - SEP 1994)			SYSTEM CRITICAL PERIOD (AUG 1944 - JAN 1950)			AVERAGE (OCT 1920 - SEP 1994)			SYSTEM CRITICAL PERIOD (AUG 1944 - JAN 1950)		
	IRRIG Mm^3/a	EWR Mm^3/a	TOTAL Mm^3/a	IRRIG Mm^3/a	EWR Mm^3/a	TOTAL Mm^3/a	IRRIG (1) Mm^3/a	EWR Mm^3/a	TOTAL Mm^3/a	IRRIG (1) Mm^3/a	EWR Mm^3/a	TOTAL Mm^3/a
A	B	C	D	E	F	G	H	I	J	K	L	M
Oxkraal/Waterdown	15,4	6,1	21,5	19,4	3,2	22,6	19,0	6,1	25,1	19,0	3,2	22,2
Xonxa	5,0	5,9	10,9	9,0	1,1	10,1	11,3	5,9	17,2	11,3	1,1	12,4
Total	20,4	**12,0**	**32,4**	**28,4**	**4,3**	**32,7**	**30,24**	**12,0**	**42,24**	**30,24**	**4,3**	**34,54**

(1) Based on releases from dams - column e in Table H.16

The yield of the integrated Lukanji system is affected by the two factors. Firstly, the dry periods in the Waterdown and Xonxa sub-systems do not always coincide, so that at times supplying the full urban demand from one sub-system provides support to the drier sub-system and reduces spillage from the wetter sub-system. Secondly, the basins of the Xonxa and Bonkolo Dams are relatively shallow and the dams are subject to significantly more evaporation than the Waterdown Dam. During times of drought it would be advisable to empty Xonxa and Bonkolo Dams first and to try to maintain a reserve storage of about 20% in Waterdown Dam. Obviously, if there is no water in Xonxa or Bonkolo Dams, then the supply capacity from Waterdown Dam to Queenstown should be sufficient for Queenstown's curtailed demand.

11.2 RESULTS

The benefit of additional capacity in the bulk water supply lines was demonstrated using the "firm" yield for the period from 1920-43 for a system supplying up to 12,5 Mm^3/a from Xonxa Dam to Queenstown and a boosted supply from Waterdown Dam of 8,7 Mm^3/a (see Figure 8.3). If Bonkolo Dam is used to store sufficient water for the peak summer demand (and possibly an emergency reserve storage) then the capacity of the pipeline from Xonxa Dam need only be sufficient to convey the average annual demand rather than the peak requirements of Queenstown.

If the demands from Xonxa and Waterdown Dams are supplied at a 1 in 50 year annual risk of failure then about 10 Mm^3/a should be supplied from Xonxa Dam (Section 9.1.7). However, because the irrigation demands are severely curtailed at times and are not supplied at a 1 in 50 year risk of failure, historical analyses were performed curtailing the supply to irrigation. Also, because of the uncertainty of the future irrigation demands the pipeline from Waterdown Dam to Queenstown was not boosted and the capacity remained at 5 Mm^3/a. These analyses in Chapter 10 show the reliability of supply for different capacities of pipeline from Xonxa Dam. This analysis indicated that the supply to Queenstown was adequate if the pipeline from Xonxa Dam supplied 7,5 Mm^3/a and an even greater security of supply was obtained if the capacity was larger. The reliability of the supply was also tested using 401 stochastic inflow sequences. In an extreme inflow sequence (driest in 401 years) only 30% of the urban demand was supplied but the available active storage in the dams supplying the urban demand (Xonxa/Bonkolo Dams and Waterdown Dam) was 7 Mm^3 (11 Mm^3 less dead storage). The supply could have been increased to 40% by using more of this stored water (Section 10.2). At a 1 in 100 year risk about 60% of the 2045 urban demand (Sada plus Queenstown complex) of 15,5 Mm^3/a was supplied (see Figure 10.13 and Section 10.2).

Stopping irrigation releases earlier, when the dams have more storage, would increase the reliability of the urban supply. The irrigation releases from Waterdown Dam could be stopped below 30%, instead of 25%, (Figure 10.16) and from Xonxa Dam could be stopped below 25%, instead of 20% (Figure 10.17).

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ADDENDA

Addendum 4.1	**:**	**Detailed Tables of Irrigation Requirements**
Addendum 4.2	**:**	**Dam Basin Characteristics**
Addendum 4.3	**:**	**Short-term Characteristic Curves for Individual Dam Systems**
Addendum 4.4	**:**	**Urban Demand Curtailment**
Addendum 4.5	**:**	**Previous Operating Rules**
Addendum 4.6	**:**	**Drawdown Strategy for the System during the Critical Drawdown Period**
Addendum 4.7	**:**	**Urban Supply Estimates**
Addendum 4.8	**:**	**Supply of Water Requirements Downstream of the Major Dams**

ADDENDUM 4.1

Detailed Tables of
Irrigation Requirements

ADDENDUM 4.1 : DETAILED TABLES OF IRRIGATION REQUIREMENTS

Table 4.1.1 presents the values of irrigation as taken from the QRWSFS *Water Requirements* report (left side of table) and WRSA report (right side of table). For the majority of the schemes, there is no expected future irrigation development and so the "current" values presented in the report are also representative of the potential future values. Where future development is expected, this is indicated and the increased values of irrigation are shown. Although the future irrigation values presented in Table 3.18 of the QRWSFS report are shown for year 2045, this maximum irrigation value is in fact reached by 2010 (DWAF, 1993c). The current modelled values of irrigation configured for 2020 (WRYM QUEE20) are therefore directly comparable to the projections provided by the QRWSFS.

TABLE 4.1.1 COMPARISON OF QRWSFS AND WRSA IRRIGATION DATA FOR THE UPPER KEI BASIN

Irrigation Scheme	Land Use Zone	QWRSFS Irrigation Requirements (DWAF Nov 1996) (Mm^3/a)					WRSA Irrigation Requirements (DWAF July 2001) (Mm^3/a)					
		Irrigated Scheduled Land	Opportunistic Irrigation Adjacent to Rivers	Opportunistic Irrigation Remote from Rivers	Land zone Total	Irrigation Scheme Total	Irrigation Scheme Total	Quaternary Irrigation value	Shared with	Proportion	Unfactored Total Irrigation	Quaternary No(s). corresponding to land use zone
Upper Klipplaat Irrigation Scheme	1	-	7.15	3.78	10.93	**10.93**	**5.02**	2.64		1.0	2.64	S32D
								2.38		1.0	2.38	S32E
	2	4.51	-	-	4.51			6.41	18	1.0	6.41	S32G
	3	2.37	-	0.08	2.45			2.17	4	0.61	6.2	S32H
	4	1.46	-	0.13	1.59			4.03	3	0.39	6.2	S32H
Klipplaat River Government Water Scheme						**16.34**	**18.39**	1.63		1.0	1.63	S32K
	5	5.55	-	2.24	7.79			1.19		1.0	**1.19**	S32L
								1.67		1.0	1.67	S32M
								1.29		1.0	1.29	S32J
	6	-	-	1.97	1.97			3.36		1.0	3.36	S20A
Doorn River Government Water Scheme	7	1.35	-	0.93	2.28			2.17		1.0	2.17	S20B
						4.25 (1)	**6.41**	0.88		1.0	0.88	S20C
	8	-	0.58	2.52	3.1			2.87		1.0	2.87	S31A
	-							1.72		1.0	1.72	S31B
	9	-	1.63	0.83	2.46			4.63	11	0.27	9.26	S31E
	10	-	0.82	2.15	2.97			3.14		1.0	3.14	S31C
Klaas Smits River Irrigation Scheme	11	-	5.73	1.06	6.79			4.63	9	0.73	9.26	S31E
	12	-	0.72	1.04	1.76			1.90		1.0	1.9	S31D
	13	-	2.26	0.71	2.97			3.52	16	0.48	10.56	S31G
	14	-	-	2.09	2.09			1.16	15	0.33	2.91	S31F
	15	-	3.34	0.91	4.25			1.75	14	0.67	2.91	S31F
	16	-	1.35	1.87	3.22	**29.61**	**32.36**	7.04	13	0.52	10.56	S31G
Zweledinga Irrigation Scheme (near Bushmankrantz Dam)	17	1.5	-	-	1.5	**1.5**	**0**	0		1.0	0	S32F
Oxkraal Irrigation Scheme	18	-	-	-	0	**0** (2)	**0.00**	0.00	2	0.0	6.41	S32G
	19	-	1.35	0.47	1.82			0.27		1.0	0.27	S32A
Ntabethemba Irrigation Scheme (Upper Black Kei)	20	-	0.95	3.15	4.1			0.70		1.0	0.7	S32B
	21	-	-	1.64	1.64			0.14	22	0.23	1.14	S32C
	22	-	4.33	1.04	5.37	**12.93** (3)	**2.11**	1.00	21	0.77	1.14	S32C
Qamata Irrigation Scheme (ds Lubisi Dam)	23	16.69	-	-	16.69			2.57		1.0	2.57	S20D
						16.69	**2.75**	**0.18**		1.0	0.18	S10J
	24	-	0.64	2.16	2.8			0.74		1.0	0.74	S10A
								1.11		1.0	1.11	S10B
								0.66		1.0	0.66	S10C
Xonxa Irrigation Scheme								0.89		1.0	0.89	S10D
								0.27		1.0	0.27	S10E
	25	-	-	0.91	0.91			0.59		1.0	0.59	S10F
								0.81		1.0	0.81	S10G
	26	14.84	-	-	14.84	**18.55**	**5.22**	0.15		1.0	0.15	S10H
Total		48.3	30.8	31.8		**110.8**	**72.26**					

1. The scheduled irrigation for the Doring River Government Water Scheme is expected to increase to 3.81 Mm^3/a by 2010 (DWAF Nov 1996). There are no expected increases for opportunistic irrigation.
2. The scheduled irrigation for the Oxkraal Irrigation Scheme is expected to increase to 3.24 Mm^3/a by 2010 (DWAF Nov 1996).
3. Ntabethemba Irrigation Scheme is expected to increase to 14.8 Mm^3 by 2010, with 3.93 Mm^3 allocated to scheduled irrigation and 10.87 Mm^3/a allocated to opportunistic irrigation.

Table 4.1.2 shows the values of scheduled irrigation most recently approved by the Provincial Department of Agriculture and the Chris Hani District Municipality. This table was extracted from the Lukanji Regional Water Supply Feasibility Study "October 2003 Discussion Document".

TABLE 4.1.2 SCHEDULED IRRIGATION WATER REQUIREMENTS APPROVED BY THE PROVINCIAL DEPARTMENT OF AGRICULTURE AND THE CHRIS HANI DISTRICT MUNICIPALITY (2003)

Scheme/Rivers	Dam	Location	Irrigation in 2002		Potential Maximum Future Irrigation	
			Irrigated Area (ha)	Water Requirements (Mm^3/a)	Irrigated Area (ha)	Water Requirements (Mm^3/a)
Klipplaat River Irrigation Scheme	Waterdown (1)	Waterdown to Oxkraal	206	1,57	600	4,58
		Oxkraal to Black Kei	315	2,40	315	2,40
		Black Kei to Klaas Smits	192	1,47	192	1,47
		Klaas Smits to White Kei	817	6,23	817	6,23
		Total	1530	11,67	1924	14,68
Oxkraal Irrigation Scheme	Oxkraal (1)	Downstream of Oxkraal Dam	0	0	541	4,13
	Shiloh (1)	Downstream of Shiloh Dam	0	0	25	0,19
		Total	0	0	566	4,32
Xonxa Irrigation Scheme	Xonxa (2)	Downstream of Xonxa Dam	60	6,75	1000	11,25

1. Water requirement calculated as 6100 m^3/ha/a + 25% conveyance losses. (The allocation of 6100 m^3/ha/a is lower than the actual field edge requirements of the crops grown at present which has been calculated to be 7300 m^3/ha/a (DWAF, 1993)).
2. Water requirement calculated as 9000 m^3/ha/a + 25% conveyance losses

Table 4.1.3 shows the factors by which the original model scheduled and opportunistic irrigation demands were multiplied in order to achieve the 'preferred' irrigation values to be used in the current system model (WRYM QUEE20).

TABLE 4.1.3 FACTORS APPLIED TO ORIGINAL MODEL VALUES

Irrigation Scheme	Land Use Zone	UKBS/QRWSFS Current Irrigation Water Requirements (1990) (Mm^3/a)					Inherited (QUEE20) Modeled values of irrigation demands (Mm^3/a)						Factors to be Multiplied to Lukanji Irrigation Demands	
		Irrigated Scheduled Land	Opportunistic Irrigation Adjacent to Rivers	Opportunistic Irrigation Remote from Rivers	Total Scheduled/Opportunistic Irrigation Adjacent to Rivers	Total Opportunistic Irrigation Remote from Rivers	Irrigated Scheduled Land/Opportunistic Irrigation Adjacent to Rivers	Opportunistic Irrigation Remote from Rivers	Dem File Name	IRR File Name	Total Scheduled/Opportunistic Irrigation Adjacent to Rivers	Total Opportunistic Irrigation Remote from Rivers	Factors to be Multiplied to Lukanji Scheduled Irrigation Demands	Factors to be Multiplied to Lukanji Opportunistic Irrigation Demands
Upper Klipplaat Irrigation Scheme	1	-	7.15	3.78	7.15	3.78	-	10.552		3301994.irr		10.552		0.482[1]
Klipplaat River Government Water Scheme	2	4.51	-	-	4.51		4.496	0.278	klp11994.dem	331a1994.irr	4.496	0.278	1.01[2]	0.000
	3	2.37	-	0.08	2.37	0.08	2.354	0.721	klp21994.dem	331b1994.irr	2.354	0.721	1.01[2]	0.111
		1.46	-	0.13				0.466		331c1994.irr				0.220
								0.089		3041994.irr				0.220
	4						0.44		304a1994.dem				1.01[2]	
								0.035		3041994.irr				0.220
					1.46	0.13	1.011		304b1994.dem		1.451	0.59	1.01[2]	
		5.55	-	2.24	5.55	2.24		0.257		3051994.irr				0.601
							3.38		305aa94i.dem				1.01[2]	
	5							1.533		3051994.irr				0.601
							2.59		305ab-94.dem				1.01[2]	
								1.939		3051994.irr				0.601
							0.327		305b1994.dem		6.297	3.729	1.01[2]	
Doorn River Government Water Scheme	6	-	-	1.97			-	2.015	-	2101994.irr				1.439
	7	1.35	-	0.93			1.359	-	2111994.dem	-			2.804[3]	
					1.35	2.9					1.359	2.015		
Klaas Smits River Irrigation Scheme	8	-	0.58	2.52	0.58	2.52	-	4.03	-	3101994.irr		4.03		0.769
	9	-	1.63	0.83				-	-					
	10	-	0.82	2.15										
	11	-	5.73	1.06										
	12	-	0.72	1.04	8.9	5.08	8.692	5.726	3111994.dem	3111194.irr	8.692	5.726	1.024	0.887
	13	-	2.26	0.71				0.28		312c1994.irr				2.536
	14	-	-	2.09				0.675		312a1994.irr				1.000
	15	-	3.34	0.91			1.06	0.764	312b1994.dem	312b1994.irr			3.151	1.191
	16	-	1.35	1.87	6.95	5.58	2.819	0.788	312d1994.dem	312d1994.irr	3.879	2.507	1.281	2.373
Zweledinga Irrigation Scheme (near Bushmankrantz Dam)							1.703		320a1994.dem				0.881	
	17	1.5	-	-	1.5	-		0.14		320b1994.irr	1.703	0.14		0.000
Oxkraal Irrigation Scheme	18	-	-	-	-	-	4.265		min/max (117)					1.01[4]
								0.191		320c1994.irr	4.265	0.191		0.000
Ntabethemba Irrigation Scheme (Upper Black Kei)	19	-	1.35	0.47				2.05		3011994.irr				1.000
								0.9		302a1994.irr				1.000
	20	-	0.95	3.15				5.359		302b1994.irr				1.000
	21	-	-	1.64			0.972		302bn-94.dem				1.000	
	22	-	4.33	1.04			3.02		302bi-94.dem				1.000	
					6.63	6.3	0.93	0.06	303i1994.dem	3031994.irr	4.922	8.369	1.000	1.000
Qamata Irrigation Scheme (ds Lubisi Dam)		16.69	-	-			16.701		20051994.dem				1.000	
	23				16.69	-					16.69			
Xonxa Irrigation Scheme	24	-	0.64	2.16			0.901		min/max (106)				0.996[4]	
	25	-	-	0.91				2.916		20021994.irr				1.119
	26	14.84	-	-			10.394	0.399	20032045.dem	20031994.irr			0.996[4]	1.119
					15.48	3.07					11.295	3.315		

1 Opportunistic irrigation value factored to represent the WARMS value of 5.089 Mm^3/a.
2 Total scheduled irrigation value of 14.598 Mm^3/a (for land use zones 2, 3, 4, 5) was factored upward to the October 2003 Decision Document scheduled value of 14.68 Mm^3/a, i.e. a factor of 1.01 was applied.
3 Scheduled irrigation value factored to represent QRWSFS fully developed future (2010) value of 3.81 Mm^3/a.
4 Scheduled irrigation values factored to represent October 2003 Decision Document scheduled values.

ADDENDUM 4.2

Dam Basin Characteristics

ADDENDUM 4.2 : DAM BASIN CHARACTERISTICS

4.2.1 GROSS AND NET STORAGE

The dam basin characteristics (relationship between elevation, storage and surface) for the major dams are summarized in Table 4.2.1.

Figure 4.2.1 is based on Table 4.2.1 and shows the increase in surface area with increasing gross storage volume. Note how the surface area of Waterdown Dam is significantly less than that of the other dams for a given gross storage volume.

The pipe outlet works do not always access the bottommost water in the dam. Unless special emergency measures are introduced to pump this water to the water treatment works then this water cannot be supplied to consumers. This "dead" storage is deducted from the gross storage to obtain the active storage that is modelled in the Water Resources Yield Model (WRYM). With time, flood events transport silt into the dam basin and reduce the available storage. Around Lukanji, poor agricultural practices mean that the storage in most of the dams, with the exception of Waterdown, will reduce from siltation. The estimated extent of this siltation by 2020 is listed in Table 4.2.2 and has been added to the dead storage to obtain the total reduction in storage.

This reduced storage has been plotted against the associated surface area in Table 4.2.2 using the thick line. The original gross storage is represented using the light line for comparison. Note that when the dams have zero net storage (i.e. cannot supply any consumers) the surface areas are not zero and significant evaporation still takes place. For instance the surface areas corresponding with zero net storage are 4, 1,0.4 and 0.5 km^2 for Xonxa (1), Oxkraal, Waterdown and Bonkolo. This is partly because of the lumping of siltation with dead storage, that effectively assumes that all siltation occurs at the bottom of the dam. If the stream containing silt enters into a wide basin then a delta may form near the inlet and the silt may not reach the bottom of dam (though it could possibly be moved closer to the dam wall by a later flood). In the case of Xonxa, additional dam survey information was available that indicated that some of the siltation to date has been away from the bottom of the dam and the future catchment basin characteristics were recalculated using this data, instead of merely increasing the dead storage. The calculations are detailed in Section B3, but this approach halved the evaporative area associated with a zero storage from 4 (Xonxa (1) plot) to about 2 (Xonxa (2) plot) which increased the system yield.

4.2.1 GROSS AND NET STORAGE

Table 4.2.4 shows the annual free water evaporation (i.e. after reducing the evaporation by the free water evaporation constant to take into account the reduction in evaporation occurring from a large body of water) applied to each of the dams. The evaporation from Xonxa is higher than from the other dams, in particular Waterdown Dam.

TABLE 4.2.1 SURVEYED DAM BASIN CHARACTERISTICS

Xonxa S1R001			Lubisi S2R001			Doring River Dam S2R002			Waterdown Dam S3R001			Oxkraal Dam S3R003			Bonkolo Dam		
Oct 2002 Basin survey			Nov 1965/68 Basin survey			Oct 1998 Basin survey			Oct 1988 Basin survey			Nov 1989 Basin survey			1994 Survey from Bernadine Barnardo (DWAF)		
Min outlet RL914.48 (5.24 Mm^3)			Min outlet RL981.65 (0.23 Mm^3)			Min outlet RL1241.99 (0 Mm^3)			Min outlet RL1143.18 (1.08 Mm^3)			Min outlet RL1108.035 (0 Mm^3)			Dead storage 0 according to DWAF, 1993a		
RL (m)	Volume (Mm^3)	Area (km^2)	RL (m)	Volume (Mm^3)	Area (km^2)	RL (m)	Volume (Mm^3)	Area (km^2)	RL (m)	Volume (Mm^3)	Area (km^2)	RL (m)	Volume (Mm^3)	Area (km^2)	RL (m)	Volume (Mm^3)	Area (km^2)
908	0.00	0.00	976	0.00	0.01	1242	0.00	0.00	1134	0.00	0.00	1110	0.00	0.02	1126.38	0.00	0.00
909	0.01	0.04	977	0.00	0.03	1243	0.00	0.03	1135	0.00	0.02	1111	0.08	0.13	1126.50	0.00	0.00
910	0.24	0.32	978	0.02	0.04	1244	0.27	0.54	1136	0.03	0.04	1112	0.26	0.22	1127.00	0.02	0.07
911	0.77	0.74	979	0.06	0.06	1245	1.05	1.02	1137	0.09	0.06	1113	0.52	0.31	1127.50	0.06	0.11
912	1.61	1.18	980	0.11	0.08	1246	2.13	1.29	1138	0.16	0.08	1114	0.87	0.39	1128.00	0.13	0.16
913	2.86	1.29	981	0.18	0.09	1247	3.64	1.66	1139	0.25	0.11	1115	1.31	0.49	1128.50	0.22	0.21
914	4.31	1.66	982	0.26	0.13	1248	5.43	1.97	1140	0.38	0.14	1116	1.84	0.58	1129.00	0.34	0.26
915	6.38	2.26	983	0.37	0.22	1249	7.56	2.27	1141	0.53	0.18	1117	2.47	0.67	1129.50	0.48	0.29
916	8.95	2.79	984	0.54	0.33	1250	9.90	2.50	1142	0.75	0.25	1118	3.19	0.76	1130.00	0.63	0.33
917	11.98	3.45	985	0.81	0.46	1251	12.60	2.87	1143	1.03	0.32	1119	4.00	0.87	1130.50	0.81	0.38
918	15.74	4.10	986	1.20	0.62	1252	15.64	3.20	1144	1.38	0.38	1120	4.94	1.00	1131.00	1.02	0.44
919	20.15	4.87	987	1.74	0.79	**1252.68FSL**	**17.93**	**3.59**	1145	1.78	0.44	1121	6.00	1.13	1131.50	1.25	0.51
920	25.24	5.29	988	2.44	0.97	1253	19.11	3.77	1146	2.24	0.49	1122	7.22	1.31	1132.00	1.52	0.57
921	30.72	5.67	989	3.33	1.14	1254	23.16	4.32	1147	2.76	0.55	1123	8.61	1.46	1132.50	1.82	0.62
922	36.62	6.33	990	4.38	1.32	1255	27.72	4.80	1148	3.34	0.61	1124	10.13	1.59	1133.00	2.14	0.68
923	43.19	6.80	991	5.61	1.51	1256	32.73	5.23	1149	3.98	0.67	1125	11.80	1.75	1133.50	2.50	0.74
924	50.25	7.32	992	7.02	1.76	1257	38.25	5.83	1150	4.69	0.74	1126	13.65	1.93	1134.00	2.88	0.79
925	57.73	7.71	993	8.65	2.03	1258	44.43	6.50	1151	5.47	0.82	**1127.00FSL**	**15.68**	**2.13**	1134.50	3.29	0.85
926	66.00	8.61	994	10.55	2.32				1152	6.32	0.90				1135.00	3.73	0.91
927	74.77	8.98	995	12.73	2.59				1153	7.26	0.97				1135.50	4.20	0.99
928	84.00	9.44	996	15.18	2.87				1154	8.26	1.04				1136.00	4.72	1.07
929	93.71	9.96	997	20.92	3.15				1155	9.34	1.13				1136.50	5.27	1.14
930	103.95	10.66	998	24.20	3.41				1156	10.51	1.23				1137.00	5.86	1.23
931	115.16	11.80	999	27.75	3.68				1157	11.79	1.32				1137.50	6.51	1.35
931.48FSL	**121.10**	**12.88**	1000	31.57	3.96				1158	13.14	1.41				**1137.82FSL**	**6.95**	**1.39**
932	128.00	13.60	1001	35.68	4.26				1159	14.60	1.51				1138.00	7.20	1.42
933	142.08	14.71	1002	40.10	4.58				1160	16.14	1.59						
934	157.21	15.54	1003	44.85	4.91				1161	17.78	1.69						
935	173.17	16.34	1004	49.93	5.26				1162	19.51	1.78						
936	189.87	17.07	1005	55.37	5.62				1163	21.34	1.87						
937	207.35	17.90	1006	61.18	6.00				1164	23.26	1.97						
938	225.58	18.57	1007	67.38	6.39				1165	25.27	2.06						
939	244.50	19.26	1008	73.96	6.79				1166	27.36	2.14						
940	264.15	20.05	1009	80.96	7.20				1167	29.55	2.25						
941	284.62	20.92	1010	88.36	7.62				1168	31.85	2.35						
			1011	96.19	8.05				1169	34.25	2.45						
			1012	104.47	8.51				1170	36.74	2.55						
			1013	113.23	9.03				**1170.64FSL**	**38.39**	**2.61**						
			1014	122.52	9.56				1171	39.34	2.64						
			1015	132.35	10.09				1172	42.03	2.75						
			1016	135.53	10.59				1173	44.83	2.85						
			1017	142.69	11.08				1174	47.74	2.96						
			1017.42FSL	**158.23**	**11.29**				1175	50.74	3.06						
			1018	164.86	11.56				1176	53.86	3.17						
			1019	176.66	12.03				1177	57.08	3.28						
			1020	188.92	12.50				1178	60.42	3.40						
			1021	201.65	12.96				1179	63.88	3.52						

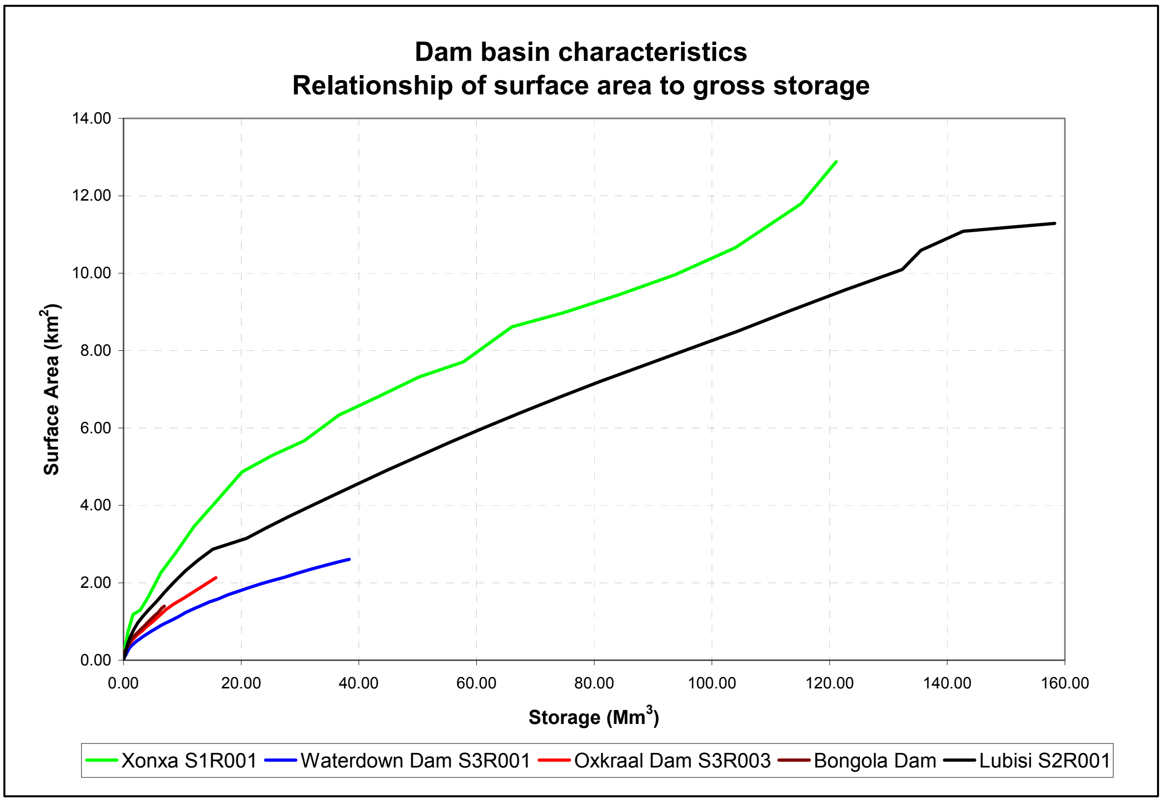


Figure 4.2.1 Relationship of surface area to gross storage from Table 4.2.1

TABLE 4.2.2 DAM STORAGES (GROSS AND NET) AND LEVEL USED FOR THE WRYM ANALYSES (2020)

DAM	GROSS	DEAD	SURVEY DATE	SILTATION SINCE SURVEY (TABLE 2.2)		DEAD STORAGE PLUS SILTATION		LEVELS		
								FULL	DEAD + SILTATION	
				TILL 2020	2045	2020	2045		2020	2045
Waterdown	38.39	1.08	1988	0.24	0.37	1.08(1)	1.45	1170.64	1142.67	1144.13
Oxkraal	15.68	0	1987	4.78	5.97	4.78	5.97	1127.00	1119.78	1120.97
Xonxa 1	121.10	5.24	2002	9.74	16.45	14.98	21.69	931.48	917.73	919.14
Xonxa 2								931.48	N/A (2)	
Bonkolo	6.95	0	1992	1.01	1.44	1.01	1.44	1137.82	1130.89	1131.75
Doring River	17.93	0	1998	1.89	2.69	1.89	2.69	1252.68	1245.74	1246.34
Lubisi	158.23	0.23	1968	30.64	33.93	30.87	34.16	1017.42	999.70	1000.48

(1) The estimated increase in siltation from1988 is 0.2 Mm^3. Historically the siltation accumulated below the dead storage and the future siltation was also assumed to merely deplete the dead storage zone and not reduce the net storage.

(2) Storage elevation curve adjusted instead – In 2020 these curves give a gross storage of 112.34 Mm^3 and a dead storage below the outlet level of 1.21 Mm^3.

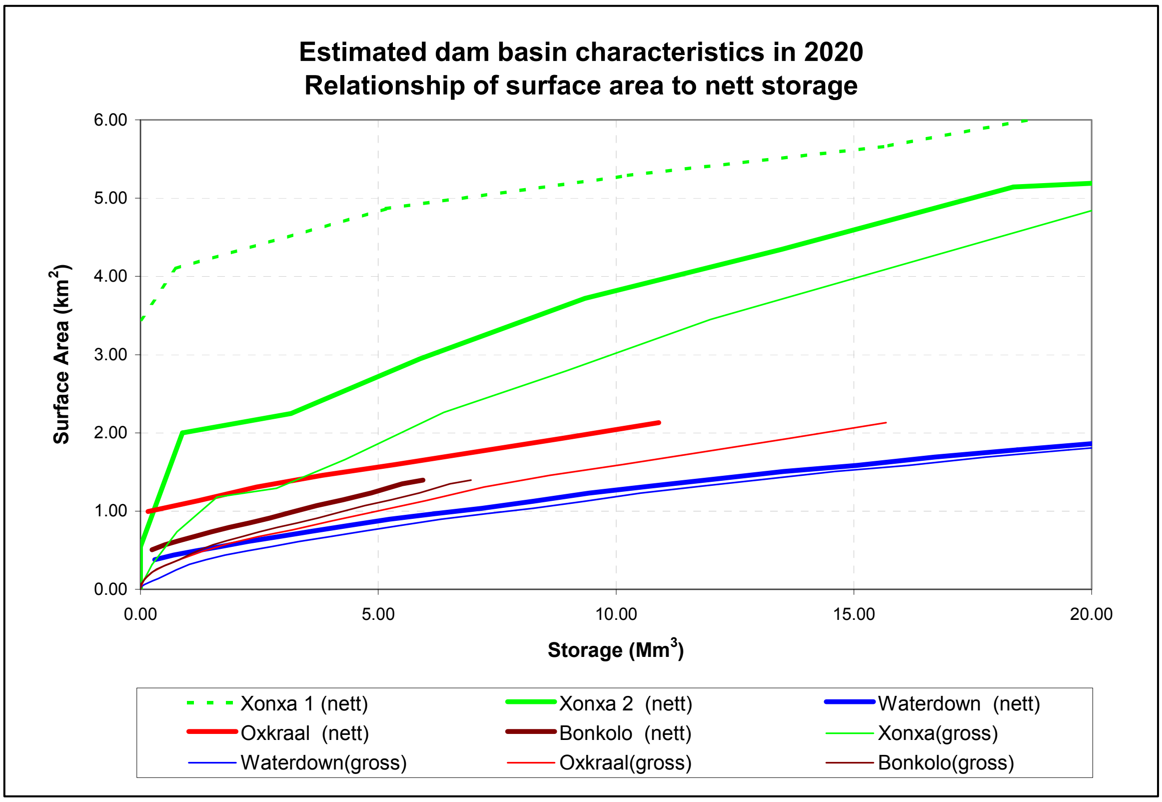


Figure 4.2.2 Relationship of surface area to net storage

4.2.3 PROJECTING DAM BASIN CHARACTERISTICS FOR XONXA

The Xonxa storage basin has been surveyed regularly since its construction in 1974 to monitor the rapid reduction in capacity through siltation. The loss in storage from 1974 to 2020 and 2045 was estimated to be 47 Mm^3 and 53 Mm^3 in 2020 using Prof Rooseboom's method (see Table 4.2.2) and the historical records showing the deposition of sediment were used to determine revised dam level-storage relationships for 2020 and 2045.

Figure 4.2.3 shows the build up of sediment below any level in the dam basin. The blue line represents the original storage volume and the difference between the original storage and the sediment is the available storage and can be used to derive an elevation–storage curve. For instance about 40 Mm^3 of storage may accumulate below RL925 by the year 2045. Originally just over 80 Mm^3 of storage were available below RL925 so that by 2045 only 40 Mm^3 will be available. The elevation-storage relationship for 2020 and 2045 are defined using columns A, F and G in Table 4.2.3.

The following procedure was used to derive and check the elevation-storage relationship for Xonxa Dam in 2020 and 2045 :

1) Obtain the available surveyed storage for 1972, 1982, 1986 and 2002.
2) Calculate the storage reduction since 1972 shown by the later surveys.

3) Determine the distribution of the total reduction with increasing level to see how much was deposited in a delta at the point of inflow and how much of the material was deposited in near the dam wall.
4) Assume this same distribution to the estimated silt volumes for 2020 and 2045.
5) Calculate the reduction in storage associated with the silt distribution assumed in 4).
6) Estimate the storage in 2020 and 2045 by deducting the storage reduction from siltation from the original dam storage volume.
7) Use the trapezoidal rule to determine the surface areas associated the 2020 and 2045 elevation storage relationship. Start with an area of 0 at the bottom of the dam and use 1 metre thick layers and the known change in volume between layers to work out the area at the top of the next layer.
8) Check the area calculation to see how the coarse 1 metre interval affects the results. Apply the areas of the 1 metre thick slices determined in 7) to calculate the storage volume and compare the result with the desired storages determined in 6). The error is about 2% which is acceptable.

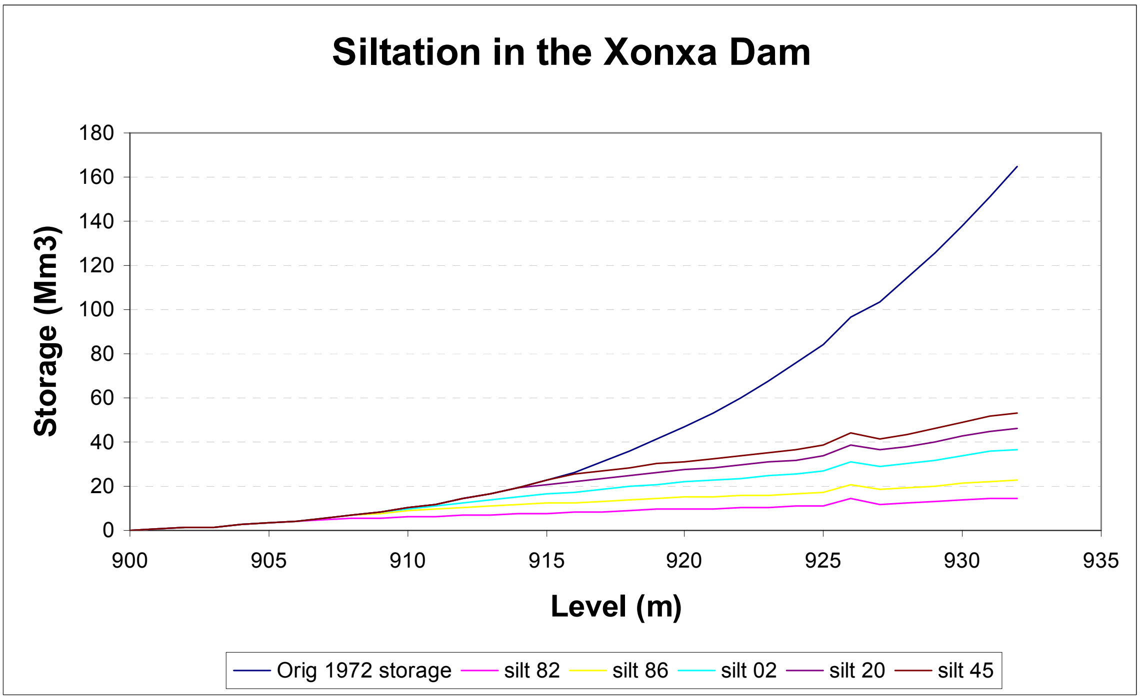


Figure 4.2.3 Projected siltation and available storage in the Xonxa Dam

TABLE 4.2.3 ELEVATION-STORAGE RELATIONSHIP FOR XONXA DAM IN 2020 AND 2045

Level	Storage (Mm3)						Reduction in storage (Mm3)					Reduction in storage(%)					Area		Check volume calculation (using areas)	
	72	82	86	02	20	45	82	86	02	20	45	82	86	02	20	45	02	20	20	45
	1)Surveyed storage				6) Calculated storage		2) Calculated storage reduction			5) Calculated reduction in storage		3) Distribution of storage reduction			4) Assumed distribution of storage reduction		7) Estimated area		8) Check volumes using estimated area	
Col A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
894	0	0	0	0													0	0	0	0
895	0	0	0	0													0	0	0	0
896	0	0	0	0													0	0	0	0
897	0	0	0	0													0	0	0	0
898	0	0	0	0													0	0	0	0
899	0	0	0	0													0	0	0	0
900	0	0	0	0													0	0	0	0
901	0	0	0	0													0	0	0	0
902	1	0	0	0													0	0	0	0
903	2	0	0	0													0	0	0	0
904	2	0	0	0													0	0	0	0
905	3	0	0	0			-3					22%					0	0	0	0
906	4	0	0	0			-4					28%					0	0	0	0
907	5	0	0	0			-5					33%					0	0	0	0
908	7	1	0	0			-5	-7				36%	28%				0	0	0	0
909	8	2	1	0			-6	-8	-8			38%	33%	22%			0	0	0	0
910	10	4	1	0			-6	-9	-10			40%	38%	26%			0	0	0	0
911	12	6	2	1			-6	-10	-11			42%	42%	30%			1	0	0	0
912	14	8	4	2			-7	-10	-13			44%	45%	34%			1	0	0	0
913	17	10	6	3			-7	-11	-14			46%	48%	37%			1	0	0	0
914	20	12	8	4	0		-7	-12	-15	-19		49%	50%	40%	40%		1	1	0	0
915	23	15	11	6	2		-8	-12	-16	-21		51%	52%	44%	44%		2	2	2	0
916	26	18	14	9	4	1	-8	-13	-18	-22	-25	54%	55%	47%	47%	47%	3	2	4	1
917	31	22	17	12	7	4	-9	-13	-19	-24	-27	57%	58%	50%	50%	50%	3	3	7	3
918	36	27	22	16	11	7	-9	-14	-20	-25	-29	60%	60%	53%	53%	53%	4	4	10	6
919	41	32	27	20	15	11	-9	-14	-21	-26	-30	62%	62%	56%	56%	56%	5	4	14	10
920	47	37	32	25	20	16	-10	-15	-22	-27	-31	64%	64%	58%	58%	58%	5	5	19	15
921	53	43	38	31	25	21	-10	-15	-23	-29	-33	66%	66%	60%	60%	60%	6	5	24	20
922	60	50	45	37	30	26	-10	-16	-24	-30	-34	68%	68%	63%	63%	63%	6	6	30	25
923	68	57	52	43	37	32	-11	-16	-25	-31	-35	70%	70%	65%	65%	65%	7	7	36	31
924	76	65	59	50	44	39	-11	-17	-25	-32	-37	72%	71%	68%	68%	68%	7	7	43	38
925	84	73	67	58	51	46	-11	-17	-27	-34	-38	76%	74%	71%	71%	71%	8	7	50	45
926	97	82	76	66	58	53	-15	-21	-31	-39	-44	98%	89%	82%	82%	82%	9	7	57	52
927	104	92	85	75	67	62	-12	-18	-29	-36	-41	80%	79%	77%	77%	77%	9	10	66	60
928	114	102	95	84	76	71	-13	-19	-30	-38	-44	83%	83%	81%	81%	81%	9	8	75	70
929	126	113	105	94	85	80	-13	-20	-32	-40	-46	86%	88%	85%	85%	85%	10	10	84	78
930	138	124	117	104	95	89	-14	-21	-34	-43	-49	90%	92%	90%	90%	90%	10	10	94	88
931	151	137	129	115	106	99	-14	-22	-36	-45	-52	95%	95%	95%	95%	95%	12	11	104	98
932	165	150	142	128	118	112	-15	-23	-37	-46	-53	98%	98%	98%	98%	98%	13	13	116	110
933	180	165	157	142	132	126	-15	-23	-37	-47	-54	100%	99%	100%	100%	100%	14	14	130	123
934	195	180	172	157	147	141	-15	-23	-38	-47	-54	100%	100%	100%	100%	100%	15	15	145	138
935	211	196	188	173	163	157	-15	-23	-38	-47	-54	100%	100%	100%	100%	100%	16	16	161	154
936	227	212	204	190	180	173	-15	-23	-38	-47	-54	100%	100%	100%	100%	100%	17	17	177	171
937	245	230	222	207	198	191	-15	-23	-38	-47	-54	100%	100%	100%	100%	100%	18	18	195	188
938	263	248	240	226	216	209	-15	-23	-38	-47	-54	100%	100%	100%	100%	100%	18	18	213	206
939	282	267	259	244	235	228	-15	-23	-38	-47	-54	100%	100%	100%	100%	100%	19	19	232	225
940	302	287	279	264	254	248	-15	-23	-38	-47	-54	100%	100%	100%	100%	100%	20	20	251	244
941	322	307	299	285	275	268	-15	-23	-38	-47	-54	100%	100%	100%	100%	100%	21	21	271	265

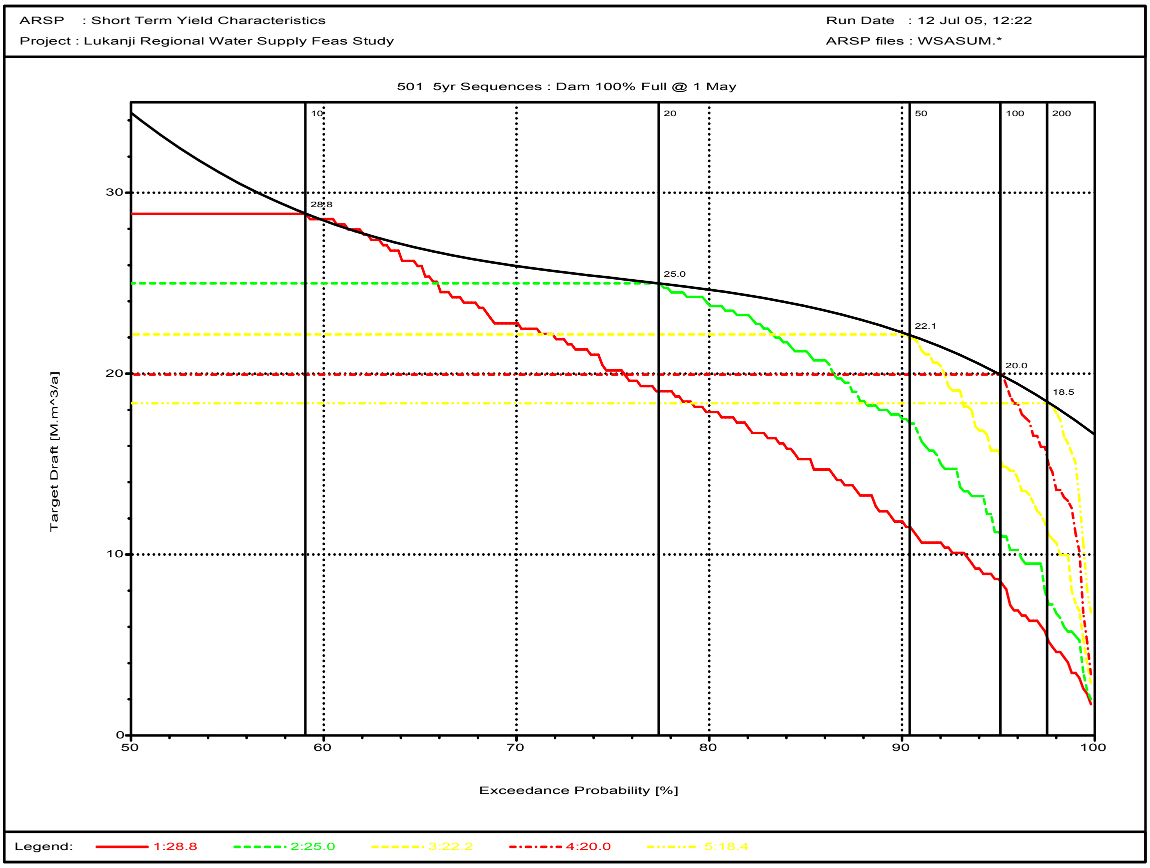
TABLE 4.2.4 ANNUAL EVAPORATION AT MAJOR DAMS

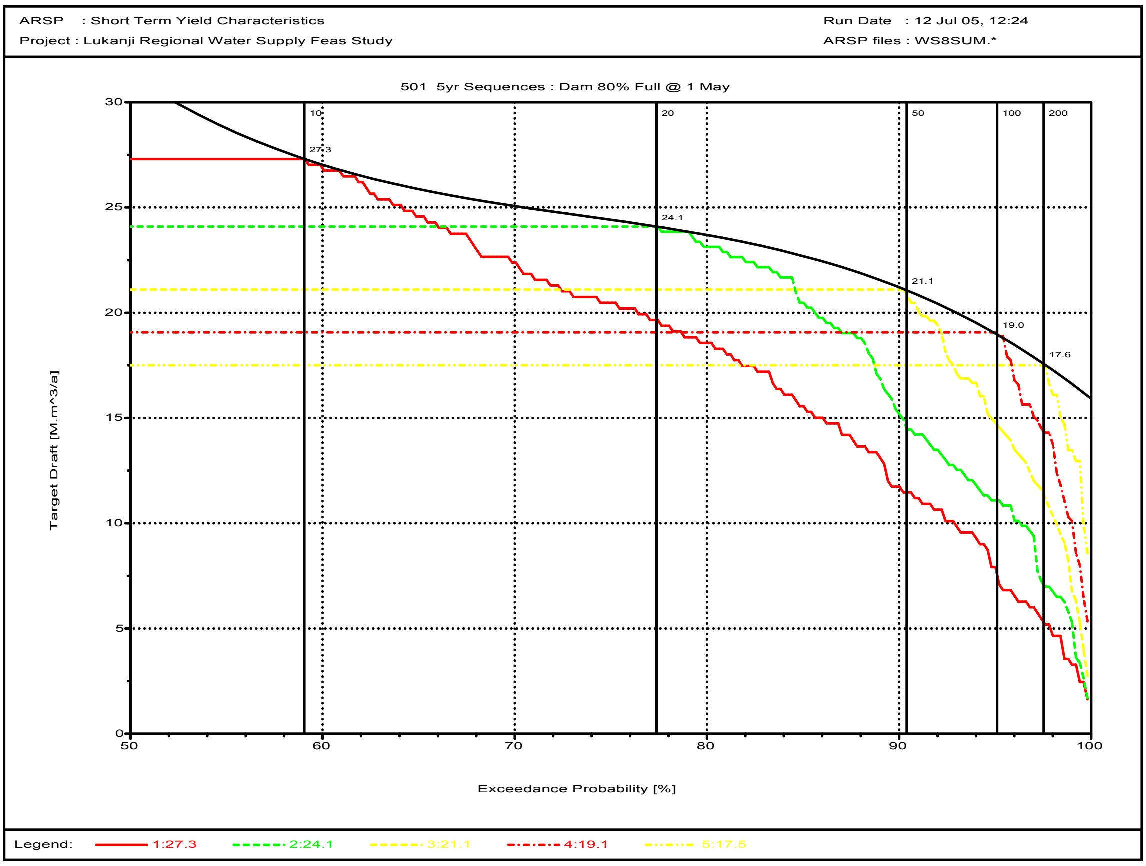
Dam	Annual evaporation (mm)
Bushmanskrantz Dam	1 526
Oxkraal Dam	1 526
Waterdown Dam	1 400
Bonkolo Dam	1 519
Lubisi Dam	1647
Xonxa Dam	1823

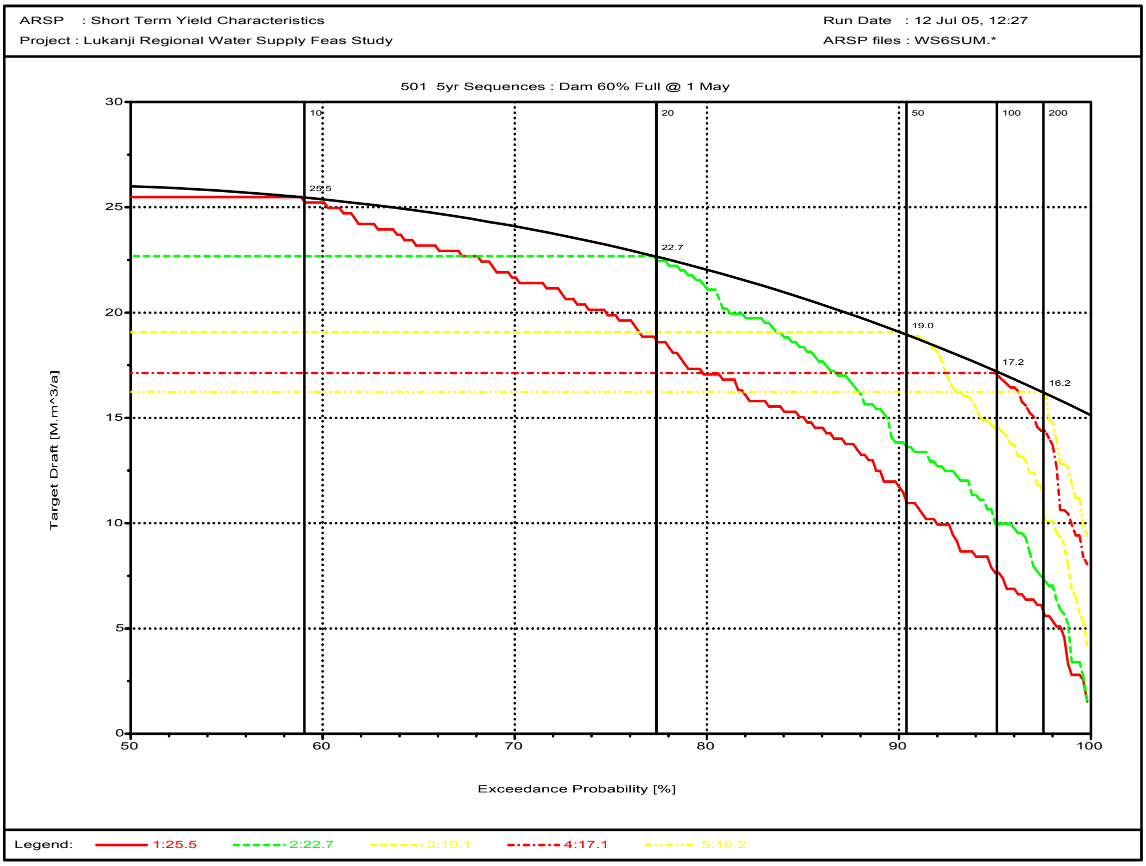
ADDENDUM 4.3

Short-term Characteristic Curves
for Individual Dam Systems

4.3.1 WATERDOWN DAM



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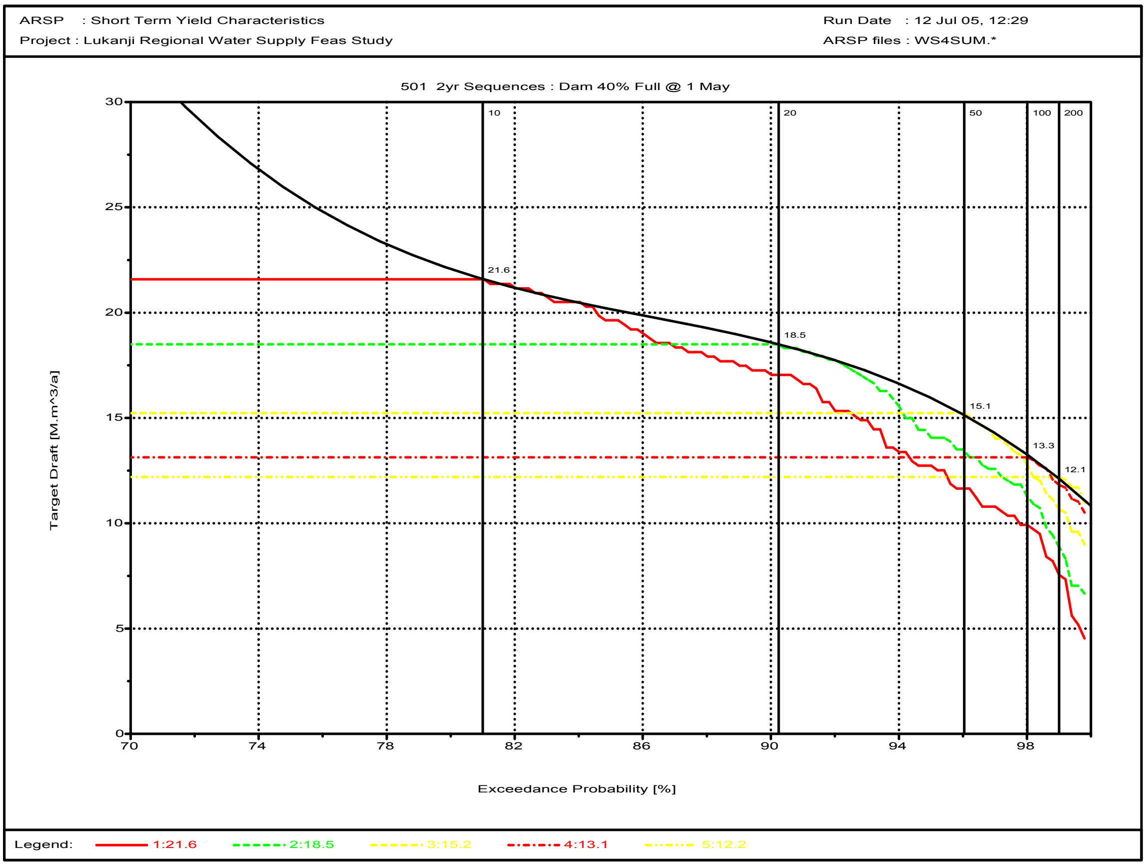
Project : Lukanji Regional Water Supply Feas Study
Run Date : 12 Jul 05, 12:27
ARSP files : WS6SUM.*
501 5yr Sequences : Dam 60% Full @ 1 May
Target Draft [M.m^3/a]
Exceedance Probability [%]
0 5 10 15 20 25 30
50 60 70 80 90 100
10 20 50 100 200
25.5 22.7 19.0 17.2 16.2
Legend: 1:25.5 2:22.7 3:19.1 4:17.1 5:16.2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Project : Lukanji Regional Water Supply Feas Study
Run Date : 12 Jul 05, 12:29
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Target Draft [M.m^3/a]
Exceedance Probability [%]
0 5 10 15 20 25 30
70 74 78 82 86 90 94 98
10 20 50 100 200
21.6 18.5 15.1 13.3 12.1
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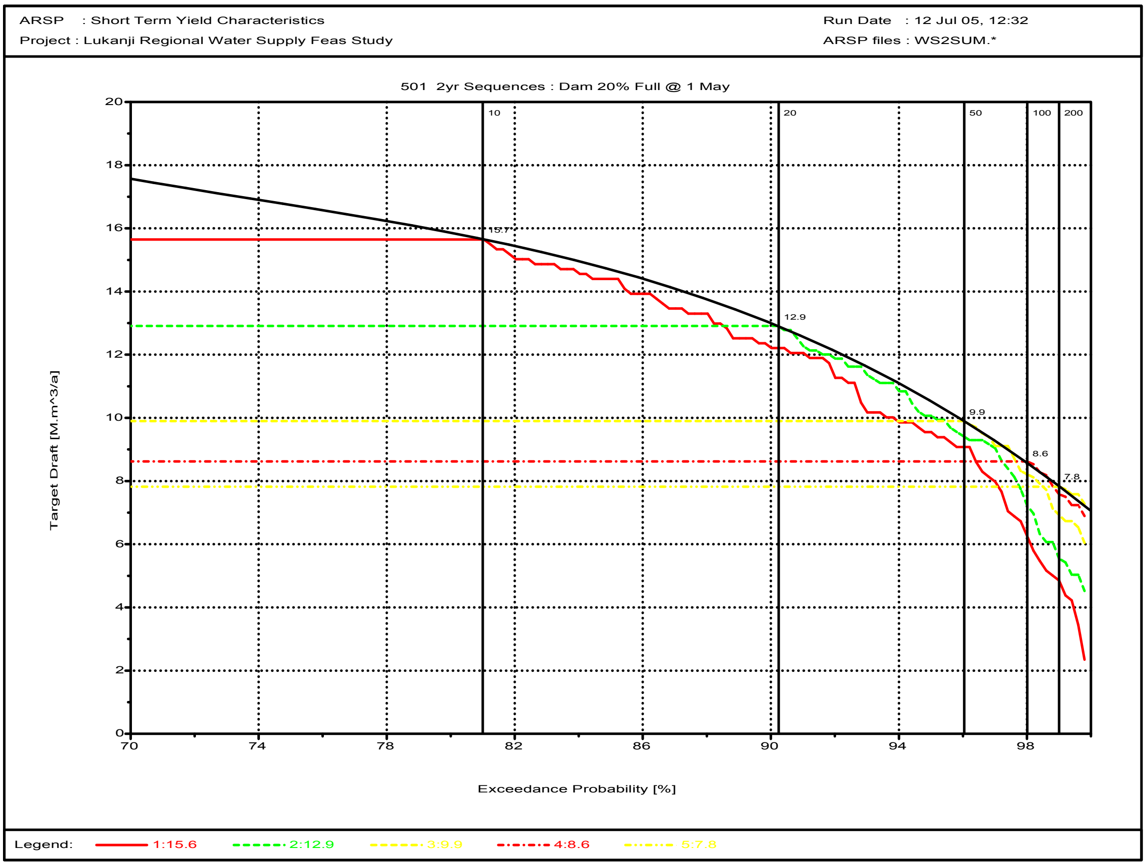
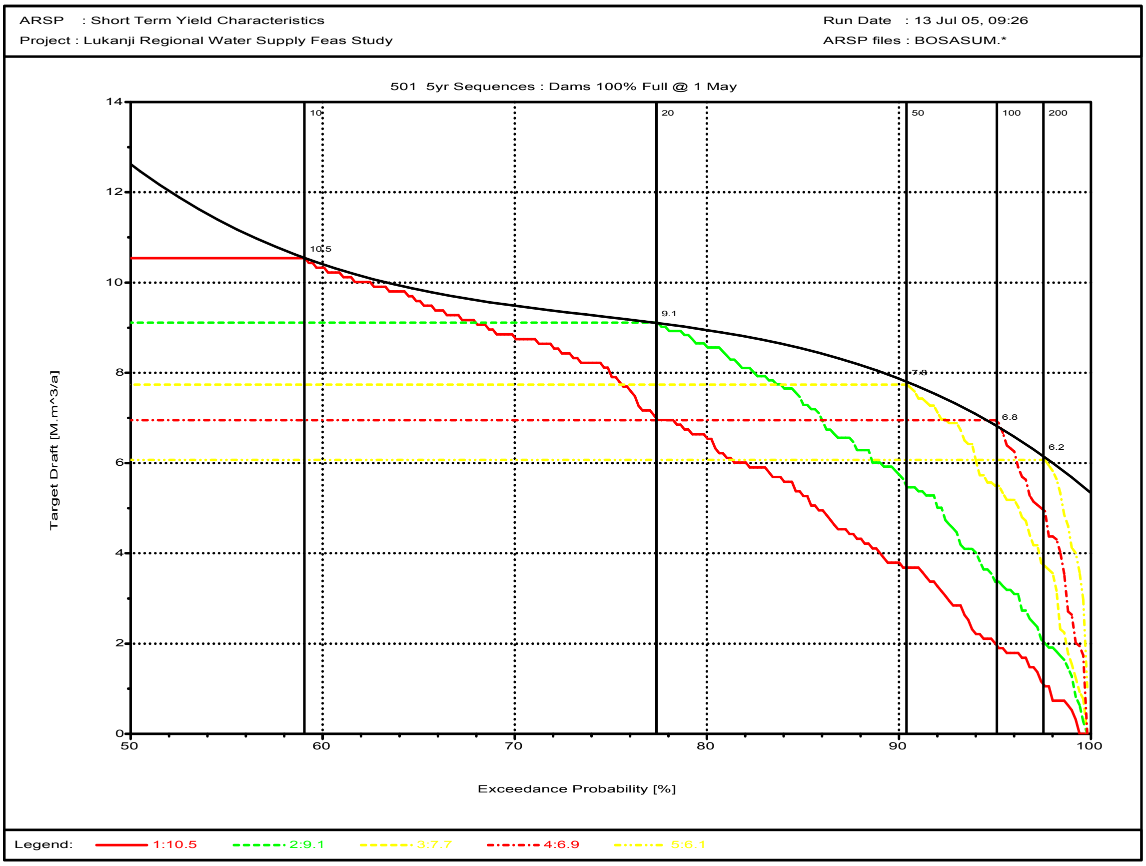
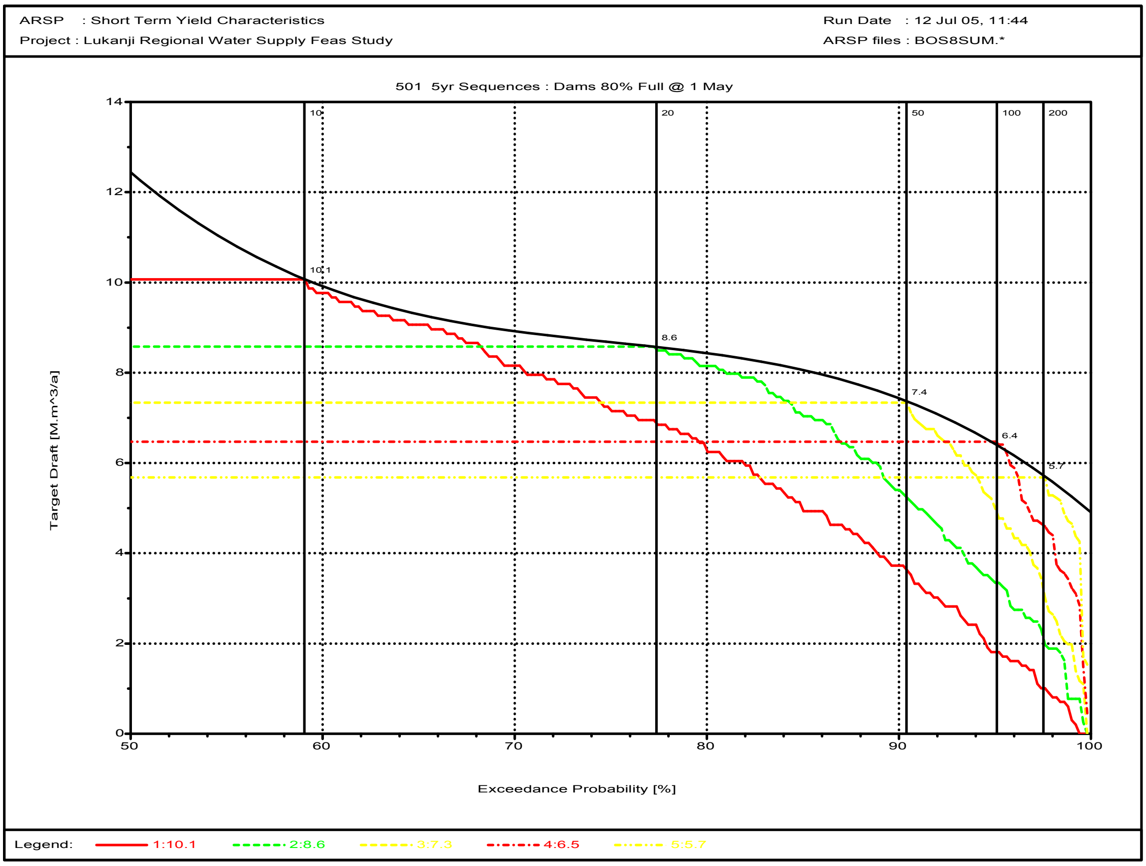


4.3.2 OXKRAAL DAM

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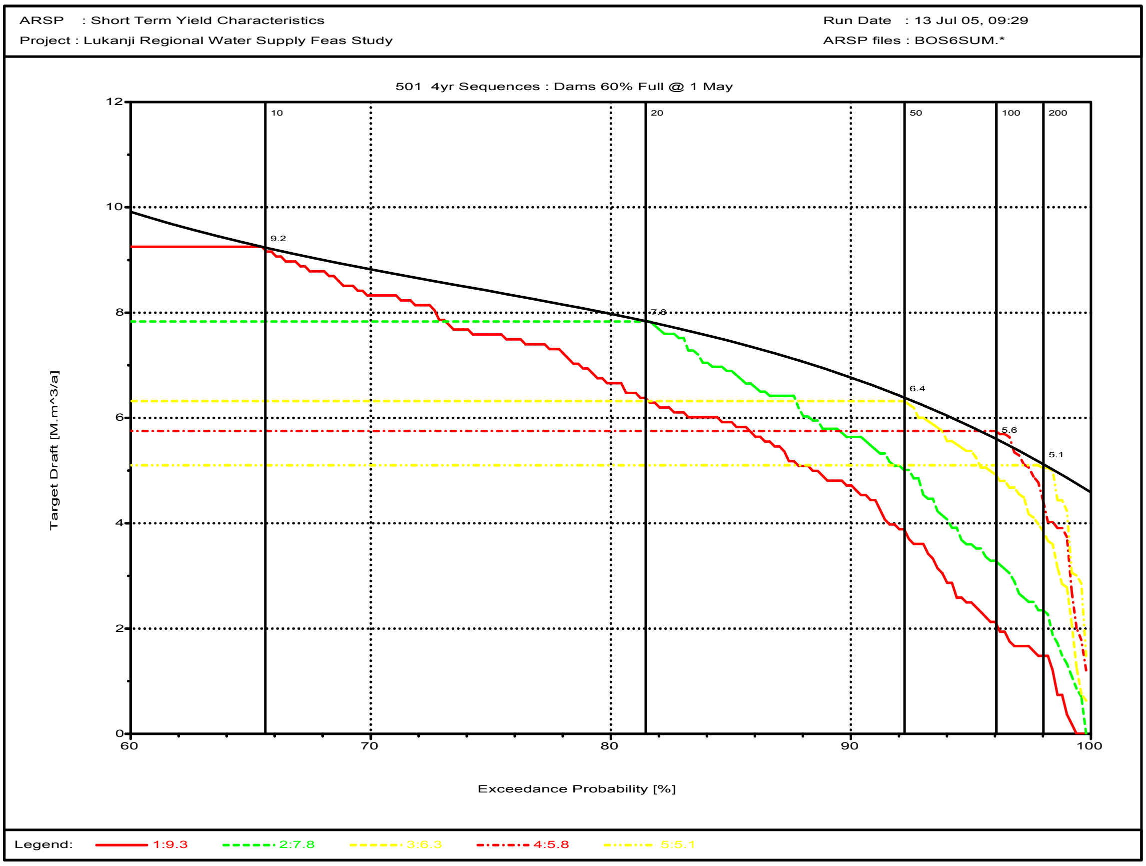
Run Date : 12 Jul 05, 11:44
ARSP files : BOS8SUM.*
501 5yr Sequences : Dams 80% Full @ 1 May
Target Draft [M.m^3/a]
Exceedance Probability [%]
10.1
8.6
7.4
6.4
5.7
Legend: 1:10.1 2:8.6 3:7.3 4:6.5 5:5.7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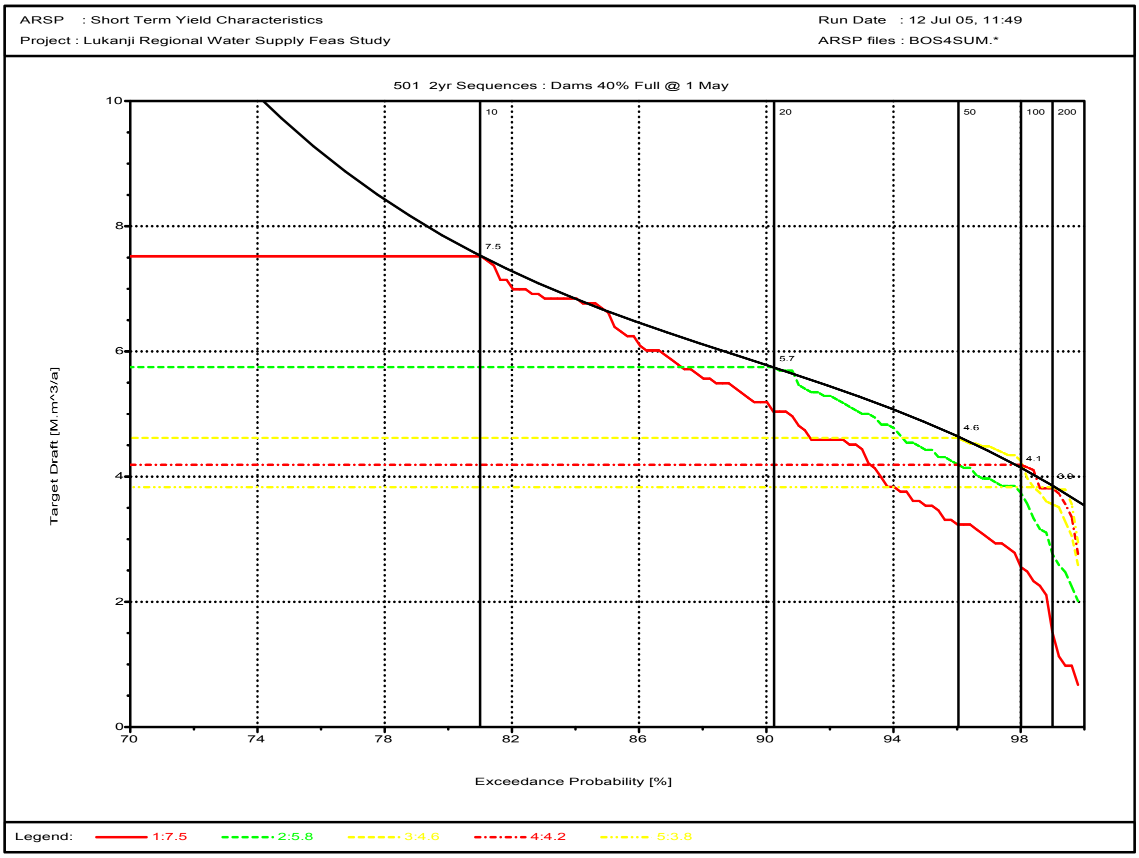
Project : Lukanji Regional Water Supply Feas Study
Run Date : 13 Jul 05, 09:29
ARSP files : BOS6SUM.*
501 4yr Sequences : Dams 60% Full @ 1 May
Target Draft [M.m^3/a]
Exceedance Probability [%]
9.2
7.8
6.4
5.6
5.1
Legend: 1:9.3 2:7.8 3:6.3 4:5.8 5:5.1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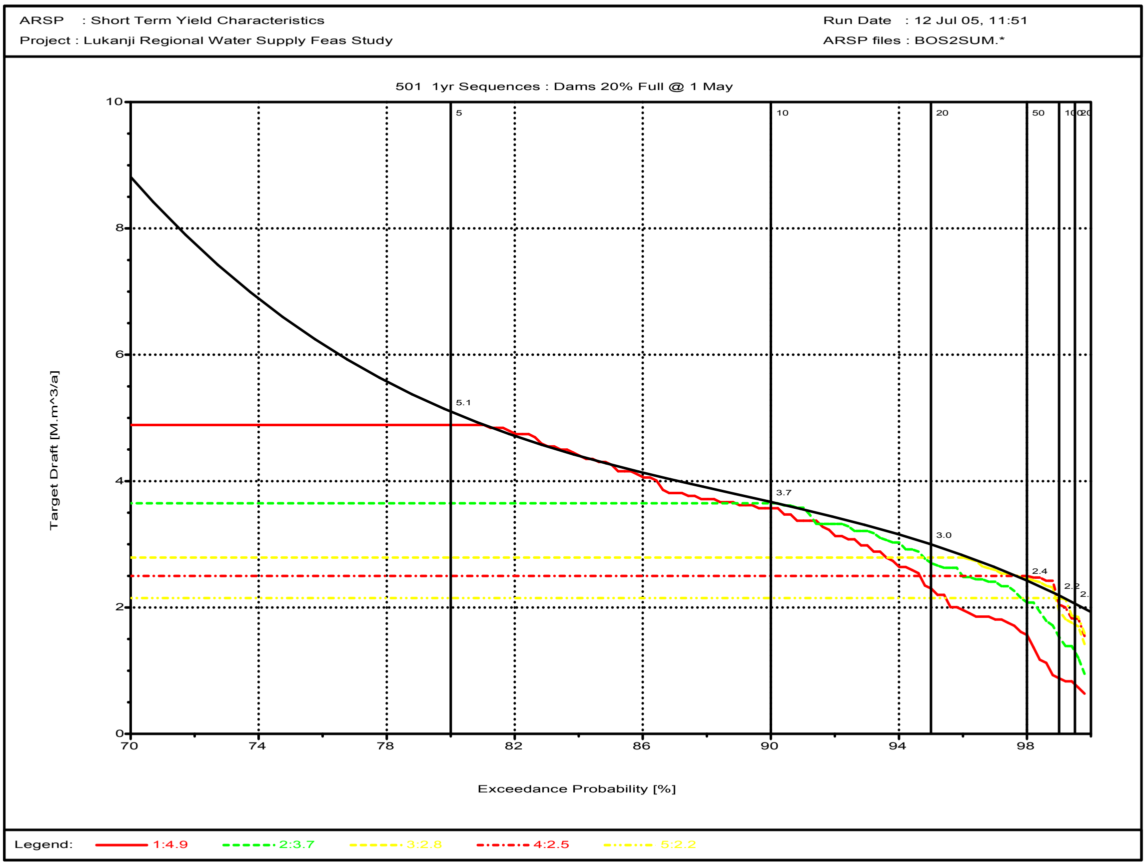
Project : Lukanji Regional Water Supply Feas Study
Run Date : 12 Jul 05, 11:49
ARSP files : BOS4SUM.*
501 2yr Sequences : Dams 40% Full @ 1 May
Target Draft [M.m^3/a]
Exceedance Probability [%]
10
20
50
100
200
7.5
5.7
4.6
4.1
3.8
Legend:
1:7.5
2:5.8
3:4.6
4:4.2
5:3.8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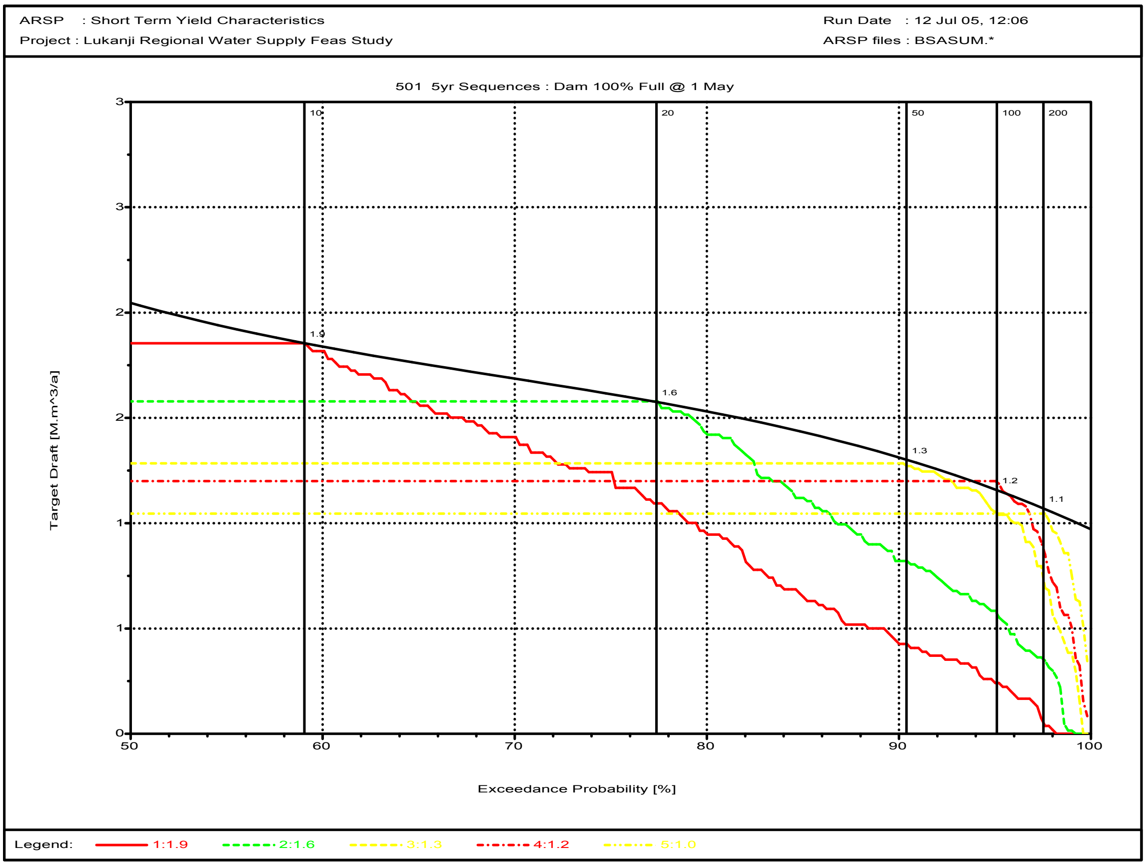
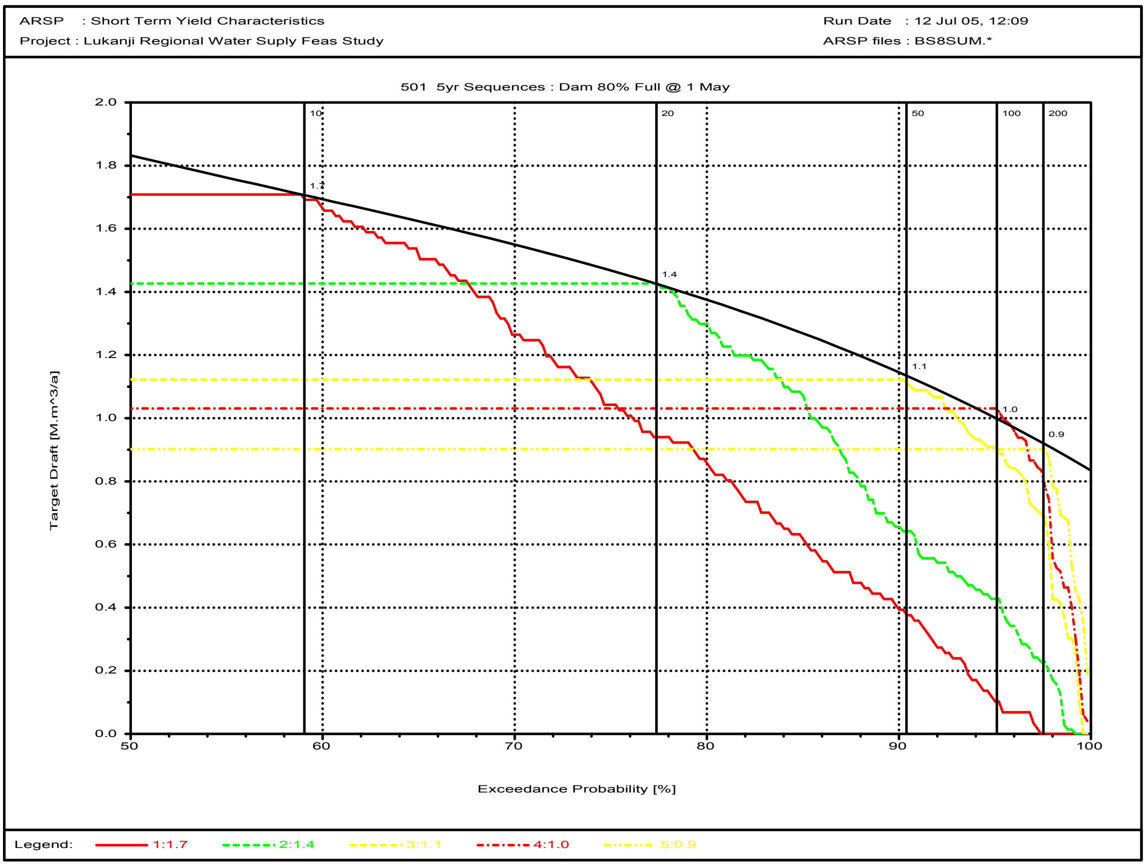
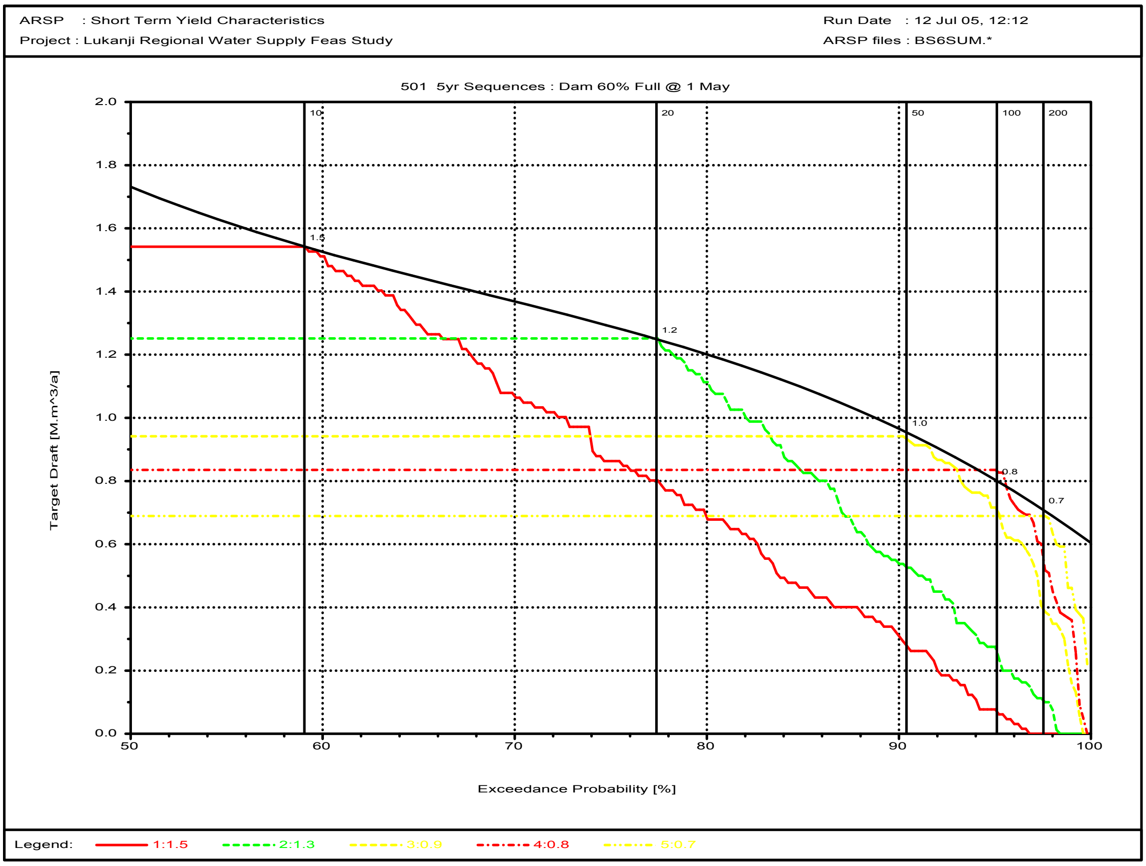
Run Date : 12 Jul 05, 11:51
ARSP files : BOS2SUM.*
501 1yr Sequences : Dams 20% Full @ 1 May
Target Draft [M.m^3/a]
Exceedance Probability [%]
5
10
20
50
5.1
3.7
3.0
2.4
Legend:
1:4.9
2:3.7
3:2.8
4:2.5
5:2.2

4.3.3 BONKOLO DAM



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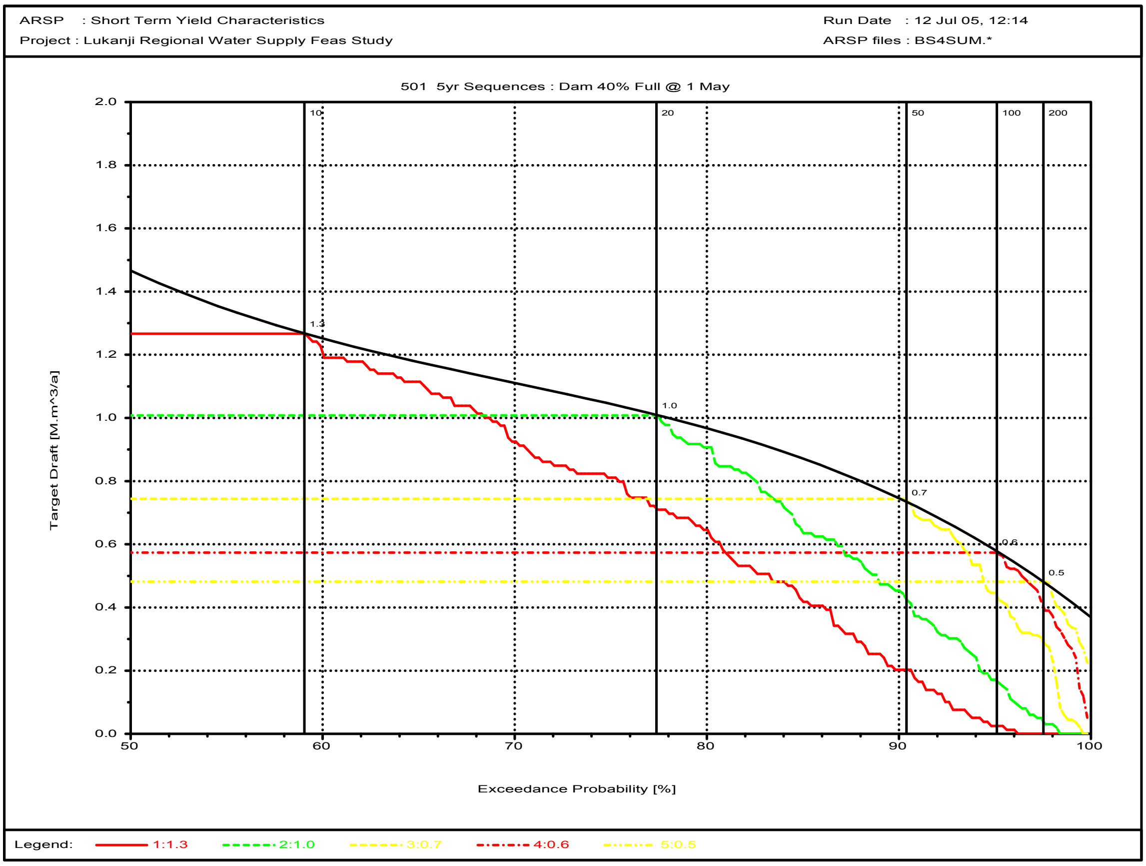
Project : Lukanji Regional Water Supply Feas Study
Run Date : 12 Jul 05, 12:12
ARSP files : BS6SUM.*
501 5yr Sequences : Dam 60% Full @ 1 May
Target Draft [M.m^3/a]
Exceedance Probability [%]
Legend:
1:1.5
2:1.3
3:0.9
4:0.8
5:0.7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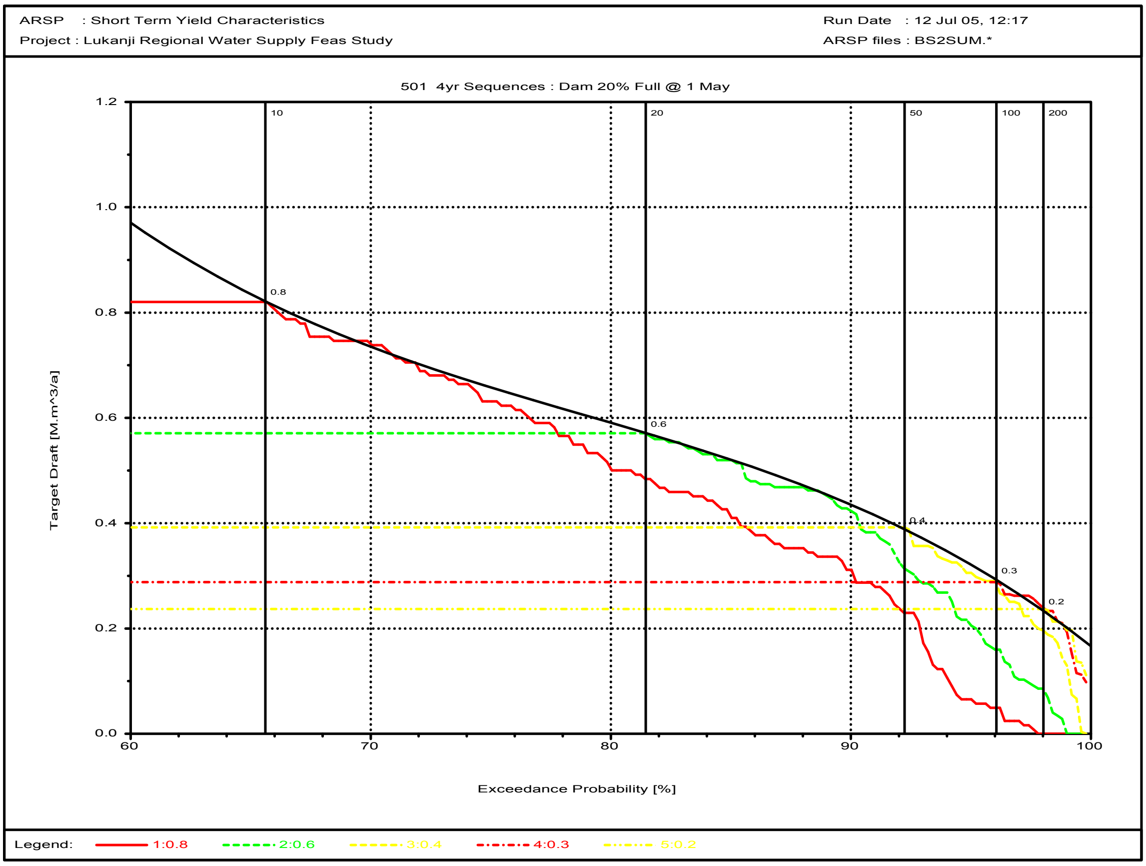
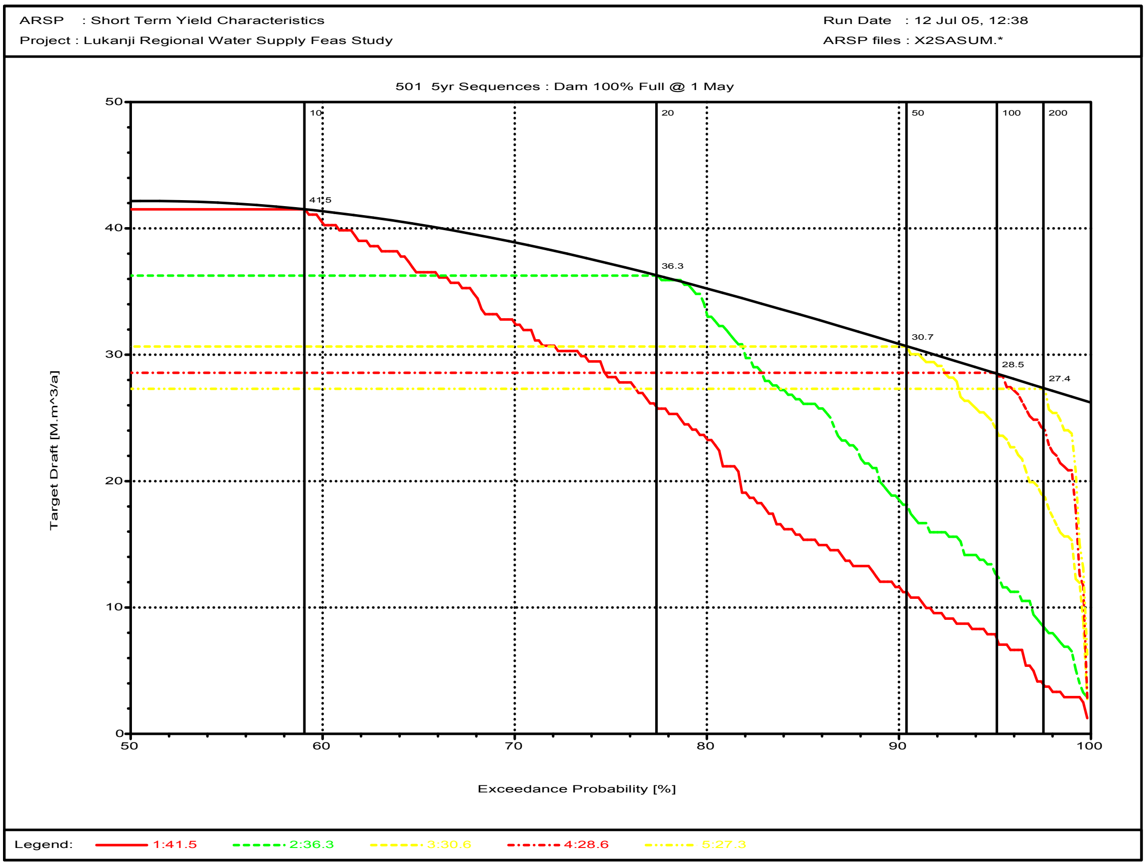
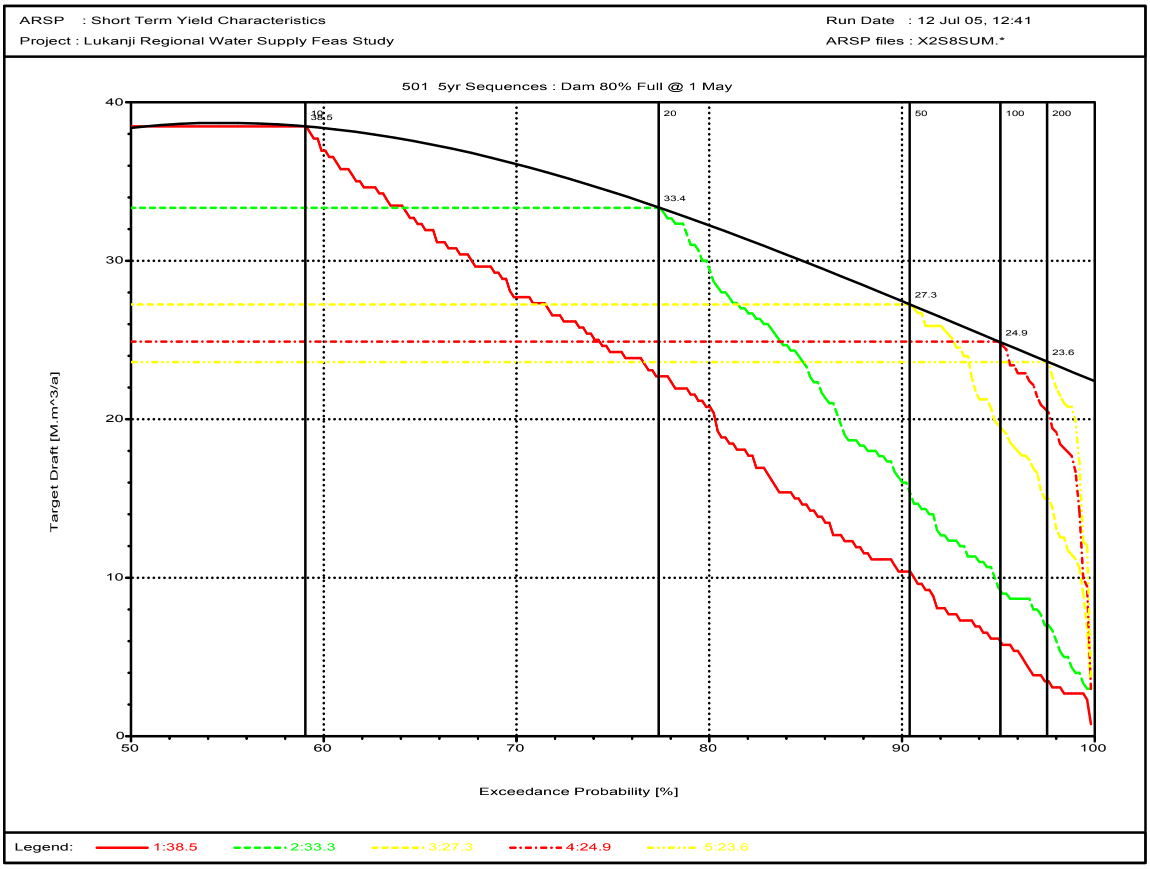
Project : Lukanji Regional Water Supply Feas Study
Run Date : 12 Jul 05, 12:14
ARSP files : BS4SUM.*
501 5yr Sequences : Dam 40% Full @ 1 May
Target Draft [M.m^3/a]
Exceedance Probability [%]
Legend:
1:1.3
2:1.0
3:0.7
4:0.6
5:0.5



4.3.4 XONXA DAM

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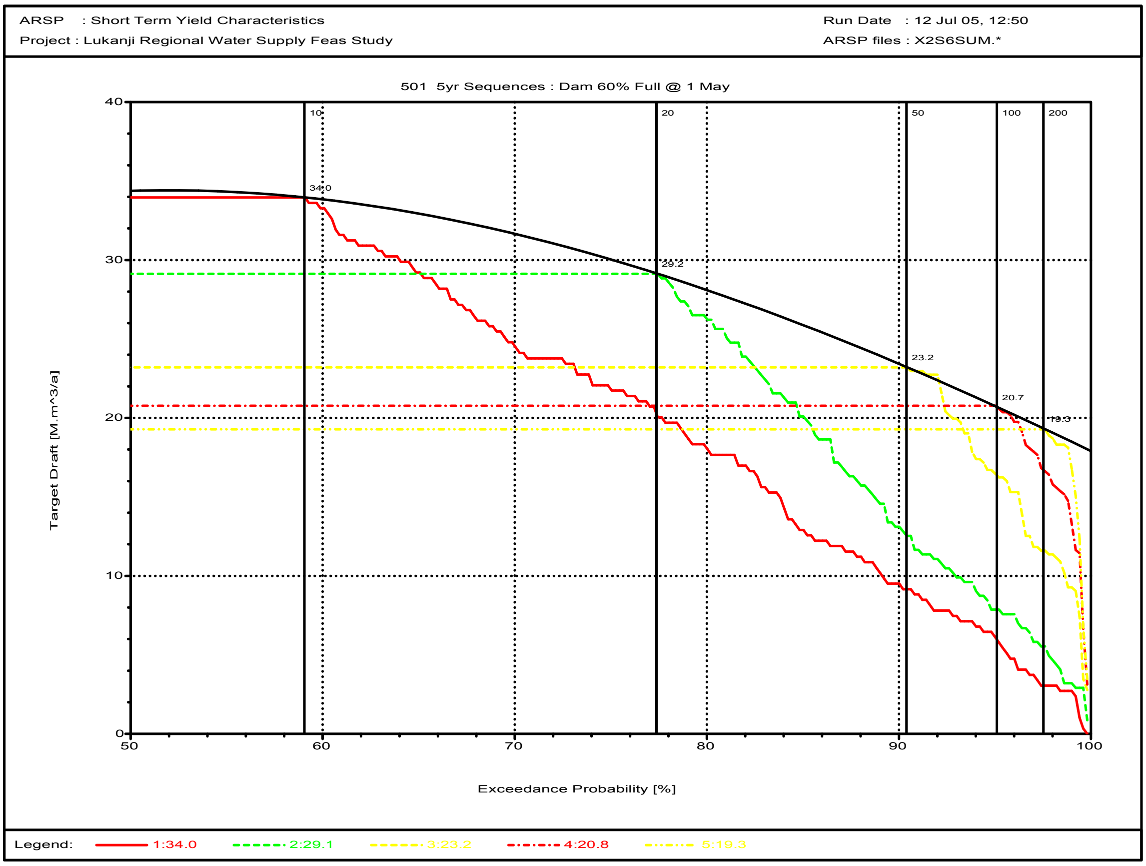
Project : Lukanji Regional Water Supply Feas Study
Run Date : 12 Jul 05, 12:41
ARSP files : X2S8SUM.*
501 5yr Sequences : Dam 80% Full @ 1 May
Target Draft [M.m^3/a]
Exceedance Probability [%]
10
20
50
100
200
38.5
33.4
27.3
24.9
23.6
Legend:
1:38.5
2:33.3
3:27.3
4:24.9
5:23.6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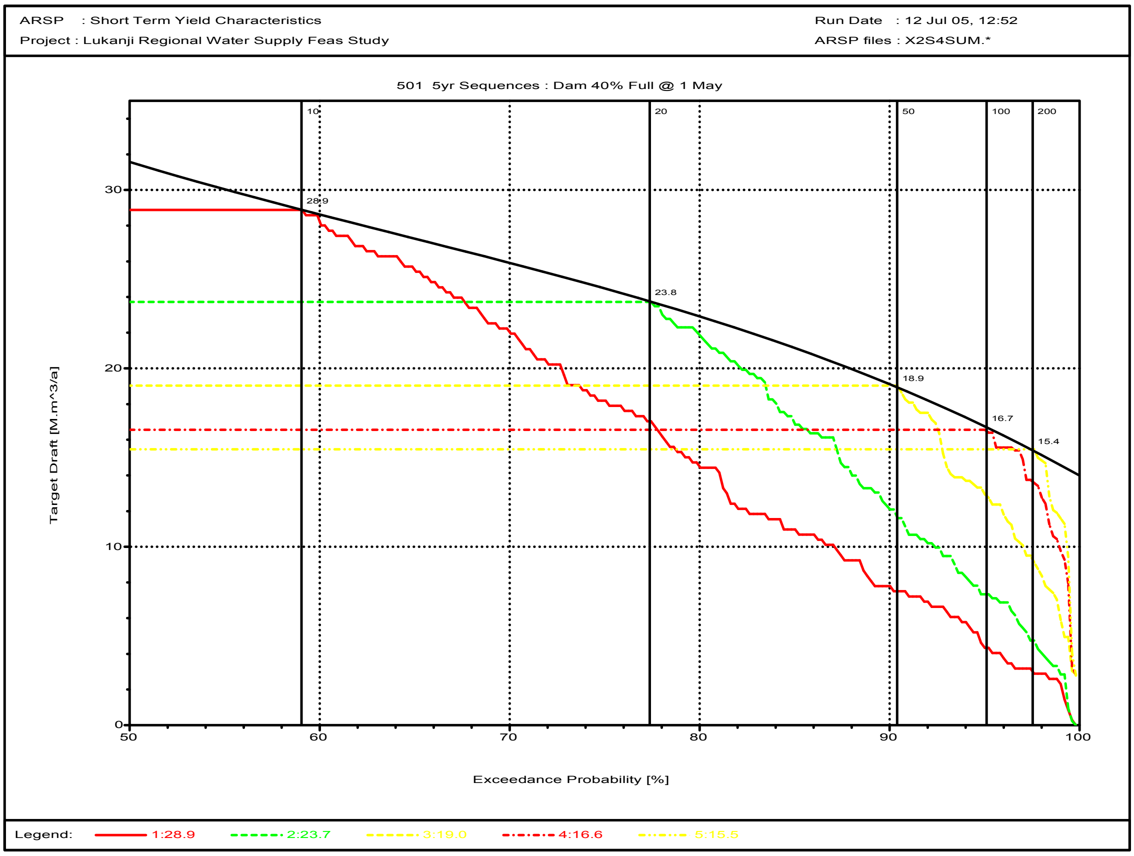
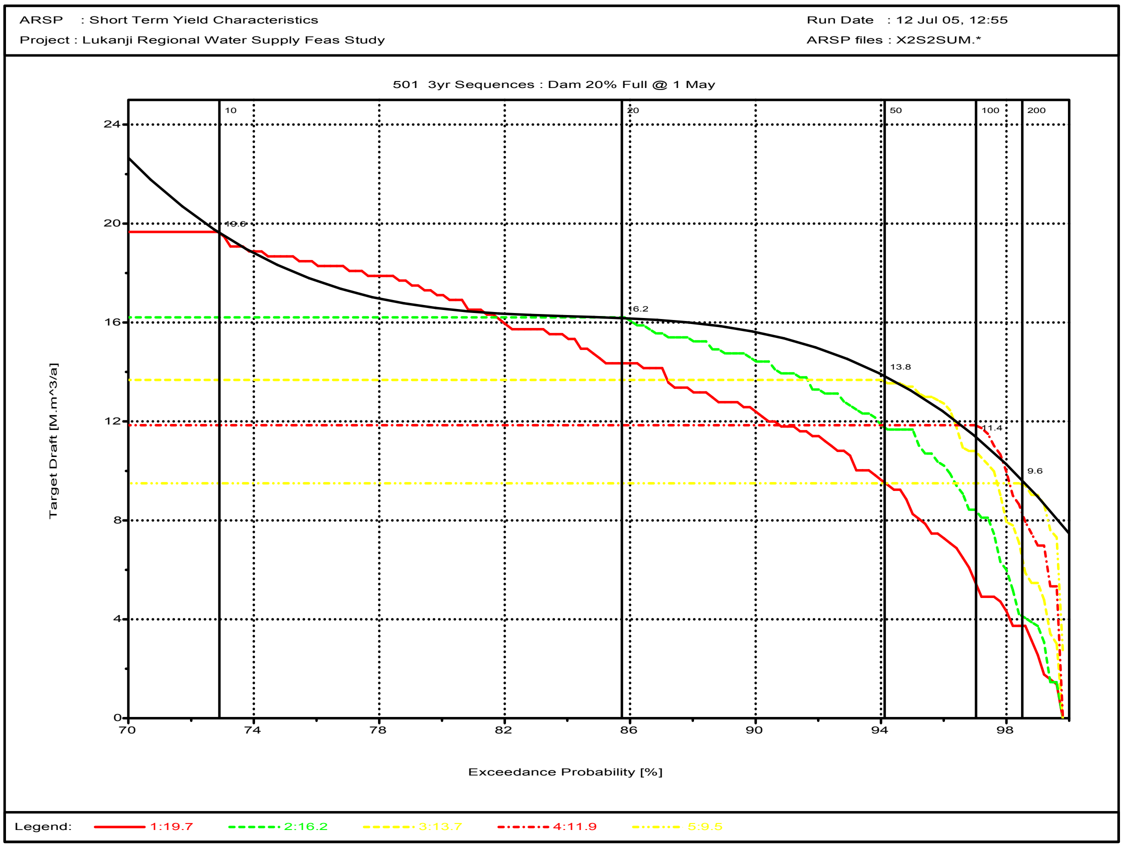
Run Date : 12 Jul 05, 12:50
ARSP files : X2S6SUM.*
501 5yr Sequences : Dam 60% Full @ 1 May
Target Draft [M.m^3/a]
Exceedance Probability [%]
10
20
50
100
200
34.0
29.2
23.2
20.7
19.3
Legend:
1:34.0
2:29.1
3:23.2
4:20.8
5:19.3


ARSP : Short Term Yield Characteristics
Project : Lukanji Regional Water Supply Feas Study
Run Date : 12 Jul 05, 12:52
ARSP files : X2S4SUM.*
501 5yr Sequences : Dam 40% Full @ 1 May
Target Draft [M.m^3/a]
Exceedance Probability [%]
28.9
23.8
18.9
16.7
15.4
Legend: 1:28.9 2:23.7 3:19.0 4:16.6 5:15.5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Project : Lukanji Regional Water Supply Feas Study
Run Date : 12 Jul 05, 12:55
ARSP files : X2S2SUM.*
501 3yr Sequences : Dam 20% Full @ 1 May
Target Draft [M.m^3/a]
Exceedance Probability [%]
16.2
13.8
9.6
Legend: 1:19.7 2:16.2 3:13.7 4:11.9 5:9.5

ADDENDUM 4.4

Urban Demand Curtailment

TABLE 4.4.1 ESTIMATING SAVINGS FROM POSSIBLE URBAN CURTAILMENTS

Area	Industrial/ Commercial/Domestic	Category	No of consumers	Consumption		Estimated annual demand	WDM Savings	Assumed restricted supply (m3)								Comments
								Light		Intermediate		Heavy		Crisis		
				Low month	High Month			Month	Year	Month	Year	Month	Year	Month	Year	
Queenstown consumption estimate																
Mlungisi 1	D	Medium	232	22.9	25.9	67,929.6		20	55680	13	36192	10	27840	5	13920	
Mlungisi 2	D	Low	202	8.9	10.1	23,028.0		10	23028	10	23028	10	23028	5	12120	
Mlungisi 3	D	Low-medium	847	14.9	16.8	161,172.0		16	161172	13	132132	10	101640	5	50820	
Mlungisi 4	D	Low	961	15.6	17.5	190,918.7		17	190919	13	149916	10	115320	5	57660	
Mlungisi 5	D	Low	2,385	26.1	29.4	793,182.9	-286,200	20	572400	13	372060	10	286200	5	143100	old area with significant leaks in cisterns etc. - being addressed
CONDEV 1	D	Low (RDP-type houses)	1,367	15.0	18.0	270,666.0		17	270666	13	213252	10	164040	5	82020	
CONDEV 2	D	Low (RDP-type houses)	1,580	10.0	12.0	208,560.0		11	208560	11	208560	10	189600	5	94800	
VAN 1	D	Low-medium	105	19.8	22.4	26,586.0		20	25200	13	16380	10	12600	5	6300	
VAN 2	D	Low-medium	404	14.6	16.5	75,548.0		16	75548	13	63024	10	48480	5	24240	
VAN 3	D	Medium	70	16.6	18.8	14,868.0		18	14868	13	10920	10	8400	5	4200	
VAN 4	D	Upper medium	33	21.5	24.2	9,058.5		20	7920	13	5148	10	3960	5	1980	
VAN 5	D	Medium (small erven)	126	17.1	19.3	27,518.4		18	27518	13	19656	10	15120	5	7560	
VAN 6	D	Low	273	17.3	19.6	60,457.1		18	60457	13	42588	10	32760	5	16380	
VAN 7	D	Low-medium (big erven)	162	22.4	25.2	46,267.2		20	38880	13	25272	10	19440	5	9720	
Ezibeleni 1	D	Low-medium	403	13.8	15.6	71,089.2		15	71089	13	62868	10	48360	5	24180	
Ezibeleni 2	D	Low-medium	1,362	14.0	15.7	242,825.1		15	242825	13	212472	10	163440	5	81720	
Ezibeleni 3	D	Low-medium	264	15.4	17.4	51,876.0		16	51876	13	41184	10	31680	5	15840	
Ezibeleni 4	D	Low-medium	1,238	13.2	14.9	209,222.0		14	209222	13	193128	10	148560	5	74280	
Ezibeleni 5	I	Light industry (dry)	20	58.1	65.6	14,845.7		56	13361	49	11877	43	10392	31	7423	most of these 20 are mostly idle.
Ezibeleni 6	D	Low-medium	979	22.3	25.1	278,337.2		20	234960	13	152724	10	117480	5	58740	
Ezibeleni 7	D	Low (RDP-type houses)	1,006	8.9	10.1	114,684.0		10	114684	10	114684	10	114684	5	60360	
Ezibeleni 8	D	Low (RDP-type houses)	1,560	-		-		0	0	0	0	0	0	0	0	Scheduled for completion end 2005
Queenstown 1	D	Upper medium	190	19.4	21.9	47,120.0		20	45600	13	29640	10	22800	5	11400	
Queenstown 2	D	High (smaller erven)	220	50.8	57.2	142,560.0		20	52800	13	34320	10	26400	5	13200	
Queenstown 3	I	Light industrial	44	55.3	62.4	31,076.6		53	27969	47	24861	41	21754	29	15538	Mainly commercial (panel-beaters, engineering works etc.
Queenstown 4	D	High (smaller erven)	247	16.8	18.9	52,858.0		18	52858	13	38532	10	29640	5	14820	Many are now becoming commercial (professional offices etc.)
Queenstown 5	D	Upper medium (small erven)	205	21.1	23.8	55,174.3		20	49200	13	31980	10	24600	5	12300	
Queenstown 6	D	Medium (large erven)	81	24.6	27.7	25,434.0		20	19440	13	12636	10	9720	5	4860	
Queenstown 7	C	Commercial / CBD	614	102.2	115.3	801,650.2		103	761568	98	721485	92	681403	87	641320	
Queenstown 8	D	High (large erven)	866	41.1	46.4	454,650.0		20	207840	13	135096	10	103920	5	51960	The main garden area
Queenstown 9	D	High (large erven)	186	17.7	20.0	42,089.1		19	42089	13	29016	10	22320	5	11160	Seems low as it is also a garden area
Queenstown 10	D	Upper medium (small erven)	125	21.2	23.9	33,750.0		20	30000	13	19500	10	15000	5	7500	
Queenstown 11	I	Industrial	57	280.7	316.5	204,234.4		269	183811	239	163387	209	142964	149	102117	
Queenstown 12	D	Medium (small erven)	80	19.4	21.9	19,840.0		20	19200	13	12480	10	9600	5	4800	
Sabata	D	Low (RDP-type houses)	240	-	-	-		0	0	0	0	0	0	0	0	Scheduled for completion July 2005
Enkululekweni	D	Low (RDP-type houses)	531	18.0	24.0	133,812.0		20	127440	13	82836	10	63720	5	31860	Scheduled for completion July 2005
Schools	C		30	40.0	50.0	16,200.0		43	15390	41	14580	38	13770	36	12960	
Other	C	Govt, municipal, flats, sport clubs etc	255	35.0	45.0	122,400.0		38	116280	36	110160	34	104040	32	97920	
	C	Abbatoir and cold-drink bottler	2	2,500.0	2,500.0	60,000.0		2375	57000	2250	54000	2125	51000	2000	48000	
Metered sub-total						5,201,488.2			4,479,318		3,621,575		3,025,674		1,929,078	
UAF		Dependent on supply				1,000,286.2		15%	861,407		696,457		581,860		370,977	
		Assume that some UAW is constant – independent of supply.				466,800.2		7%	466,800		466,800		466,800		466,800	
Total consumption						6,668,574.6			5,807,526		4,784,831		4,074,335		2,766,855	
Whittlesea consumption estimate (Approx 2002)																
Commercial	C		44	170.5	170.5	90,000.0		162	85500	153	81000	145	76500	136	72000	
Domestic	D		8,490	16.6	19.0	1,810,290.4		18	1810290	13	1324440	10	1018800	5	509400	
UAW		Dependent on supply				348,132.8		15%	348,133		254,700		195,923		97,962	
		Assume that some UAW is constant – independent of supply.				162,462.0		7%	162,462		162,462		162,462		162,462	
Whittlesea consumption						2,248,423.1			2,243,923		1,660,140		1,291,223		679,362	
Total for Queenstown plusWhittlesea				4,255,206	4,849,638	8,916,997.7	8,630,797.7		8,051,449		6,444,971		5,365,558		3,446,217	
Reduction possible through restrictions (relative to total after WDM implemented)									93%		75%		62%		40%	

The Mlungisi, VAN and eZibeleni areas have spaza shops and taverns dotted about.
The informal areas are served by approximately 10 standpipes.
Data kindly provided by Mr Chris Wilcock of the Lukanji Engineering Department.

TABLE 4.4.2 ASSUMED RESTRICTION LEVELS

Restriction level					
CODE	CATEGORY	LIGHT	INTERMEDIATE	EXTREME	CRISIS
D	Domestic (m^3/month)	20	13	10	5
C	Commercial (% supply)	90%	80%	70%	50%
I	Industrial (% supply)	95%	90%	85%	80%
		93%	75%	62%	40%

ADDENDUM 4.5

Previous Operating Rules

4.5.1 OPERATION OF WATERDOWN DAM

Extract from pp8.2.2.4 to 8.2.2.5 of the report for the Upper Kei Basin Study titled "Volume 4 Existing Water Development".

The Waterdown Dam was originally operated on a fixed draft basis.

In 1979 an analysis by DWAF indicated that the dam could be operated on a variable draft basis with restrictions on irrigation and urban use of 30% and 10%, respectively, during periods of drought (DWAF, 1979). The unrestricted allocation for irrigation at the dam was 11,13 Mm^3/a and the remaining yield would be for urban use. The decision months regarding the imposition of restrictions were March and September and the associated storage levels were 13,6 Mm^3 in March and 14,8 Mm^3 in September. The analysis indicated that restrictions would be in place for about 10% of the time.

In 1986 the yield of the dam was recalculated (DWAF, 1986) based on the same set of operating rules and allowing for further afforestation. The unrestricted allocations at the dam for irrigation and urban use were assumed to be 14,83 Mm^3/a and 12,71 Mm^3, respectively. The analysis indicated that restrictions would be in place for 21% of the time with the decision months and associated storage levels being March (14,57 Mm^3) and September (28,48 Mm^3).

Since then analyses of varying operating rules have been carried out (DWAF, 1988 and 1989) to ascertain whether or not it would be possible to supply an increased allocation to irrigators. The latest proposed operating rule (DWAF, 1989) is as follows :

No restrictions are to be applied when the dam capacity exceeds 35% of full supply capacity (13,37 Mm^3). As the storage progressively reduces from 35% to 19% of full supply capacity (7,26 Mm^3), the irrigation and urban supplies are to be progressively reduced by a maximum of 50% and 20% of the full water requirement. While storage is below 19% of full supply capacity no irrigation supplies are to be provided and the 20% restriction on urban supplies is to remain in force.

Up until August 1992, at the time of writing this chapter, these new operating rules had not yet been put into practice as the Waterdown Dam storage level has not dropped below 50% in recent years (the lowest levels were 50% in March 1988 and 53% in October 1991).

The operators of Waterdown Dam attempt to provide irrigation releases in excess of the irrigation allocation in order to offset the river conveyance losses between the dam and the irrigation lands. The Kat River Dam/Waterdown Dam Works Committee of the South Africa/Ciskei Permanent Water Commission recently agreed, as a temporary arrangement, to release 9 150 $m^3/ha/a$ from the dam to try and provide the quota of 6 100 $m^3/ha/a$ at field edge. This represents an allowance for river losses of 5,81 Mm^3/a for the 1 905 ha of irrigated land.

The actual releases from the dam are achieved by releasing slugs of water (or "turns") of between 1,03 and 1,16 Mm^3 from the dam over a period of 9 to 10 days with discharge rates starting at about 200 m^3/s and gradually reducing to above 15 m^3/s over the 9 or 10 day period (this seems to high - possibly 20m^3/s reducing to 1.5m^3/s). The total amount that is planned to be released for irrigation purposes during 1992/1993 is about 18 Mm^3.

4.5.2 RESTRICTION OF WATER SUPPLY FROM BONKOLO AND WATERDOWN DAMS

Extract from Appendix 3 of the report for the Upper Kei Basin Study titled "Volume 4 Existing Water Development.

The water supplied to Queenstown by Bonkolo and Waterdown Dams is restricted by the capacity of the pipelines. The maximum capacities of the pipelines are 0,29 m^3/s and 0,132 m^3/s for Waterdown Dam and Bonkolo Dam, respectively. A summary of the water restrictions placed on water supplied from Bonkolo Dam is given in Table 4.5.2.

TABLE 4.5.1 CURTAILMENT OF IRRIGATORS AND SADA-WHITTLESEA DEPENDING ON THE STORAGE IN WATERDOWN DAM

CAPACITY OF WATERDOWN DAM	IRRIGATORS	SADA-WHITTLESEA
35% of Full Supply Capacity	50% of full allocation	100% of full allocation
19% of Full Supply Capacity	0% of full allocation	100% of full allocation
10% of Full Supply Capacity	0% of full allocation	45% of full allocation
10-0% of Full Supply Capacity	0% of full allocation	45-0% of full allocation

TABLE 4.5.2 CURTAILMENT OF QUEENSTOWN AND THE IRRIGATORS DEPENDING ON THE STORAGE IN BONKOLO DAM

GROSS CAPACITY OF BONKOLO DAM		MAXIMUM QUEENSTOWN ABSTRACTION (m^3/s)	IRRIGATORS
SEPTEMBER-FEBRUARY	MARCH-AUGUST		
0 - 0,9	0 – 1,8	0,026	No abstraction
0,9 - 2,765	1,8 – 3,215	0,052	3 days out of 7
2,765 - 4,63	3,215 - 4,63	0,078	4 days out of 7
4,63 - full	4,63 - full	0,13	No restriction

Appendix 3 (Water Requirements) gives details of proposed water restrictions associated with acceptable risks of failure to supply the full Queenstown demand. These restrictions are not built into the system model.

4.5.3 ACCEPTABLE RISK OF FAILURE

Extract from p3.22 of the report for the Queenstown Regional Water Supply Feasibility Study titled "Appendix 3 Water Requirements"

The cost of providing a water supply with a very low risk of failure is high. For this reason the concept of "Acceptable Risk of Failure" has been investigated. The benefit of this approach is that as opposed to designing for the total demand to be met by the firm yield, a water supply scheme can be designed for a reduced demand (water rationing) at an agreed probability of failure. This would delay capital expenditure, thereby reducing the cost of supplying water.

The irrigators in the Klipplaat Government Water Supply Scheme currently operate under a system of progressively more serious restrictions on water usage as the level of Waterdown Dam drops. The current levels of restriction are as follows :

- Waterdown Dam above 35% full - Full allocation
- Waterdown Dam between 35% and 19% full - Allocation progressively reduced to 50% of allocation
- Waterdown Dam below 19% full - No allocation

These restrictions correspond roughly with partial restrictions once in five years and full restriction once in ten years.

The key water levels in Waterdown Dam are also the trigger levels for applying water restrictions in Queenstown. It would be sensible to link the domestic and irrigation restrictions to the same trigger mechanism and hence the same assurance levels.

It is proposed that the following restrictions be applied to irrigation releases in the study area.

TABLE 4.5.3 RETURN PERIODS OF RESTRICTIONS

RESTRICTION	RETURN PERIOD (YEARS)	PERCENTAGE REDUCTION (%)
Partial restriction	1:5	0 - 50% (progressive)
Full restriction	1:10	100%

ADDENDUM 4.6

Drawdown Strategy for the System during the Critical Drawdown Period

The evaporation from the Xonxa and Bonkolo Dams is significantly higher than that from the Waterdown Dam. When the system is severely drawn the agricultural demands will no longer be supplied from Xonxa Dam. Also the peak (curtailed) demand of the Queenstown complex will no longer exceed the conveyance capacity from Xonxa Dam so that Bonkolo Dam need not maintain sufficient storage to meet the Queenstown complex's peak demands. At this time it may be advantageous to draw as much as possible from Bonkolo Dam and Xonxa Dam to empty these dams completely (i.e. to use as much as possible of the dead storage) first and reduce evaporation.

To illustrate the sensitivity of the system to the drawdown strategy the volume of water to supply the Queenstown Complex for a number of scenarios was determined. In all scenarios 60% of the 2045 demand was supplied until the last year when the supply was reduced to 40%. The sources of supply for the scenarios were varied :

- Supply only from Waterdown alone (i.e. Xonxa and Bonkolo emptied and drawn from preferentially)
- Supply from Waterdown and Xonxa
- Supply from Xonxa alone.

The inflow to the system was also varied :

- For one scenario no inflow was modelled while in others the driest simulated inflow sequences into Waterdown and Xonxa were assumed to occur concurrently and were combined.
- In another scenario 30% of this combined inflow sequence was assumed to be released as EWR, leaving 70% of the inflow available at the dams.
- In the last scenario an additional 20% was assumed to be lost to evaporation at Bonkolo leaving 50% of the inflow available at the dams.

The results of the analyses for the three inflow sets are presented in Figures 4.6.1, 4.6.2 and 4.6.3 and the calculations for Figures 4.6.2 and 4.6.3 are included in Tables 4.5.1 and 4.5.2.

Figure 4.5.1 illustrates that if no inflows are received for two years then 17 Mm^3 is required in Waterdown to supply the required demands. However, if the demands are supplied from Xonxa alone or equally from Waterdown and Xonxa then about 27 Mm^3 is required in storage. If the demands are first supplied from Xonxa until Xonxa is empty and then switched to Waterdown then about 22 Mm^3 is required in storage, halfway between the other scenarios.

The above is an extreme case, but if 70% of the inflows are assumed to be available for storage and abstraction then the storage requirements reduce. In Figure 4.6.2, about 8 Mm^3 is required in Waterdown and 14 Mm^3 is required when Xonxa provides the full allocation or half the required demand.

The losses may be higher than in the assumed case, because inflows into Xonxa and Bonkolo may make it difficult to keep these dams empty and more evaporation may occur than was estimated. Figure 4.6.3 illustrates the case when about 50% of inflows are lost through EWR releases and evaporation. About 9 Mm^3 is required if the Queenstown Demand is supplied from storage in Waterdown (plus any inflows into Xonxa), while about 16 Mm^3 is required if the demands are also supplied from storage in Xonxa.

If the system is operated to reduce the storage in Xonxa and Bonkolo by as much as possible before using the water in Waterdown Dam then the bulk water supply pipelines from both the Xonxa/Bonkolo and Waterdown systems should each be able to supply at least the curtailed requirements of the Queenstown complex (about 60% of the overall requirement). The capacity from the Xonxa/Bonkolo system may be further increased depending on how much of the non-curtailed urban demands on the stressed Waterdown system need to be shifted to the Xonxa/Bonkolo system.

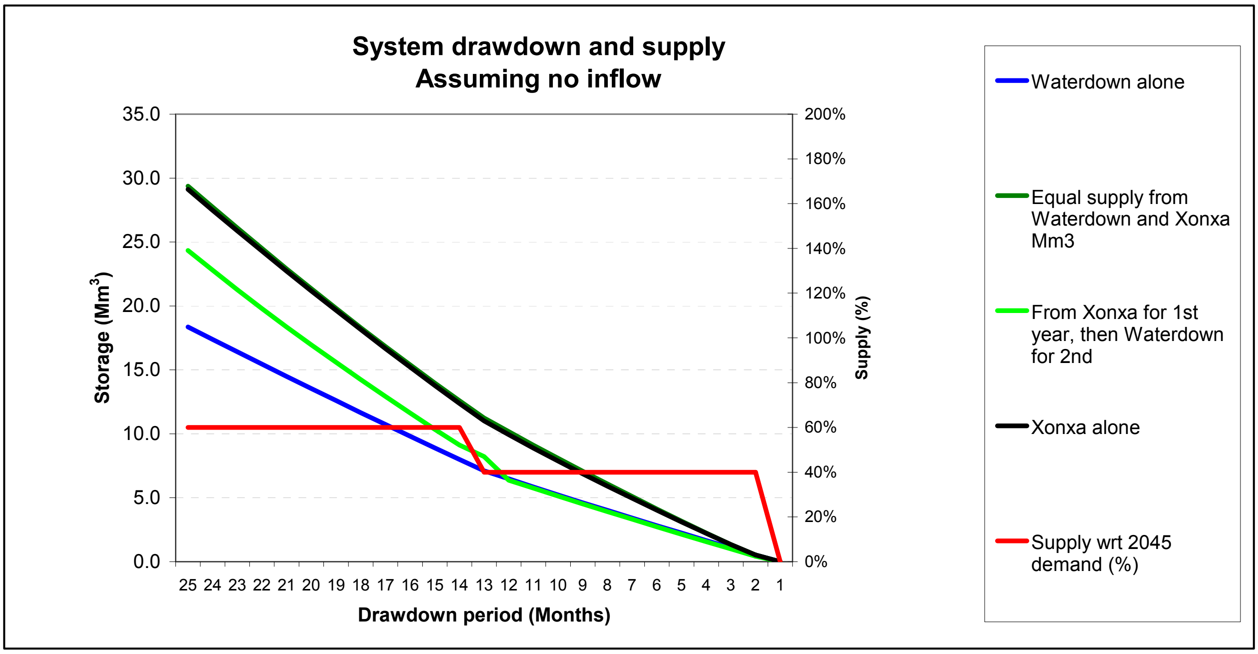

Figure 4.6.1 System drawdown and supply assuming no inflow

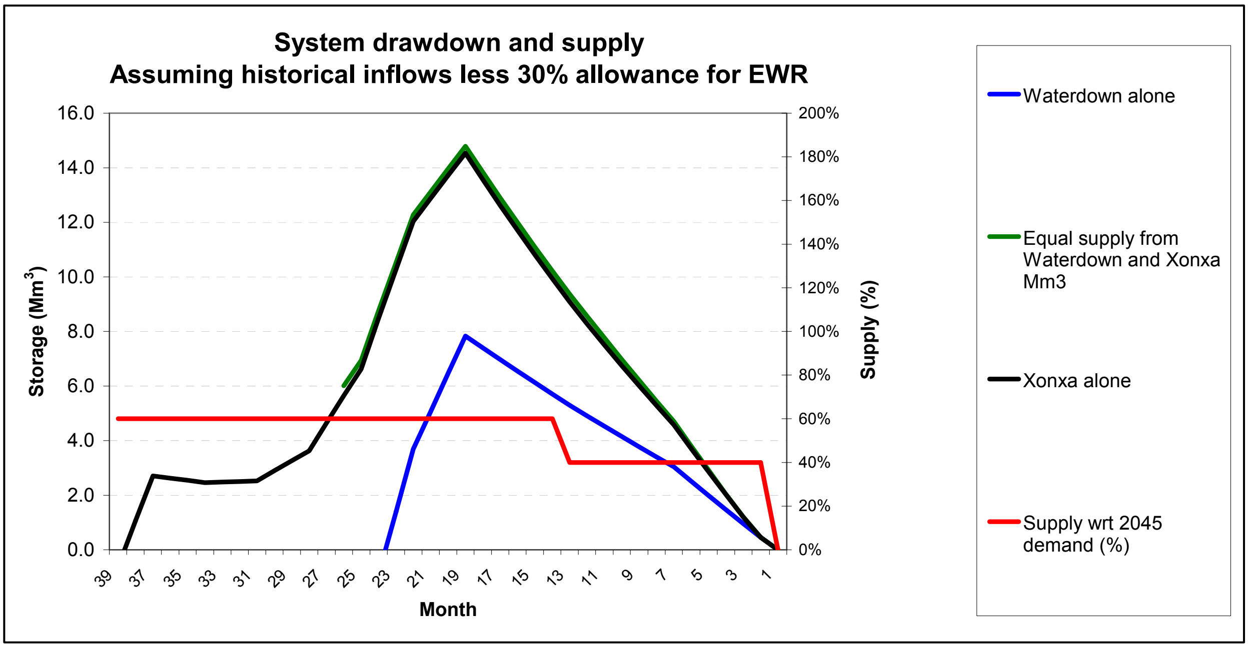

Figure 4.6.2 System drawdown and supply assuming 30% deduction for EWR

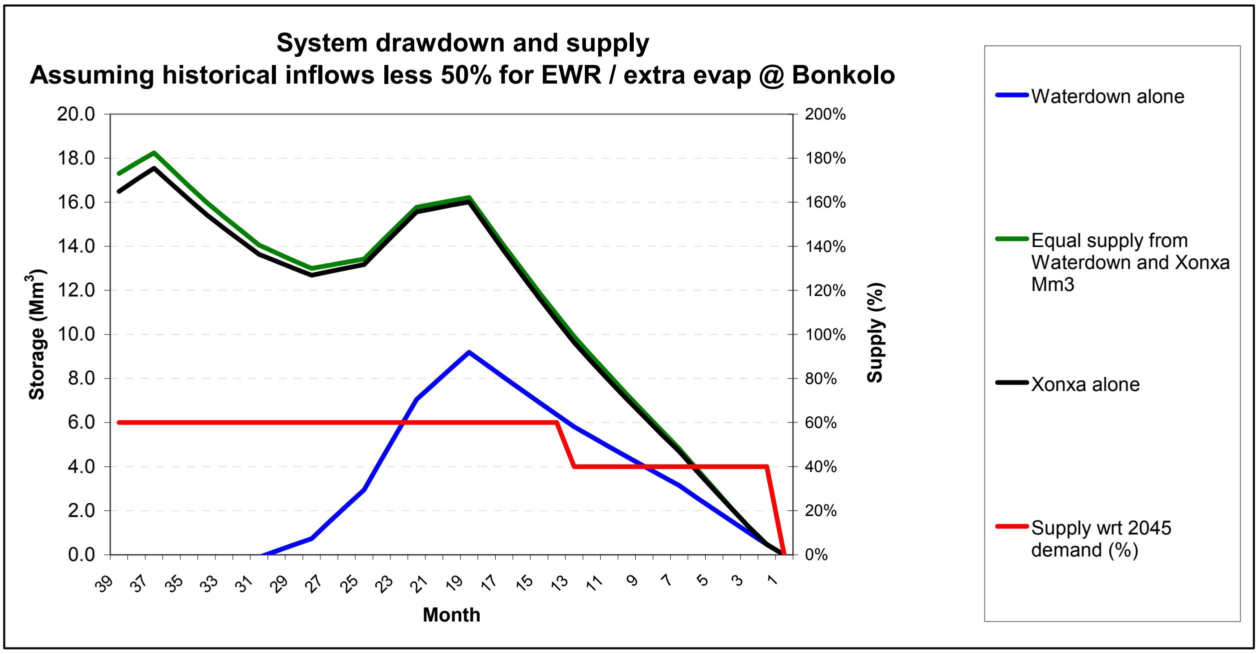

Figure 4.6.3 System drawdown and supply assuming 50% deduction for EWR and extra evaporation from Bonkolo

TABLE 4.6.1 SYSTEM DRAWDOWN AND SUPPLY : ASSUMING HISTORICAL INFLOWS LESS 30% ALLOWANCE FOR EWR

Simulation period	Waterdown alone							Equal supply from Waterdown and Xonxa														Xonxa alone						
	Waterdown							Waterdown						Xonxa								Xonxa						
	Storage	Storage (% Wdown + Xonxa Capacity)	Supplied	Evaporation	Area	Evap	Wdown + Xonxa Inflow x 50%	Storage	Supplied	Evaporation	Area	Evap	Wdown + Xonxa Inflow x 50% x 50%	Storage	Supplied	Evaporation	Area	Evap	Wdown + Xonxa Inflow x 50% x 50%	Combined storage (Wdown + Xonxa)		Storage	Storage (% Wdown + Xonxa Capacity)	Supplied	Evaporation	Area	Evap	Wdown + Xonxa Inflow x 50%
	Mm^3	%	Mm^3	mm	Km^2	Mm^3	Mm^3	Mm^3	%	Mm^3	mm	Km^2	Mm^3	Mm^3	%	Mm^3	mm	Km^2	Mm^3	Mm^3	%	Mm^3	%	Mm^3	mm	Km^2	Mm^3	Mm^3
39	0.0	0%	.78	117	0.0	0.00	2.01	0.9	.39	117	0.25	0.03	1.01	18.7	.39	152	4.7	0.72	1.01	19.6	12%	17.7	11%	.78	152	4.63	0.70	2.01
38	0.0	0%	.78	117	0.0	0.00	2.01	1.4	.39	117	0.39	0.04	1.01	18.6	.39	152	4.7	0.72	1.01	20.1	12%	18.2	11%	.78	152	4.68	0.71	2.01
37	0.9	0%	.78	117	0.3	0.03	2.01	2.0	.39	117	0.45	0.05	1.01	18.6	.39	152	4.7	0.71	1.01	20.5	12%	18.8	12%	.78	152	4.72	0.72	2.01
36	0.9	0%	.78	117	0.3	0.03	0.77	1.9	.39	117	0.44	0.05	0.39	17.8	.39	152	4.6	0.70	0.39	19.8	12%	18.0	11%	.78	152	4.66	0.71	0.77
35	0.9	0%	.78	117	0.3	0.03	0.77	1.9	.39	117	0.44	0.05	0.39	17.1	.39	152	4.6	0.69	0.39	19.0	11%	17.3	11%	.78	152	4.59	0.70	0.77
34	0.8	0%	.78	117	0.3	0.03	0.77	1.8	.39	117	0.43	0.05	0.39	16.5	.39	152	4.5	0.68	0.39	18.3	11%	16.7	10%	.78	152	4.53	0.69	0.77
33	0.9	0%	.78	117	0.3	0.03	0.85	1.8	.39	117	0.43	0.05	0.42	15.8	.39	152	4.4	0.68	0.42	17.6	10%	16.0	10%	.78	152	4.47	0.68	0.85
32	0.9	0%	.78	117	0.3	0.03	0.85	1.8	.39	117	0.43	0.05	0.42	15.2	.39	152	4.4	0.67	0.42	17.0	10%	15.4	10%	.78	152	4.41	0.67	0.85
31	1.0	0%	.78	117	0.3	0.03	0.85	1.8	.39	117	0.43	0.05	0.42	14.6	.39	152	4.3	0.66	0.42	16.4	9%	14.9	9%	.78	152	4.36	0.66	0.85
30	1.2	0%	.78	117	0.3	0.04	1.10	1.9	.39	117	0.44	0.05	0.55	14.1	.39	152	4.2	0.64	0.55	16.0	9%	14.5	9%	.78	152	4.31	0.65	1.10
29	1.5	0%	.78	117	0.4	0.05	1.10	2.0	.39	117	0.45	0.05	0.55	13.6	.39	152	4.1	0.63	0.55	15.6	9%	14.2	9%	.78	152	4.25	0.65	1.10
28	1.8	0%	.78	117	0.4	0.05	1.10	2.1	.39	117	0.46	0.05	0.55	13.2	.39	152	4.1	0.62	0.55	15.3	9%	13.9	8%	.78	152	4.19	0.64	1.10
27	2.6	1%	.78	117	0.5	0.06	1.59	2.5	.39	117	0.50	0.06	0.79	13.0	.39	152	4.0	0.61	0.79	15.4	9%	14.1	9%	.78	152	4.23	0.64	1.59
26	3.3	1%	.78	117	0.6	0.07	1.59	2.8	.39	117	0.54	0.06	0.79	12.8	.39	152	4.0	0.61	0.79	15.6	9%	14.2	9%	.78	152	4.26	0.65	1.59
25	4.0	2%	.78	117	0.7	0.08	1.59	3.2	.39	117	0.58	0.07	0.79	12.6	.39	152	3.9	0.60	0.79	15.7	9%	14.4	9%	.78	152	4.28	0.65	1.59
24	5.4	3%	.78	117	0.8	0.09	2.25	3.8	.39	117	0.65	0.08	1.12	12.7	.39	152	4.0	0.60	1.12	16.5	10%	15.2	9%	.78	152	4.39	0.67	2.25
23	6.8	4%	.78	117	0.9	0.11	2.25	4.5	.39	117	0.71	0.08	1.12	12.8	.39	152	4.0	0.61	1.12	17.3	10%	16.0	10%	.78	152	4.46	0.68	2.25
22	8.1	5%	.78	117	1.0	0.12	2.25	5.1	.39	117	0.77	0.09	1.12	13.0	.39	152	4.0	0.61	1.12	18.1	11%	16.8	10%	.78	152	4.54	0.69	2.25
21	8.9	5%	.78	117	1.1	0.13	1.62	5.4	.39	117	0.8	0.09	0.81	12.8	.39	152	4.0	0.61	0.81	18.2	11%	16.9	11%	.78	152	4.6	0.69	1.62
20	9.6	6%	.78	117	1.1	0.13	1.62	5.8	.39	117	0.8	0.10	0.81	12.6	.39	152	4.0	0.60	0.81	18.4	11%	17.1	11%	.78	152	4.6	0.69	1.62
19	10.3	6%	.78	117	1.2	0.14	1.62	6.1	.39	117	0.9	0.10	0.81	12.4	.39	152	3.9	0.60	0.81	18.5	11%	17.2	11%	.78	152	4.6	0.70	1.62
18	9.7	6%	.78	117	1.1	0.13	0.33	5.8	.39	117	0.8	0.10	0.17	11.6	.39	152	3.8	0.57	0.17	17.4	10%	16.1	10%	.78	152	4.5	0.68	0.33
17	9.1	5%	.78	117	1.1	0.13	0.33	5.5	.39	117	0.8	0.09	0.17	10.9	.39	152	3.6	0.55	0.17	16.3	9%	15.0	9%	.78	152	4.4	0.66	0.33
16	8.6	5%	.78	117	1.1	0.12	0.33	5.1	.39	117	0.8	0.09	0.17	10.1	.39	152	3.5	0.53	0.17	15.3	9%	13.9	8%	.78	152	4.2	0.64	0.33
15	8.0	5%	.78	117	1.0	0.12	0.33	4.8	.39	117	0.7	0.09	0.17	9.4	.39	152	3.4	0.51	0.17	14.2	8%	12.9	8%	.78	152	4.0	0.61	0.33
14	7.4	4%	.78	117	1.0	0.11	0.33	4.5	.39	117	0.7	0.08	0.17	8.7	.39	152	3.2	0.49	0.17	13.2	7%	11.9	7%	.78	152	3.8	0.58	0.33
13	6.9	4%	.52	117	0.9	0.11	0.33	4.2	.26	117	0.7	0.08	0.17	8.0	.26	152	3.1	0.47	0.17	12.2	7%	10.9	6%	.52	152	3.6	0.55	0.33
12	6.4	4%	.52	117	0.9	0.10	0.16	4.0	.26	117	0.7	0.08	0.08	7.3	.26	152	3.0	0.45	0.08	11.3	6%	10.0	6%	.52	152	3.5	0.53	0.16
11	6.0	3%	.52	117	0.8	0.10	0.16	3.7	.26	117	0.6	0.07	0.08	6.7	.26	152	2.9	0.44	0.08	10.4	5%	9.1	5%	.52	152	3.3	0.50	0.16
10	5.5	3%	.52	117	0.8	0.09	0.16	3.5	.26	117	0.6	0.07	0.08	6.1	.26	152	2.8	0.43	0.08	9.6	5%	8.3	5%	.52	152	3.2	0.48	0.16
9	5.1	3%	.52	117	0.8	0.09	0.16	3.2	.26	117	0.6	0.07	0.08	5.5	.26	152	2.8	0.42	0.08	8.8	4%	7.5	4%	.52	152	3.0	0.46	0.16
8	4.7	2%	.52	117	0.7	0.08	0.16	3.0	.26	117	0.6	0.07	0.08	4.9	.26	152	2.7	0.41	0.08	7.9	4%	6.7	4%	.52	152	2.9	0.44	0.16
7	4.2	2%	.52	117	0.7	0.08	0.16	2.8	.26	117	0.5	0.06	0.08	4.4	.26	152	2.6	0.40	0.08	7.1	3%	5.9	3%	.52	152	2.8	0.43	0.16
6	3.7	2%	.52	117	0.6	0.07	0.04	2.5	.26	117	0.5	0.06	0.02	3.7	.26	152	2.6	0.39	0.02	6.2	3%	5.0	3%	.52	152	2.7	0.41	0.04
5	3.1	1%	.52	117	0.6	0.07	0.04	2.2	.26	117	0.5	0.05	0.02	3.1	.26	152	2.5	0.38	0.02	5.3	2%	4.2	2%	.52	152	2.6	0.40	0.04
4	2.6	1%	.52	117	0.5	0.06	0.04	1.9	.26	117	0.4	0.05	0.02	2.5	.26	152	2.4	0.37	0.02	4.4	1%	3.3	1%	.52	152	2.5	0.38	0.04
3	2.1	1%	.52	117	0.5	0.05	0.04	1.6	.26	117	0.4	0.05	0.02	1.9	.26	152	2.2	0.33	0.02	3.5	1%	2.5	1%	.52	152	2.4	0.37	0.04
2	1.6	0%	.52	117	0.4	0.05	0.04	1.3	.26	117	0.4	0.04	0.02	1.5	.26	152	1.7	0.25	0.02	2.8	0%	1.7	0%	.52	152	1.9	0.29	0.04
1	1.1	0%	.00	117	0.0	0.00	0.04	1.1	.00	117	0.0	0	0.02	1.22	.00	152	0.0	0	0.02	2.3	0%	1.22	0%	.00	152	0.0	0	0.04
	Dead storage																											

TABLE 4.6.2 TYPICAL CALCULATION FOR DRAWDOWN SCENARIO WITH 50% OF THE INFLWOS LOST TO EWR RELEASES AND EVAPORATION

	Waterdown alone							Waterdown + Xonxa														Xonxa						
	Waterdown							Waterdown						Xonxa								Xonxa						
Simulation period	Storage	Storage (% Wdown + Xonxa Capacity)	Supplied	Evaporation	Area	Evap	Wdown + Xonxa Inflow x 50%	Storage	Supplied	Evaporation	Area	Evap	Wdown + Xonxa Inflow x 50% x 50%	Storage	Supplied	Evaporation	Area	Evap	Wdown + Xonxa Inflow x 50% x 50%	Combined storage	Storage (% Wdown + Xonxa Capacity)	Storage	Storage (% Wdown + Xonxa Capacity)	Supplied	Evaporation	Area	Evap	Wdown + Xonxa Inflow x 50%
Mth	Mm^3	%	Mm^3	mm	km^2	Mm^3	Mm^3	Mm^3	Mm^3	mm	km^2	Mm^3	Mm^3	Mm^3	Mm^3	mm	km^2	Mm^3	Mm^3	Mm^3	%	Mm^3	%	Mm^3	km^2	Mm^3	Mm^3	Mm^3
37	0.9	0%	.78	117	0.3	0.03	2.01	2.0	.39	117	0.45	0.05	1.01	18.6	.39	152	4.7	0.71	1.01	20.5	12%	18.8	12%	.78	152	4.72	0.72	2.01
36	0.9	0%	.78	117	0.3	0.03	0.77	1.9	.39	117	0.44	0.05	0.39	17.8	.39	152	4.6	0.70	0.39	19.8	12%	18.0	11%	.78	152	4.66	0.71	0.77
35	0.9	0%	.78	117	0.3	0.03	0.77	1.9	.39	117	0.44	0.05	0.39	17.1	.39	152	4.6	0.69	0.39	19.0	11%	17.3	11%	.78	152	4.59	0.70	0.77
34	0.8	0%	.78	117	0.3	0.03	0.77	1.8	.39	117	0.43	0.05	0.39	16.5	.39	152	4.5	0.68	0.39	18.3	11%	16.7	10%	.78	152	4.53	0.69	0.77
33	0.9	0%	.78	117	0.3	0.03	0.85	1.8	.39	117	0.43	0.05	0.42	15.8	.39	152	4.4	0.68	0.42	17.6	10%	16.0	10%	.78	152	4.47	0.68	0.85
32	0.9	0%	.78	117	0.3	0.03	0.85	1.8	.39	117	0.43	0.05	0.42	15.2	.39	152	4.4	0.67	0.42	17.0	10%	15.4	10%	.78	152	4.41	0.67	0.85
31	1.0	0%	.78	117	0.3	0.03	0.85	1.8	.39	117	0.43	0.05	0.42	14.6	.39	152	4.3	0.66	0.42	16.4	9%	14.9	9%	.78	152	4.36	0.66	0.85
30	1.2	0%	.78	117	0.3	0.04	1.10	1.9	.39	117	0.44	0.05	0.55	14.1	.39	152	4.2	0.64	0.55	16.0	9%	14.5	9%	.78	152	4.31	0.65	1.10
29	1.5	0%	.78	117	0.4	0.05	1.10	2.0	.39	117	0.45	0.05	0.55	13.6	.39	152	4.1	0.63	0.55	15.6	9%	14.2	9%	.78	152	4.25	0.65	1.10
28	1.8	0%	.78	117	0.4	0.05	1.10	2.1	.39	117	0.46	0.05	0.55	13.2	.39	152	4.1	0.62	0.55	15.3	9%	13.9	8%	.78	152	4.19	0.64	1.10
27	2.6	1%	.78	117	0.5	0.06	1.59	2.5	.39	117	0.50	0.06	0.79	13.0	.39	152	4.0	0.61	0.79	15.4	9%	14.1	9%	.78	152	4.23	0.64	1.59
26	3.3	1%	.78	117	0.6	0.07	1.59	2.8	.39	117	0.54	0.06	0.79	12.8	.39	152	4.0	0.61	0.79	15.6	9%	14.2	9%	.78	152	4.26	0.65	1.59
25	4.0	2%	.78	117	0.7	0.08	1.59	3.2	.39	117	0.58	0.07	0.79	12.6	.39	152	3.9	0.60	0.79	15.7	9%	14.4	9%	.78	152	4.28	0.65	1.59
24	5.4	3%	.78	117	0.8	0.09	2.25	3.8	.39	117	0.65	0.08	1.12	12.7	.39	152	4.0	0.60	1.12	16.5	10%	15.2	9%	.78	152	4.39	0.67	2.25
23	6.8	4%	.78	117	0.9	0.11	2.25	4.5	.39	117	0.71	0.08	1.12	12.8	.39	152	4.0	0.61	1.12	17.3	10%	16.0	10%	.78	152	4.46	0.68	2.25
22	8.1	5%	.78	117	1.0	0.12	2.25	5.1	.39	117	0.77	0.09	1.12	13.0	.39	152	4.0	0.61	1.12	18.1	11%	16.8	10%	.78	152	4.54	0.69	2.25
21	8.9	5%	.78	117	1.1	0.13	1.62	5.4	.39	117	0.8	0.09	0.81	12.8	.39	152	4.0	0.61	0.81	18.2	11%	16.9	11%	.78	152	4.6	0.69	1.62
20	9.6	6%	.78	117	1.1	0.13	1.62	5.8	.39	117	0.8	0.10	0.81	12.6	.39	152	4.0	0.60	0.81	18.4	11%	17.1	11%	.78	152	4.6	0.69	1.62
19	10.3	6%	.78	117	1.2	0.14	1.62	6.1	.39	117	0.9	0.10	0.81	12.4	.39	152	3.9	0.60	0.81	18.5	11%	17.2	11%	.78	152	4.6	0.70	1.62
18	9.7	6%	.78	117	1.1	0.13	0.33	5.8	.39	117	0.8	0.10	0.17	11.6	.39	152	3.8	0.57	0.17	17.4	10%	16.1	10%	.78	152	4.5	0.68	0.33
17	9.1	5%	.78	117	1.1	0.13	0.33	5.5	.39	117	0.8	0.09	0.17	10.9	.39	152	3.6	0.55	0.17	16.3	9%	15.0	9%	.78	152	4.4	0.66	0.33
16	8.6	5%	.78	117	1.1	0.12	0.33	5.1	.39	117	0.8	0.09	0.17	10.1	.39	152	3.5	0.53	0.17	15.3	9%	13.9	8%	.78	152	4.2	0.64	0.33
15	8.0	5%	.78	117	1.0	0.12	0.33	4.8	.39	117	0.7	0.09	0.17	9.4	.39	152	3.4	0.51	0.17	14.2	8%	12.9	8%	.78	152	4.0	0.61	0.33
14	7.4	4%	.78	117	1.0	0.11	0.33	4.5	.39	117	0.7	0.08	0.17	8.7	.39	152	3.2	0.49	0.17	13.2	7%	11.9	7%	.78	152	3.8	0.58	0.33
13	6.9	4%	.52	117	0.9	0.11	0.33	4.2	.26	117	0.7	0.08	0.17	8.0	.26	152	3.1	0.47	0.17	12.2	7%	10.9	6%	.52	152	3.6	0.55	0.33
12	6.4	4%	.52	117	0.9	0.10	0.16	4.0	.26	117	0.7	0.08	0.08	7.3	.26	152	3.0	0.45	0.08	11.3	6%	10.0	6%	.52	152	3.5	0.53	0.16
11	6.0	3%	.52	117	0.8	0.10	0.16	3.7	.26	117	0.6	0.07	0.08	6.7	.26	152	2.9	0.44	0.08	10.4	5%	9.1	5%	.52	152	3.3	0.50	0.16
10	5.5	3%	.52	117	0.8	0.09	0.16	3.5	.26	117	0.6	0.07	0.08	6.1	.26	152	2.8	0.43	0.08	9.6	5%	8.3	5%	.52	152	3.2	0.48	0.16
9	5.1	3%	.52	117	0.8	0.09	0.16	3.2	.26	117	0.6	0.07	0.08	5.5	.26	152	2.8	0.42	0.08	8.8	4%	7.5	4%	.52	152	3.0	0.46	0.16
8	4.7	2%	.52	117	0.7	0.08	0.16	3.0	.26	117	0.6	0.07	0.08	4.9	.26	152	2.7	0.41	0.08	7.9	4%	6.7	4%	.52	152	2.9	0.44	0.16
7	4.2	2%	.52	117	0.7	0.08	0.16	2.8	.26	117	0.5	0.06	0.08	4.4	.26	152	2.6	0.40	0.08	7.1	3%	5.9	3%	.52	152	2.8	0.43	0.16
6	3.7	2%	.52	117	0.6	0.07	0.04	2.5	.26	117	0.5	0.06	0.02	3.7	.26	152	2.6	0.39	0.02	6.2	3%	5.0	3%	.52	152	2.7	0.41	0.04
5	3.1	1%	.52	117	0.6	0.07	0.04	2.2	.26	117	0.5	0.05	0.02	3.1	.26	152	2.5	0.38	0.02	5.3	2%	4.2	2%	.52	152	2.6	0.40	0.04
4	2.6	1%	.52	117	0.5	0.06	0.04	1.9	.26	117	0.4	0.05	0.02	2.5	.26	152	2.4	0.37	0.02	4.4	1%	3.3	1%	.52	152	2.5	0.38	0.04
3	2.1	1%	.52	117	0.5	0.05	0.04	1.6	.26	117	0.4	0.05	0.02	1.9	.26	152	2.2	0.33	0.02	3.5	1%	2.5	1%	.52	152	2.4	0.37	0.04
2	1.6	0%	.52	117	0.4	0.05	0.04	1.3	.26	117	0.4	0.04	0.02	1.5	.26	152	1.7	0.25	0.02	2.8	0%	1.7	0%	.52	152	1.9	0.29	0.04
1	1.1	0%	.00	117	0.0	0.00	0.04	1.1	.00	117	0.0	0	0.02	1.22	.00	152	0.0	0	0.02	2.3	0%	1.22	0%	.00	152	0.0	0	0.04

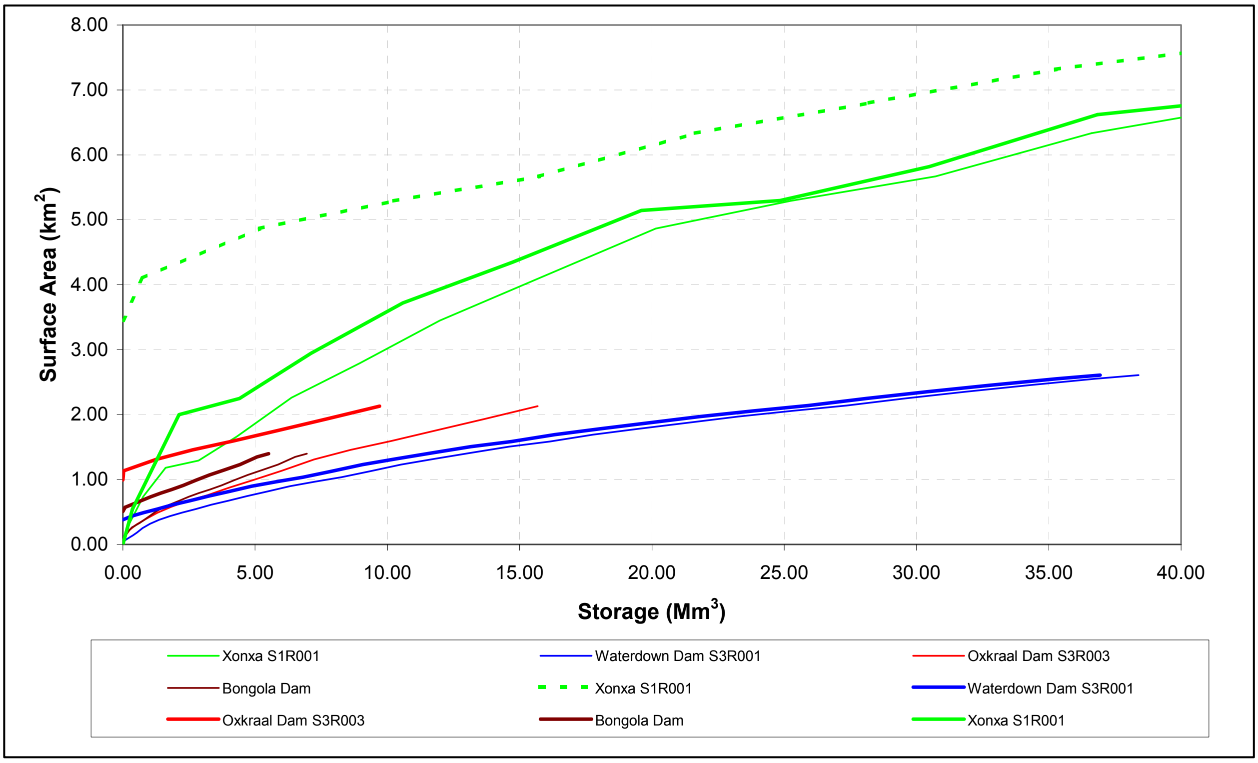

Figure 4.6.4 Relationship of surface area to net storage

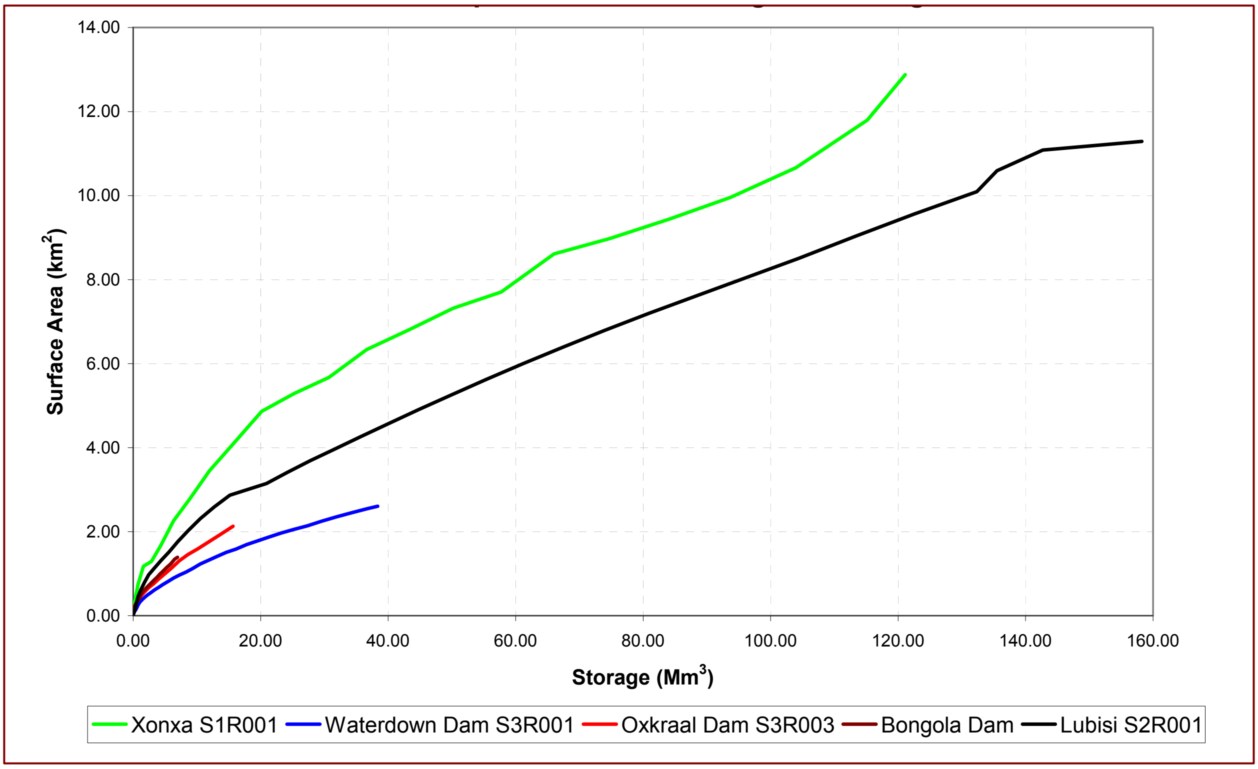

Figure 4.6.5 Relationship of surface area to gross storage

TABLE 4.6.3 AVERAGE ANNUAL EVAPORATION AT DIFFERENT DAMS

DAM	ANNUAL EVAPORATION (mm)
Bushmanskrantz Dam	1526
Oxkraal Dam	1526
Waterdown Dam	1400
Bonkolo Dam	1519
Lubisi Dam	1647
Xonxa Dam	1823

ADDENDUM 4.7

Urban Supply Estimates

UPPER YIELD ESTIMATE

Assuming 50% transmission losses in the Black Kei River, no transmission losses downstream of Xonxa and no inefficiency in the usage of accruals.

ASSUMPTIONS		
100%	a	Factor applied to reduce Xonxa's yield
50%	b	Percentage of evapotranspiration loss applied on Klipplaat/Oxkraal/Black Kei. Reduction obtained by reducing the distance from Waterdown to the last irrigator?
145%	c	Increase in losses during droughts
73%	d	Effective change in losses during the critical period (Multiply above two factors: d=b*c)
-20%	e	Evapo-transpiration / transmission losses for irrigation releases d/s Xonxa (irrigation already factored by 125% to allow for losses)
0%	f	Additional releases to make up for spillage of accruals by irrigators d/s of Waterdown. Calculated by factoring the contribution of accruals to the demand.
0%	g	Additional releases to make up for spillage of accruals by irrigators d/s of Xonxa
100%	h	Percent of EWR demands supplied
0%	I	Percentage of Bushmanskrantz Irrigation demands supplied
125%	j	Factor converting irrigation release requirement during average year to release requirement for drought years (Oxkraal)
118%	k	Factor converting irrigation release requirement during average year to release requirement for drought years (Waterdown)
120%	l	Factor converting irrigation release requirement during average year to release requirement for drought years (Xonxa)
65%	m	Factor converting irrigation demand to a 1 in 50 year by applying restrictions
81%	n	Ratio of irrigation during dry year to irrigation during wet year considering increased requirement offset by curtailment for Oxkraal (n=j*m)
77%	o	Ratio of irrigation during dry year to irrigation during wet year considering increased requirement offset by curtailment for Waterdown/Oxkraal(o=k*m)
78%	p	Ratio of irrigation during dry year to irrigation during wet year considering increased requirement offset by curtailment for Xonxa (p=l*m)
75%	q	Factor converting median EWR releases to 1 in 50 year (considering the running average over three years)
100%	r	Extent of allocated irrigation d/s of Waterdown actually developed / established
145%	s	Increase in losses during droughts
75%	t	Reduction in accruals to irrigation d/s of Xonxa during the dry period
76%	u	Reduction in accruals to irrigation d/s of Waterdown during the dry period

Sub-system	1 in 50 yr LTCC			Demand description	Estimating a required release during an average period					Estimating a required release during a critical drawdown period				
	Simulated	Factor	Factored		Unfactored	Factor	Total requirement	Accruals	Average release	Factor	Dam supply	Irrigation* & losses	EWR	Urban**
Bonkolo	0.934	100%	0.934	Urban demand					0.9	100%	0.9			0.9
Oxkraal / Bushmans-krantz	6.95	100%	6.95	Bushmanskrantz irrigation	1.5	0%	0.0		0.0	100%	0.0	0.0		
				Bushmanskrantz urban	-				0.1	100%	0.1		0.1	
				Oxkraal R / Shiloh Irrigation	-				3.4	81%	2.8	2.8		
				Residual for Black Kei irrigation/EWR	-						4.1			
Waterdown	20.25	100%	20.25	Klipplaat irrigation releases*	-				6.8	77%	5.2	5.2		
				Black Kei releases from Waterdown	-				4.2	77%	3.3	3.3		
				Add extra releases to make up for inefficiency in uptake of accruals to irrigation downstream of Waterdown/Oxkraal by factoring contribution of accruals to irrigation.	7.9	0%			0	76%	0.0	0.0		
				Less contribution from Oxkraal	-						-4.1			
				Evapotranspiration losses	-				4.0	73%	2.9	2.9		
				Environmental releases	-				6.2	75%	4.7		4.7	
				Urban (Sada and possibly Queenstown)	-				8.4		8.4			8.4
Subtotal	28.1		28.1	Existing (2005) sub-system without Xonxa	-						28.1	14.1	4.7	9.3
Xonxa	22.97	100%	22.97	Irrigation releases*	-				5.0	78%	3.9	3.9		
				Transmission loss estimate based on a fraction of the release	5.0	-20%			-1	78%	-0.8	-0.8		
				Add extra releases to make up for inefficiency in uptake of accruals to irrigation downstream of Xonxa by factoring contribution of accruals to irrigation.	5.3	0%			0	75%	0.0	0.0		
				EWR releases	-				5.8	75%	4.4		4.4	
				Residual urban available (Queenstown, Illinge, Macibini)	-				15.5	100%	15.5			15.5
Xonxa subtotal	23.0		23.0	Xonxa sub-system total	-				25.3		23.0	3.1	4.4	15.5
System total	51.1		51.1						25.3		51.1	17.2	9.1	24.8
Surplus with regard to 2020	-			Providing adequate bulk-water supply capacity is available	-									11.3

* Irrigation releases include the shared and swopped contributions

** Urban requirements are 12.5 Mm^3/a (2005), 13.5 (2020) and 15.5 (2045)

LOWER ESTIMATE

Assuming full transmission losses in the Black Kei River and 50% inefficiency in the usage of accruals and 12% transmission losses downstream of Xonxa

ASSUMPTIONS		
8	a	Factor applied to reduce Xonxa's yield
100%	b	Percentage of evapotranspiration loss applied on Klipplaat/Oxkraal/Black Kei. Reduction obtained by reducing the distance from Waterdown to the last irrigator?
145%	c	Increase in losses during droughts
145%	d	Effective change in losses during the critical period (Multiply above two factors: d=b*c)
-10%	e	Evapo-transpiration / transmission losses for irrigation releases d/s Xonxa (irrigation already factored by 125% to allow for losses). The net losses modeled are 12.5% ie 125%*(100%-10%)
50%	f	Additional releases to make up for spillage of accruals by irrigators d/s of Waterdown. Calculated by factoring the contribution of accruals to the demand.
50%	g	Additional releases to make up for spillage of accruals by irrigators d/s of Xonxa
100%	h	Percent of EWR demands supplied
0%	I	Percentage of Bushmanskrantz Irrigation demands supplied
125%	j	Factor converting irrigation release requirement during average year to release requirement for drought years (Oxkraal)
118%	k	Factor converting irrigation release requirement during average year to release requirement for drought years (Waterdown)
120%	l	Factor converting irrigation release requirement during average year to release requirement for drought years (Xonxa)
65%	m	Factor converting irrigation demand to a 1 in 50 year by applying restrictions
81%	n	Ratio of irrigation during dry year to irrigation during wet year considering increased requirement offset by curtailment for Oxkraal (n=j*m)
77%	o	Ratio of irrigation during dry year to irrigation during wet year considering increased requirement offset by curtailment for Waterdown/Oxkraal (o=k*m)
78%	p	Ratio of irrigation during dry year to irrigation during wet year considering increased requirement offset by curtailment for Xonxa (p=l*m)
75%	q	Factor converting median EWR releases to 1 in 50 year (considering the running average over three years)
100%	r	Extent of allocated irrigation downstream of Waterdown actually developed/established
145%	s	Increase in losses during droughts
75%	t	Reduction in accruals to irrigation downstream of Xonxa during the dry period
76%	u	Reduction in accruals to irrigation downstream of Waterdown during the dry period

Sub-system	1 in 50 yr LTCC			Demand description	Estimating a required release during an average period					Estimating a required release during a critical drawdown period				
	Simulated	Factor	Factored		Unfactored	Factor	Total requirement	Accruals	Average release	Factor	Dam supply	Irrigation* & losses	EWR	Urban**
Bonkolo	0.934	100%	0.934	Urban demand					0.9	100%	0.9			0.9
Oxkraal/ Bushmanskrantz	6.95	100%	6.95	Bushmanskrantz irrigation	1.5	0%	0.0		0.0	100%	0.0	0.0		
				Bushmanskrantz urban					0.1	100%	0.1		0.1	
				Oxkraal R / Shiloh Irrigation					3.4	81%	2.8	2.8		
				Residual for Black Kei irrigation/EWR							4.1			
Waterdown	20.25	100%	20.25	Klipplaat irrigation releases*					6.8	77%	5.2	5.2		
				Black Kei releases from Waterdown					4.2	77%	3.3	3.3		
				Add extra releases to make up for inefficiency in uptake of accruals to irrigation downstream of Waterdown/ Oxkraal by factoring contribution of accruals to irrigation.	7.9	50%			3.95	76%	4.0	4.0		
				Less contribution from Oxkraal							-4.1			
				Evapotranspiration losses					4.0	145%	5.8	5.8		
				Environmental releases					6.2	75%	4.7		4.7	
				Urban (Sada and possibly Queenstown)					1.5		1.5			1.5
Sub-total	28.1		28.1	Existing (2005) sub-system without Xonxa							28.1	21.0	4.7	2.5
Xonxa	22.97	80%	18.376	Irrigation releases*					5.0	78%	3.9	3.9		
				Transmission loss estimate based on a fraction of the release	5.0	-10%			-0.5	78%	-0.4	-0.4		
				Add extra releases to make up for inefficiency in uptake of accruals to irrigation downstream of Xonxa by factoring contribution of accruals to irrigation.	5.3	50%			2.65	75%	2.0	2.0		
				EWR releases					5.8	75%	4.4		4.4	
				Residual urban available (Queenstown, Illinge, Macibini)					8.5	100%	8.5			8.5
Xonxa sub-total	23.0		18.4	Xonxa sub-system total					21.5		18.4	5.5	4.4	8.5
System total	51.1		46.5						21.5		46.5	26.5	9.1	11.0
Surplus with regard to 2020				Providing adequate bulk-water supply capacity is available										-2.5

ADDENDUM 4.8

Supply of Water Requirements
Downstream of the Major Dams

4.8.1 INTRODUCTION

This annexure summarises the modelled water requirements downstream of the major dams, including how much of these requirements can be supplied from accruals and how much need to be supplied from releases from the dams. The transmission losses were also modelled separately to determine the additional volume lost. This summary should enable the assumptions used in the model to be compared with experiences from operating the system.

With time this will help reduce the uncertainties in the current modelled analysis such as:

- **Ungauged streamflows downstream of the dams**. This affects the estimate of the how much of the demands can be supplied without any releases from the dams (i.e. from run-of-river flow referred to in this document as "accruals"). The streamflows used in this study are based on those of the Queenstown Regional Water Supply Feasibility Study (QRWSFS) which were simulated from rainfall because no gauged measurements were available
- **Transmission losses**. Uncertainty as to how much water is intercepted and lost through evapotranspiration from pools in the river channel.
- **Abstraction efficiency**. Uncertainty as to how much water is abstracted by irrigators from pools. In this case the pools would intercept and store some of the freshettes until the water is needed to irrigate the lands. In this analysis it was assumed that the irrigators would be able to abstract streamflows from pools. This increased the efficiency with which runoff from downstream of the major dams could be used. However, these same pools would also intercept ecological water releases (EWR) and increase the releases required to reach lower EWR sites.

The analysis was complicated because EWR releases are not consumed and are sometimes used by irrigators located downstream of the EWR site i.e. these releases are "shared". However, at other times these releases spill from the bottom of the system and are effectively "consumed" in that they are unavailable for other uses.

The analysis was based on the releases necessary from the major dams to meet the irrigation and EWR requirements, acting both individually and simultaneously. These releases were modelled to excluded spills from the dam that weren't for irrigation or EWR requirements. The increase in the releases required after switching off the streamflows downstream of the major dams gave an indication of the contribution from accruals. Table 4.8.2 details the scenarios used to determine the releases with accruals (Cases A1 to A6) and without accruals (cases A7 to A9).

In the Waterdown/Oxkraal system the results of these analyses were used to determine the components of the supply from accruals using the formulae in the third column of Table 4.8.3 and Table 4.8.11. Thereafter the calculation of selected components is discussed. Plots of the components are included in Section 4.8.8.

Sections 4.8.5 and 4.8.6 contain similar data for the Xonxa system.

Section 4.8.7 contains a simplified summary of the modelled releases required from Waterdown/Oxkraal and Xonxa during average conditions and during the critical period and the shorter acute period at the end of the critical period.

4.8.2 BACKGROUND INFORMATION ON STREAMFLOW GAUGING, TRANSMISSION LOSSES AND ABSTRACTION EFFICIENCY

Streamflow gauging

The availability of water for irrigation and ecological requirements from accruals downstream of the major dam is uncertain. This is primarily because the flows are ungauged and were estimated from simulations using monthly rainfall records and estimating the impacts of run-of-river abstractions, pools and evapo-transpiration losses

The gauge constructed on the Black Kei upstream of the confluence with the White Kei in around 2003 will help quantify :

- The run-of-river water available for irrigation
- The low flows required for ecological purposes,
- The periods when the river stops flowing
- Transmission losses

Transmission losses

The magnitude of the transmission losses is significant and could significantly increase the volumes that need to be released from the dams. The Upper Kei Basin Study (Volume 4 page 8.2.2.4 which is repeated in Annexure E of this report) mentions that a temporary arrangement was made to increase the releases from 6 100 m^3/ha/a to 9 150 m^3/ha/a to allow for river losses. This equates to an allowance for river losses of 5,81 Mm^3/a for the 1905 ha of irrigated land.

In the Queenstown Regional Water Supply Feasibility Study, which followed the Upper Kei Basin Study, the pools were modelled in the river channel to intercept releases. The surface area of the pools corresponded with the riparian area causing evapo-transpiration. The losses appear to increase lower down the river, with 50% of the losses occurring in the last 15 km upstream of the confluence with the White Kei (see Table 4.8.1).

TABLE 4.8.1 DISTRIBUTION OF LOSSES DOWNSTREAM OF WATERDOWN/ OXKRAAL DAMS

Waterdown/Oxkraal to Klaas Smits	22%
Klaas Smits to White Kei (Upper 15 km)	25%
Klaas Smits to White Kei (Lower 15 km)	53%

The exact nature of the pools and losses should be determined. Are the "pools" physical pools that can be used to intercept water or are they merely and indication of the volume of water stored in the river channel? Are the losses due to evapo-transpiration or due to abstraction from the river pools, which would be an unauthorised use rather than a loss?

In either case, it appears that the longer the distance that releases must travel to reach the bottommost consumer, the more difficult the system is to manage and the greater the losses that will be incurred. The irrigation demands in the lower reach of the Black Kei are only about 0,3 Mm^3/a, which is about a tenth of the water transmission losses incurred along that section. To minimise the problems of managing the releases extensions to the irrigated area should be planned as close as possible to the supply dams. Also, during times of restrictions, it might reduce losses if the lower irrigators did not plant and releases were preferentially made to the upper irrigators.

This does not necessarily mean that there should be no irrigation lower down in the catchment. During wet years these irrigators may benefit from accruals in the system. Reaches below the confluence of two rivers (such as the Klipplaat / Black Kei or the Klaas Smits/Black Kei) benefit from "cross-support" between the rivers. If one system is dry then the other system may still provide some water. The reach downstream of the Queenstown Waste Water Treatment Works may benefit from the fairly reliable return flows from the works.

However, during dry years supplying these irrigators from the dams could incur additional losses to the detriment of the system. If significant pools are located in the Black Kei upstream of the confluence with the White Kei and irrigators draw these pools down during droughts then it will be necessary to first fill these pools before the water can reach the environmental reserve site upstream of the confluence. A significant loss of up to 6 million m3 may be incurred to obtain a small flow at the lower EWR sites if the hypothetical pools must be filled before water reaches the EWR site.

Accruals and abstraction efficiency
The greater the contribution of the inflows downstream of the major dams (accruals) to the irrigation and ecological flow requirements, the less water needs to be released from the dams. The accuracy of this estimate is dependent on the accuracy of the streamflows. In addition, the volumes that can be abstracted by irrigators depend on the variability of the streamflow. If a streamflow is highly variable then during days having peak flows the streamflow will exceed the capacity of the abstraction pumps and result in spillage. On the other hand, during low flow periods the streamflow will be insufficient for the pumps. The less variable the streamflow, the greater the volume that can be abstracted for the same pumping capacity. If there are pools in the Black Kei then these pools can store some of the peak flows for abstraction later. The magnitude of these pools will have a significant impact on the accruals that can be used by irrigators. The following will help improve the estimate of the volumes available from accruals:

- Streamflows from the gauge on the Black Kei just upstream of the confluence with the White Kei
- Field verification of the pools in the Black Kei
- Feedback and possibly measurement of the abstractions by irrigators from accruals in the Black Kei

The present model WRYM configuration assumes that the irrigators can abstract all of the monthly river flow and does not make an allowance for the efficiency of the abstraction. This would be correct if the proposed abstraction sites are located at river pools that have sufficient capacity to store the freshets until they are needed for irrigation. However, if this is not the case then the water supplied from accruals will be over-estimated.

The WRYM is a monthly model and can overestimate the efficiency of abstraction from a naturally varying streamflow. Even though the average monthly flow is within the abstraction capacity of the irrigators small freshets can cause the daily flow to exceed the average flow so only a fraction of the monthly flow can be used. The greater the abstraction capacity, the greater the fraction of the average monthly flow that can be abstracted.

A multi-step approach may enable the system to be modelled on a monthly basis. The first step determines the spillage from the system when irrigation is supplied from accruals (and possibly the high flow/flood component of the ecological water requirement) using the diversion relationships. No releases or spills from the major dams will be included in this system spillage. This spillage sequence would change when the riparian irrigation changed.

The releases from the dams would be modelled in a second step. Because of the uniformity of the releases from the dams the diversion functions would no longer be applicable. They would need to be removed and replaced by a rule ensuring that the system spillage was at least equal to the spillage determined in step 1. The spillage would be significantly more at times because the spillage from the major dams would now be included.

TABLE 4.8.2 SCENARIOS ANALYSED

	Description	Scenario	Spills		Irrigation/EWR Releases (R), Spills (S) Urban Pipeline (P) Releases+Spills+Pipeline(RSP)				Accruals d/s of Waterdown, Bonkolo, Oxkraal and Xonxa	Demand Priority (P=passive – i.e. no pull from dams though "surplus" water that might otherwise spill would be used			Losses from evapotranspiration pools
			Major tributaries		Major dams								
			Upper Black Kei	Klaas Smits	Waterdown	Oxkraal	Xonxa	Bonkolo		Irrigation	Environment	Urban	
Releases from major dams (no spills) for downstream demands													
A1	Supplying irrigation + EWR	RETI	Y	Y	RP	R	RP	P	Y	2	1	N/A	N
A2	Supplying EWR	RET	Y	Y	RP	R	RP	P	Y	P	1	N/A	N
A3	Supplying irrigation	RIEZ	Y	Y	RP	R	RP	P	Y	1	P	N/A	N
A4	Supplying irrigation + EWR baseflows	RIEb	Y	Y	RP	R	RP	P	Y	2	1 (baseflow)	N/A	N
A5	Supplying irrigation + EWR excluding Site 3	RIEN3	Y	Y	RP	R	RP	P	Y	2	1 (not Site 3)	N/A	N
A6	Supplying irrigation + EWR + Losses	RETIL	Y	Y	RP	R	RP	P	Y	2	1	N/A	Y
Releases from major dams (no spills) for downstream demands assuming no inflows from tributaries or from inflows accruing downstream of the dams													
A7	Supplying irrigation + EWR	RETIX	N	N	RP	R	RP	P	N	2	1	N/A	N
A8	Supplying EWR	RETX	N	N	RP	R	RP	P	N	P	1	N/A	N
A9	Supplying irrigation	RIEZX	N	N	RP	R	RP	P	N	1	P	N/A	N
Auxilliary analyses													
Historical firm yields													
A10		Hiet	Y	Y	RSP	RS	RSP	SP	Y	1	1	2	N
A11	Artificial link allows Xonxa to support releases from Oxkraal	Liet	Y	Y	RSP	RS	RSP	SP	Y	1	1	2	N
Flooding the system with spare water to ensure that all irrigation and EWR requirements are supplied so that these demands can be determined													
A12		Fiet	Additional spills to ensure demands are in fact supplied							1	1	2?	N
Determining how much of the irrigation and EWR demands can be supplied from inflows accruing downstream of the major dams, including inflows from the Upper Black Kei R and the Klaas Smits tributary.													
A13	Preferentially supply Irrigation	AiEt	Y	Y	0	0	0	0	Y	1	2	N/A	N
A14	Preferentially supply environment	AEtI	Y	Y	0	0	0	0	Y	2	1	N/A	N

4.8.3 WATERDOWN COMPONENTS

TABLE 4.8.3 DETERMINING COMPONENTS SUPPLIED DOWNSTREAM OF WATERDOWN ND OXKRAAL FOR SELECTED MONTHS

Components		Formulae	Aug-42	Sep-42	Oct-42	Nov-42	Dec-42	Jan-43	Feb-43	Mar-43	Apr-43	May-43	Jun-43	Jul-43	Aug-43	Sep-43	Oct-43	Nov-43	Dec-43	Jan-44	Nov-50	Ave	Aug44-Jan50	Jun48-Jan50
Inputs	Releases if no accruals (RETIx)	A	1.02	1.91	3.13	5.03	5.48	4.79	4.43	2.43	3.54	2.51	2.03	1.67	1.77	2.08	2.64	5.23	6.35	4.71	4.76	34.0	29.6	22.4
	Irrigation requirement (RIEZx)	B	0.70	0.71	1.41	1.89	2.84	2.86	2.99	2.28	0.73	0.62	0.58	0.69	0.68	0.74	2.08	1.11	2.66	3.38	2.20	18.9	20.1	20.5
	Ecological requirement (RETx)	C	0.32	1.21	1.72	3.42	2.64	1.94	1.82	0.15	2.81	1.90	1.46	0.98	1.10	1.33	0.70	4.23	3.69	1.34	2.98	15.5	9.8	2.3
	Releases if accruals (RETI)	D	0.83	0.75	0.96	1.23	2.05	1.17	3.57	1.59	0.88	0.81	0.81	0.89	1.21	1.48	2.25	1.28	2.53	3.73	3.11	17.4	17.9	19.3
	Irrigation releases if accruals (RIEZ)	E	0.61	0.48	0.12	0.38	1.21	1.08	1.75	1.45	0.41	0.29	0.27	0.40	0.44	0.41	1.79	0.00	0.00	2.59	0.55	10.6	14.0	18.1
	Ecological release if accruals (RET)	F	0.23	0.42	0.90	1.16	1.79	0.98	1.37	0.11	0.58	0.52	0.53	0.45	0.53	0.73	0.70	1.28	2.53	0.93	1.33	7.9	4.8	1.4
Shared requirements	Approximate shared demand	G=(b+c)-a	0.00	0.00	0.00	0.28	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.11	0.00	0.00	0.41	0.4	0.2	0.5
	Irrigation unshared	h=b-g	0.70	0.71	1.41	1.61	2.84	2.86	2.61	2.28	0.73	0.62	0.58	0.69	0.68	0.75	1.94	1.01	2.66	3.37	1.78	18.5	19.8	20.0
	EWR unshared	i=c-g	0.32	1.21	1.72	3.14	2.65	1.93	1.44	0.15	2.81	1.90	1.46	0.98	1.10	1.33	0.56	4.12	3.69	1.34	2.57	15.1	9.6	1.8
Releases	Overall release minus individual releases	j=d-(e+f)	-0.01	-0.15	-0.05	-0.30	-0.95	-0.89	0.45	0.02	-0.12	0.00	0.00	0.05	0.24	0.34	-0.24	0.00	0.00	0.21	1.23	-1.2	-0.9	-0.3
	Shared release	k=max(-j,0)	0.01	0.15	0.05	0.30	0.95	0.89	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	1.8	1.6	0.6
	Release solely to irrigation	l=e-k	0.60	0.33	0.07	0.08	0.26	0.19	1.75	1.45	0.30	0.29	0.27	0.40	0.44	0.41	1.55	0.00	0.00	2.59	0.55	8.9	12.4	17.6
	Release solely to EWRs 1-3	m=f-k	0.22	0.27	0.85	0.86	0.84	0.09	1.37	0.11	0.46	0.52	0.53	0.45	0.53	0.73	0.46	1.28	2.53	0.93	1.33	6.2	3.2	0.8
	Swopped accruals	n=max(j,0)	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.02	0.00	0.00	0.00	0.05	0.24	0.34	0.00	0.00	0.00	0.21	1.23	0.6	0.6	0.3
Prelim Estimate of accruals	Overall contribution of accruals	o=a-d	0.18	1.16	2.16	3.80	3.43	3.62	0.86	0.84	2.66	1.71	1.23	0.78	0.56	0.60	0.39	3.95	3.81	0.99	1.65	16.6	11.7	3.1
	Accruals to irrigation alone	p=b-e	0.08	0.22	1.29	1.52	1.63	1.78	1.24	0.82	0.31	0.33	0.30	0.29	0.24	0.34	0.29	1.11	2.66	0.79	1.64	8.3	6.0	2.4
	Irrigation accrual spills when EWR also supplied	q=max(p-o,0)	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0
	Accruals to irrigation after deducting spills when EWR also supplied	r=p-q	0.08	0.22	1.29	1.52	1.63	1.78	0.86	0.82	0.31	0.33	0.30	0.29	0.24	0.34	0.29	1.11	2.66	0.79	1.64	8.2	6.0	2.4
	Accruals to EWR alone	s=c-f	0.09	0.79	0.82	2.26	0.85	0.95	0.44	0.04	2.23	1.38	0.93	0.54	0.56	0.60	0.00	2.95	1.16	0.41	1.65	7.6	5.0	0.9
Corrected overall supply from accruals	Swopped accruals	t=n	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.02	0.00	0.00	0.00	0.05	0.24	0.34	0.00	0.00	0.00	0.21	1.23	0.6	0.6	0.3
	Overall non-swoppable accruals	u=o-n	0.18	1.16	2.16	3.80	3.43	3.62	0.42	0.82	2.66	1.71	1.23	0.73	0.32	0.26	0.39	3.95	3.81	0.78	0.42	16.1	11.1	2.7
	Non-swoppable accruals to irrigation alone	v=b-(k+l+n)	0.08	0.22	1.29	1.52	1.63	1.78	0.79	0.80	0.31	0.33	0.30	0.24	0.00	0.00	0.29	1.11	2.66	0.58	0.41	7.7	5.4	2.1
	Non-swoppable accruals to EWR alone	w=c-(k+m+n)	0.09	0.79	0.82	2.26	0.85	0.95	0.00	0.02	2.23	1.38	0.93	0.49	0.32	0.26	0.00	2.95	1.16	0.20	0.42	7.0	4.3	0.6
	Irrigation accrual displaced by surplus u/s EWR when EWR supplied	x=max(v-u,0)	0.00	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0
	Non-swoppable accruals to irrigation when EWR also supplied	y=v-x	0.08	0.22	1.29	1.52	1.63	1.78	0.42	0.80	0.31	0.33	0.30	0.24	0.00	0.00	0.29	1.11	2.66	0.58	0.41	7.7	5.4	2.1
	Overall accrual less individual accruals	z=u-(w+y)	0.01	0.15	0.05	0.02	0.95	0.89	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.10	-0.11	0.00	0.00	-0.41	1.4	1.3	0.1
	Shared accrual	A=max(-z,0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.41	0.1	0.0	0.0
	Accrual solely to irrigation	B=y-A	0.08	0.22	1.29	1.52	1.63	1.78	0.42	0.80	0.31	0.33	0.30	0.24	0.00	0.00	0.29	1.01	2.66	0.58	0.00	7.6	5.4	2.1
	Accrual solely to EWR	C=w-A	0.09	0.79	0.82	2.26	0.85	0.95	0.00	0.02	2.23	1.38	0.93	0.49	0.32	0.26	0.00	2.84	1.16	0.20	0.01	6.9	4.3	0.6
	If accruals are not modelled (RIETZ case) the possible sharing of releases is under-estimated and the contribution from accruals is overestimated	D=max(z,0)	0.01	0.15	0.05	0.02	0.95	0.89	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	1.5	1.3	0.1
	Corrected overall supply from accruals	E=o-D	0.17	1.01	2.11	3.78	2.48	2.73	0.86	0.84	2.54	1.71	1.23	0.78	0.56	0.59	0.29	3.95	3.81	0.99	1.65	15.1	10.4	3.0
Releases and losses	Losses (extra releases required if all losses inc lowest loss dam are modelled)	F	0.52	0.09	0.01	0.01	0.02	0.01	0.16	0.13	0.01	0.01	0.01	0.56	0.48	0.50	0.63	0.00	0.00	0.88	0.14	4.2	4.9	7.4
	Releases if no accruals (RETIx) + Losses	G=a+F	1.53	2.00	3.13	5.04	5.50	4.80	4.59	2.56	3.55	2.52	2.04	2.23	2.26	2.58	3.27	5.23	6.35	5.59	4.90	38.2	34.5	29.8
	Irrigation requirement (RIEZx) + Losses	H=b+F	1.21	0.79	1.41	1.91	2.85	2.87	3.15	2.41	0.73	0.62	0.58	1.25	1.16	1.24	2.71	1.11	2.66	4.25	2.34	23.1	24.9	27.9
	Ecological requirement (RETx) + Losses	I=c+F	0.84	1.29	1.72	3.43	2.66	1.95	1.98	0.28	2.82	1.90	1.46	1.54	1.58	1.83	1.33	4.23	3.69	2.22	3.12	19.7	14.7	9.7
	Releases if accruals (RETI) + Losses	J=d+F	1.35	0.84	0.97	1.24	2.07	1.18	3.73	1.71	0.88	0.81	0.81	1.45	1.69	1.98	2.88	1.28	2.53	4.60	3.25	21.6	22.8	26.7
	Irrigation releases if accruals (RIEZ) + Losses	K=e+F	1.13	0.57	0.12	0.39	1.22	1.09	1.91	1.58	0.42	0.29	0.28	0.96	0.92	0.91	2.42	0.00	0.00	3.47	0.69	14.9	18.9	25.5
	Ecological release if accruals (RET) + Losses	L=f+F	0.75	0.51	0.90	1.17	1.81	0.99	1.54	0.24	0.59	0.53	0.54	1.01	1.02	1.23	1.33	1.28	2.53	1.81	1.47	12.2	9.7	8.8

TABLE 4.8.4 KEY

Source				
Total		Releases		Accruals
Demand				
irrigation solely	EWR solely	shared	swopped	Over-estimate

Table 4.8.5 is a graphical representation of the contribution of accruals that were calculated in Table 4.8.3 for August 43. If only irrigation is supplied and accruals make no contribution then 0.68 Mm^3 must be released from Waterdown and Xonxa (Riezx case – row b in Table 4.8.3). If accruals contribute a portion of the requirement then 0.44 Mm^3 is released (in the Riez case), and the remaining 0.24 Mm^3 must be supplied from accruals. Similarly, if only EWR are supplied then 1.1 Mm^3 must be released if there are no accruals, which reduces by 0.56 to 0.53 Mm^3 if accruals are modelled. If both irrigation and EWR are supplied then 1.77 Mm^3 must be released from the dams if there is no contribution from accruals, which reduces by 0.56 Mm^3 to 1.21 Mm^3 if accruals are modelled. What is interesting is that the releases required when both irrigation and EWR are supplied is greater than the releases for irrigation and EWR separately by about 0.24 Mm^3. When the irrigation and EWR are supplied separately then 0.24 Mm^3 of accruals either supplies irrigation or an EWR requirement further downstream. The accrual cannot however supply both requirements simultaneously, instead it swops between the two competing requirements.

The bottom line of Table 4.8.5 summarises the components supplied downstream of Waterdown/Oxkraal Dam.

Of the irrigation requirement of 0.68 Mm^3 :

- 0.44 Mm^3 is met from releases solely for irrigation,
- 0.24 Mm^3 is met either from either a swoppable accrual or the release to make good the portion of the swoppable accrual used for the EWR,
- 0 Mm^3 is met from accruals that can only supply irrigation.

Of the EWR requirement of 1.1 Mm^3 :

- 0.53 Mm^3 is met from releases solely for irrigation,
- 0.24 Mm^3 is met either from either a swoppable accrual or the release to make good the portion of the swoppable accrual used for the EWR,
- 0 32 Mm^3 is met from accruals that can only supply irrigation.

TABLE 4.8.5 NO SHARING OF RELEASES/ACCRUALS : AUGUST 43

Demand	Source										Scenarios	
	Combined	Releases				Accruals						
Irrigation	0.68(see b)	0.44(e)	.	.	.	.	0.24(r)	.	.	.	Riezx	riez
EWR	1.1(c)	.	.	.	0.53(f)	.	.	.	.	0.56(s)	Retx	ret
irrigation + EWR	1.77(a)	1.21(d)				0.56(o)					Retix	reti
Sub-components	.	0.44(l)	0.(k)	0.53(m)	0.24(n)	0.24(t)	0.(v)	0.(D)	0.(A)	0.32(C)	deduced	

In Table 4.8.6 the contribution from accruals is determined in the same way as in Table 4.8.5. However, there are two differences.

The first difference is that the releases to supply both irrigation and EWR requirements simultaneously are smaller (instead of larger) than the sum of the releases supplying each requirement individually. Approximately 0.3 million m^3 of the release from Waterdown Dam to meet the EWR just downstream of the dam is not required for the EWR further downstream, probably because accruals are sufficient to provide a portion of the downstream EWRs. As a result the 0.3 million m^3 can be used by irrigators downstream and can be shared rather than being swopped.

The second difference is that the estimated contribution of the accruals to the combined EWR / irrigation requirement (3.8 million m^3) exceeds the accrual required if one adds together the requirements of irrigation and EWR (3.78 = 1.52 + 2.26). The additional 3.8 million m^3 of releases required when the accruals are omitted (RETIX – RETI cases) underestimates the benefit of sharing possible between irrigation and EWR releases and hence overestimates the contribution required from accruals.

The benefit of sharing between irrigation and EWR releases increases when accruals are modelled. Accruals sometimes supply the water requirements of the downstream EWRs but can't supply the upper EWR downstream of Waterdown Dam because all the potential accruals are intercepted by the dam itself. This means that releases to supply the upper EWR can actually be used for irrigation along the Klipplaat River and Black Kei Rivers and need not be supplied to EWR sites further downstream on the Black Kei River.

TABLE 4.8.6 SHARED RELEASE NOVEMBER 1942

Demand	Source										Scenarios	
	Combined	Releases				Accruals						
Irrigation	1.89(see b)	0.38(e)	.	.	.	.	1.52(r)	.	.	.	riezx	riez
EWR	3.42(c)	.	.	.	1.16(f)	.	.	.	.	2.26(s)	retx	ret
irrigation + EWR	5.03(a)	1.23(d)				3.8(o)->3.78(E)					retix	reti
Sub-components	.	0.08(l)	0.3(k)	0.86(m)	0.(n)	0.(t)	1.52(v)	0.02(D)->0	0.(A)	2.26(C)	deduced	

Table 4.8.7 illustrates a situation where both swoppable and shared accruals occur simultaneously.

As in the case described in Table 4.8.5, the releases when supplying both irrigation and EWR exceed the sum of the releases when supplying irrigation and EWR by themselves. This occurs because accruals are swopped between irrigation and EWR when they are supplied by themselves. This swopping is not possible when they are both supplied and an additional 1.23 Mm^3 must be released.

When examining the accruals the contribution of accruals to both EWR and irrigation supplied alone and both supplied simultaneously is about 1.64 Mm^3. The additional 0.41 Mm^3 is shared between the EWR and irrigation. This means that the 1.64 Mm^3 contribution of accruals to irrigation comprises 1.23 swopped plus 0.41 shared. This means that the 1.65 Mm^3 contribution of accruals to irrigation comprises 1.23 swopped plus 0.41 shared plus 0.1 exclusively to EWR. When both irrigation and EWR are supplied simultaneously then this comprises 1.23 (swopped accruals) plus 0.41 (shared accruals) plus 0.1 (exclusively to EWR)

TABLE 4.8.7 SHARED AND SWOPPED ACCRUALS : NOVEMBER 1950

Demand	Source										Scenarios	
	Combined	Releases				Accruals						
Irrigation	2.2(see b)	0.55(e)	.	.	.	.	1.64(r)	.	.	.	riezx	riez
EWR	2.98(c)	.	.	.	1.33(f)	.	.	.	.	1.65(s)	retx	ret
irrigation + EWR	4.76(a)	3.11(d)				1.65(o)					retix	reti
Sub-components	.	0.55(l)	0.(k)	1.33(m)	1.23(n)	1.23(t)	0.(v)	0.(D)	0.41(A)	0.01(C)	deduced	

The following tables summarise the components supplied for the long-term period (October 1920 – Sep 1994), the Waterdown/Xonxa system's critical period (August 1944 to Jan 1950) and an extremely dry period at the end of that period (Sep 1947 to Jan 1950).

TABLE 4.8.8 AVERAGE FOR OCTOBER 1920 TO SEPTEMBER 1994

Demand	Source										Scenarios	
	Combined	Releases				Accruals						
Irrigation	18.92(see b)	10.64(e)	.	.	.	.	8.28(h)-> 8.24(r)	.	.	.	riezx	riez
EWR	15.52(c)	.	.	.	7.94(f)	.	.	.	.	7.58(s)	retx	ret
irrigation + EWR	34.02(a)	17.38(d)				16.64(o)->15.13(E)					retix	reti
Sub-components	.	8.86(l)	1.77(k)	6.17(m)	0.57(n)	0.57(t)	7.55(v)	1.51(D)->0	0.12(A)	6.89(C)	deduced	

TABLE 4.8.9 AVERAGE FOR AUGUST 1944 TO JANUARY 1950

Demand	Source										Scenarios	
	Combined	Releases				Accruals						
Irrigation	20.07(see b)	14.02(e)	.	.	.	.	6.05(h)-> 6.05(r)	.	.	.	riezx	riez
EWR	9.8(c)	.	.	.	4.81(f)	.	.	.	.	4.99(s)	retx	ret
irrigation + EWR	29.62(a)	17.9(d)				11.72(o)->10.39(E)					retix	reti
Sub-components	.	12.44(l)	1.58(k)	3.23(m)	0.65(n)	0.65(t)	5.4(v)	1.33(D)->0	0.(A)	4.34(C)	deduced	

TABLE 4.8.10 AVERAGE FOR JUNE 1948 - JANUARY 1950

Demand	Source										Scenarios	
	Combined	Releases				Accruals						
Irrigation	20.52(see b)	18.14(e)	.	.	.	.	2.38(h)-> 2.38(r)	.	.	.	riezx	riez
EWR	2.32(c)	.	.	.	1.41(f)	.	.	.	.	0.91(s)	retx	ret
irrigation + EWR	22.36(a)	19.29(d)				3.07(o)->2.96(E)					retix	reti
Sub-components	.	17.56(l)	0.58(k)	0.83(m)	0.32(n)	0.32(t)	2.05(v)	0.11(D)->0	0.(A)	0.58(C)	deduced	

4.8.4 WATERDOWN PLOTS

Figures 4.8.1, 4.8.2 and 4.8.3 show the monthly water requirements, contribution from accruals and the releases for the period 1940 to 1950, which includes the system's critical drawdown period. Figures 4.8.4 and 4.8.5 show the irrigation and EWR releases from Waterdown/Oxkraal with and without an allowance for losses. The series in the above plots have been stacked on top of each other, so that the thickness of the colour band represents the magnitude of the component - not its height on the y axis. Figures 4.8.6 and 4.8.7 present the supply to irrigation and EWR from accruals (Figure 4.8.6) and from releases (Figure 4.8.7). The supply associated with the highest annual natural flow for the period May to April has been plotted on the left axis and for the lowest annual natural flow (i.e. the drought periods) against the right axis. Figures 4.8.8 and 4.8.9 show the damping effect of averaging the irrigation and environmental requirements over three instead of over one year.

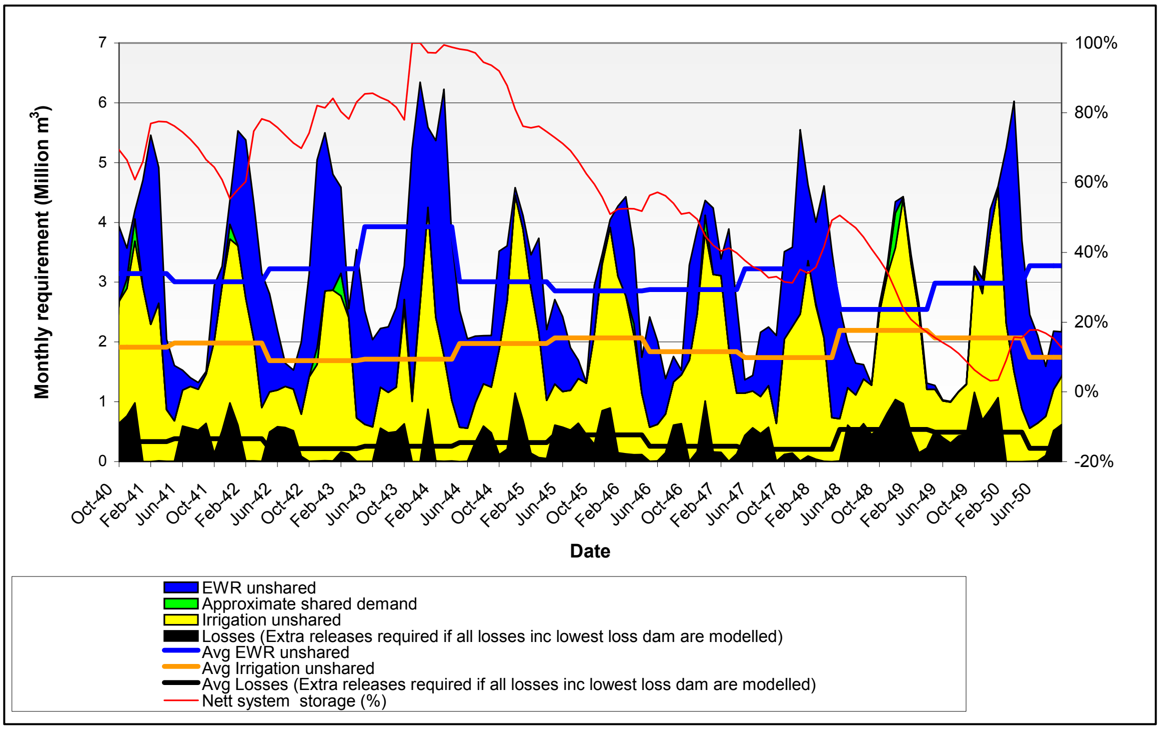

Figure 4.8.1 Water requirements downstream of Waterdown and Oxkraal (stacked)

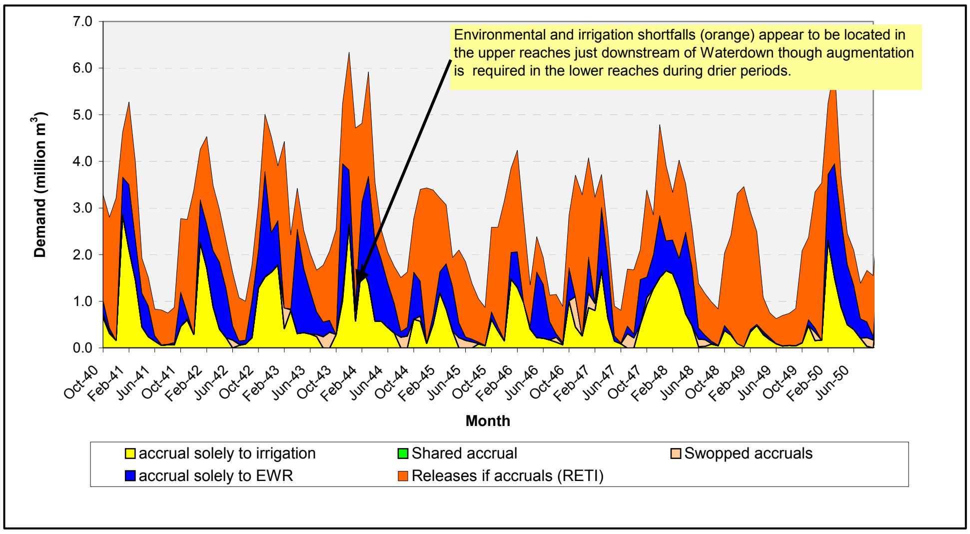

Figure 4.8.2 Contribution of accruals to the water requirements downstream of Waterdown and Oxkraal (stacked)

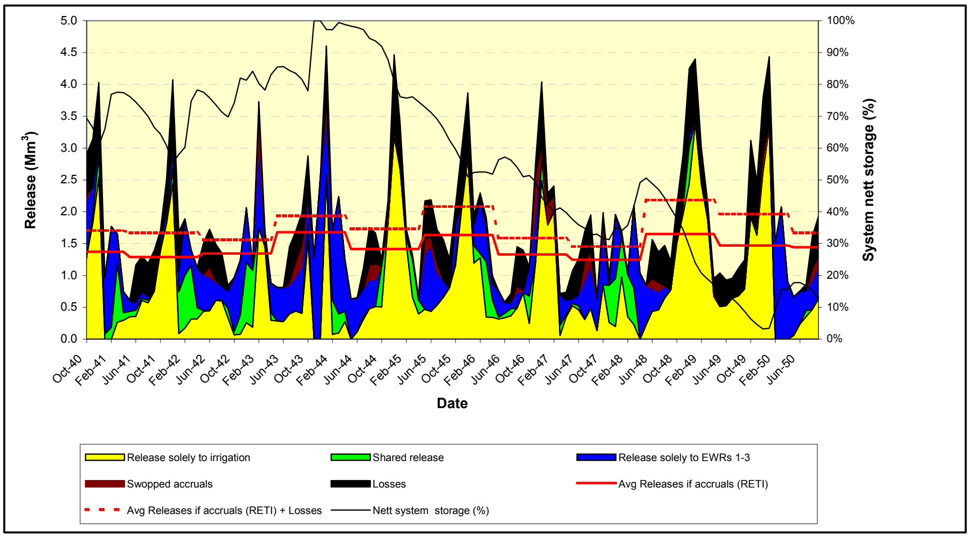

Figure 4.8.3 Releases from Waterdown and Oxkraal (stacked)

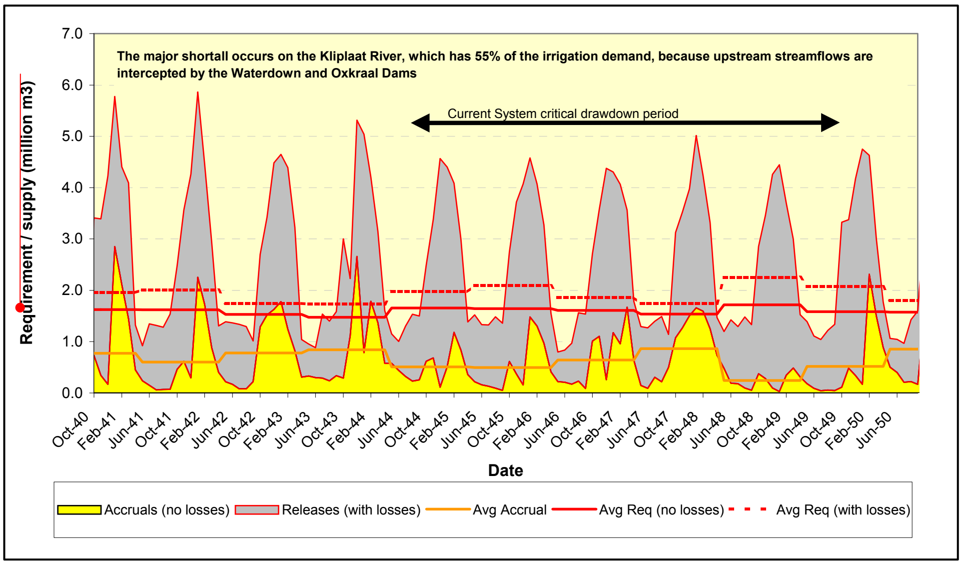

Figure 4.8.4 Irrigation releases required from Waterdown and Oxkraal in addition to the accruals (stacked)

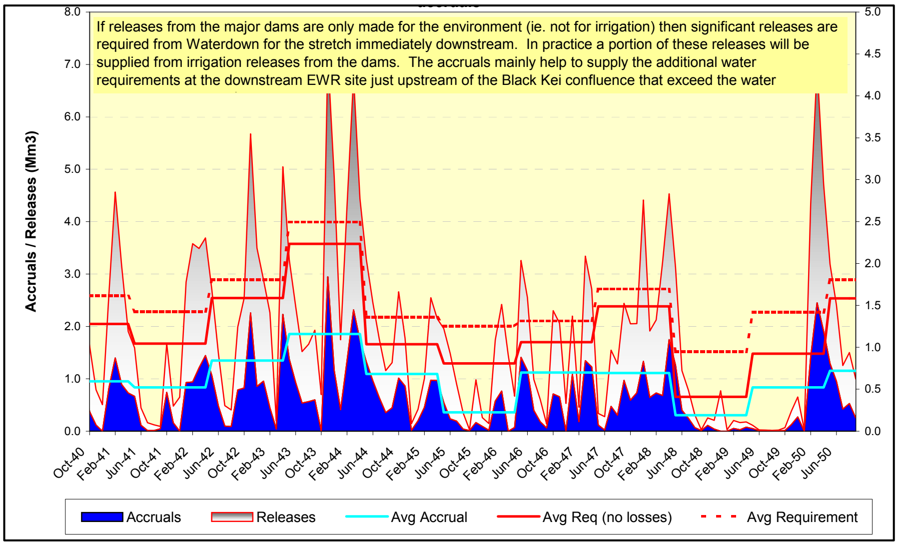

Figure 4.8.5 Environmental requirements required from Waterdown and Oxkraal in addition to the accruals (stacked)

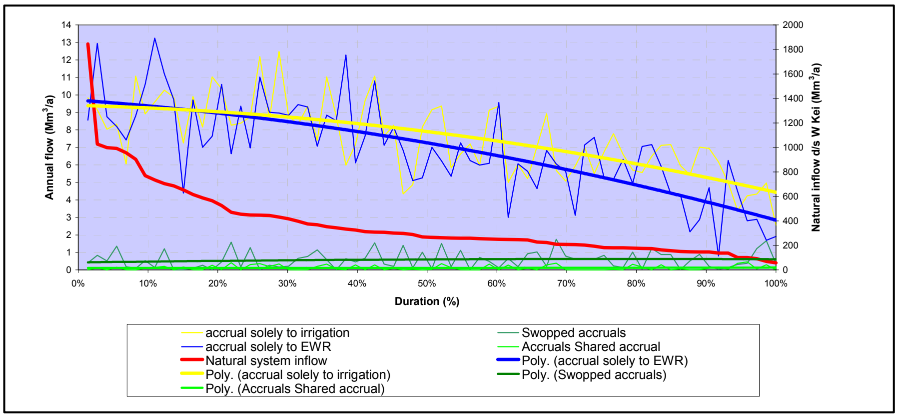

Figure 4.8.6 Probability of supply to irrigation and EWR from accruals downstream of Waterdown and Oxkraal Dams (not stacked)

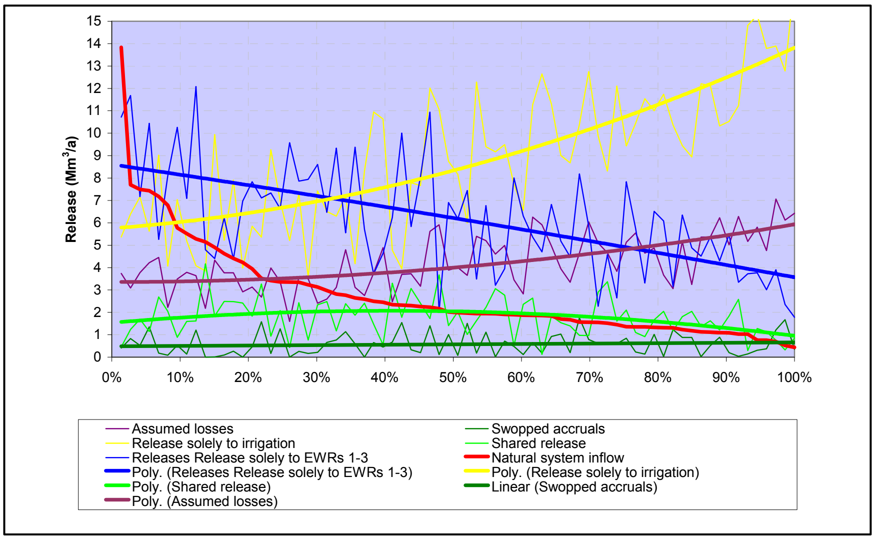

Figure 4.8.7 Probability of annual releases to irrigation and EWR from Waterdown and Oxkraal Dams (not stacked)

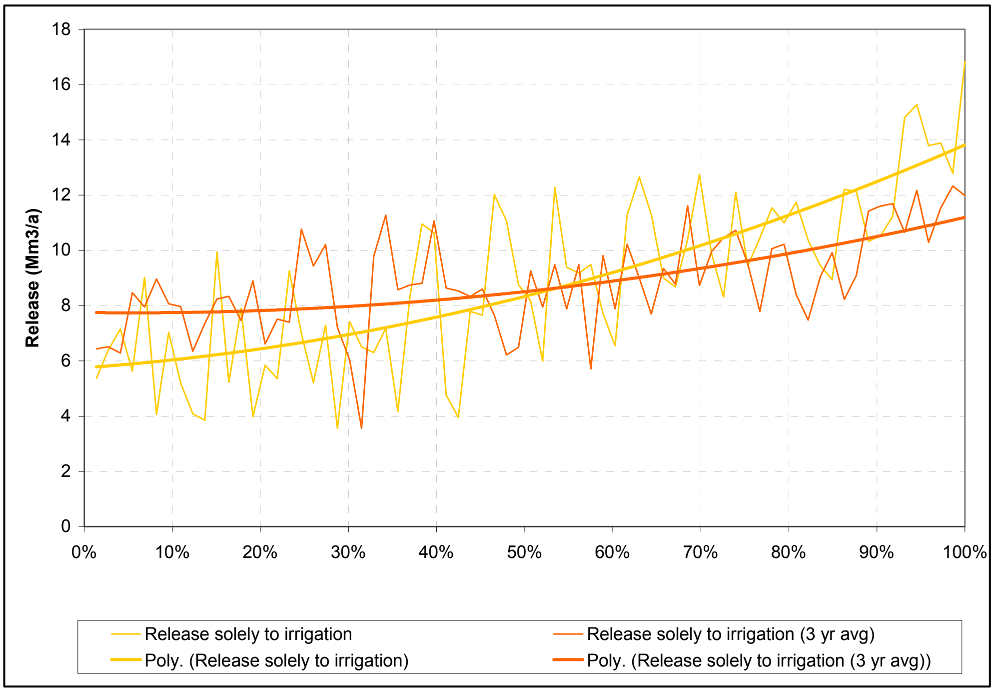

Figure 4.8.8 Probability of releases to irrigation from Waterdown and Oxkraal Dams averaged over one and three years (not stacked)

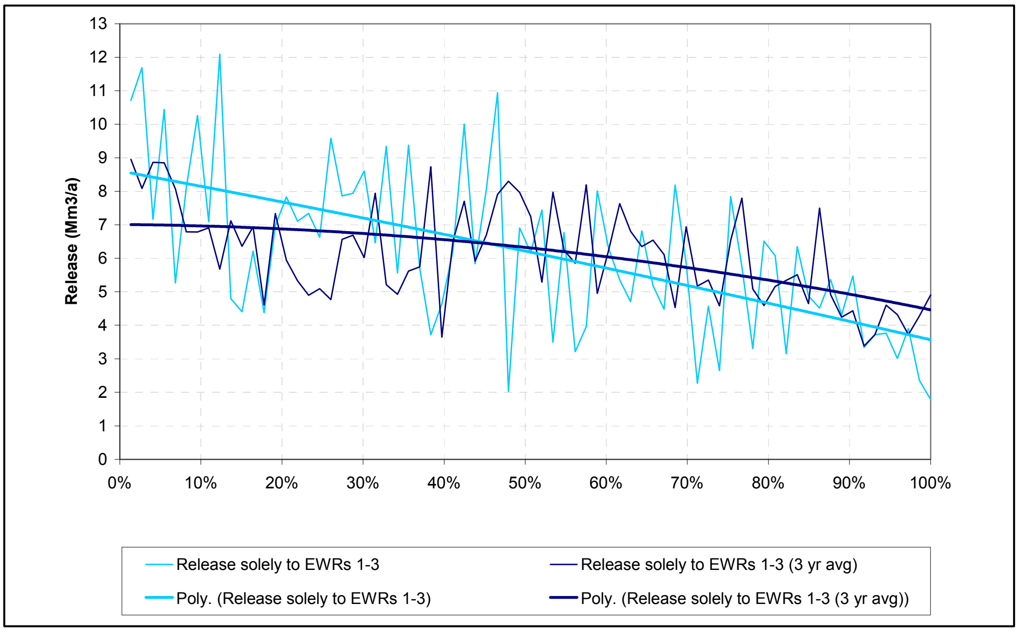

Figure 4.8.9 Probability of EWR releases from Waterdown and Oxkraal Dams averaged over one and three years (not stacked)

TABLE 4.8.11 DETERMINING COMPONENTS SUPPLIED DOWNSTREAM OF XONXA FOR SELECTED MONTHS

	Component	.Formula	Aug-42	Sep-42	Oct-42	Nov-42	Dec-42	Jan-43	Feb-43	Mar-43	Apr-43	May-43	Jun-43	Jul-43	Aug-43	Sep-43	Nov-50	Average	Aug44-Jan50	Jun48-Jan50
Inputs	Releases if no accruals (RETIx)	a	1.19	1.95	2.10	5.61	7.58	2.83	1.95	4.59	5.17	1.51	1.56	1.40	1.50	2.08	0.80	30.2	25.9	15.6
	Irrigation requirement (RIEZx)	b	0.67	1.17	0.70	0.30	0.69	1.31	1.69	0.77	0.31	0.46	0.60	0.55	0.64	1.33	0.60	10.4	10.8	11.2
	Ecological requirement (RETx)	c	0.52	0.78	1.40	5.31	6.89	1.52	0.26	3.82	4.86	1.04	0.96	0.85	0.86	0.75	0.20	19.8	15.1	4.4
	Releases if accruals (RETI)	d	0.46	0.69	0.45	1.71	2.22	0.49	1.53	1.23	1.57	0.34	0.31	0.27	0.28	0.81	0.47	11.0	10.1	10.1
	Irrigation releases if accruals (RIEZ)	e	0.29	0.54	0.00	0.00	0.00	0.00	1.53	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.47	4.9	5.6	8.8
	Ecological release if accruals (RET)	f	0.17	0.25	0.45	1.71	2.22	0.49	0.08	1.23	1.57	0.34	0.31	0.27	0.28	0.24	0.06	6.4	4.9	1.5
Shared requirements	Approximate shared demand	g=(b+c)-a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0
	Irrigation unshared	h=b-g	0.67	1.17	0.70	0.30	0.69	1.31	1.69	0.77	0.31	0.46	0.60	0.55	0.64	1.33	0.60	10.4	10.8	11.2
	EWR unshared	i=c-g	0.52	0.78	1.40	5.31	6.89	1.52	0.26	3.82	4.86	1.04	0.96	0.85	0.86	0.75	0.20	19.8	15.1	4.4
Releases	Overall release minus individual releases	j=d-(e+f)	0.00	-0.10	0.00	0.00	0.00	0.00	-0.08	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	-0.06	-0.3	-0.5	-0.2
	Shared release	k=max(-j,0)	0.00	0.10	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.5	0.6	0.4
	Release solely to irrigation	l=e-k	0.29	0.44	0.00	0.00	0.00	0.00	1.44	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.41	4.4	5.1	8.3
	Release solely to EWR	m=f-k	0.17	0.15	0.45	1.71	2.22	0.49	0.00	1.23	1.57	0.34	0.31	0.27	0.28	0.24	0.00	5.9	4.3	1.1
	Swopped accruals	n=max(j,0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.2	0.1	0.2
Prelim Est of supply from accruals	Overall contribution of accruals	o=a-d	0.73	1.25	1.65	3.90	5.36	2.34	0.42	3.36	3.60	1.17	1.25	1.12	1.22	1.28	0.33	19.2	15.8	5.5
	Accruals to irrigation alone	p=b-e	0.38	0.62	0.70	0.30	0.69	1.31	0.16	0.77	0.31	0.46	0.60	0.55	0.64	0.76	0.13	5.5	5.2	2.4
	Irrigation accrual spills when EWR also supplied	q=max(p-o,0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0
	Accruals to irrigation after deducting spills when EWR also supplied	r=p-q	0.38	0.62	0.70	0.30	0.69	1.31	0.16	0.77	0.31	0.46	0.60	0.55	0.64	0.76	0.13	5.5	5.2	2.4
	Accruals to EWR alone	s=c-f	0.35	0.53	0.95	3.60	4.67	1.03	0.18	2.59	3.29	0.71	0.65	0.57	0.58	0.51	0.14	13.4	10.2	2.8
Detailed estimate of supply from accruals	Swopped accruals	t=n	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.2	0.1	0.2
	Overall non-swoppable accruals	u=o-n	0.73	1.25	1.65	3.90	5.36	2.34	0.42	3.36	3.60	1.17	1.25	1.12	1.22	1.28	0.33	19.1	15.7	5.3
	Non-swoppable accruals to irrigation alone	v=b-(k+l+n)	0.38	0.62	0.70	0.30	0.69	1.31	0.16	0.77	0.31	0.46	0.60	0.55	0.64	0.76	0.13	5.3	5.0	2.2
	Non-swoppable accruals to EWR alone	w=c-(k+m+n)	0.35	0.53	0.95	3.60	4.67	1.03	0.18	2.59	3.29	0.71	0.65	0.57	0.58	0.51	0.14	13.2	10.1	2.6
	Irrigation accrual displaced by surplus upstream EWR when EWR supplied	x=max(v-u,0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0
	Non-swoppable accruals to irrigation when EWR also supplied	y=v-x	0.38	0.62	0.70	0.30	0.69	1.31	0.16	0.77	0.31	0.46	0.60	0.55	0.64	0.76	0.13	5.3	5.0	2.2
	Overall accrual less individual accruals	z=u-(w+y)	0.00	0.10	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.5	0.6	0.4
	Shared accrual	A=max(-z,0)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.0	0.0
	Accrual solely to irrigation	B=y-A	0.38	0.62	0.70	0.30	0.69	1.31	0.16	0.77	0.31	0.46	0.60	0.55	0.64	0.76	0.13	5.3	5.0	2.2
	Accrual solely to EWR	C=w-A	0.35	0.53	0.95	3.60	4.67	1.03	0.18	2.59	3.29	0.71	0.65	0.57	0.58	0.51	0.14	13.2	10.1	2.6
	If accruals are not modelled (RETIX case) the possible sharing of releases is under-estimated and the contribution from accruals is over-estimated	D=max (z,0)	0.00	0.10	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.5	0.6	0.4
	Corrected overall supply from accruals	E=o-D	0.73	1.15	1.65	3.90	5.36	2.34	0.34	3.36	3.60	1.17	1.25	1.12	1.22	1.27	0.26	18.7	15.3	5.1

Table 4.8.12 Average for October 1920 to September 1994

Demand	Source										Scenarios	
	Combined	Releases				Accruals						
Irrigation	10.39(see b)	4.9(e)	.	.	.	.	5.5(j,h)	.	.	.	riezx	riez
EWR	19.83(c)	.	.	.	6.42(f)	.	.	.	.	13.42(k)	retx	ret
Irrigation + EWR	30.23(a)	10.99(d)				19.24(g)->18.74(B)					retix	reti
Demand components	.	4.4(n)	0.5(m)	5.92(o)	0.18(p)	0.18(q)	5.32(y)	0.5(A)->0	0.(x)	13.24(z)	deduced	

Table 4.8.13 Average for June 1948 to January 1950

Demand	Source										Scenarios	
	Combined	Releases				Accruals						
Irrigation	11.22(see b)	8.79(e)	.	.	.	.	2.43(j,h)	.	.	.	riezx	riez
EWR	4.37(c)	.	.	.	1.52(f)	.	.	.	.	2.84(k)	retx	ret
Irrigation + EWR	15.58(a)	10.08(d)				5.50(g)->5.05(B)					retix	reti
Demand components		8.34(n)	0.45(m)	1.07(o)	0.22(p)	0.22(q)	2.21(y)	0.45(A)->0	0.(x)	2.62(z)	deduced	

Table 4.8.14 Average for August 1944 to January 1950

Demand	Source										Scenarios	
	Combined	Releases				Accruals						
Irrigation	10.8(see b)	5.64(e)	.	.	.	.	5.16(j,h)	.	.	.	riezx	riez
EWR	15.13(c)	.	.	.	4.92(f)	.	.	.	.	10.22 (k)	retx	ret
irrigation + EWR	25.93(a)	10.09(d)				15.85(g)->15.26(B)					retix	reti
demand components		5.05(n)	0.59(m)	4.33(o)	0.12(p)	0.12(q)	5.04(y)	0.59(A)->0	0.(x)	10.1(z)	deduced	

4.8.6 XONXA PLOTS

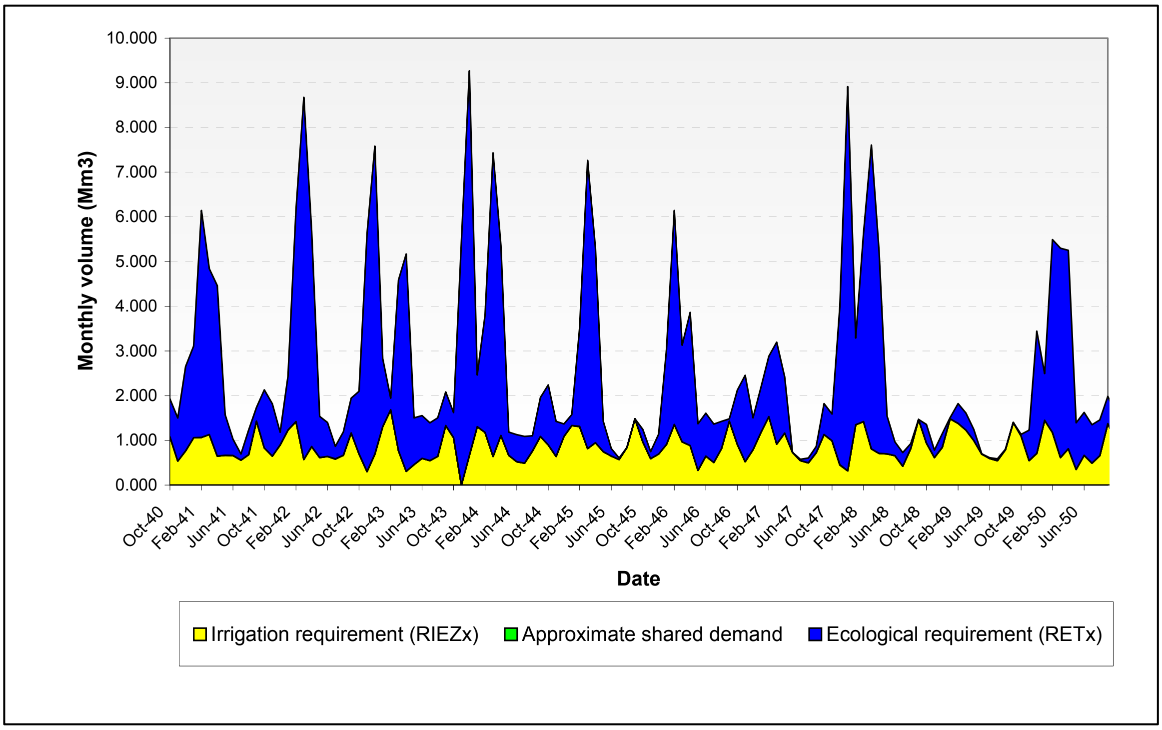

Figure 4.8.10 Water requirements downstream of Xonxa

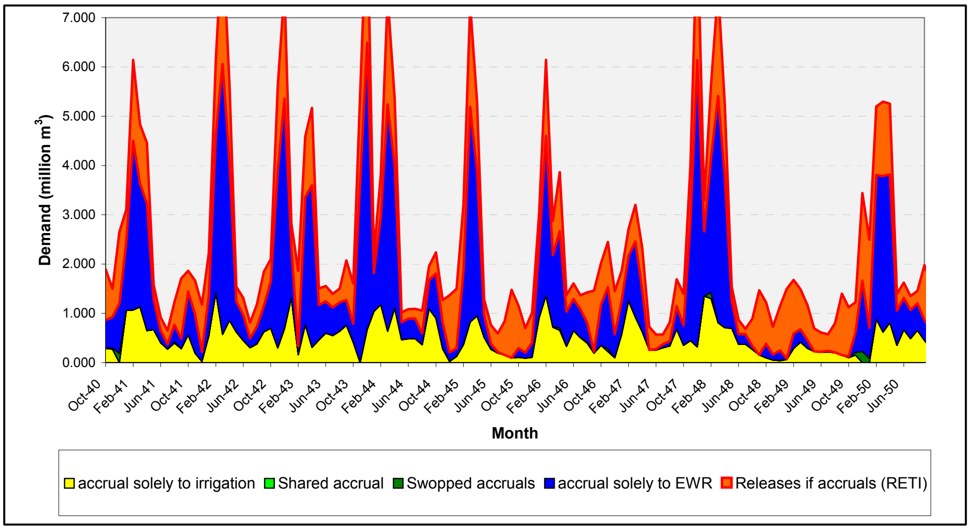

Figure 4.8.11 Contribution of accruals to the total water requirements downstream of Xonxa

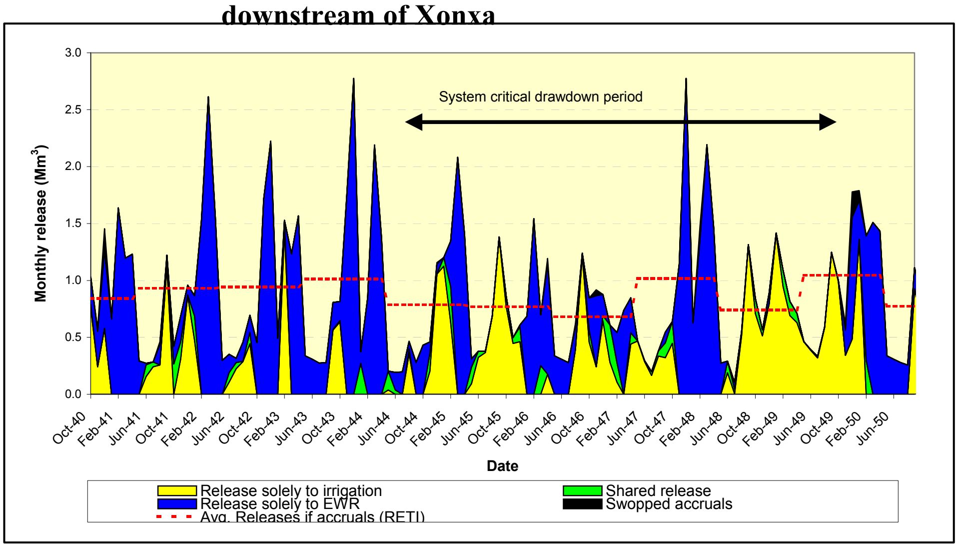

Figure 4.8.12 Releases from Xonxa (demands increased by 25% to include losses)

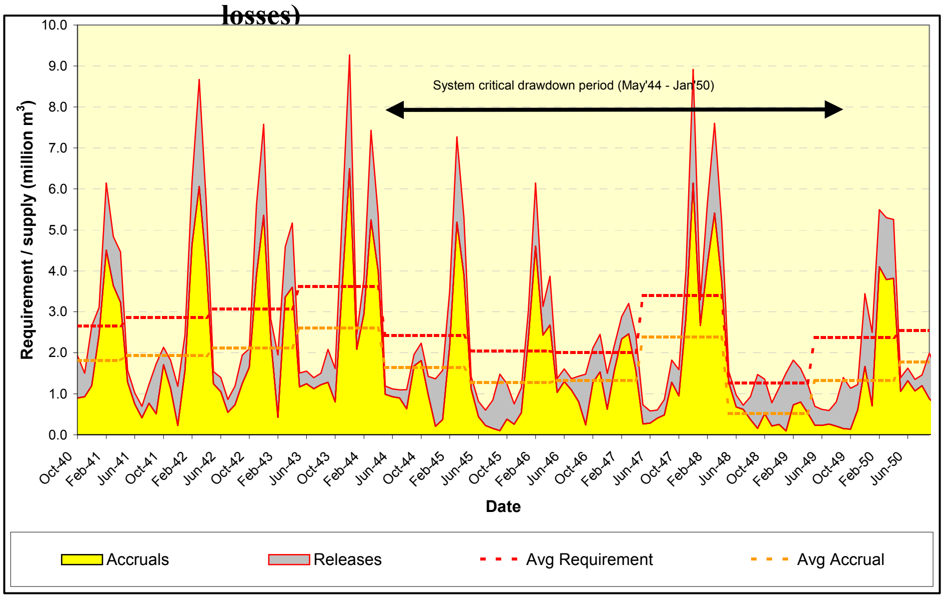

Figure 4.8.13 Irrigation releases required from Xonxa

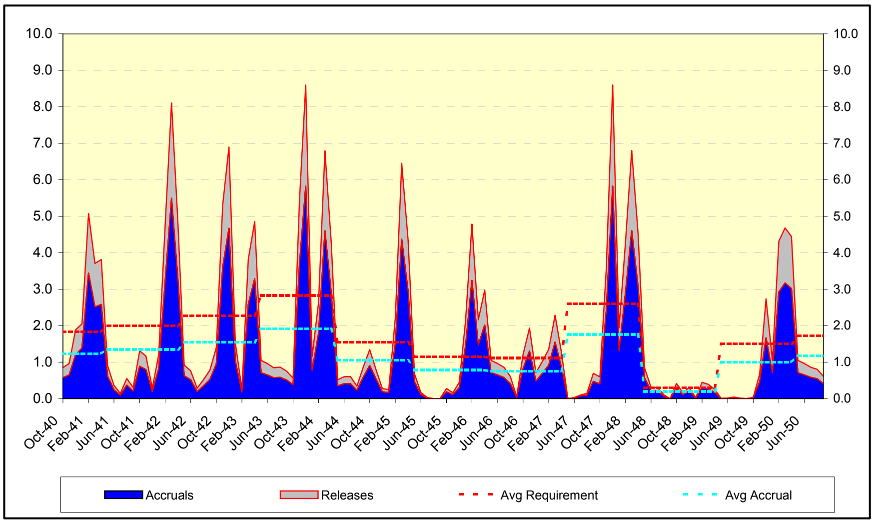

Figure 4.8.14 Environmental requirements required from Xonxa

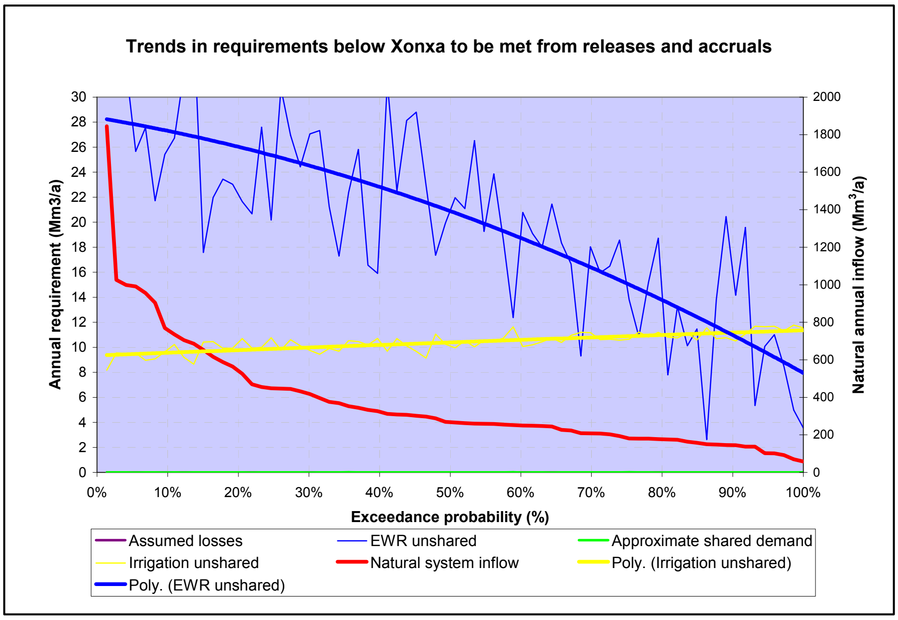

Figure 4.8.15 Probability of supply to irrigation and EWR from accruals downstream of Xonxa Dam

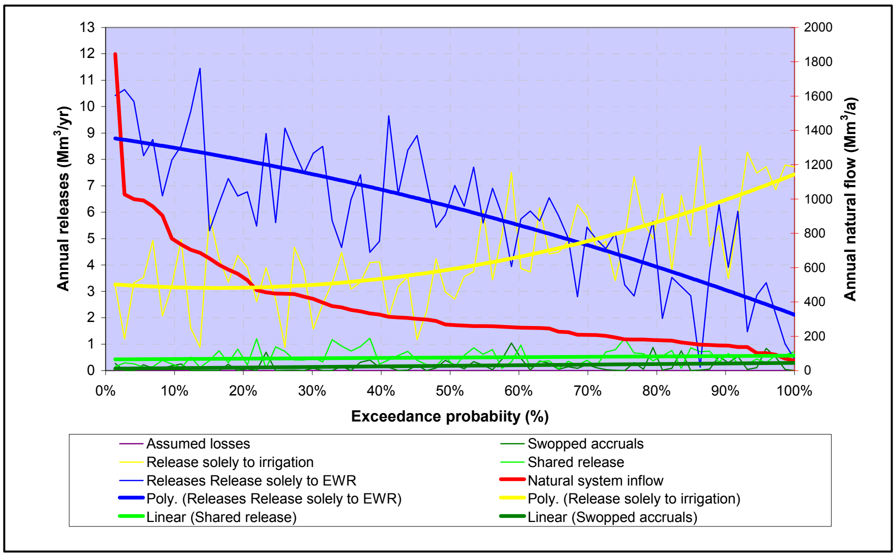

Figure 4.8.16 Probability of annual releases to irrigation and EWR from Xonxa Dam

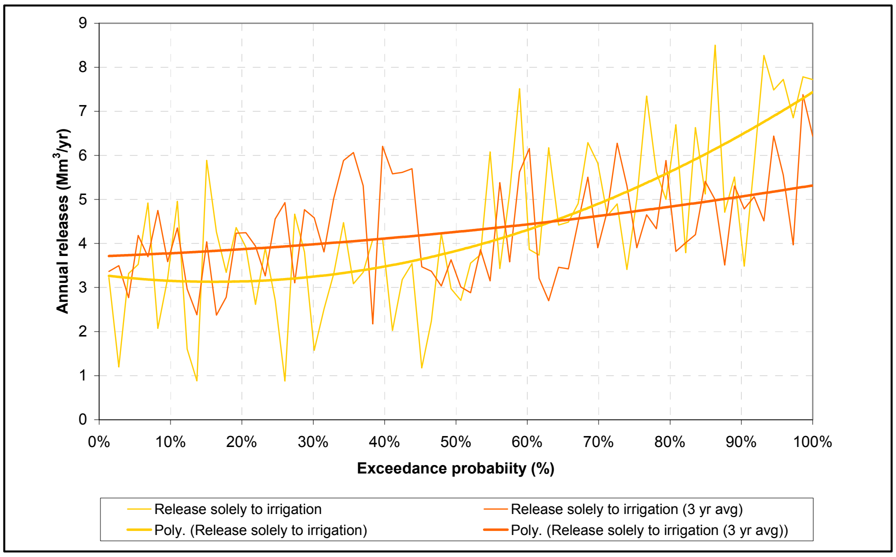

Figure 4.8.17 Probability of releases to irrigation from Xonxa Dam – averaged over one and three years

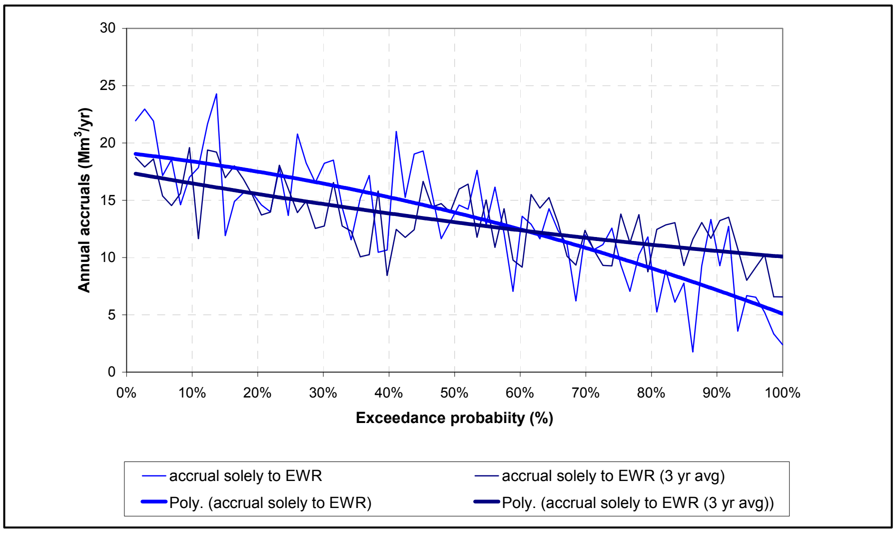

Figure 4.8.18 Probability of EWR releases from Xonxa Dam – averaged over one and three years

4.8.7 SIMPLIFIED SUMMARY OF WATER SUPPLY DOWNSTREAM OF THE WATERDOWN/OXKRAAL DAMS AND THE XONXA DAM

The accruals (e.g. column c) and releases (e.g. column d) contributing to the requirements (e.g. column b) downstream of the Waterdown/Oxkraal and Xonxa Dams for different periods (from Tables 4.8.8 to 4.8.10 and Tables 4.8.12 to Table 4.8.14) have been summarised in Table 4.8.15. Losses have been coloured in orange, the irrigation requirements and the accruals and releases contributing to these requirements have been shaded yellow. EWR components have been coloured blue. Where an accrual is swopped and can only supply either irrigation or EWR it was assumed that the accrual supplied the EWR (e.g cell Dc) and an extra release of the same magnitude was required for irrigation (e.g. cell Dd).

During the system's critical drawdown period the modelled irrigation releases from Waterdown/Oxkraal averaged 19,4 Mm^3/a while the additional releases required for the EWR were 3,2 Mm^3/a giving a total of 22,64 Mm^3/a. During the same period the modelled irrigation releases from Xonxa averaged 9,0 Mm^3/a while the additional releases required for the EWR were 1,1 Mm^3/a, giving a total of 10,1 Mm^3/a.

TABLE 4.8.15 MODELLED REQUIREMENTS DOWNSTREAM OF WATERDOWN/ OXKRAAL DAMS AND XONXA DAMS, DIFFERENTIATING BETWEEN THE SUPPLY FROM RELEASES AND FROM TRIBUTARIES ACCRUALS DOWNSTREAM OF THE DAMS

Component	Average				System's critical drawdown period Aug'44-Jan50				Last 18 months of the system's critical period Jun'48-Jan '50			
	Requirement	Accruals	Release	Release incl. losses with irrig	Requirement	Accruals	Release	Release incl. losses with irrig	Requirement	Accruals	Release	Release incl. losses with irrig
a	b	c	d	e	f	g	h	i	j	k	l	m
Waterdown plus Oxkraal Dams												
A. Losses	4.2		4.2	15.4	4.8		4.8	19.4	7.4		7.4	25.8
B. Irrigation	18.9	7.6	8.8		20.0	5.4	12.4		20.5	2.1	17.5	
C. Shared (to irrigation)	.	0.1	1.8		.	0.0	1.6		.	0.0	0.6	
D. Swopped (assume the accrual supplies EWR so that the release must be made for irrigation)	.	0.6	0.6		.	0.6	0.6		.	0.3	0.3	
E. Shared (to EWR - double counting above shared)	.	0.1	1.8	*	.	0.0	1.6	*	.	0.0	0.6	*
F. EWR	15.5	6.9	6.1	6.1	9.8	4.3	3.2	3.2	2.3	0.6	0.8	0.8
G. Sub-total	38.6	15.3	23.3	.	34.6	10.3	24.2	.	30.2	3.0	27.2	.
H. Less shared (double counted above)	0.0	-0.1	-1.8	.	0.0	0.0	-1.6	.	0.0	0.0	-0.6	.
I. Contributed volume	38.6	15.2	21.5	21.5	34.6	10.3	22.6	22.6	30.2	3.0	26.6	26.6
Xonxa Dam												
J. Losses	.	.	0.0	5.0	.	.	0.0	9.0	.	.	0.0	5.8
K. Irrigation (increased by 25% for losses)	10.4	5.3	4.4		11.2	2.2	8.3		10.8	5.0	5.1	
L. Shared (to irrigation)	.	0.0	0.5		.	0.0	0.5		.	0.0	0.6	
M. Swopped (assume the accrual supplies EWR so that the release must be made for irrigation)	.	0.2	0.1		.	0.2	0.2		.	0.1	0.1	
N. Shared (to EWR)	.	0.0	0.5	*	.	0.0	0.5	*	.	0.0	0.6	*
O. EWR (inc Indwe)	19.8	13.2	5.9	5.9	4.4	2.6	1.1	1.1	15.1	10.1	4.3	4.3
P. Sub-total	30.2	18.7	11.4	.	15.6	5.0	10.6	.	25.9	15.2	10.7	.
Q. Less shared (double counted above)	0.0	0.0	-0.5	.	0.0	0.0	-0.5	.	0.0	0.0	-0.6	.
R. Contributed volume	30.2	18.7	10.9	10.9	15.6	5.0	10.1	10.1	25.9	15.2	10.1	10.1
S. Total (not double counting shared)	68.8	33.9	32.4	32.4	50.2	15.3	32.7	32.7	56.1	18.2	36.7	36.7

* EWR shared volume already included with the irrigation total in the cell above.

4.8.8 COMPARISON OF MODELLED RELEASES WITH THE ALLOCATED RELEASES IN THE MAIN REPORT

In the main report the allocations of irrigation were calculated using the following assumptions :

Waterdown/Oxkraal. 6 100 m^3/ha out of the optimal 7 500 m^3/ha desired by the irrigators would be supplied from Waterdown/Oxkraal. The remaining 1 400 m^3/ha would be provided from streamflows downstream of the major dams. The releases from the dams would be increased by 25% to cater for transmission losses.

Xonxa. 9 000 m^3/ha would be supplied from Xonxa. The releases from the dam would be increased by 25% to cater for transmission losses.

The average allocations/releases from the dams based on these assumptions have been summarised in column e in Table 4.8.16.

TABLE 4.8.16 DETERMINING ALLOCATED RELEASES FROM THE DAMS

Reach	Area	Quota provided from dams	% Loss on releases from dams	Release from dams [=b*c*(1+d)/1000000]	Optimal quota desired	Additional supply from inflows downstream of dams [h=b*g/1000000]		Field edge requirement (desired volume) [=b*f/1000000]
	Ha	m^3/Ha	(%)	Mm^3/a	m^3/Ha	m^3/Ha	Mm^3/a	Mm^3/a
a	b	c	d	e	f	g	h	i
Oxkraal	541	6100	25%	4.1	7500	1400	0.8	4.1
Shiloh	25	6100	25%	0.2	7500	1400	0.0	0.2
Waterdown - Klipplaat	915	6100	25%	7.0	7500	1400	1.3	6.9
Waterdown - Black Kei	1009	6100	25%	7.7	7000	900	0.9	7.1
Sub-total	2490.0			19.0			3.0	18.2
Xonxa	1000	9000	25%	11.3	9000	0	0.0	9.0
Total	3490.0			30.2			3.0	27.2

In the reaches downstream of Waterdown / Oxkraal evapotranspiration dams have been modelled to simulate transmission losses. Therefore the modelled irrigation demands should be field edge requirements, excluding any allowance for losses. Due to a misunderstanding the demands modelled in the system were scaled to equal the allocations from the dams. However, in the Waterdown/Oxkraal system this error makes very little difference and means that the irrigation requirement may be overestimated by 0,8 Mm^3/a (see Table 4.8.17).

The situation is different downstream of Xonxa Dam. No transmission losses are modelled so the irrigation demands should be increased to include an allowance for losses. The demands adopted had been increased by 25% as assumed in the main report.

TABLE 4.8.17 COMPARISON OF ALLOCATED AND AVERAGE MODELLED IRRIGATION RELEASES

Reach	Optimal field edge requirement (1)	Modelled field edge requirement	Modelled field edge requirement plus losses	Conservative error
	Mm³/a	Mm³/a	Mm³/a	Mm³/a
a	b	c	d	e
Oxkraal	4.1	4.1	varies - used evapotranspiration loss dams	
Shiloh	0.2	0.2		
Waterdown - Klipplaat	6.9	7.0		
Waterdown - Black Kei	7.1	7.7		
sub-total	18.2	19.0		0.8
Xonxa	9.0	na	11.3	0.0
Total	27.2			0.8

From \hydro\10676\ym\integ\DamMassBalanceV48.xls or later version, sheet Demand overestimate (2)

(1) Based on the estimated releases - column i in Table 4.8.17 above.
(2) For Xonxa the losses were not separately modelled and were included with the irrigation demand to give a total requirement of 11.3.

In the WRYM the releases from the dams are usually only made when insufficient water is available from inflows downstream of the dams. In Table 4.8.18 these modelled releases are compared with the average allocations determined in column e of Table 4.8.16. On average, the modelled accruals are larger than those assumed when determining the allocations. Downstream of Oxkraal/Waterdown the accruals mean that the modelled irrigation releases (column c) are 3,6 Mm³/a less than the allocation (column b). Downstream of Xonxa the allocations are 6,3 Mm³/a more than the modelled releases because the model assumes that accruals reduce the release requirements.

During the critical period the modelled losses increased so that the modelled irrigation releases from Oxkraal/Waterdown were 0,4 Mm³/a more than the allocation (column f *vs* column b). This increase was mainly due to the dry 18 months at the end of the critical period where the desired irrigation releases were 6,8 Mm³/a more than the allocation (column j *vs* column b).

During the system critical period the allocated releases from Xonxa were 2,3 Mm³/a more than the modelled releases. This difference is less than during average years because of the reduction in accruals during the critical period.

Table 4.8.18 Comparison of allocated and modelled releases over different periods

Reach	Releases									
	Allocated (1)	Modelled								
		Average (Oct '20-Sep '94)			System critical period Aug '44-Jan'50			Dry portion of critical period Jun'48-Jan'50		
	Irrigation	Irrig	EWR	Total	Irrig	EWR	Total	Irrig	EWR	Total
	Mm³/a	Mm³/a	Mm³/a	Mm³/a	Mm³/a	Mm³/a	Mm³/a	Mm³/a	Mm³/a	Mm³/a
a	b	c	d	e	f	g	h	I	j	k
Oxkraal/Waterdown	19.0	15.4	6.1	21.5	19.4	3.2	22.6	25.8	0.8	26.6
Xonxa	11.3	5.0	5.9	10.9	9.0	1.1	10.1	5.8	4.3	10.1
Total	**30.24**	**20.40**	**12.00**	**32.40**	**28.40**	**4.30**	**32.70**	**31.60**	**5.10**	**36.70**

(1) Based on releases from dams - column e in Table 4.8.16.

As explained in Section 4.8.1 the modelled releases assume a high abstraction efficiency. For the analysis in Section 4.10 the releases from the dams were forced to be equal to the allocation to minimise the impact of the accruals.