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DEPARTMENT OF WATER AFFAIRS AND FORESTRY
DIRECTORATE OF OPTIONS ANALYSIS

LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY

MAIN REPORT

FINAL

NINHAM SHAND
CONSULTING SERVICES

January 2006

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

DIRECTORATE OF OPTIONS ANALYSIS

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MAIN REPORT

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LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY

MAIN REPORT

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-Whittlesea 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 to 2045 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, in addition, 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 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.

Since the QRWSFS was completed, new information on groundwater potential in the area has shown that large volumes of groundwater could be abstracted on a sustainable basis.

Consequently, the augmentation of the existing surface water supplies by means of groundwater abstraction is also considered in this report.

2. THE LUKANJI SURFACE WATER RESOURCES SYSTEM

The existing Lukanji Water Resources System consists of the Black Kei River and its major tributaries, the Klaas Smits River and the Klipplaat River, and several dams that are situated on tributaries of the Black Kei River. Run-of-river flow is abstracted from all of the rivers for irrigation. In addition, Xonxa Dam on the White Kei River, although not currently part of the system, may well become part of it in the future if it is selected as the source of water for the next augmentation scheme. Therefore, in this study, Xonxa Dam and the main stem of the White Kei River are considered to be part of the System. The Lukanji System is part of the larger Upper Kei System which includes the Doring River Dam and the Lubisi Dam, both on the Indwe River, a major tributary of the White Kei River.

The System supplies water to the urban areas of Queenstown and Sada-Whittlesea, as well as to several irrigation schemes. The urban supply is abstracted from Waterdown and Bonkolo Dams. Waterdown Dam also supplies water for irrigation. As a result of steady growth in the urban water requirements, the capacities of the pipelines that convey water from Waterdown Dam to the water treatment works will soon be inadequate. In addition, the assurance at which the water can be provided has decreased to a level that may not be appropriate for urban supplies. Consequently, a supplementary source of raw water needs to be provided, or the proportions in which the water from Waterdown Dam is allocated between urban supplies and irrigation need to be amended. In addition, a second pipeline to convey water to Queenstown is needed.

The other dams that are components of the System were constructed to supply water to irrigation schemes. In some instances, even though the dams were constructed, the irrigation schemes were never developed. In other instances, the irrigation schemes were only partially developed or, if fully developed, have subsequently fallen into disrepair, with a consequent decrease in water use. As a result of this situation, the yields of several of the dams are not fully allocated or utilised at present.

3. GROUNDWATER

The QRWSFS concluded that, although conditions are relatively favourable for the development of supplies from groundwater, it is not feasible to develop a borehole field to meet even 10% of Queenstown's demand.

Umvoto Africa was appointed by Ninham Shand as specialist consultant for the groundwater component of the study to review the original findings and to determine the potential for augmenting the water supply to Queenstown from groundwater.

The investigation was undertaken at a pre-feasibility desktop level with a minor field reconnaissance component. Recently published reports and maps on groundwater potential in the

Queenstown area and the relevance and application of research and additional data that has been undertaken and/or acquired since 1995 were considered.

The focus was on identifying potential targets for groundwater exploration close to Queenstown, Sada-Whittlesea and or the existing or proposed infrastructure (i.e. pipeline from Waterdown Dam and proposed pipeline from Xonxa Dam).

The review of different investigations revealed that the figures of groundwater potential and yield, given in previous water resource assessments for the Queenstown area are too low and unrealistic. There is generally a good to high potential to develop sustainable groundwater schemes for both rural and urban water supply.

The two crucial keys to sustainable groundwater development in the Lukanji region are (1) the ultimate storage capacity (both unconfined and confined) of the deeper Katberg fractured-rock aquifer, especially along the Katberg-dolerite contact hydrotects, and (2) its system recharge-discharge response characteristics in relation to the Katberg-Amatola range summit, where highest precipitation in the region occurs.

The target generation identified eight potential target areas for groundwater development, associated with dolerite dykes, most of which are situated within ring structures or are associated with dolerite sheets or sills, and that comply with the following criteria:

- Katberg sandstone as host rock
- Close to existing or planned water supply infrastructure
- Within the boundary of the Lukanji local municipality
- Within the S32 catchment, to avoid unnecessary pumping costs

However, three additional target areas associated with dolerite ring structures were identified in the proximity of Queenstown.

Based on estimated costs, location and hydrogeological prospect, five target areas in the vicinity of Sada-Whittlesea were selected for further investigation if a groundwater supply were to be selected for the next augmentation scheme.

Each of the target areas is expected to sustainably deliver 0.5 to 1 Mm^3 of water per annum. The unit reference values for the different options vary from R0.79/m^3 to R2.78/m^3, depending on the distance of the target area to the existing infrastructure and the assumed yield.

Based on the findings of the study, it was concluded that a more detailed hydrogeological investigation and exploration program in the priority target areas would be justified if groundwater sources were found to be competitive with surface water sources for the augmentation scheme.

4. EXISTING WATER SUPPLY SCHEMES

The Lukanji Surface Water Resources System supplies raw water to the urban areas of Queenstown and Sada-Whittlesea, the rural villages of Yonda and Mbekweni, and a number of irrigation schemes.

The town of Ilinge is currently supplied from boreholes, as are many of the rural villages in the area. Supplies to rural villages do not fall within the scope of this study, except where they are situated close to urban areas and can feasibly be included in the urban water supplies.

Queenstown receives raw water from Bonkolo Dam and from Waterdown Dam, while Sada-Whittlesea is supplied form Waterdown Dam only.

Water from Waterdown Dam is supplied to Queenstown through a 46 km long, 450 mm diameter, steel pipeline constructed in 1960. The pipeline was originally designed to operate under gravity only, but its capacity was later boosted by a pump station.

In about 1983, in order to supply the newly established Sada resettlement area adjacent to the existing town of Whittlesea and to meet the growing demand of Queenstown, a second pipeline was constructed along the first 15 km of the route from Waterdown Dam, and an offtake to Sada Water Treatment Works was provided.

The Waterdown Dam to Queenstown pipeline was designed to deliver between 11,3 Mℓ/day and 9,5 Mℓ/day to Queenstown under gravity, depending on the water level in Waterdown Dam. A new booster pump station was installed to increase the delivery to between 25 Mℓ/day and 23 Mℓ/day, depending on the water level in Waterdown Dam. The design provided for the supply of 23Mℓ/day to Queenstown to be maintained, with Waterdown Dam at its lowest level, while providing an additional 17 Mℓ/day at the Sada offtake for delivery to the Sada Water Treatment Works. Because of the relative levels, the full 17 Mℓ/day could not be supplied to the Sada Treatment Works by gravity. Therefore, a booster pump station was required on the branch pipeline to Sada. However, this was not constructed when the pipeline was laid in about 1983 because the water requirements at that time could be supplied by gravity alone. The booster pump station has still (2005) not been constructed but the requirements of the Sada Water Treatment Works have increased to the extent that it is necessary to keep the pressure in the Waterdown Dam to Queenstown pipeline at the Sada offtake at a higher level than originally intended if sufficient water is to be supplied to Sada. This can only be done by limiting the delivery to Queenstown by operating the booster pumps at less than their full capacity.

As a result of this situation, Queenstown can obtain a maximum of 13,7 Mℓ/day (5 Mm^3/a) through the pipeline, instead of the minimum of 23 Mℓ/day for which it is designed. As the present requirement of Queenstown, excluding Ilinge and the Macibini Villages, is about 7,8 Mm^3/a, it is necessary to supply from Bonkolo Dam the difference of 2,8 Mm^3/a between the

5 Mm^3/a that can be obtained through the Waterdown Dam pipeline and the total requirement. The quantity of 2,8 Mm^3/a is well in excess of the 1 in 10 year yield of Bonkolo Dam and can be supplied only at very low assurance. It is clear, therefore, that augmentation of the existing raw water supply scheme is urgently required.

Ilinge and the adjacent Macibini Villages are not connected to the Queenstown water supply at present, but are supplied from six boreholes with an estimated yield of 1,3 Mm^3/a. The present water requirements are estimated to be 2,2 Mm^3/a, which suggests that the scheme requires augmentation. Borehole yields in the area are generally good, and it should, therefore, be feasible to augment the scheme by developing additional boreholes. However, the scheme has proved difficult to manage and problems in operating it effectively have been experienced for many years. Consequently, the Chris Hani District Municipality would prefer to supply the area by means of a new pipeline from the Queenstown Water Treatment Works.

The urban water supply from Waterdown Dam is a component of the Klipplaat River Government Water Scheme which also has an irrigation component.

The scheme was established in 1957 and has the Waterdown Dam as its central component. Water is released from the dam into the river channel to supply a scheduled irrigation area of 1 924 ha 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. The scheme extends over an almost 150 km length of river and there are considerable losses between the dam and the lower irrigators. At present about 1 530 ha of the scheduled area of 1 924 ha is irrigated. The current area irrigated is less than the scheduled area mainly because most of the 394 ha of land developed for small scale farmers in the ex-Ciskei homeland have fallen into disuse. However, this land is being re-furbished and officials of the Provincial Department of Agriculture expect the irrigated area of the whole scheme to eventually increase to the full scheduled area of 1 924 ha again, but do not expect any increase in the scheduled area.

The Zweledinga Irrigation Scheme in the ex-Ciskei homeland obtains water from Bushmanskrantz Dam which is situated on the Oxkraal River upstream of Oxkraal Dam. Water is supplied by pipeline from the dam to several small scale farmer schemes which together comprise the Zweledinga Irrigation Scheme. Bushmanskrantz Dam also supplies water to the villages of Yonda and Mbekweni.

According to DWAF records, no releases of water for irrigation have been made from Bushmanskrantz Dam since 1995 and it is understood from discussions with officials of the Provincial Department of Agriculture and DWAF that the irrigation scheme has fallen into disuse. It may, nevertheless, be re-vitalised in the future.

The Oxkraal Irrigation Scheme, also in the ex-Ciskei homeland, comprises the Oxkraal and Shiloh Dams which were constructed with the intention of irrigating 541 ha of land from Oxkraal Dam and 25 ha from Shiloh Dam for small scale farmers. The lands have not been developed, but as an interim measure, water from Oxkraal Dam is released down the river for use on land scheduled under Waterdown Dam. The small Shiloh Dam is unused at present. According to officials of the Provincial Department of Agriculture, it is planned to develop the land for irrigation in the near future.

The Xonxa Dam was constructed in 1972 with the intention of providing water for some 4 900 ha of land along the White Kei River in the ex-Transkei homeland. To date, only 1 643 ha of land have been developed under the Xonxa Irrigation Scheme. Water is released from the dam into the White Kei River and extracted by means of diversion weirs or by pumping from the river into storage reservoirs. The scheme originally supported 224 farmers. Difficulties in maintaining pumps and irrigation equipment have been experienced and the scheme has not been financially viable for the small scale farmers it was intended to serve. As a result, it has declined to the extent that an area of only about 60 ha of land is currently irrigated.

It appears unlikely, because of unsuitability of much of the soil, that the irrigated area will ever increase to more than 1 000 ha. Therefore, water from Xonxa Dam could be used for other purposes. One possibility is for domestic supplies to villages in the area and to Queenstown.

5. ECOLOGICAL WATER REQUIREMENTS

IWR Source-to-Sea was appointed as a sub-consultant to Ninham Shand to determine the ecological water requirements of the rivers downstream of the main dams of the Lukanji Water Resources System. The determination was carried out using the Intermediate Ecological Reserve Methodology.

It was found that the recommended releases from Waterdown and Oxkraal Dams would reduce the combined yields of the dams available for other uses by 3,7 Mm^3/a at 1:50 year assurance. The corresponding impact on the available yield from Xonxa Dam would be a reduction of 3,1 Mm^3/a.

6. WATER REQUIREMENTS

6.1 GENERAL

The water requirements that affect the Lukanji Water Resources System are :

- Urban and rural domestic requirements supplied from the dams of the System or from run-of-river flow.
- Irrigation requirements, supplied from the dams, run-of-river abstractions and boreholes.
- Afforestation, to the extent that it reduces natural runoff and, hence, the quantity of water available for other users.
- Invasive alien vegetation which has the same effect as afforestation.

Each of these categories of water requirements was investigated in the context of its implications for possible schemes to augment the water supply to Queenstown.

The past and projected water requirements of the urban areas are shown in Table 6.1. There is some uncertainty about future irrigation water requirements because it is not known precisely when irrigation schemes that have fallen into disuse, or have never been developed to their originally planned size, will begin to use their full allocations of water. The assumptions made in respect of the total quantities of water that will eventually be required for irrigation from dams that are possible sources of additional urban water supply are shown in Table 6.2. It should be noted that the assumption of no future requirement for the Zweledinga Irrigation Scheme was made purely for purposes of comparing possible augmentation schemes and in no way precludes the re-instatement of this scheme at any time in the future.

TABLE 6.1 PROJECTED WATER REQUIREMENTS FOR QUEENSTOWN AND RURAL VILLAGES

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

TABLE 6.2 ASSUMED IRRIGATION WATER REQUIREMENTS FROM DAMS THAT ARE POSSIBLE SOURCES OF ADDITIONAL URBAN WATER SUPPLY

SCHEME	DAM	ASSUMED AREA IRRIGATED (ha)	QUOTA ($m^3/ha/a$)	ALLOWANCE FOR CONVEYANCE LOSSES ($m^3/ha/a$)	WATER REQUIREMENTS (Mm^3/a)
Klipplaat River Government Water Scheme	Waterdown	1 924	6 100	1 525	14,7
Oxkraal Irrigation Scheme	Oxkraal Shiloh	541 25	6 100 6 100	1 525 1 525	4,1 0,2
Zweledinga	Bushmanskrantz	0	-	-	0
TOTALS IN CATCHMENT OF BLACK KEI RIVER		**2 490**	**-**	**-**	**19,0**
Xonxa Irrigation Scheme	Xonxa	1 000	9 000	2 250	11,3

Afforested areas occur mainly in the catchments of Waterdown and Oxkraal Dams, and are estimated to reduce streamflow by 1,24 Mm^3/a.

The main occurrence of alien vegetation is in the catchment of Waterdown Dam where thickets of black wattle with an estimated total consolidated area of 5,5 km^2 are estimated to reduce streamflow by about 0,8 Mm^3/a.

7. WATER AVAILABILITY

The Water Resources Yield Model, configured to represent the Lukanji Water Resources System, was used to determine the quantities of water available to meet the requirements of consumers.

The original model was developed for the QRWSFS and some modifications were made to it to take account of changes in irrigated areas, to model environmental releases from dams, and to facilitate determining the assurances at which various quantities of run-of-river flow could be abstracted from the Black Kei River. In addition, estimates of the probable loss in capacities of the main dams by the year 2020 as a result of sediment accumulation were made using the results of the most recent basin surveys carried out by DWAF. The results of this exercise were used to determine the yields of the dams in the year 2020 for use in considering alternative possibilities for augmenting the urban water supply.

Finally, stochastic flow sequences were developed and long-term and short-term yield characteristic curves were derived for the main dams of the system in order to obtain the reliabilities of the yields.

The estimated yields for conditions in 2020 of those dams that are existing or potential future sources of urban water supply are shown in Table 7.1. Land-use in the catchments of the dams was assumed to remain as it is at present (2005).

TABLE 7.1 ESTIMATED YIELDS OF MAIN DAMS FOR CONDITIONS IN 2020

DAM	NATURAL MAR (Mm^3/a)	MAR IN 2020 (Mm^3/a)	LIVE STORAGE IN 2020 (Mm^3/a)	YIELDS					
				HISTORICAL FIRM YIELD (Mm^3/a)	1:10 year (Mm^3/a)	1:20 year (Mm^3/a)	1:50 year (Mm^3/a)	1:100 year (Mm^3/a)	1:200 year (Mm^3/a)
Waterdown Dam	45,7	36,7	36,07	16,8	24,5	23,3	20,3	18,8	17,6
Bushmanskrantz and Oxkraal Dams	17,9	17,9	15,60	6,2	8,6	8,0	7,0	6,2	5,7
Bonkolo Dam	3,20	2,5	5,94	0,7	1,2	1,1	0,9	0,8	0,7
Xonxa Dam	47,87	42,8	110,4	20,6	29,6	27,2	23,0	20,7	19,0

The combined yields of Bushmanskrantz and Oxkraal Dams were calculated because it was assumed, for the purpose of considering possible augmentation schemes, that the Zweledinga Irrigation Scheme will not be brought back into use.

Run-of-river flows at various reliabilities were derived for the Klipplaat River between Waterdown Dam and the Black Kei River confluence, and for the Black Kei River between its confluences with the Klipplaat River and the White Kei River, assuming present day (2005) abstractions continue upstream of these reaches and that environmental flow requirements take preference. The estimated quantities of water available are shown in Table 7.2. As flood flows are included, the quantities of water that could be abstracted for run-of-river irrigation would be less than those shown in the table.

TABLE 7.2 ESTIMATED RUN-OF-RIVER FLOWS AFTER ALLOWING FOR PRESENT DAY (2005) UPSTREAM WATER USE AND ENVIRONMENTAL FLOW REQUIREMENTS

RIVER REACH	YIELDS			
	1:10 year (Mm^3/a)	1:50 year (Mm^3/a)	1:100 year (Mm^3/a)	1:200 year (Mm^3/a)
Black Kei between Klipplaat and White Kei	0,43	0,40	0,31	0,28
Klipplaat downstream of Waterdown Dam	0,01	0,01	0,01	0,01

8. POTENTIAL AUGMENTATION SCHEMES

Conceptual designs of a number of alternative schemes for augmenting the water supply to Queenstown were prepared, capital and operating costs were estimated for each scheme, and the long-term costs of the schemes were compared on the basis of the costs, expressed as unit reference values, of the water that they could provide.

It was shown by this analysis that the existing pipeline between Waterdown Dam and Queenstown is of high economic value. Therefore, it is likely to remain in service for the foreseeable future, even though it is now forty-five years old, as it is reported to still be in good condition. The analysis also showed that augmentation of the Queenstown water supply from a new dam or diversion weir to be constructed on the Black Kei River would be considerably more costly than augmentation from the existing Xonxa Dam, or from the existing Waterdown Dam, if sufficient water could be made available from it by re-allocating some of the irrigation demand to the Oxkraal Dam, or by switching Sada onto groundwater as a source of supply.

The investigations carried out for this study have shown that there is sufficient unallocated water available from Xonxa Dam to meet the expected increase in the water requirements of Queenstown to beyond the year 2045.

With the availability of water from Oxkraal Dam to provide some of the water for irrigation previously provided from Waterdown Dam, there is currently (2005) unutilised yield from Waterdown Dam that could be used to augment the water supply to Queenstown. However, the quantity is insufficient to meet the expected increase in the requirements of Queenstown to the year 2045, and a supplementary source would be required to do so. The financial comparison of possible augmentation schemes showed that it would not be economical to supplement the raw water supply by raising Waterdown Dam. However, a pre-feasibility level desktop assessment of groundwater potential in the area has shown good prospects for the development of wellfields in the vicinity of Sada. Therefore, the possibility was considered of increasing the quantity of water that could be supplied to Queenstown from Waterdown Dam by developing a groundwater supply for Sada, and thereby making available for the Queenstown supply the water currently supplied to Sada from Waterdown Dam.

It can be concluded from the financial comparison of schemes that :

- it would be more economical to construct a pipeline between Xonxa Dam and Queenstown sized initially to convey the full quantity of water required in the year 2045 than to construct two smaller pipelines in phases;
- in terms of the unit reference values for water supplied over the period from 2005 to 2045, there would be little difference between augmentation from Waterdown Dam, with a new groundwater supply included, and augmentation entirely from Xonxa Dam;
- augmentation partially from Waterdown Dam, (without groundwater supply but with a second pipeline) and partially from Xonxa Dam would cost about 30% more, in terms of unit reference values, than augmentation exclusively from either of the sources.

In view of the above, it is necessary to make a choice between augmentation from Waterdown Dam and augmentation from Xonxa Dam. The choice is made easier by certain advantages which are apparent in the Xonxa Dam option, namely:

(i) The raw water source already exists, whereas the groundwater source for the Waterdown Dam option has still to be proved in the field, and the cost of developing it may be significantly higher than estimated.

(ii) The initial capital cost of the Xonxa Pipeline, estimated to be R68 million, is considerably lower than the estimated R90 million for the Waterdown Pipeline, and it would, therefore, be easier to finance. (The disadvantage is that the Xonxa Pipeline pumping costs would be higher than those from Waterdown Dam).

(iii) A supply from Xonxa Dam would be from a completely separate source, which would reduce the risk of complete disruption of the supply in the event of a natural disaster.

(iv) There is unutilised yield available from Xonxa Dam, whereas the additional water that would be used from Waterdown Dam is very likely to be required in the near future for use for irrigation by small scale farmers.

(v) Xonxa Dam lies in a region with different hydrological characteristics to the region in which Waterdown Dam is situated. Droughts in the two regions do not have a high correlation, a factor which has benefits for the operation of the system.

For the above reasons, augmentation from Xonxa Dam is preferred to augmentation from Waterdown Dam.

9. SYSTEM OPERATING RULES

Short-term yield characteristic curves derived from stochastic analysis were used to determine operating rules for Waterdown, Bushmanskrantz, Oxkraal, and Xonxa Dams. The operating rules determined in this way were simulated in the system model to verify that they would be satisfactory.

10. CONCLUSIONS AND RECOMMENDATIONS

The main objectives of this study were :

- 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, and
- to propose system operating rules for the existing water supply scheme 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.

With regard to the next augmentation scheme it was concluded that :

- The urban water requirements in the areas supplied by the existing schemes were 11,7 Mm^3/a in 2005 and are expected to increase to 13,5 Mm^3/a by 2020 and 15,5 Mm^3/a by 2045.
- The capacity of the existing raw water supplies to these schemes is 9,7 Mm^3/a at 1:50 year assurance, of which 7,5 Mm^3/a is provided from Waterdown Dam, 0,9 Mm^3/a from Bonkolo Dam and 1,3 Mm^3/a from boreholes at Ilinge.
- Because the water requirements exceed the 1:50 year assured yields of the water sources, water is currently provided at a low assurance of supply. This is not a desirable situation and an augmentation scheme is urgently required.
- With the availability of water from Oxkraal Dam to provide some of the water for irrigation previously provided from Waterdown Dam, there is currently (2005) an additional 3,7 Mm^3/a of water available from Waterdown Dam if it is assumed that the allocation of water to irrigation will not be increased in the future or, alternatively, that additional irrigation water will be supplied, but the Reserve will not be implemented in the near future. However, the quantity is insufficient to meet the expected increase in the requirements of Queenstown to the year 2045, and a supplementary source would be required to do so. Also, even though the additional water is available in Waterdown Dam, it is not possible to supply it through the existing pipeline arrangement.

- After evaluation of a number of alternative augmentation schemes, a pipeline from Xonxa Dam to Queenstown was identified as the preferred scheme.

- There would be some scope for boosting the capacity of the existing Waterdown to Queenstown pipeline at relatively low cost, thereby postponing the date when the pipeline from Xonxa Dam will be required, if the currently unutilised yield available from Waterdown could be allocated to urban supplies. However, it appears from discussions held with the Department of Agriculture and the Chris Hani District Municipality that the water will be required in the near future for irrigation.

- There is also uncertainty as to whether the existing groundwater supply to Ilinge will continue in use or be shut down when a planned supply from the Queenstown Water Treatment Works becomes available to Ilinge and the Macibini Villages.

- Irrespective of the decision made in respect of the future of the Ilinge boreholes, the augmentation scheme from Xonxa Dam is required immediately. However, the decision on the Ilinge boreholes will affect the design capacity of the pipeline and should, therefore, be made as soon as possible.

With regard to the development of system operating rules it was concluded that :

- Waterdown Dam and Xonxa Dam do not always experience critical droughts at the same time. Therefore, supplying Queenstown with water from both dams would increase the security of supply in comparison to that achieved by using Waterdown Dam alone, even if there were sufficient water available from it.

- In order to achieve the maximum benefit, in terms of security of supply, of using the two dams, the pipeline from Xonxa Dam should have sufficient capacity to convey 70% of the full annual water requirement of Queenstown with allowance made for seasonal and operational variations in demand. In order to minimise the required pipeline peak factor, the pipeline should be designed so that water can be delivered into Bonkolo Dam for storage when necessary.

The above conclusions lead to the recommendations set out below.

1. The portions of the yields of Oxkraal, Bushmanskrantz and Shiloh Dams that are not used for supplying local irrigation schemes should be used to supply irrigation water for the Klipplaat Government Water Scheme that would otherwise be supplied from Waterdown Dam.
2. The next augmentation scheme should be a pipeline from Xonxa Dam to Queenstown with a facility for also discharging water into Bonkolo Dam.
3. The required capacity of the pipeline will depend upon whether it is intended to retain or abandon the existing groundwater supply to Ilinge. Therefore, the future of the Ilinge groundwater supply should be decided as soon as possible by those responsible for

managing the water supplies, and, if it is decided to retain it, its assured yield should be determined.

4. The size of the pipeline from Xonxa Dam should be determined as part of the detailed design. In order to maximise the assurance of supply of the augmented water supply scheme, the pipeline should be sized so as to at least be able to deliver 65% of the total estimated annual demand of Queenstown, Ilinge and the Macibini Villages with adequate allowance made for seasonal and operational variations in demand, up to a design demand of 11,5 Mm^3/a. For higher design demands, the pipeline capacity should be increased to at least 80% of the demand.
5. System operating rules, as proposed in Section 9.4 of this document, should be implemented.

A further objective of this study was to make a recommendation on how Thrift and Limietskloof Dams, which are located close to the headwaters of the White Kei River should be used. These dams were originally intended to be used to expand the Ntabethemba Irrigation Scheme, but this has not been done, apparently because of the high capital cost that would be involved. Consequently, the dams are unused at present. The combined 1:10 year yield of the dams is only 1,25 Mm^3/a. It is recommended that the present owners of the farms on which the dams are located be approached to find out if they are interested in buying the dams with a view to re-establishing irrigated lands in the area that was originally supplied from the dams, or that the Government acquire and develop the land for resource poor farmers.

LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY

MAIN REPORT

CONTENTS

Page No.

TABLES

CONTENTS

Page No.

FIGURES

ABBREVIATIONS

/a	per annum
DRIFT	Downstream Response to Imposed Flow Transformation
DWAF	Department of Water Affairs and Forestry
EC	Electrical conductivity
ECA	Environmental Conservation Act
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirement
ha	hectare
IERM	Intermediate Ecological Reserve Method
IFR	Instream flow requirements
IWRM	Integrated Water Resources Management
kℓ	kilolitre
km	kilometre
ℓ/c/d	litres per capita per day
ℓ/s	litres per second
m^3	cubic metres
Ma	million years
MAR	mean annual runoff
MAP	mean annual precipitation
Mℓ/d	Megalitres per day
Mm^3/a	Million cubic metres per year
NGDB	National Groundwater Database
NPV	Net Present Value
p.a.	per annum
PES	Present Ecological State
PVC	Polyvinyl chloride
QRWSFS	Queenstown Regional Water Supply Feasibility Study
R	Rand
REC	Recommended Ecological Category
SABS	South African Bureau of Standards
Sc	Scenario
URV	Unit Reference Value
WASSA	Water and Sanitation Services South Africa
WRC	Water Research Commission
WRSA	Water Resources Situation Assessment
WWTW	Wastewater Treatment Works

LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY

MAIN REPORT

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-Whittlesea 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 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.

Since the QRWSFS was completed, new information on groundwater potential in the area has shown that large volumes of groundwater could be abstracted on a sustainable basis. Consequently, the augmentation of the existing surface water supplies by means of groundwater abstraction is also considered in this report.

1.2 STRUCTURE OF THIS DOCUMENT

The complete set of reports on the study consists of this "Main Report" and six Appendices, each of which is bound separately and is a complete report on its own. Each of the appendices covers a topic that is included in the Main Report, but deals with it in greater detail. Thus, the volumes making up the full set of reports are :

Main Report
Appendix 1 : Water Requirements
Appendix 2 : Ecological Reserve (Quantity)
Appendix 3 : Water Quality Reserve
Appendix 4 : System Yield Analysis
Appendix 5 : Groundwater
Appendix 6 : Potential Augmentation Schemes

The Main Report, after this introduction, describes the Lukanji Surface Water Resources System in some detail. This is followed by chapters on groundwater potential in the area and on water quality. Thereafter, the existing water supply schemes are described, followed by discussions on ecological flow requirements, water requirements to meet urban, rural domestic, and irrigation needs, and the availability of water to meet these requirements. These lead to chapters on potential augmentation schemes to meet urban water requirements, operating rules for the water resources system and, finally, recommendations on actions required for the further development and operation of the system.

2. THE LUKANJI SURFACE WATER RESOURCES SYSTEM

2.1 COMPONENTS OF THE SYSTEM

The existing Lukanji Water Resources System consists of the Black Kei River and its major tributaries, the Klaas Smits River and the Klipplaat River, from all of which run-of-river flow is abstracted for irrigation, and several dams that are situated on tributaries of the Black Kei River. In addition, Xonxa Dam on the White Kei River, although not currently part of the system, may well become part of it in the future. The reasons for this are given later in this document. Therefore, in this study, Xonxa Dam and the main stem of the White Kei River are considered to be part of the System. The Lukanji System is part of the larger Upper Kei System which includes the Doring River Dam and the Lubusi Dam, both on the Indwe River, a major tributary of the White Kei River (see Figure 2.1).

The System supplies water to the urban areas of Queenstown and Sada-Whittlesea, as well as to several irrigation schemes. The urban supply is abstracted from Waterdown and Bonkolo Dams. Waterdown Dam also supplies water for irrigation. As a result of steady growth in the urban water requirements, the capacities of the pipelines that convey water from Waterdown Dam to the water treatment works will soon be inadequate. In addition, the assurance at which the water can be provided has decreased to a level that may not be appropriate for urban supplies. Consequently, a supplementary source of raw water needs to be provided, or the proportions in which the water from Waterdown Dam is allocated between urban supplies and irrigation need to be amended. In addition, a second pipeline to convey water to Queenstown needs to be provided. These issues are discussed in detail in Chapter 8.

The other dams that are components of the System were constructed to supply water to irrigation schemes. In some instances, even though the dams were constructed, the irrigation schemes were never developed. In other instances, the irrigation schemes were only partially developed or, if fully developed, have subsequently fallen into disrepair, with a consequent decrease in water use. As a result of this situation, the yields of several of the dams are not fully allocated or utilised at present. Details of the irrigation schemes are given in Chapter 4.

The main dams of the System are listed in Table 2.1, together with some of their physical characteristics and their yield characteristics. The yield characteristics were determined in this study as described in Chapter 7.

It can be calculated from the statistics given in Table 2.1 that the total live storage in the main dams in the catchment of the Black Kei River is about 70 Mm^3. Comparing this with the natural mean annual runoff (MAR) of 222 Mm^3/a, gives a ratio of storage to MAR of 0,31. Therefore, the Black Kei River is not heavily regulated by dams.

Brief descriptions of the individual dams and the river reaches that are components of the System are given below.

LOCALITY MAP:

LEGEND:	GIS COV:
WMA Boundaries	
Towns	Waterman Intp (Amended)
Rivers	Wri500
Dams	Ndams
Quaternary Catchment	Drgnquat
E24D Quaternary Number	Drgnquat
Secondary Catchment	Drgsnd
G3 Secondary Catchment Number	Drgsnd
Tertiary Catchment	
Study Area	

Potable Water Infrastructure
- Bulk Supply Pipes
- Water Treatment Works

PREPARED BY:

NINHAM SHAND CONSULTING SERVICES

CLIENT:

Department: Water Affairs and Forestry
Directorate: Options Analysis

PROJECTION:

ALBERS EQUAL AREA

SCALE : 1:500 000

0 2.5 5 10 Kilometers

TITLE:

LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY

LOCALITY PLAN

Prepared by:	A Lawrence	Figure 2.1
Date:	01/2006	
Data Type:	Fig1_1_localityplan.mxd	

TABLE 2.1 CHARACTERISTICS OF MAIN DAMS

DAM	DATE OF CONSTRUCTION	HYDROLOGICAL CATCHMENT NO. *	CATCHMENT AREA (km^2)	PRESENT DAY MAR (Mm^3)	FULL SUPPLY LEVEL (masl)	ORIGINAL FULL SUPPLY CAPACITY (Mm^3)	ORIGINAL DEAD STORAGE (Mm^3)	ORIGINAL LIVE STORAGE (Mm^3)	SOURCE OF DATA	ESTIMATED LIVE STORAGE IN 2020 (Mm^3)	YIELD IN 2020		
											1:10 YEAR (Mm^3/a)	1:20 YEAR (Mm^3/a)	1:50 YEAR (Mm^3/a)
Waterdown	1958	S32E	606	36,7	1 170,64	38,61	1,34	37,27	DWAF 1993	37,31**	24,5	23,3	20,3
Oxkraal	1989	S32G	315	13,0	1 127	17,8	0	17,8	DWAF 1993	13,03	5,6	5,2	4,8
Bushmanskrantz	1983	S32F	76	4,9	1 310	4,72	0	4,72	DWAF 1993	4,72	3,0	2,8	2,2
Shiloh	1983	S32G	22	0,89	1 182	0,85	0,03	0,82	DWAF 1993	0,20	0,33	-	0,26
Thrift	1974	S32A	131	3,3	-	2,90	0	2,9	DWAF 1993	2,60	0,43	0,41	0,40
Limietskloof	1975	S32A	42	0,6	1 375	0,88	0	0,88	DWAF 1993	0,78	0,01	0,01	0,01
Tentergate	1978	S32C	51	0,62	1 281,1	1,92	0	1,92	DWAF 1993	1,72	0,36	0,34	0,33
Glenbrock	1982	S32C	22,5	0,34	1 330,9	0,61	0	0,61	DWAF 1993	0,41	0,17	0,16	0,15
Mitford	1983	S32C	47	0,39	1 209	1,19	0	1,19	DWAF 1993	0,89	0,07	0,07	0,06
Xonxa	1974	S10E	1 460	42,8	931,5	157,6	7,6	150,0	DWAF 1993	110,4	29,6	27,2	23,0
Bonkolo	1908 raised in 1935	S31F	102	2,5	1 137,82	8,25	0	8,25	DWAF 1993	5,91	1,2	1,1	0,9

* Hydrological catchments are shown on Figure 2.1.

** A basin survey carried out in 1988 showed the full supply capacity to be greater than the original design capacity. The survey also showed that most of the sediment accumulation had been in the dead storage area, and this pattern was assumed to continue to 2020.

2.2 WATERDOWN DAM

Waterdown Dam, completed in 1957, is situated on the Klipplaat River, about 46 km south of Queenstown. The Klipplaat River is one of the main tributaries of the Black Kei River. The catchment of the dam, covering an area of 606 km^2, consists of mountainous terrain which is used mainly for sheep farming. The streams in the area are perennial and about 5 Mm^3/a of water is abstracted for the irrigation of mainly fodder crops, while afforestation and alien vegetation are estimated to reduce the MAR by 2,4 Mm^3/a. The present day MAR into the dam is 36,7 Mm^3/a, while the original live storage capacity of the dam was thought to be 37,27 Mm^3. A basin survey carried out in 1988 showed that the live storage was 37,31Mm^3, and that the dead storage volume had decreased from the original 1,34 Mm^3 to 1,08 Mm^3 as a result of the accumulation of silt.

In this study, the yields of dams were calculated on the basis of the expected live storage in the year 2020, after allowing for sediment accumulation. In the case of Waterdown Dam, the volume of sediment is expected to have increased from 0,26 Mm^3 in 1988 to 1,20 Mm^3 by 2020. However, it was assumed that the sediment would continue to accumulate in the dead storage area, so that the live storage capacity would remain at 37,31 Mm^3. On this basis the 1:50 year yield was calculated to be 20,3 Mm^3/a.

Waterdown Dam supplies water by pipeline to Sada-Whittlesea and Queenstown, and by releases into the river channel for irrigators downstream as far as the confluence of the Black and White Kei Rivers. Irrigation water is supplied by releasing between 1,0 Mm^3 and 1,2 Mm^3 of water from the dam over a period of 9 to 10 days, with discharge rates starting at about 2 m^3/s and gradually reducing over the period. Water can be released to the river through intakes at four different levels in the 35 m deep dam. The outlet capacity is about 5 m^3/s when the dam is full and 3,5 m^3/s when it is about 25% full.

The original allocations of water from Waterdown Dam total 27,48 Mm^3/a, to which an additional 3,6 Mm^3/a need to be added for river channel losses associated with irrigation releases. This quantity is well in excess of the 1:50 year yield of 20,3 Mm^3/a, or even the 1:10 year yield of 24,5 Mm^3/a. However, it appears that, as discussed below, it may be feasible to supplement supplies of irrigation water from Waterdown Dam with releases from Oxkraal Dam.

At present, no releases are made from Waterdown Dam to meet ecological flow requirements. When the ecological Reserve is implemented, it will reduce the quantity of water available from the dam for irrigation and urban water supplies. This aspect is discussed further in Chapters 5, 6 and 7.

2.3 BUSHMANSKRANTZ DAM

Bushmanskrantz Dam is located on the Oxkraal River, which is a tributary of the Klipplaat River, the confluence of the two rivers being some 20 km downstream of Waterdown Dam.

Bushmanskrantz Dam, which is situated in the former Ciskei homeland in the upper reaches of the Oxkraal River, is a rockfill structure that was completed in 1983. It had an original gross storage capacity of 4,72 Mm^3, with negligible dead storage. The capacity was slightly less than the natural MAR at the dam site of 4,9 Mm^3/a from a catchment area of 76 km^2. As no information on accumulation of sediment is available, and as the dam is high up in the river catchment, it has been assumed that the live storage capacity has remained at 4,72 Mm^3/a and will continue to do so to the year 2020. The historical firm yield of the dam was determined to be 2,0 Mm^3/a. No stochastic yield analysis was carried out for Bushmanskrantz Dam, but assuming the ratio between historical firm yield and 1:50 year yield to be the same as that determined (see Chapter 7) for the nearby Oxkraal Dam, the 1:50 year yield is estimated to be 2,2 Mm^3/a.

Bushmanskrantz Dam was constructed as part of the Zweledinga Irrigation Scheme to supply water by means of a pipeline to small scale farmers along the Oxkraal River. Water is also supplied to the villages of Yonda and Mbekweni, each of which has its own water treatment works. There are no specific operating rules and water is supplied as and when required. According to DWAF records, no water has been supplied from Bushmanskrantz Dam since 1995.

Water can be released from the 30 m deep dam into the river channel at about 2 m^3/s, when the dam is full, through a 700 mm diameter outlet pipe with a 400 mm diameter sleeve valve. At present, no releases are made for the ecological Reserve.

2.4 OXKRAAL DAM

Oxkraal Dam, also located on the Oxkraal River in the former Ciskei homeland, is about 20 km downstream of Bushmanskrantz Dam, and about 3 km west of Sada-Whittlesea. It was completed in 1989 and had an original gross storage capacity of 17,8 Mm^3, with negligible dead storage. No survey of sediment accumulation in the dam has been carried out since it was first built. However, the sediment load from the catchment between Oxkraal Dam and Bushmanskrantz Dam is known to be high, and it is estimated that the storage capacity will have decreased to about 13 Mm^3 by the year 2020. The 1:50 year yield at this capacity has been calculated to be 4,8 Mm^3/a if the full 1:50 year yield is abstracted from the upstream Bushmanskrantz Dam. If no water were abstracted directly from Bushmanskrantz Dam, but water was released in a controlled manner into the river channel to flow into Oxkraal Dam, a quantity of water of 7,0 Mm^3/a could be abstracted from Oxkraal Dam at 1:50 year assurance.

Oxkraal Dam, together with Shiloh Dam, which is described below, was constructed as part of the Oxkraal Irrigation Scheme. However, the land to be irrigated has not been developed and Oxkraal Dam has, as an interim measure, been used to supply water by means of river channel releases to some of the irrigated land scheduled under Waterdown Dam.

Water can be released from the 22 m deep dam into the channel of the Oxkraal River through outlets from different levels. When the dam is full the flow volume is 11 m^3/s, falling to about 7 m^3/s when the dam is 25% full (DWAF 2003).

2.5 SHILOH DAM

Shiloh Dam, located on the Shiloh River in the former Ciskei homeland, is an earthfill structure that was completed in 1983. The Shiloh River flows into the Oxkraal River downstream of Oxkraal Dam. Shiloh Dam had an original gross storage capacity of 0,85 Mm^3 and dead storage of 0,03 Mm^3. The present day MAR is estimated to be 0,89 Mm^3/a. It is estimated that, as a result of sediment accumulation, the live storage capacity has reduced to 0,52 Mm^3. The 1:50 year yield is estimated to be 0,3 Mm^3/a and the 1:10 year yield 0,4 Mm^3/a. Shiloh Dam was constructed as part of the Oxkraal Irrigation Scheme but the land that it was planned to irrigate has not been developed.

2.6 THRIFT, LIMIETSKLOOF, TENTERGATE, MITFORD AND GLENBROCK DAMS

Five dams, Thrift, Limietskloof, Tentergate, Mitford and Glenbrock Dams provide storage for the Nthabethemba Irrigation Scheme which consists of several small irrigation developments located in the former Ciskei homeland along tributaries of the Black Kei River upstream of its confluence with the Klipplaat River. The dams all belong to DWAF, and the yields of Tentergate, Mitford and Glenbrock Dams have in the past been fully utilised for irrigation, but the areas irrigated have decreased in recent years (see Section 4.7). The Thrift and Limietskloof Dams were not originally part of the scheme, but were purchased from the original owners to augment water supplies to the scheme. However, the existing Thibet Park diversion canal needs to be upgraded to achieve effective augmentation from these dams, or a pipeline needs to be constructed. As neither of these options has been implemented to date the two dams are unused at present.

The characteristics of the dams are shown in Table 2.1.

2.7 BONKOLO DAM

Bonkolo Dam is a concrete arch structure on the Bonkolo River which is a tributary of the Komani River. The Komani River is a tributary of the Klaas Smits River, one of the major tributaries of the Black Kei River. Bonkolo Dam is located about 4 km east of Queenstown, and its sole purpose is to provide water to Queenstown.

Construction of the dam was completed in 1908, and the wall was raised by 1,2 m in 1935. Its catchment area is 102 km^2 and the natural MAR at the dam site was 3,2 Mm^3/a. About 0,7 Mm^3/a of water is abstracted for diffuse irrigation in the catchment, with the result that the present day MAR is 2,5 Mm^3/a. The original full supply capacity of the dam was 8,25 Mm^3, with negligible dead storage. A survey carried out in 1994 showed that the full supply capacity had decreased to 6,95 Mm^3. This is still considerably in excess of the present day MAR of 2,5 Mm^3/a. For purposes of this study, it was estimated that the capacity will have decreased to 5,91 Mm^3 by the year 2020. The corresponding 1:50 year yield was calculated to be 0,9 Mm^3/a. Upstream abstractions are restricted during a drought in terms of a Water Court Order but it is doubtful whether these restrictions are effectively applied.

2.8 XONXA DAM

Xonxa Dam, completed in 1972, is a rockfill dam on the White Kei River, some 30 km east of Queenstown. It was originally built to supply water for the irrigation of land within the former Transkei homeland along the White Kei River downstream of the dam. However, the full planned area of irrigated land was never developed and, at present, only a small portion of the land that was developed is still irrigated.

The original full supply capacity of Xonxa Dam was 157,6 Mm^3. A survey carried out in 2002 showed that the full supply capacity had reduced to 121,1 Mm^3 with dead storage of 5,2 Mm^3, giving a live storage volume of 115,9 Mm^3. The live storage volume in the year 2020 was estimated to be 110,4 Mm^3.

The natural MAR at the site of Xonxa Dam was 47,9 Mm^3/a. It is estimated that 5,1 Mm^3/a is abstracted for diffuse irrigation in the catchment of the dam, reducing the MAR to a present day MAR of 42,8 Mm^3/a. Using the estimated live storage capacity in 2020, the 1:50 year yield of the dam was calculated to be 23,0 Mm^3/a.

Water can be released from the 20 m deep Xonxa Dam into the river channel through five outlets at different levels through a 1 000 mm diameter sleeve valve. The maximum flow when the dam is full is 10 m^3/s, and this reduces to about 7 m^3/s when the dam is 40% full (DWAF 2003). DWAF records show that no releases have been made from the dam since 1995.

2.9 THE BLACK KEI RIVER UPSTREAM OF THE KLIPPLAAT RIVER CONFLUENCE

The Black Kei River upstream of its confluence with the Klipplaat River has a catchment area of 1 438 km^2. The natural MAR was 26,9 Mm^3/a. An estimated 12,6 Mm^3/a was abstracted by the major dams and through run-of-river abstraction for diffuse irrigation when the irrigated area was at its peak. This reduced the MAR at the confluence with the Klipplaat River to 14,3 Mm^3/a. Since then, irrigation water use from the dams has decreased. This is discussed in more detail in Section 4.7.

2.10 THE KLIPPLAAT RIVER

The natural MAR of the Klipplaat River at its confluence with the Black Kei River was 71,5 Mm^3/a, from a catchment area of 1 380 km^2. The MAR is reduced by an estimated 1,2 Mm^3/a by afforestation and 0,8 Mm^3/a by alien vegetation, while 5,2 Mm^3/a is abstracted for diffuse irrigation and the major dams use varying quantities of water, depending on the way in which they are operated. The present day incremental MAR of the catchment between the Black Kei River confluence and Oxkraal and Waterdown Dams is 4,9 Mm^3/a.

2.11 THE KLAAS SMITS RIVER

The Klaas Smits River has a catchment area of 2 679 km^2 and a natural MAR at its confluence with the Black Kei River of 57,2 Mm^3/a. Bonkolo Dam is the only major dam in its catchment. The effect of that dam and water abstractions for diffuse irrigation and by farm dams is to reduce the MAR by 21,5 Mm^3/a. These losses are offset to some extent by return flows from the Queenstown sewage treatment works to give a present day MAR of 37,9 Mm^3/a.

2.12 THE BLACK KEI RIVER BETWEEN THE KLIPPLAAT RIVER CONFLUENCE AND THE WHITE KEI RIVER CONFLUENCE

The incremental catchment of this reach of the Black Kei River has an area of 1 412 km^2 and a natural MAR of 63,8 Mm^3/a generated from this catchment. Farm dams, river channel losses, and run-of-river abstractions for diffuse irrigation reduce the MAR to a present day value of 50,3 Mm^3/a, which, together with the runoff from the catchments upstream, gives a present day MAR at the confluence with the White Kei River of 122 Mm^3/a.

2.13 THE WHITE KEI RIVER UPSTREAM OF XONXA DAM

The White Kei River upstream of Xonxa Dam has a catchment area of 1 460 km^2 and the natural MAR at the dam site was 47,9 Mm^3/a. Diffuse irrigation and supply to rural communities upstream of the dam site reduces the MAR by about 5 Mm^3/a, to give a present day value of 42,9 Mm^3/a. The supply to domestic communities from Macubeni Dam on the Cacada River was assumed to be included in the abovementioned 5 Mm^3 reduction. Macubeni Dam had an original live storage capacity of 1,85 Mm^3/a. As it is situated in an area of high sediment yield, its capacity might have decreased significantly since it was constructed during the 1980s.

2.14 THE WHITE KEI RIVER DOWNSTREAM OF XONXA DAM

Except to the extent that it requires irrigation releases from Xonxa Dam and may, in the future, require ecological flow releases, the White Kei River downstream of Xonxa Dam does not form part of the Lukanji Water Resources System. Therefore, it is not discussed further here, but it is included in the study area and in the system modelling described in Appendix 4.

3. GROUNDWATER

3.1 SCOPE OF THE INVESTIGATION

The Queenstown Regional Water Supply Feasibility Study (DWAF, 1997) concluded that, even though conditions in the area are relatively favourable for development of supplies from groundwater, it was not feasible to develop a borehole field to meet even 10% of Queenstown's requirements. Based on the information that was available in 1995, it was calculated that nearly 200 boreholes would have to be drilled, spread over 100 km^2, in order to locate the 60 to 70 boreholes likely to be needed to provide a yield of 1 Mm^3/a.

However, certain factors affecting the development of groundwater supplies have emerged since 1995, and the available technology has been enhanced. In view of this, it was considered necessary to review the findings of the previous study.

Therefore, Umvoto Africa, a firm of specialist groundwater consultants, was appointed as a sub-consultant to determine the potential for augmenting the water supply to Queenstown from groundwater. The investigation was undertaken at a pre-feasibility desktop level with a minor field reconnaissance component.

The investigation focused on analysing existing data regarding groundwater utilisation in the vicinity of Queenstown. Information from eleven relevant reports and data sets (see Appendix 5 for details) was collated to obtain a first overview of the potential for supplementing the bulk water supply in the region. The information from the reports and additional insight into the hydrogeological structure of the area were then applied to the study area to identify possible target areas for groundwater development.

The full report on the groundwater component of the study is presented in Appendix 5. Only an outline of the investigation and its findings is given in this chapter.

3.2 REVIEW OF EXISTING REPORTS

It was concluded from the review of the existing reports that the reports on the regional water resources studies (Upper Kei Basin Study, Queenstown Region Water Supply Feasibility Study, Mzimvubu to Keiskamma WMA Water Resources Situation Assessment), which used mainly pre-1996 data, give estimates of groundwater potential and yield that are too low in the light of the more recent groundwater specific studies, namely the Queenstown Hydrogeological Map (DWAF 1998), the Chris Hani District Municipality Investigation by SRK (Du Plooy *et al*, 2002), and the investigation of the eco-geohydrology of the Qoqodala Ring Complex undertaken by the Council for Geoscience (Chevallier *et al*, 2004).

It was concluded from the recent groundwater specific studies that thorough hydrogeological investigation and scientifically based siting of exploration boreholes would result in wellfields each of which would be suitable to deliver up to 1 Mm^3/a.

3.3 REGIONAL GEOLOGY AND HYDROGEOLOGY

3.3.1 Geology

There are two main types of rocks in the study area, namely sedimentary rocks and magmatic intrusions. The spatial distribution is shown on the geological map in Figure 3.1.

The main sedimentary rocks in the study area are deposits of the Beaufort Group of the Karoo Supergroup. The Beaufort Group of the Karoo Supergroup is further sub-divided into five formations within the catchment, as described in more detail below. Young alluvium deposits are found in the valleys along the river courses. Descriptions of the characteristics of the geological formations follow :

Balfour and Middleton Formation

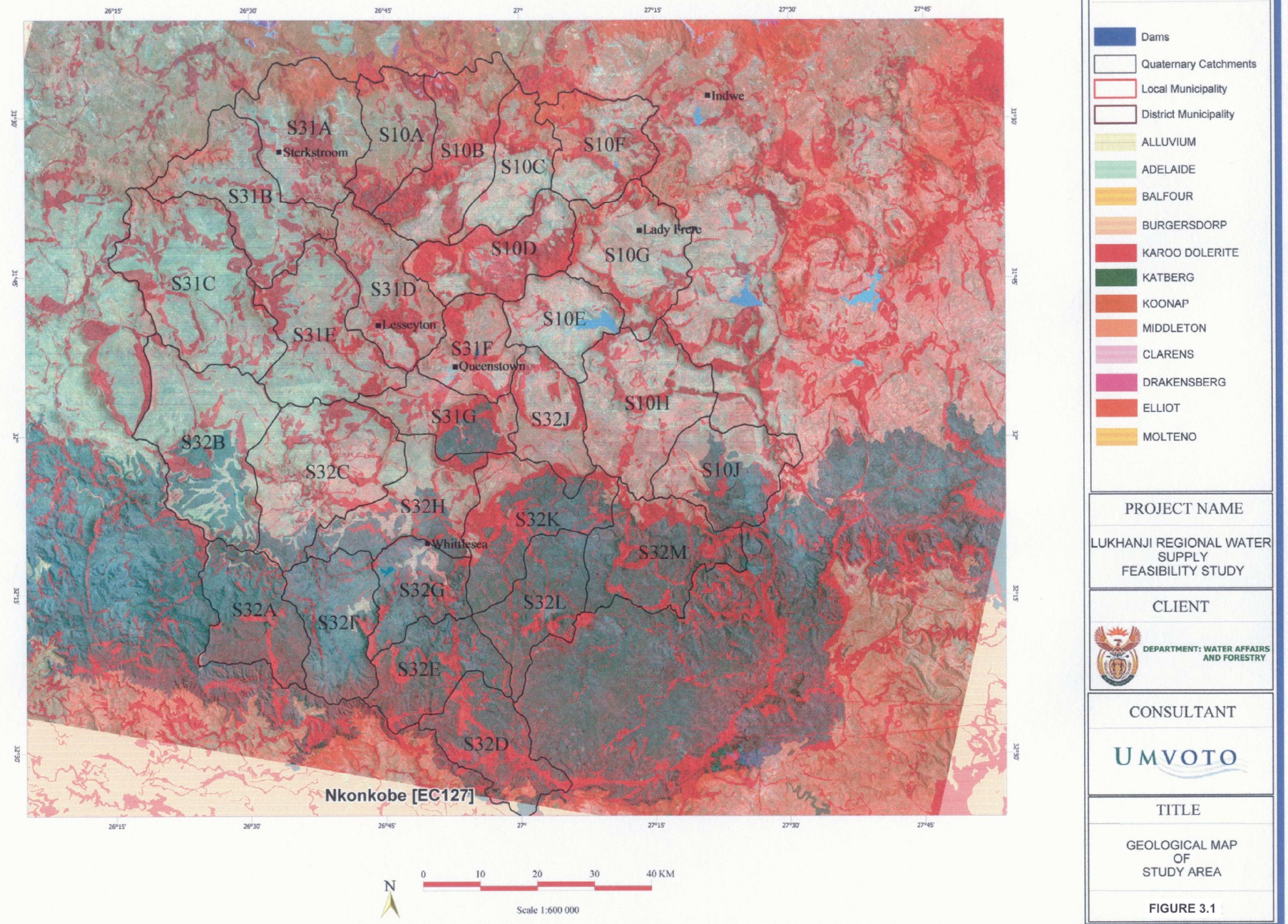
The oldest formations occurring in the region are the Middleton and Balfour Formations of the Adelaide Subgroup. Both are approximately 2 000 m thick and comprise mainly mudstone with multi-layered river channel sandstones. However, these rocks are not exposed within the study area.

Katberg Formation

The oldest formation exposed in the study area and predominant in the southern half of the study area is the sandstone-rich Katberg Formation. It consists of 500 m to 1 000 m thick, fine-grained to medium-grained massive sandstones. The Katberg Formation conformably overlies the Balfour Formation.

The Katberg Formation has a special hydrogeological significance (see Section 3.3.2 below). By virtue of its siliceous composition, thickness and mechanical strength relative to surrounding shale-rich units, it has substantial potential as a major fractured rock system in the region, within which open, hydraulically conductive apertures can persist to kilometre-scale depths beneath the superficial "fractured-and-weathered" zone.

Previous work (Groenewald, 1996) has noted the generally upward-fining character of the formation, which indicates that the preferred hydrogeological target zone would be in the lower parts of the sequence. These coarser-grained, lower Katberg sandstone units are best exposed in the higher mountains in the southern part of the study area, where they receive the highest mean annual rainfall in the region.



PROJECT NAME

LUKHANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY

CLIENT

DEPARTMENT: WATER AFFAIRS AND FORESTRY

CONSULTANT

UMVOTO

TITLE

GEOLOGICAL MAP OF STUDY AREA

FIGURE 3.1

Burgersdorp Formation

The northern part of the study area is predominated by the Burgersdorp Formation, which conformably overlies the Katberg Formation. The Burgersdorp Formation is mudstone rich with sandstone layers of typically 2 to 3 m thickness. The lower Burgersdorp Formation has a basal sandstone rich interval, while the upper Burgersdorp Formation has a top sandstone rich interval. Within the middle Burgersdorp Formation a laterally extensive sandstone layer, the so-called Middle Marker, is prominent. The total thickness of the Burgersdorp Formation in the Queenstown area is about 700 m. The middle part is best exposed at Nonesi's Nek road section, north east of Queenstown.

Molteno Formation

At the far northern part of the study area the Molteno Formation is exposed, which overlies the Burgersdorp Formation with a low angle unconformity. Mudstone and sandstone are the dominant rock types with varying composition, e.g. in some instances the sandstone content reaches 75%. The thickness of the formation is between 250 m and 450 m.

Alluvium

The valleys along the river courses are filled with alluvial material of different composition. The thickness is generally limited, rarely exceeding 2 m, except in the northern area, which is underlain by the Burgersdorp Formation, where the alluvium reaches up to 10 m in thickness.

Dolerite Intrusions

The sediments of the Karoo Basin were intruded by dolerites during magmatic activities (Jurassic or 180 Ma) that fed the Drakensberg flood basalt. The Karoo dolerites represent the roots and feeders of the Drakensberg basalts.

Two main categories of dolerite intrusion can be distinguished, *viz.* vertical dykes and sheets. The regional variations and spatial distribution of these two types is related to the stratigraphic level of the host rock.

Dykes in the study area are usually 1 to 10 m wide and several kilometers long. The most prominent direction of the vertical dykes is northwest (NW) to southeast (SE). Other major trends are NNE, NE and East to West. The E-W direction occurs mainly in the southern part of the catchment with long and thick (up to 300 m) dykes. Due to the higher resistance of the dolerites to weathering, the dykes often build long hills and visible landscape features.

The dykes often cut through the dolerite ring structures and the host rock, connecting large areas of otherwise separated aquifer units.

The topography of the study area is formed by dolerite sheets, mainly in the form of ring complexes. Flat lying, bedding plane sheets are called sills. These dolerite ring structures form the mountain ridges, with flat lying areas within the ring structure. The dolerite ring structures can be described as saucer-shaped (Chevalier *et al*, 2001). They comprise :

- The inner sill, within the ring structure
- The inclined sheet, building the ring structure
- The outer sill

The inner and outer sill are often intruded at different elevations. It is also common to find parallel layers of inner or outer sill within the ring structure.

According to Chevallier *et al* (2004):

- Extensive flat lying sills are intruded inside the Adelaide Subgroup;
- Large size dolerite ring complexes are intruded in the Katberg Formation;
- Smaller size dolerite rings are intruded in the Burgersdorp and Molteno Formation;
- Very few dolerite rings cut through the Elliot Formation.

3.3.2 Hydrogeology

Groundwater in the study area occurs mainly in fractured rock or fractured-intergranular aquifers, which are associated with dolerite intrusions. The conceptual model, presented by Smart (1998) indicates different types of aquifer settings:

- Aquifer in weathered zone of fractured rocks with
    - fractures concentrated in topographic lows
    - fractures at weathered to fresh rock transition zone

- Aquifer in highly fractured zone of the contact between dolerite intrusion and host rock with
    - fractures associated with dolerite dykes
    - fractures concentrated at curved portions of dolerite sheets
    - fractures associated with dolerite ring structures

- Aquifer in alluvium along river courses

Of these types, only the aquifers associated with dolerite intrusions are considered to have the potential of high yielding boreholes. The general trends of the groundwater potential and yield in these aquifers are summarised by Smart (1998) as follows:

- *Yields associated with dolerite intrusions are higher than those associated with sedimentary rocks only;*
- *Yield characteristics of dykes and sheets are broadly similar;*
- *Yields associated with dolerite intrusions are highly variable at both local and regional scale;*

- *Regions that have higher yields on average in the sedimentary rocks will also have correspondingly higher than average yields in the dolerite associated aquifers.*

The investigation by Chevallier *et al* (2004) verifies the statements from the Hydrogeological Map and further details the different aquifer settings associated with dolerite intrusions. They identified at least three distinct aquifer units within their study domain, the Qoqodala dolerite ring complex:

- A shallow, unconfined aquifer in the weathered zone above the inner sill with predominant horizontal to sub-horizontal bedding-plane fractures;
- A shallow, semi-confined to confined aquifer between the inclined sheet and the outer sill with fractures within the sediments and at the lithological contacts;
- A deeper, confined aquifer below the outer sill with discrete, open fractures developed at the contact of dolerite intrusion and sedimentary host rock, which produced the highest yields.

The two crucial keys to sustainable groundwater development and IWRM in the Lukanji region are (1) the ultimate storage capacity (both unconfined and confined) of the deeper Katberg fractured rock aquifer, especially along the Katberg dolerite contact hydrotects, and (2) its system recharge-discharge response characteristics in relation to the Katberg-Amatola summit range of highest precipitation in the region. These key hydrogeological factors inform the overall strategic direction of the present investigation, but more quantitative sub-surface information (e.g. from Soekor stratigraphic boreholes in the region, combined with new deep exploration drilling) is needed to support it.

On the largest scale, the Katberg aquifer has a wedge-like form, as it has its maximum thickness in the south along the Katberg-Amatola summit, in the area of greatest mean annual precipitation, and thins northwards beneath the Burgersdorp beds around and north of Queenstown. Because of the sub-horizontal to very low northward dip angles in this region, the targeting of the fractured sandstones and sandstone/dyke or sandstone/sill contacts at substantial depth beneath the Katberg-Burgersdorp (K-B) contact, i.e. in the more competent, coarser-grained lower part of the Katberg sequence, is probably feasible over wide areas along the sinuous surface trace of the K-B boundary.

The strategy for sustainable groundwater development and IWRM in the Lukanji area, and the concentration of Target Sites in this project to the south of Queenstown, is based on this fresh perception of the hydrogeological significance of the deeper, confined portions of the Katberg Formation, which directly underlies the major part of the study area. By comparison the Molteno Formation, which has previous recognition for its fractured rock potential, is located in the far northern part of the study area, is stratigraphically thinner and more shale-rich, has lesser surface exposure in mountain areas of high rainfall and potentially great recharge, and also has no sub-surface extensions in a southerly direction beneath the areas of most water demand.

3.4 HYDROCLIMATOLOGY

The study area falls in the summer rainfall area, with mean annual rainfall (MAP) varying between 1 000 mm in the mountains in the south-west and less than 500 mm in the north-west. In general, rainfall decreases from east to west, while evaporation increases in the same direction. The mean annual rainfall for Queenstown is listed as approximately 600 mm and the mean annual temperature as 15°C. Using published MAP values per quaternary catchment (Midgley *et al*, 1994) the total rainfall in the study area was calculated to be 6 431 Mm^3/a, of which only a small portion results in surface water runoff.

The spatial distribution of rainfall is orographically controlled, which results in higher rainfall in the regions of higher elevation. Since these are mainly formed by the dolerite intrusions, it can be expected that aquifers associated with dolerite intrusions receive higher recharge than the flat-lying alluvium or fractured rock aquifers. More importantly, the summits of the Katberg-Amatola range, formed by the resistant Katberg sandstone, receive the highest annual rainfall (~1000 mm) in this region. Chevallier *et al* estimated the recharge towards the dolerite aquifers as 6,4% of MAP on average, resulting in values of 35 to above 60 mm/a in the Qoqodala ring complex. Applying these ranges to the study area results in recharge of 411 Mm^3/a, which is far more than the estimated harvest potential of 160 Mm^3/a. With the lack of a more comprehensive and aquifer-specific recharge estimation, the exploitation potential as used in the WRSA (DWAF, 2002) was used for sustainable yield estimations (i.e. 97 Mm^3/a).

3.5 HYDROCHEMISTRY

The groundwater is generally of good quality with electric conductivity (EC) mostly below 70 mS/m, in some areas between 70 and 300 mS/m (Smart, 1998). The water is classified as Calcium Magnesium Bicarbonate water with some Sodium and Chloride enrichment, indicating active groundwater circulation.

A detailed analysis of chemistry data from the National Groundwater Database (NGDB) verifies this finding. As indicated in Figure 3.2a, the EC of the groundwater is generally below 100 mS/m, in some cases between 100 and 150 mS/m, and only few samples were above 150 mS/m.

The pH for the groundwater mostly ranges within slightly above neutral levels of pH 7.2 – 8.6. The majority of samples had pH readings between 7.5 and 8 (see Figure 3.2b). However, some areas indicate a more basic range of pH 8 – 8.5 possibly linked to variables such as current land use activities (cattle farms, grazing lands) and vegetation ecosystems (grasslands, savanna and forests).

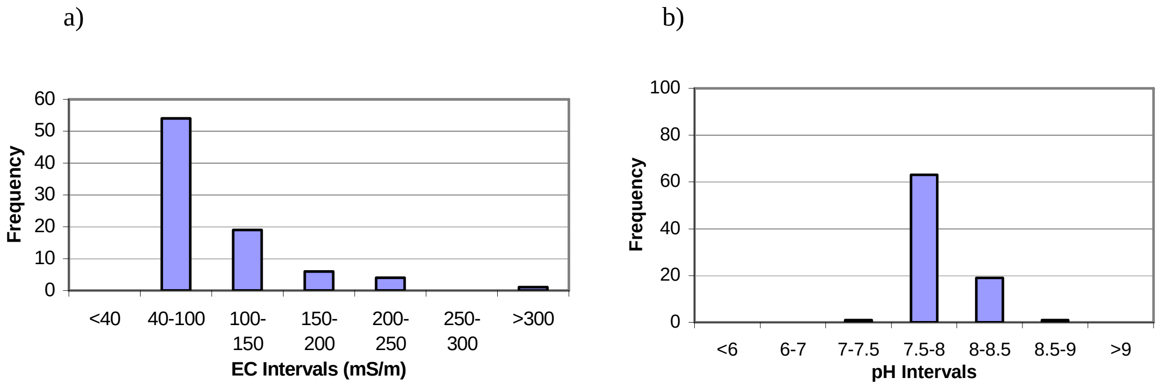


Figure 3.2 Histogram of chemical data; a) EC measurements, b) pH measurements

Nitrates, expressed as nitrogen analysis levels, mostly occur within a range up to 5 mg/ℓ. In some areas the SABS maximum acceptable level of 10 mg/ℓ (DWAF, 1993) is exceeded as levels range to above 60 mg/ℓ. Nitrate pollution from cattle excrement and downward leaching of nitrogenous fertilizers are likely contributors to high nitrate levels.

Chloride levels vary mainly within 10 – 100 mg/ℓ with some areas between 100 – 600 mg/ℓ. Higher chloride levels are linked with the enrichment of the water type of the area due to ionic exchange in the groundwater flow paths (Smart, 1998).

3.6 GROUNDWATER DEVELOPMENT OPTIONS

3.6.1 Hydrogeological Analysis

The concept of "groundwater resource potential" Vegter (1995) embraces the following and these factors must be considered (inter alia) when evaluating a potential scheme:

- Accessibility - aquifer depth and drilling risk;
- Exploitability - yield and pumping depth;
- Availability - resource (i.e., storage) and recharge;
- Suitability - chemistry and risk of pollution; and
- Conservation - size and hydrodynamic situation.

Accessibility has been defined as the "probability of drilling a successful borehole" (i.e., one having a yield of at least 0,1 ℓ/s)", and it has been estimated on the basis of "country-wide government-sponsored drilling operations over the past eighty years on non-scientifically selected sites" (Vegter, 1995). Recent work in the Olifants-Doring WMA and in Hermanus, Western Cape and in the Eastern Cape (Qoqodala study and others) has illustrated that a scientific approach to borehole siting yields different standards of "success", substantially greater than the 0,1 ℓ/s threshold.

Exploitability is defined as the "probability of obtaining a yield equal to or exceeding 2,0 ℓ/s" (*op. cit*.) and in the context of urban and commercial irrigation supply, rather than (emergency) rural supply is a modest threshold.

In terms of a revised definition of Accessibility, Exploitability must be a function of proposed drilling depth, expected yield as well as dynamic head. Only the former two elements are addressed at the conceptualisation level of this study.

The focus during this study, is to identify target zones and particular sites where accessibility and exploitability are reasonably assured and secondly, on the preliminary (unless already documented in available reports) estimation of water availability. The latter is considered with due regard also for its suitability for different uses.

There is another aspect to availability that depends on whether or not the resource is replenished periodically; groundwater may be exploited either as a renewable or a non-renewable resource. The ultimate limit to which a non-renewable resource can be exploited (or "mined") is storage. Sharp (1999) defines it as "water contained within an aquifer or within a surface-water reservoir". This definition emphasises the point that groundwater in aquifer storage has to bridge the gaps between replenishment events, just as a dam supplies water during times when the river ceases to flow. A risk management approach is required to manage aquifer storage over more than an annual cycle. This is beyond the scope of work in this study but in general should be included even at conceptualisation level.

The ultimate limit to a perennial supply is replenishment, also termed recharge, defined (Sharp, 1999) as "the process by which water enters the groundwater system or, more precisely, enters the phreatic zone" (i.e. the zone beneath the water table). The process may occur in two possible modes, (1) by infiltration from stream and river flow, and (2) by direct infiltration of rainfall or precipitation (e.g. snow).

In both cases the quantification of recharge must be purposefully pursued (Vegter, 1995; Bredenkamp *et al*, 1995). Whatever the methods of recharge estimation that are used (GIS-based modelling methods and or more traditional chemical and/or isotopic approaches), it is advisable that the estimates and the associated issues of sustainability of particular aquifers are refined on an ongoing basis with a substantial level of groundwater abstraction from, and monitoring of, those aquifers as well as the relevant hydroclimatic factors.

The concept of suitability refers to "fitness for use" as well as aquifer vulnerability. The study has evaluated available hydrochemical data on the NGDB database with respect to different geological units. The data indicates that the aquifers are of general good water quality.

Conservation, in the strictly hydrogeological sense of Vegter (1995), involves issues of storage ("size") and recharge-flowpath-discharge considerations ("hydrodynamic situation"). In a wider sense, it is an issue in terms of which questions are raised about the longer-term ecological impact of groundwater resource exploitation and this is addressed in Section 3.7.

3.6.2 Target Areas

All previous investigations highlighted the fact that groundwater occurrence in the study area is mainly associated with intrusions of dolerites, either as dykes or sills. The intrusions result in intense fracturing of the host rock at the contact zone.

As outlined in Section 3.3 the type of sedimentary rocks changes between Queenstown and Sada-Whittlesea from the mudstone of the Burgersdorp Formation in the Queenstown area to the Katberg sandstone in the Sada-Whittlesea area. The Katberg sandstone is considered to have the higher storage potential due to a much greater depth-persistence of fracture porosity and higher fracture permeability. Therefore the focus of the target generation was to identify target areas (Figure 3.3) that comply with the following conditions:

- Associated with extensive dolerite dykes
- Katberg sandstone as host rock
- Close to existing or planned water supply infrastructure
- Within the boundary of the Lukanji local municipality
- Within the S32 catchment, to avoid unnecessary pumping costs

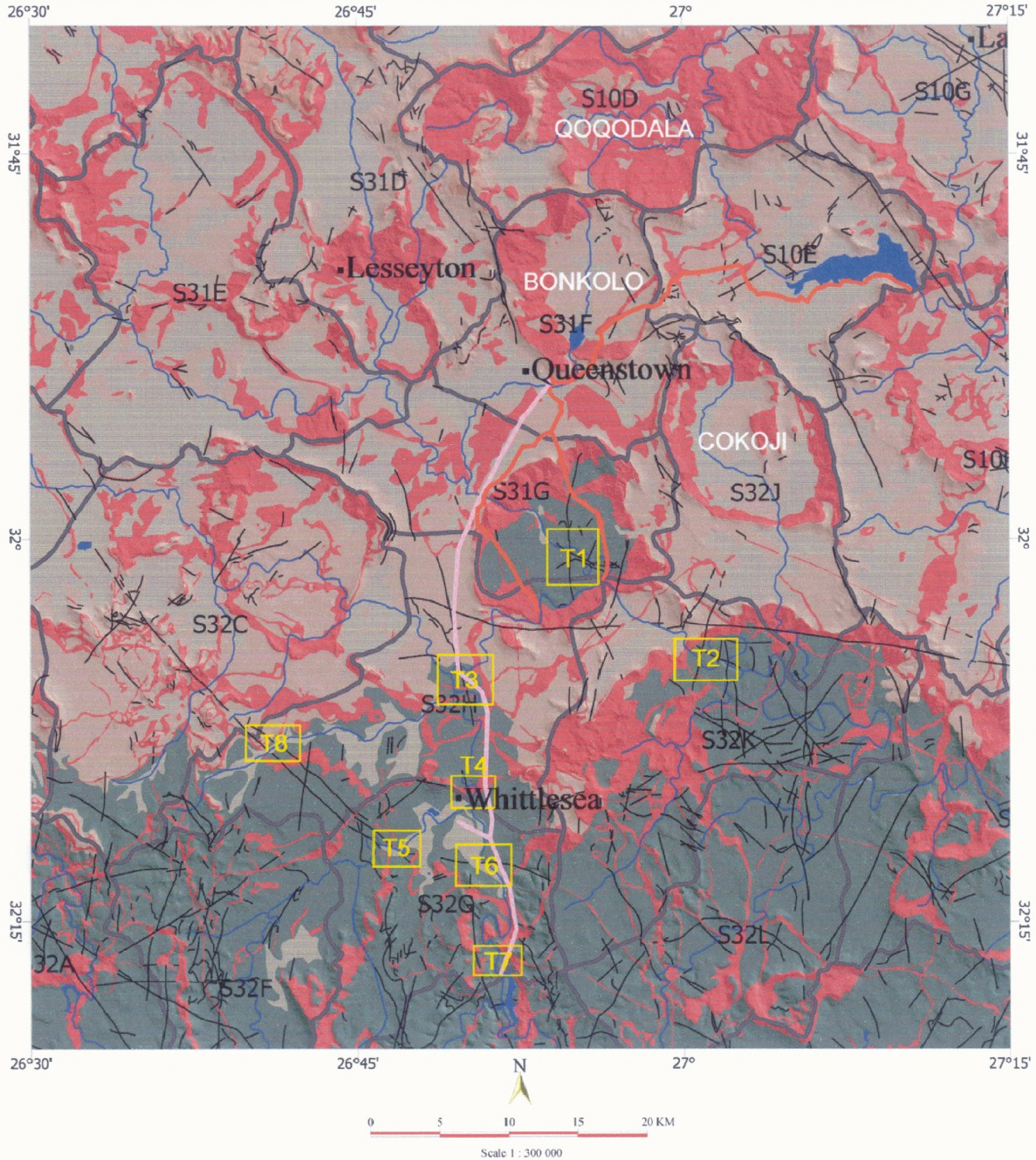
However, additional target areas associated with dolerite ring structures were identified in the proximity of Queenstown (see Section 3.6.2.2 below).

3.6.2.1 Target Areas Associated with Dolerite Dykes

The desktop study identified eight potential target areas for groundwater development, associated with dolerite dykes, most of which are situated within ring structures or are associated with dolerite sheets or sills (see Figure 3.3.).

- Target area T1 is situated about 12 km south of Queenstown near the confluence of the Black Kei and Klaas Smits Rivers. The hydrogeological target is the fractured-rock aquifer of the Katberg sandstone, associated with NW trending dykes within a dolerite ring intrusion. The two NW trending dykes intersect with a N-S striking dyke. Possible aquifers are a shallow aquifer above the inner sill or a deeper, confined aquifer below the inner sill.

- Target area T2 is situated just downstream of T1 at the northern boundary of the Cathcart dolerite ring structure. The Cathcart ring is the largest such structure in the region, and is mainly confined within the outcrop boundaries of the Katberg Formation. The southern rim of this huge structure forms part of the Katberg-Amatola summit ridge of high annual rainfall. The potential aquifer at T2 is the Katberg sandstone along a NW trending dyke on the inner side of the inclined dolerite sheet. The NW trending dyke intersects a N-S striking dyke. In addition, a complex system of inclined sheets and inner sills results in a nested, ring-within-ring structure.



LEGEND

- Towns
- Rivers
- Augmentation Scheme (Planned)
- Augmentation Scheme (Existing)
- Dykes
- Dams
- Quaternary Catchments
- Target Areas
- ALLUVIUM
- BURGERSDORP
- KAROO DOLERITE
- KATBERG

PROJECT NAME

LUKHANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY

CLIENT

DEPARTMENT: WATER AFFAIRS AND FORESTY

CONSULTANT

UMVOTO

TITLE

TARGET AREAS

FIGURE 3.3

- Target area T3 is located between Sada-Whittlesea and Queenstown at the confluence of the Black Kei River and Klipplaat River. The Katberg sandstone is the predominant formation, while the Lower Burgersdorp Formation with its sandstone rich layers outcrop in the northern part of T3. The potential aquifer is associated with a N-S trending dyke and several E-W trending inclined dolerite sheets. The target area is adjacent the existing pipeline from the Waterdown Dam to Queenstown.

- Target area T4 is located just north of Sada-Whittlesea along a NNW trending dyke, intersecting an inclined sheet. The T4 target area lies close to or within the NW periphery of the Cathcart ring. The ring structure is not dominant in this area; however, the occurrence of inner and outer sills can be assumed. The sedimentary rock in which the dolerite is embedded is mainly sandstone belonging to the Katberg Formation. The target area is adjacent the existing pipeline from the Waterdown Dam to Queenstown.

Target area T5 is located a few kilometres southwest of Sada-Whittlesea along the Oxkraal River and is also in the NW periphery of the Cathcart ring. The target is comprised of two major NW trending dykes intersecting an inclined dolerite sheet within the Katberg sandstone. This target could supply water direct to Sada-Whittlesea or via connection to the main pipeline to Queenstown.

Target area T6 also in the NW periphery of the Cathcart ring, is situated south of Sada-Whittlesea along the Klipplaat River, and is comprised of an E-W trending dyke on the probable outer side of an inclined dolerite sheet. The pipeline from the Waterdown Dam runs parallel to the river through the eastern part of T6.

Target area T7 is located just below the Waterdown Dam. The eastern part of T7 is characterised by the inclined sheet of the Cathcart dolerite ring (or a nested ring within its western margin (Figure 3.3)), while NNW trending dykes run through its western part.

Target area T8 is located west of T3 along the Hukuma River. As at T3, it is at the contact between the Katberg and the Burgersdorp Formations. It features the same two NW trending dykes as identified in T5 intersecting inclined dolerite sheets.

3.6.2.2 Target Areas Associated with Dolerite Ring Structures

All the above target areas are associated with dolerite dykes and or dolerite sheets in the Katberg sandstone, and therefore are located south of Queenstown and towards Sada-Whittlesea. Possible target areas around and north of Queenstown do not fully comply with the criteria listed above, as they are associated with dolerite intrusions in the Burgersdorp Formation. However, for comparison some of these areas are described below (see Figure 3.3).

Qoqodala Ring

The Qoqodala ring complex is situated north of Queenstown within the S10D quaternary catchment. The geological and hydrogeological structure was investigated in detail by Chevallier *et al* (2004). This dolerite ring is a complex system of several layers and inclined sheets of dolerite intrusions within the Burgersdorp mudstone. Chevallier *et al* (2004) estimated a sufficient yield for bulk water supply and suggested developing the groundwater resource for rural upliftment. Since the catchment boundary between the S10 and S31 tertiary catchments runs between the Qoqodala ring and Queenstown, a supply to Queenstown is not considered feasible.

Bonkolo Ring

The Bonkolo dolerite ring is located directly north of Queenstown within the S31F quaternary catchment (south of Qoqodala). The geological structure is assumed to be similar to the Qoqodala ring structure (based on the cross-section from Chevallier *et al*, 2004). There are intensive farming activities within the flat area of the ring and the NGDB indicates a dense distribution of boreholes. Furthermore, the Bonkolo Dam captures surface water runoff from the ring for bulk water supply to Queenstown.

Although the Water Resource Situation Assessment (DWAF, 2002) does not indicate an over utilisation of groundwater in the S31F catchment, the intensive farming activities and the dense distribution of boreholes show a high reliance on groundwater supply. An additional wellfield would most probably not deliver sufficient water on a sustainable basis to warrant the investment.

Cokoyi Ring

The Cokoyi ring is a dolerite ring of similar structure to Qoqodala and Bonkolo, and is located a few kilometers east of Queenstown within the S32J quaternary catchment. The Macibini River runs through the catchment towards the Black Kei. At the lower part of the catchment and the southern edge of the ring structure is an existing wellfield to supply potable water to Ilinge. It is unlikely that an additional wellfield within the ring structure would be sustainable, given the management problems with the existing wellfield.

These ring structures are not considered further in the investigation, as they are either already utilised (Bonkolo and Cokoyi) or the distance and hydraulic head render the target site not feasible for urban supply to Queenstown (Qoqodala).

3.7 ENVIRONMENTAL CONSIDERATIONS

A field visit of the target areas was undertaken to verify the findings from the desktop study and to clarify environmental and economic considerations.

3.7.1 Hydrocensus Information

The hydrocensus information gathered during the field visit was complemented with available data about the water use in the specific area. Sources for these data are:

- The National Groundwater Database, containing borehole information, e.g. yield, water use, depth, chemistry
- The Water Resources Situation Assessment, containing summaries of water use per quaternary catchment

Within the study area groundwater is extracted mainly for domestic and agricultural use, supplied either from boreholes or protected springs (DWAF, 1993). Increasing population growth and the availability of Eskom power pressurises these types of water supply. In conjunction, variable amounts of groundwater are extracted for stockwatering, estimated at about 2,6 M m^3/a (DWAF, 1993). The total use of groundwater in the study area is estimated at ~12 M m^3/a, with the highest amount used in the S31E catchment.

Borehole depths average 53 m, with maximum yields of up to 12 ℓ/s. The range of borehole depths varied between 20 and 100 m with an average yield of 1,1 ℓ/s, and very few boreholes exceeding 4 ℓ/s. Borehole yields in relation to depth below surface show a significant variation with depth. Average water level for the region was 16,5 m below ground (mbg).

A detailed description of each target area is given in Appendix 5.

3.7.2 Sensitive Ecosystems

Chevallier *et al* (2004) indicate a high dependency of springs and wetlands on groundwater from dolerite associated aquifers. However, the hydrocensus and the existing database on springs in the catchment do not indicate any potentially groundwater dependent ecosystems in the vicinity of the target areas.

Should the development in specific target areas go ahead, it is suggested that the occurrence of springs and wetlands in the vicinity of the target areas be investigated.

3.8 FINAL SELECTION OF TARGET AREAS

The eight selected target areas were ranked according to the following criteria:

- Verification of geological and hydrogeological characteristics
- Current groundwater development and use
- Proximity to existing infrastructure

Based on the criteria above, the following five target areas are suitable for augmenting the existing water supply to Queenstown and Sada-Whittlesea:

- T1 – favourable hydrogeological structure, but distant from existing infrastructure
- T3 – proximity to existing pipeline, but existing groundwater use

- T4 – proximity to Sada-Whittlesea and existing pipeline
- T5 – proximity to Sada-Whittlesea
- T6 –hydrogeological structure, proximity to Sada-Whittlesea and existing pipeline

Although the geological and hydrogeological characteristics of the remaining target areas are ranked high, they are not considered for augmentation to urban supply due to expected high capital costs for the development.

In addition to the above list, the target areas T2 and T8 should be considered for rural water supply, if the need arises in the close vicinity. However, in further discussions and costing of options, these target areas are omitted.

Because of the rough terrain and possible access problems, target area T7 is not considered further.

3.9 COSTING OF POSSIBLE WELLFIELDS

3.9.1 Approach To Estimating Costs

For the study the costs for the proposed wellfield development had to be estimated. Since the hydrogeological investigation was undertaken on a pre-feasibility level, assumptions with regard to pertinent parameters are required:

- potential yield
- borehole depth
- distance between boreholes
- total size of wellfield
- wellfield capacity

The assumptions and proposed unit costs for the scenario calculations are described in the sections below. For this detailed costing exercise only the priority target areas are considered:

- T1 – confluence of Black Kei and Klaas Smits River
- T3 – Between Sada-Whittlesea and Queenstown
- T4 – North of Sada-Whittlesea
- T5 – South east of Sada-Whittlesea
- T6 – South of Sada-Whittlesea

3.9.2 Unit Costs

Since a groundwater development project differs significantly from other civil engineering projects, the unit costs and percentages for contingency and professional fees were established independently of unit costs for surface water schemes. Tables 3.1 to 3.6 show the unit costs, used in calculating the civil capital costs for the different scenarios of the wellfield development.

The unit costs for borehole construction (see Table 3.1) depend upon several factors (e.g. required depth, lithology, required end-diameter), most of which are unknown or uncertain. The proposed unit costs per meter are based on costs of recent drilling projects in a similar geological environment and include :

- establishment on site;
- drilling in different diameters;
- installation of steel casing, if required;
- installation of PVC casing;
- construction of wellhead.

The unit costs for pump testing (see Table 3.1) depend upon the expected yield of the borehole. It was assumed that each production borehole would be tested according to the SABS standards. In addition a longer-term wellfield test for each wellfield is proposed and calculated.

TABLE 3.1 UNIT COSTS AND ASSUMPTIONS FOR BOREHOLE DRILLING AND PUMP TESTING

DESCRIPTION	YIELD ℓ/s	DEPTH DRILLING M	UNIT PRICE R/m	DRILLING COSTS R/BH	PUMP-TESTING R/Test
1 Borehole, Production	2	150	700.00	105 000.00	1500.00
1 Borehole, Production	5	200	800.00	160 000.00	2000.00
1 Borehole, Monitoring		150	600.00	90 000.00	
1 Wellfield					100 000.00

The capital costs for the borehole pumps (see Table 3.2) depend upon the assumed yield and the required hydraulic head. For all wellfields a hydraulic head of 50 m was assumed.

The electricity costs are calculated using the current Eskom tariff structure.

TABLE 3.2 UNIT COSTS AND ASSUMPTIONS FOR PUMP INSTALLATION AND RUNNING COSTS

DESCRIPTION	YIELD ℓ/s	ELECTRICITY REQUIREMENT. KW	UNIT PRICE R/KWh	RUNNING COSTS R/BH/h	PUMP-COSTS R/Pump
1 Borehole, Production	2	20	0.140	2.81	30 000.00
1 Borehole, Production	5	30	0.140	4.21	40 000.00

The required pipe diameter for the pipelines within the wellfields depends upon the assumed flow rates, as estimated above. The costs for the pipelines (see Table 3.3) are based on costs from

2003 and include the capital cost and all work required for installation, e.g. trenching, valves, manholes. Since the latter is proportionally higher for small pipeline diameters and the choice of pipeline diameter within the wellfield may be arbitrary, all pipelines smaller than 100 mm are assumed the same unit costs as the 100 mm pipeline.

TABLE 3.3 UNIT COSTS AND ASSUMPTIONS FOR PIPELINES WITHIN THE WELLFIELDS

DESCRIPTION	FLOW ℓ/s	AVERAGE VELOCITY m/s	REQUIRED PIPE DIA. mm	PIPE DIAMETER mm	PIPE COST R/m
1 Borehole, small	2	1.5	41.2	50.0	420.00
1 Borehole, big	5	1.5	65.1	75.0	420.00
1 Wellfield, safe	10	1.5	92.1	100.0	420.00
1 Wellfield, realistic 1	20	1.5	130.3	200.0	880.00
1 Wellfield, realistic 2	40	1.5	184.3	200.0	880.00

For the annual maintenance the percentages normally used in DWAF studies are applied (see Table 3.4).

TABLE 3.4 PERCENTAGES FOR MAINTENANCE COSTS

DESCRIPTION	MAINTENANCE	
	CIVIL	MECHANICAL ELECTRICAL
1 Wellfield	0.25%	4%

The percentages for Site Establishment, Contingencies and Professional Fees, as used in civil engineering projects, are not applicable for a groundwater development project. Therefore they are adjusted accordingly (see Table 3.5). The main reasons are:

- During drilling and pump testing, which are the main activities for a wellfield development, no additional site establishment costs occur, as these are already included in the unit costs.
- Because of the incremental approach for wellfield development the contingencies are increased at this stage of the project.
- Since the investigation was undertaken at a pre-feasibility level, additional investigation, planning and supervision is required during the exploration and establishment phases.

TABLE 3.5 PERCENTAGES FOR SITE ESTABLISHMENT, CONTINGENCIES AND PROFESSIONAL FEES

DESCRIPTION	ADDITIONAL COSTS		
	SITE ESTABLISHMENT	CONTINGENCIES	PLANNING AND SUPERVISION
1 Wellfield	1%	25%	30%

In addition to the unit costs listed in Tables 3.1 to 3.5, fixed costs for power supply and access routes to the proposed wellfields and costs for compliance with environmental regulations are included in the different scenarios (see below).

3.9.3 Wellfield Development Costs

The costing of the different wellfield options was undertaken only for the selected target areas, that is T1, T3, T4, T5 and T6. Based on the assumptions mentioned above and a general wellfield design within the target area, the development costs and the operational costs are calculated for two different yield scenarios. Scenario 1 (see Table 3.6) assumes a total yield of 0.6 Mm^3/a and a borehole yield of 2 ℓ/s, while Scenario 2 (see Table 3.7) assumes a total yield of 1.2 Mm^3/a and a borehole yield of 5 ℓ/s.

The development costs include capital costs, the professional fees and environmental services. Environmental services are estimated based on experiences on other water supply projects, mainly involving surface water structures and major infrastructure.

No allowance in the capital costs was made for 'dry' boreholes, because all boreholes drilled will be sited and drilled in stages from exploration to production. Exploration boreholes can either become production boreholes, if successful, or monitoring boreholes. The increased contingencies and professional fees account for this approach.

The site establishment costs include R100,000 per wellfield for constructing access roads and to permanently supply electricity.

The running costs include electricity for the pumps and general maintenance. Additional operational costs, such as monitoring or water treatment were not costed at this stage of the project, as it is assumed that these will be the same for all options.

The Unit Reference Value (URV) is calculated according to the DWAF model with a discount rate of 6% for a period of 50 years.

TABLE 3.6 COST CALCULATION FOR SCENARIO 1 (BOREHOLE YIELD OF 2 ℓ/s)

SCENARIO 1	BOREHOLE YIELD OF 2 ℓ/s AND WELLFIELD YIELD OF 0.63 Mm^3/a				
	T1	T3	T4	T5	T6
Yield (ℓ/s)	20	20	20	20	20
Yield (Mm^3/a)	0.63	0.63	0.63	0.63	0.63
Pump-Boreholes	10	10	10	10	10
Stand-by Boreholes	2	2	2	2	2
Monitor-Boreholes	10	10	10	10	10
Wellfield Pipelines (km)	4	4	2	3	3
Pipeline to supply point (km)	8	0.5	1	6	0.5
Costs Construction	11,145,000	4,545,000	4,145,000	8,965,000	4,125,000
Costs Equipment	330,000	330,000	330,000	330,000	330,000
Preliminary and General	214,750	148,750	144,750	192,950	144,550
Contingencies	2,922,438	1,255,938	1,154,938	2,371,988	1,149,888
Sub-Total	14,612,188	6,279,688	5,774,688	11,859,938	5,749,438
Professional Fees	4,383,656	1,883,906	1,732,406	3,557,981	1,724,831
Environmental services	757,955	466,416	455,691	726,619	455,149
Total Development Costs	**19,753,799**	**8,630,009**	**7,962,784**	**16,144,537**	**7,929,418**
Electricity/a	245,981	245,981	245,981	245,981	245,981
Maintenance/a	41,063	24,563	23,563	35,613	23,513
Total Running Costs	**287,043**	**270,543**	**269,543**	**281,593**	**269,493**
URV [R/m^3]	**2.78**	**1.44**	**1.36**	**2.35**	**1.36**

TABLE 3.7 COST CALCULATION FOR SCENARIO 2 (BOREHOLE YIELD OF 5 ℓ/s)

SCENARIO 2	BOREHOLE YIELD OF 5 ℓ/s AND WELLFIELD YIELD OF 1.26 Mm^3/a				
	T1	T3	T4	T5	T6
Yield (ℓ/s)	40	40	40	40	40
Yield (Mm^3/a)	1.26	1.26	1.26	1.26	1.26
Pump-Boreholes	8	8	8	8	8
Stand-by Boreholes	4	4	4	4	4
Monitor-Boreholes	12	12	12	12	12
Wellfield Pipelines (km)	4	4	2	3	3
Pipeline to supply point (km)	8	0.5	1	6	0.5
Costs Construction	11,836,000	5,236,000	4,836,000	9,656,000	4,816,000
Costs Equipment	360,000	360,000	360,000	360,000	360,000
Preliminary and General	221,960	155,960	151,960	200,160	151,760
Contingencies	3,104,490	1,437,990	1,336,990	2,554,040	1,331,940
Sub-Total	15,522,450	7,189,950	6,684,950	12,770,200	6,659,700
Professional Fees	4,656,735	2,156,985	2,005,485	3,831,060	1,997,910
Environmental services	767,977	485,262	474,879	737,170	474,355
Total Development Costs	**20,947,162**	**9,832,197**	**9,165,314**	**17,338,430**	**9,131,965**
Electricity/a	295,177	295,177	295,177	295,177	295,177
Maintenance/a	43,990	27,490	26,490	38,540	26,440
Total Running Costs	**339,167**	**322,667**	**321,667**	**333,717**	**321,617**
URV [R/m^3]	**1.50**	**0.84**	**0.80**	**1.29**	**0.79**

Based on the cost scenarios it is clear that the target areas close to the existing infrastructure are most favourable and feasible. However, for a decision on phasing of the groundwater development other criteria need to be taken into account as well. It is recommended that exploration and development should commence in target areas close to Sada-Whittlesea, as these could be developed either for local supply or for augmentation of the water supply to Queenstown, depending upon the results of initial investigations and exploration drilling.

3.10 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from the results of the desktop investigation, coupled with limited field verification :

a) The WRC study on the eco-hydrology in the Qoqodala dolerite ring (Chevallier *et al,* 2004) demonstrates the occurrence and potential of fractured rock aquifers associated with dolerite intrusions.
b) The Katberg sandstone formation has a good, until now unleashed potential as an aquifer for water supply to both rural areas and urban settlements.
c) The highest yield can be expected within the contact zones of the Katberg sandstone and dolerite intrusions, especially associated with dolerite dykes and inclined sheets.
d) The groundwater potential of ~80 Mm^3/a within the study area is currently under-utilised.
e) The desktop study identified eight potential target areas, of which five are selected for further investigation and exploration. Based on estimated costs, location and hydrogeological prospect these are in priority order:

- T6 – south of Sada-Whittlesea (ranked highest because of lowest costs and favourable hydrogeological conditions)
- T4 – north of Sada-Whittlesea
- T1 – confluence of Black Kei and Klaas Smits River (ranked higher because of most favourable hydrogeological conditions and different location – outside of T4 and T6 catchment)
- T5 – south west of Sada-Whittlesea (ranked higher than T3 because of proximity to Sada-Whittlesea and possibility of local supply)
- T3 – between Sada-Whittlesea and Queenstown (ranked lowest because of uncertain hydrogeological conditions)

f) Each of the target areas is expected to sustainably deliver 0,5 to 1 Mm^3/a.

g) The URV for the different options vary from R0,79/m^3 to R2,78/m^3, depending on the distance of the target area to the existing infrastructure and the assumed yield.

Based on the findings of the study and the above-mentioned conclusions, it is recommended that, if it is decided to commence with a more detailed hydrogeological investigation and exploration program in the priority target areas, the procedure should be as follows:

i) Commence with an exploration program in target areas T4 and T6, since both can be developed either for local supply to Sada-Whittlesea or to augment the supply to Queenstown via the existing pipeline from the Waterdown Dam. The geological structure and hydrogeological prospect in T6 is particularly favourable.
ii) A detailed hydrogeological investigation in target area T1 should be commissioned to verify the prospects of groundwater supply to Queenstown. This target area also offers a good opportunity for conjunctive use, should a small balancing dam be constructed at the Klaas Smits River.
iii) Depending upon the findings of the exploration under i) and ii) the target areas T3 and T5 should be explored further.
iv) Hydrogeological investigations should commence in target areas T2 and T8, since both are very favourable with respect to the geological and hydrogeological characteristics.
v) The exploration program in the priority target areas should comprise of :

- Detailed field work and geological mapping,
- Mapping of groundwater dependent ecosystems,
- Borehole siting for exploration and future production boreholes,
- Drilling of exploration boreholes,
- Geological and geophysical logging of exploration boreholes,
- Testing of exploration boreholes.

vi) The subsequent wellfield development comprises of :

- Siting and drilling of production boreholes,
- Development of monitoring network, including drilling and equipping of monitoring boreholes,
- Installation of selected pumps in production boreholes and connection of pumps to main delivery pipeline,
- Licensing of wellfield, including environmental impact assessment for authorisation of listed activity according to the Environmental Conservation Act (ECA).

4. EXISTING WATER SUPPLY SCHEMES

4.1 OVERVIEW

As discussed in Chapter 2, the Lukanji Surface Water Resources System supplies raw water to the urban areas of Queenstown and Sada-Whittlesea, the rural villages of Yonda and Mbekweni, and a number of irrigation schemes.

The town of Ilinge is currently supplied from boreholes, as are many of the rural villages in the area. Supplies to rural villages do not fall within the scope of this study, except where they are situated close to urban areas and can feasibly be included in the urban water supplies.

The water supply schemes that rely on the Lukanji Surface Water Resources System are:

- The Queenstown Water Supply Scheme
- The Sada-Whittlesea Water Supply Scheme
- The Upper Klipplaat Irrigation Scheme
- The Klipplaat River Government Water Scheme
- The Zweledinga Irrigation Scheme
- The Oxkraal Irrigation Scheme
- The Nthabethemba and Associated Irrigation Schemes
- The Klaas Smits River Irrigation Scheme
- The Xonxa Irrigation Scheme

In addition, as mentioned above, Ilinge is supplied from boreholes. However, this supply has proved to be unreliable in recent years and it is understood that the Lukanji Municipality intends to eventually supply Ilinge from the Queenstown Water Treatment Works.

The supply areas of the different water supply schemes are shown on Figure 4.1 and their main characteristics are summarised in Table 4.1. More detailed descriptions of the schemes and discussion of their present and expected future water requirements are given below.

4.2 THE QUEENSTOWN, SADA-WHITTLESEA AND ILINGE WATER SUPPLY SCHEMES

Queenstown receives raw water from Bonkolo Dam and from Waterdown Dam, while Sada-Whittlesea is supplied from Waterdown Dam only.

Water from Bonkolo Dam is supplied through a gravity pipeline to Berry Dam, a small balancing reservoir of about 0,3 Mm^3 capacity, and from there to the Queenstown Water Treatment Works. The pipeline from Bonkolo Dam consists of a short length of 450 mm diameter steel piping followed by 500 mm diameter fibre cement piping. The capacity of the pipeline is about 0,25 m^3/s (21,6 Mℓ/d) when Bonkolo Dam is at its minimum operating level (QRWSFS).

The water treatment works has a capacity of 42 Mℓ/day.

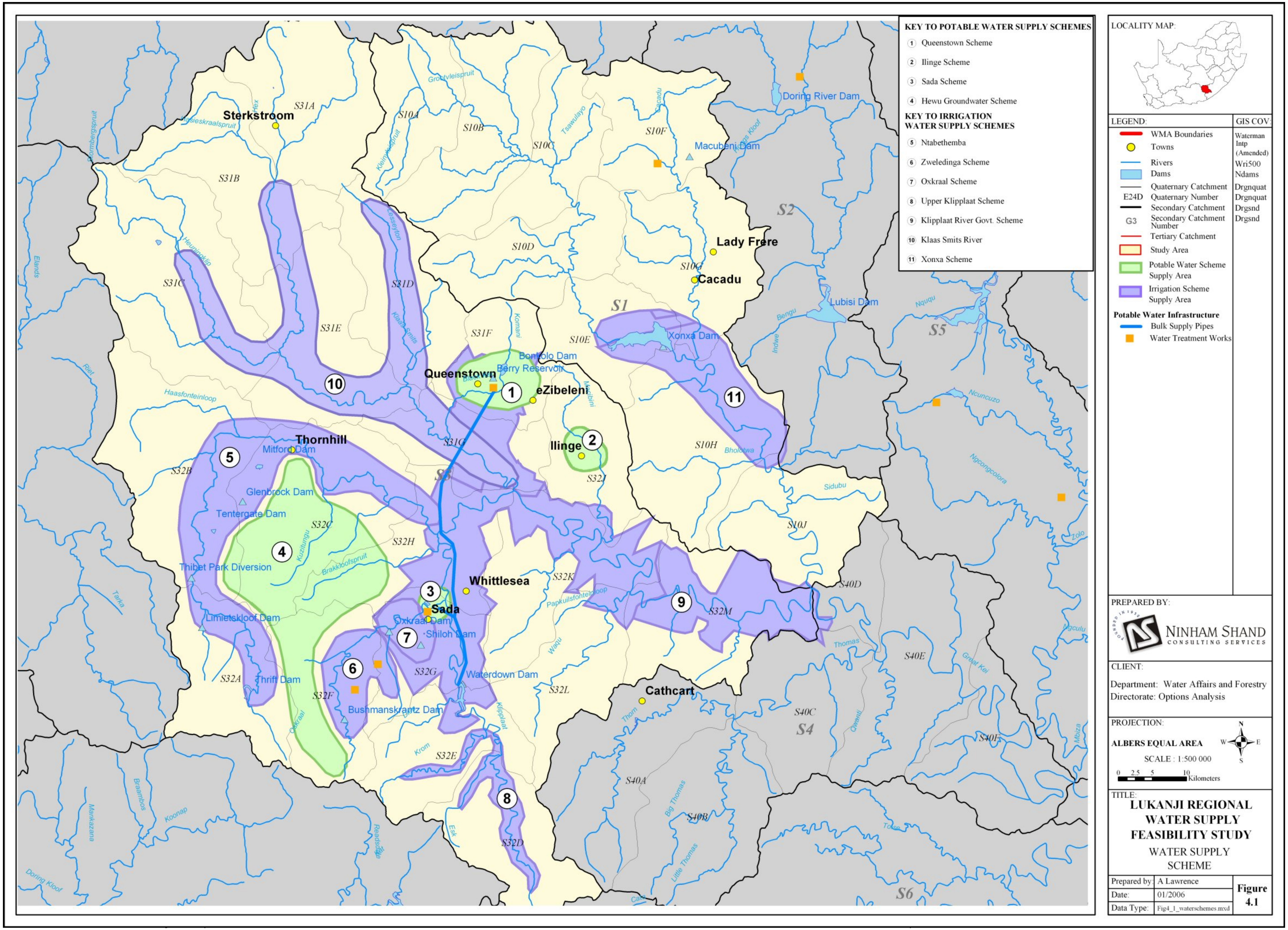

KEY TO POTABLE WATER SUPPLY SCHEMES
1 Queenstown Scheme
2 Ilinge Scheme
3 Sada Scheme
4 Hewu Groundwater Scheme
KEY TO IRRIGATION WATER SUPPLY SCHEMES
5 Ntabethemba
6 Zweledinga Scheme
7 Oxkraal Scheme
8 Upper Klipplaat Scheme
9 Klipplaat River Govt. Scheme
10 Klaas Smits River
11 Xonxa Scheme
LOCALITY MAP:
LEGEND:
WMA Boundaries
Towns
Rivers
Dams
Quaternary Catchment
E24D Quaternary Number
Secondary Catchment
G3 Secondary Catchment Number
Tertiary Catchment
Study Area
Potable Water Scheme Supply Area
Irrigation Scheme Supply Area
Potable Water Infrastructure
Bulk Supply Pipes
Water Treatment Works
GIS COV:
Waterman Intp (Amended)
Wri500
Ndams
Drgnquat
Drgnquat
Drgsnd
Drgsnd
PREPARED BY:
NINHAM SHAND CONSULTING SERVICES
CLIENT:
Department: Water Affairs and Forestry
Directorate: Options Analysis
PROJECTION:
ALBERS EQUAL AREA
SCALE : 1:500 000
0 2.5 5 10 Kilometers
N W E S
TITLE:
LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY
WATER SUPPLY SCHEME
Prepared by: A Lawrence
Date: 01/2006
Data Type: Fig4_1_waterschemes.mxd
Figure 4.1
Sterkstroom
Queenstown
eZibeleni
Thornhill
Ilinge
Whittlesea
Sada
Cathcart
Lady Frere
Cacadu
S1
S2
S3
S4
S5
S6
S31A
S31B
S31C
S31D
S31E
S31F
S31G
S32A
S32B
S32C
S32D
S32E
S32F
S32G
S32H
S32J
S32K
S32L
S32M
S10A
S10B
S10C
S10D
S10E
S10F
S10G
S10H
S10J
S40A
S40B
S40C
S40D
S40E
S40F
Doring River Dam
Macubeni Dam
Lubisi Dam
Xonxa Dam
Bonkolo Dam
Berry Reservoir
Mitford Dam
Glenbrock Dam
Tentergate Dam
Thibet Park Diversion
Limietskloof Dam
Thrift Dam
Oxkraal Dam
Shiloh Dam
Waterdown Dam
Bushmanskrantz Dam
Groötvleispruit
Klaas Smits
Komani
Brakkloofspruit
Kuzitungu
Oxkraal
Krom
Klipplaat
Esk
Papkuilsfonteinloop
Waqu
Haasfonteinloop
Riet
Elands
Tarka
Braambos
Koonap
Doring Kloof
Bholotwa
Sidubu
Bengu
Indwe
Nququ
Ncuncuzo
Ngcongcolora
Zolo
Thomas
Great Kei
Qumanco
Thom
Big Thomas
Little Thomas
Tsomo
Mbiza
Tsawulayo

TABLE 4.1 EXISTING WATER SUPPLY SCHEMES

River	Scheme Name	Consumers Supplied		Storage Dams	Receiving River
		Domestic	Irrigation		
Klipplaat	Upper Klipplaat Irrigation Scheme	-	Lands along the Klipplaat River	-	
Klipplaat	Klipplaat River Irrigation Scheme		Lands along Klipplaat and Black Kei to confluence with White Kei River Lands along Shiloh Irrigation Scheme Lands along Lower Black Kei	Waterdown Dam	Klipplaat
	Queenstown Water Supply Scheme	Queenstown eZibeleni	-	Allocation from Waterdown Dam Bonkolo Dam Berry Reservoir	-pipeline-
	Sada-Whittlesea Water Supply Scheme	Sada-Whittlesea	-	Allocation from Waterdown Dam	-pipeline-
Klaas Smits	Klaas Smits River Irrigation Scheme	-	Lands along the Klaas Smits River and its tributaries	-	
Oxkraal	Zweledinga Irrigation Scheme	Villages on Upper Oxkraal River	Lands along the Upper Oxkraal River	Bushmanskrantz Dam	-pipeline-
Oxkraal	Oxkraal Irrigation Scheme	-	Lands along the Lower Oxkraal River	Oxkraal Dam Shiloh Dam	Oxkraal
Upper Black Kei	Ntabethemba and Associated Irrigation Schemes	-	Lands along the Upper Black Kei River	Thrift Dam Limietskloof Dam Thibet Park Diversion Tentergate Dam Mitford Dam GlenbrockDam	Black Kei and its tributaries
White Kei	Xonxa Irrigation Scheme	-	Lands along the White Kei River downstream of Xonxa Dam	Xonxa Dam	White Kei

Water from Waterdown Dam is supplied to the Berry Dam in Queenstown through a 46 km long, 450 mm diameter, steel pipeline constructed in 1960. The pipe has a wall thickness of 6 mm. The pipeline was originally designed to operate under gravity only, but its capacity was later boosted by a pump station some 7 km from Queenstown.

In about 1983, in order to supply the newly established Sada-Whittlesea resettlement area and to meet the growing demand of Queenstown, a second pipeline was constructed along the first 15 km of the route from Waterdown Dam. This is a ductile iron pipeline of diameter successively 600 mm, 500 mm and 450 mm. A 400 mm diameter offtake to Sada Water Treatment Works was provided 7 km from Waterdown Dam, at the end of the 600 mm diameter section of pipeline. At about the same time, a new booster pump station was constructed on the original pipeline 16 km from Queenstown, and the original pump station was taken out of use.

According to the August 1981 report by Stewart, Sviridov & Oliver, the Waterdown Dam to Queenstown pipeline was designed to deliver between 11,3 Mℓ/day and 9,5 Mℓ/day to Queenstown under gravity, depending on the water level in Waterdown Dam. The new booster pump station, with variable speed motors, located at McEwan's Flats, some 23 km beyond the Sada-Whittlesea branch, was installed to increase the delivery to between 25 Mℓ/day and 23 Mℓ/day, depending on the water level in Waterdown Dam.

The design provided for the supply of 23Mℓ/day to Queenstown to be maintained, with Waterdown Dam at its lowest level, while providing an additional 17 Mℓ/day at the Sada-Whittlesea offtake for delivery to the Sada Water Treatment Works which have a capacity of 11,25 Mℓ/day.

Because of the relative levels, the full 17 Mℓ/day could not be supplied to the Sada Treatment Works by gravity. Therefore, a booster pump station was required on the branch pipeline to Sada-Whittlesea (report by Anstey, Blignaut and Clogg, 1980). However, this was not constructed when the pipeline was laid in about 1983 because the water requirements at that time could be supplied by gravity alone.

The booster pump station has still (2005) not been constructed but the requirements of the Sada Water Treatment Works have increased to about 2,4 Mm^3/a, which is an average of approximately 6,5 Mℓ/day, with the seasonal peak daily demand being about 10 Mℓ/day.

Because the booster pump station has not been constructed, it is necessary to keep the pressure in the Waterdown Dam to Queenstown pipeline at the Sada offtake at a higher level than originally intended if sufficient water is to be supplied to Sada-Whittlesea. This can only be done by limiting the delivery to Queenstown by operating the booster pumps at McEwan's Flats at less than their full capacity.

It is reported (Stewart Scott, January 2003) that, as a result of this situation, Queenstown can obtain a maximum of 13,7 Mℓ/day through the pipeline, instead of the minimum of 23 Mℓ/day for which it is designed. As the present requirement of Queenstown, excluding Ilinge and the Macibini Villages, is about 7,8 Mm^3/a, it is necessary to supply from Bonkolo Dam the difference of 2,8 Mm^3/a between the 5 Mm^3/a that can be obtained through the Waterdown Dam pipeline and the total requirement. The quantity of 2,8 Mm^3/a is well in excess of the 1 in 10 year yield of Bonkolo Dam and can be supplied only at very low assurance. The rainfall in the area has been good in recent years and sufficient water has been obtained from Bonkolo Dam, except in 2004, when water restrictions were imposed in Queenstown, even though sufficient water was available in Waterdown Dam. It is clear, therefore, that augmentation of the existing raw water supply scheme is urgently required.

Ilinge and the adjacent Macibini Villages are not connected to the Queenstown water supply at present, but are supplied from six boreholes with an estimated yield of 1,3 Mm^3/a (DWAF, 1993). The present water requirements are estimated to be 2,2 Mm^3/a, which suggests that the scheme requires augmentation. Borehole yields in the area are generally good, and it should, therefore, be feasible to augment the scheme by developing additional boreholes (DWAF, 1993). However, the scheme has proved difficult to manage and problems in operating it effectively have been experienced for many years. Consequently, the Chris Hani District Municipality would prefer to supply the area by means of a new pipeline from the Queenstown Water Treatment Works.

It is clear from the above description of the existing water supply to Queenstown that, in order to avoid severe water shortages, Ilinge should not be added to the Queenstown supply area before the raw water supply has been augmented. (It will probably also be necessary to increase the capacity of the water treatment works, but that is not within the scope of this study.)

4.3 THE UPPER KLIPPLAAT IRRIGATION SCHEME

For the purposes of this study the irrigated land in the catchment of the Klipplaat River upstream of Waterdown Dam is referred to as the Upper Klipplaat Irrigation Scheme. It is not, in fact, a formal irrigation scheme and water is obtained directly from the rivers, or by pumping from the rivers into small storage dams. The combined total storage capacity of these small dams appears to be about 0,8 Mm^3 (DWAF, 2003).

The Upper Kei Basin Study (DWAF 1993) reports an irrigated area of 1 457 ha with a water requirement of 7,15 Mm^3/a. The QRWSFS estimated the water requirement for irrigation to be 10,93 Mm^3/a for a total irrigated area of 2 237 ha (1 457 ha adjacent to rivers and 780 ha remote from rivers). This may have been an over-estimate arising from assuming that some of the dryland crops in the area were irrigated. The Water Resources Situation Assessment Study (DWAF, 2002), in which estimates of irrigated areas obtained from existing reports were amended in consultation with DWAF officials who were knowledgeable about the area, arrived at an irrigated area of 496 ha and a water requirement 5 Mm^3/a. These latter volumes are supported by the recent registration of water use project carried out by DWAF. This gives an irrigated area of 700 ha and water use of 5,1 Mm^3/a. Application rates range from 148 $m^3/ha/a$ to 1 760 m^3/a, with an average value of 782 $m^3/ha/a$. The quantity of 5,1 Mm^3/a was accepted as the water requirement for purposes of calculating the inflow to Waterdown Dam.

4.4 THE KLIPPLAAT RIVER GOVERNMENT WATER SCHEME

The urban water supply component of the Klipplaat River Government Water Scheme is described in Section 4.2 above. The irrigation component is described here.

The scheme was established in 1957 and has the Waterdown Dam as its central component. Water is released from the dam into the river channel to supply a scheduled irrigation area of 1 924 ha 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. Water for the Shiloh Irrigation Scheme near Sada-Whittlesea (which is part of the Klipplaat River Government Water Scheme) can be diverted at a weir on the Klipplaat River and conveyed via an earth canal to the farming units. The remainder of the irrigators extract water directly from the river channel. The crops grown are lucerne (60%), maize and pasture. The scheme extends over an almost 150 km length of river and there are considerable losses between the dam and the lower irrigators. At present about 1 530 ha of the scheduled area of 1 924 ha is irrigated. The field edge requirement is estimated (DWAF 1993) to be about 7 300 $m^3/ha/a$. This gives a current requirement of 11,17 Mm^3/a while the allocation from the dam is 14,83 Mm^3/a.

The current area irrigated is less than the scheduled area mainly because most of the 394 ha of the Shiloh Irrigation Scheme which is located in the ex-Ciskei homeland have fallen into disuse. However, this scheme is being re-furbished and officials of the Provincial Department of Agriculture expect the irrigated area of the whole scheme to eventually increase to the full scheduled area of 1 924 ha again, but do not expect any increase in the scheduled area.

The allocation of water from Waterdown Dam is calculated on a quota of 6 100 $m^3/ha/a$, which is less than the theoretical requirement of 7 300 $m^3/ha/a$. Irrigators also obtain water from run-of-river flow in the rivers. The assurance at which this water is available is discussed in Chapter 8. The run-of-river flow also supplies about 450 ha of irrigated land that is not scheduled (DWAF, 1993).

In order to ensure that irrigators at the lower end of Black Kei River obtain at least a reasonable portion of their allocations, a quantity of water of 25% in excess of the allocated amount is released from the dam, when sufficient water is available, to account for river channel losses. In Table 4.2, the distribution of present and expected future water requirements between Waterdown Dam and the White Kei River are shown. The quantities are calculated on the basis of an allocation of 6 100 $m^3/ha/a$ plus a 25% allowance for conveyance losses.

TABLE 4.2 IRRIGATION WATER REQUIREMENTS FROM WATERDOWN DAM

SCHEME/ RIVERS	LOCATION	IRRIGATION IN 2002		POTENTIAL MAXIMUM FUTURE IRRIGATION	
		IRRIGATED AREA (ha)	WATER REQUIRE-MENTS (Mm^3/a)	IRRIGATED AREA (ha)	WATER REQUIRE-MENTS (Mm^3/a)
Klipplaat River Irrigation Scheme	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	1 530	11,67	1 924	14,68

* Water requirement calculated as 6 100 m^3/ha/a + 25% conveyance losses. (The allocation of 6 100 m^3/ha/a is lower than the actual field edge requirements of the crops grown at present which has been calculated to be 7 300 m^3/ha/a (DWAF, 1993)).

4.5 THE ZWELEDINGA IRRIGATION SCHEME

The Zweledinga Irrigation Scheme which lies in the ex-Ciskei homeland obtains water from Bushmanskrantz Dam which is situated on the Oxkraal River upstream of Oxkraal Dam. Water is supplied by pipeline from the dam to several small scale farmer schemes which together comprise the Zweledinga Irrigation Scheme. The total irrigated area is 259 ha, with a water requirement of 1,50 Mm^3/a. The 1:10 year yield of Bushmanskrantz Dam is 2,52 Mm^3/a. This adequately meets the requirements of the irrigation scheme and the potable water supplies to the villages of Yonda and Mbekweni which amount to about 0,04 Mm^3a. The main crop grown is maize.

According to DWAF records, no releases of water have been made from Bushmanskrantz Dam since 1995 and it is understood from discussions with officials of the Provincial Department of Agriculture and DWAF that the scheme has fallen into disuse. It may, nevertheless, be re-vitalised in the future.

4.6 THE OXKRAAL IRRIGATION SCHEME

The Oxkraal Irrigation Scheme located within the ex-Ciskei homeland comprises the Oxkraal and Shiloh Dams which were constructed with the intention of irrigating 541 ha of land from Oxkraal Dam and 25 ha from Shiloh Dam for small scale farmers. The lands have not been developed, but as an interim measure, water from Oxkraal Dam is released down the river for use on land scheduled under Waterdown Dam. Shiloh Dam, with a firm yield of 0,34 Mm^3/a, is unused at present.

According to officials of the Provincial Department of Agriculture, it is planned to develop the land in the near future. At that stage, the water requirements, based on an allocation of 6 100 m^3/ha/a, and conveyance losses of 25%, will be 4,13 Mm^3/a from Oxkraal Dam and 0,19 Mm^3/a from Shiloh Dam.

4.7 THE NTABETHEMBA AND ASSOCIATED IRRIGATION SCHEMES

The Ntabethemba Irrigation Scheme comprises a number of separate schemes along the Black Kei River upstream of its confluence with the Klipplaat River. The schemes draw water from the Thrift, Limietskloof, Tentergate, Mitford and Glenbrock Dams and from natural flow in the river. An area of 1 200 ha of land was developed for irrigation but about 900 ha of this has subsequently fallen into disuse. Crops grown are maize, mixed vegetables, lucerne and other fodder crops.

The original irrigated areas in the sub-schemes, obtained from the Upper Kei Basin Study reports (DWAF 1993) and the currently irrigated areas, obtained from the DWAF water use registration database and discussions with DWAF officials, are shown in Table 4.3, where estimated water requirements are also shown.

TABLE 4.3 NTABETHEMBA AND ASSOCIATED IRRIGATION SCHEMES

IRRIGATED LANDS	WATER SOURCE	ORIGINALLY IRRIGATED AREA (ha)	IRRIGATED AREA IN 2005	WATER REQUIREMENTS IN 2005 (Mm^3/a)
Thrift	Thrift Dam	180	0	0
Limietskloof	Limietskloof Dam	50	0	0
Tentergate	Tentergate Dam	102	45	0,35
Rocklands	Pumped from Black Kei River	75	0	0
Mitford	Mitford Dam	73	0	0
Loudon	Pumped from Black Kei River	26	0	0
Thornhill	Pumped from Black Kei River	27	0	0
Glenbrock	Glenbrock Dam	104	19	0,15
Associated schemes between Thornhill and the Klipplaat River	Pumped from Black Kei River or from dams on tributaries	565	226	1,66
TOTALS		**1 202**	**290**	**2,16**

The scheme formally considered as the Ntabethemba Scheme is situated in what was formerly the Ciskei and comprises :

- the Tentergate irrigation development supplied from Tentergate Dam on a tributary of the Black Kei River,
- the Mitford irrigation development supplied from Mitford Dam on a tributary of the Black Kei River,

- the Glenbrock irrigation development supplied from Glenbrock Dam on a tributary of the Black Kei River (the same tributary as Mitford Dam),
- the Rocklands, Loudon and Thornhill irrigation developments supplied by pumping from the Black Kei River.

The Limietskloof Dam on a tributary of the Black Kei River and the Thrift Dam on the Black Kei River and their associated irrigated lands were originally privately owned irrigation schemes outside the borders of the former Ciskei. They were purchased from the owners by the South African Government in about 1990 to augment the water supplies to the Ntabethemba Scheme. The 230 ha of land that was irrigated from them is understood to have lain fallow since then.

The intention was, apparently, to expand the area irrigated from Tentergate Dam by releasing water from the Thrift and Limietskloof Dams into the river channel and diverting it at an existing diversion weir, known as the Thibet Park weir, into an existing earth canal leading to Tentergate Dam. In order to do this successfully, it was necessary to upgrade the canal. This has not been done, apparently because the cost would be too high.

The capacities of the storage dams in the Ntabethemba area and their 1:10 year yields are shown in Table 4.4.

TABLE 4.4 STORAGE DAMS OF THE NTABETHEMBA AND ASSOCIATED IRRIGATION SCHEMES (DWAF 1993)

DAM NAME	ORIGINAL CAPACITY (Mm^3)	1:10 YEAR YIELD (Mm^3/a)
Thrift Dam	2,90	1,00
Limietskloof Dam	0,88	0,25
Tentergate Dam	1,92	
• Yield of dam alone		0,40
• Additional yield from run-of-river flows with Thibet Park Diversion		0,20
Mitford Dam	1,19	0,13
Glenbrock Dam	0,61	0,14
	7,5	2,12

It can be seen from Table 4.4 that the total available yield from the dams at 1:10 year assurance is estimated to be 2,12 Mm^3/a. In addition, it has been estimated (DWAF 1993) that the 1:10 year run-of-river yield upstream of the Black Kei/Klipplaat River confluence is 0,33 Mm^3/a after allowing for the abstraction of water for diffuse irrigation from the minor tributaries. This gives a total availability of water at 1:10 year assurance of 2,45 Mm^3/a, which is sufficient to support about 380 ha of irrigation. The cost of providing additional storage and distribution works in this area has been investigated in the past (DWAF, 1993) and found to be uneconomical.

In addition to the schemes described above, there was, in 1993, some 700 ha of irrigated land along minor tributaries of the upper Black Kei River (DWAF, 1993). Thus, the total area of irrigated land was about 1 900 ha.

The system modelling carried out for the present study showed the average yield available from the dams and run-of-river flow combined (including the yield from the minor tributaries) to be 12,3 Mm^3/a, falling to about 6 Mm^3/a during severe droughts. Therefore, if the area of diffuse irrigation along the minor tributaries remains at 700 ha with a water requirement of about 4,6 Mm^3/a, it seems unlikely that the area of irrigated land will increase from the currently estimated 290 ha to more than 380 ha. From the point of view using the available yield most efficiently, the additional development should be close to Thrift and Limietskloof Dams in order to minimise conveyance losses.

4.8 THE KLAAS SMITS RIVER IRRIGATION SCHEME

There is no formal irrigation scheme in the Klaas Smits River catchment but, for purposes of this study, the opportunistic irrigation that occurs along the Klaas Smits River and its tributaries, the Heuningklip, Lesseyton and Komani Rivers is referred to as the Klaas Smits River Irrigation Scheme. The significance of this scheme for this study is the effect that the water abstracted for irrigation has on the availability of water from Bonkolo Dam for Queenstown, and its effect on the availability of water for run-of-river abstractions for irrigation from the Black Kei River at the lower end of the Klipplaat River Government Water Scheme.

There is some uncertainty as to the area of irrigated land in the Klaas Smits River catchment. The sources of information considered were:

- The Upper Kei Basin Study (DWAF 1993)
- The Water Resources Situation Assessment (DWAF 2002)
- The DWAF water use registration database (DWAF 2003)

The data obtained is compared in Table 4.5.

TABLE 4.5 IRRIGATED AREAS IN THE CATCHMENT OF THE KLAAS SMITS RIVER

Data Source	Total Area Irrigated (ha)	Area Irrigated from Groundwater (ha)	Area Irrigated from Run-of-River Flow (ha)	Area Irrigated from Klipplaat GWS (ha)
Upper Kei Basin Study	5 250	590	4 660	Included in surface water
Water Resources Situation Assessment	5 250 maximum 3 200 average	990	4 260 maximum 2 210 average	Included in surface water
DWAF Registration	959	283	480	196

The registered area is considerably lower than previously accepted values. The corresponding registered water use is 6,9 Mm^3/a of which 2,8 Mm^3/a is used from boreholes. Field verification of the registered areas and use has not yet been carried out. In view of this, it was decided to use the data from the Water Resources Situation Assessment in this study because it is the next most recent source of data. Therefore, it was assumed that a maximum area of 4 260 ha of land is irrigated from the surface water resources, but at a low assurance of supply.

4.9 THE XONXA IRRIGATION SCHEME

The Xonxa Dam was constructed in 1972 with the intention of providing water for some 4 900 ha of land along the White Kei River. To date, only 1 643 ha of land have been developed under the Xonxa Irrigation Scheme. Water is released from the dam into the White Kei River and extracted by means of diversion weirs or by pumping from the river into storage reservoirs. Most of the irrigation is by centre pivot, but sprinklers are used on the smaller plots. The scheme originally supported 224 farmers and the crops produced were maize, vegetables and lucerne. The scheme has experienced difficulties in maintaining pumps and irrigation equipment and has not been financially viable. As a result, it has declined to the extent that an area of only about 60 ha of land is currently irrigated.

The field edge irrigation requirement of the irrigated lands is estimated to be 9 000 $m^3/ha/a$ and conveyance losses 1,58 Mm^3/a (DWAF 1993). The 1:10 year yield of Xonxa Dam after allowing for siltation to 2020 is calculated to be 29,6 Mm^3/a. Therefore the dam will be capable of supporting 3 130 ha of irrigation at that time. It appears unlikely, because of unsuitability of much of the soil, that the irrigated area will ever increase to more than 1 000 ha (QRWSFS). Therefore, water from Xonxa Dam could be used for other purposes. One possibility is for domestic supplies to villages in the area and to Queenstown.

4.10 THE HEWU GROUNDWATER SCHEME

The Hewu Groundwater Scheme, shown on Figure 4.1, is a rural domestic water supply scheme and does not impact on this study. It is described here for completeness as it is situated amongst the irrigation schemes that are of concern to the study.

In 1993 the scheme was supplying water to 48 villages in the Hewu magisterial district from boreholes equipped with windmills or diesel driven pumps. Borehole yields in this area are normally in excess of 5 m^3/hr (DWAF 1993). Development of the scheme is ongoing. The total population served is about 66 000 people. It was estimated (DWAF 1993) that by 1991, about 72% of the population had access to an average of 30 ℓ/c/d of potable water. Supplies to the remainder of the population were inadequate but were being improved. The present status of the scheme was not investigated in this study.

5. ECOLOGICAL WATER REQUIREMENTS

5.1 BACKGROUND

The National Water Act (No. 36 of 1998) is based on the central guiding principles of sustainability and equity. Sustainability of resource use is to be ensured by the implementation of resource protection measures, including the application of the Ecological Reserve (the quality, quantity and reliability of water required to maintain the ecological functioning of aquatic ecosystems).

IWR Source-to-Sea was appointed by Ninham Shand to undertake an Ecological Reserve Determination for the Quantity component of the Kei System at an Intermediate level for selected sections of the study area using the Intermediate Ecological Reserve Methodology (IERM). The determination of the Quality component was undertaken by Ninham Shand.

The proceedings of a specialist meeting during which the Ecological Water Requirement (quantity) Scenarios were determined are documented in Appendix 2 to this report and the determination of the requirements for the water quality component of the Reserve is documented in Appendix 3. The findings are summarised in this chapter.

5.2 APPROACH TO THE STUDY

5.2.1 The Ecological Reserve and Resource Classification System

The National Water Act (No. 36 of 1998) is based on the central guiding principles of sustainability and equity. Sustainability of resource use is to be ensured by the implementation of resource protection measures, including the application of the Ecological Reserve (the quality, quantity and reliability of water required to maintain the ecological functioning of aquatic ecosystems).

However, since different levels of resource use, resource protection, and ecosystem health are possible, it is clear that it is necessary to classify each water resource for which the Reserve is to be determined. The ecological classification describes levels of ecosystem health, and from these, tolerable degrees of risk to ecosystem health, and levels of acceptable use of the resource, can be derived. The volume and quality of water allocated to the Ecological Reserve therefore depend on the level of ecological health that must be maintained.

Standard procedures for the EcoClassification of rivers and estuaries and for determining the Reserve have been developed by DWAF, and are continuously improved where experience in implementing them shows changes to be desirable. The current procedures specified by DWAF were followed in this study. The EcoClassification procedure progresses through the determination of the Present Ecological State of the resource to the derivation of a category toward which management objectives could be aimed. This is termed the "Recommended Ecological Category" (REC). The EcoClassification forms part of the Classification System during which a Management Class is selected which takes cognisance of the EcoClassification as well as other socio-economic issues. The Management Class was not determined in this study as its determination requires the consideration of many factors in addition to the ecological factors considered in this study. Consequently, this study was confined to the determination of the "Recommended Ecological Category" or REC.

The Present Ecological State is expressed as Categories A to F, where class A represents near natural conditions and class D represents a high degree of modification from natural conditions. Category E represents a serious degree of modification with extensive loss of basic ecosystem functions, and Category F represents a critically modified state with almost total loss of natural habitat and biota. The Category D is the lowest ecological class where resource use is still deemed to be sustainable. Categories E and F are deemed to be ecologically unsustainable (degraded and degrading). Since sustainability is a guiding principle, Categories E and F should not be selected for the REC.

The REC for a particular water resource is determined in relation to the Present Ecological State (PES) Category (A to F), the Ecological Importance and Sensitivity (EIS) of the resource, and possible improvements in resource quality, given that "some prior impacts or modifications may not be practically reversible due to technical, social or economic constraints" (DWAF, 1999b). The REC may be set at the same level as the PES, or may be set as an improved class, but may not normally be set at a lower class than the present state, since this would be tantamount to a deliberate intention to allow the resource to degrade. (In setting the Management Class, ecological considerations could, in exceptional circumstances, be over-ruled by an executive, political decision to meet urgent social and/or economic needs).

Once the REC is determined, it becomes the overall target for the long-term protection and management of the resource, and the flow-related recommendations made in the ecological Reserve determination processes are designed to maintain or improve the resource in the specified category.

Because the REC is a generic target, specific objectives have to be set for each resource, so that the particular characteristics of the resource are taken into account in the designated REC.

Separate suites of methods to determine the Reserve exist for rivers and estuaries. Each method is associated with a different level of confidence in the results. The choice of which of these methods to use for a particular determination depends on a number of factors such as, in the case of rivers :

- the degree to which the catchment is already utilised;
- the sensitivity and importance of the catchment, and
- the potential impact of the proposed water use (DWAF, 1999c).

Methods for determining the Ecological Reserve differ for the various levels of Reserve determination. The first, and simplest, method of Reserve determination is the Rapid Ecological Reserve Method. The procedures for deriving an REC for use in this method are described in detail (DWAF, 1999c and d) and were used as a basis and guide to formulate the process for the other methods.

The second and third methods for determining the Reserve are the Intermediate Ecological Reserve Method and the Comprehensive Ecological Reserve Method, respectively. These methods use increasingly comprehensive and detailed information bases, take more time and cost more than the rapid method, but have the advantage of increased levels of confidence in the results arising from their use.

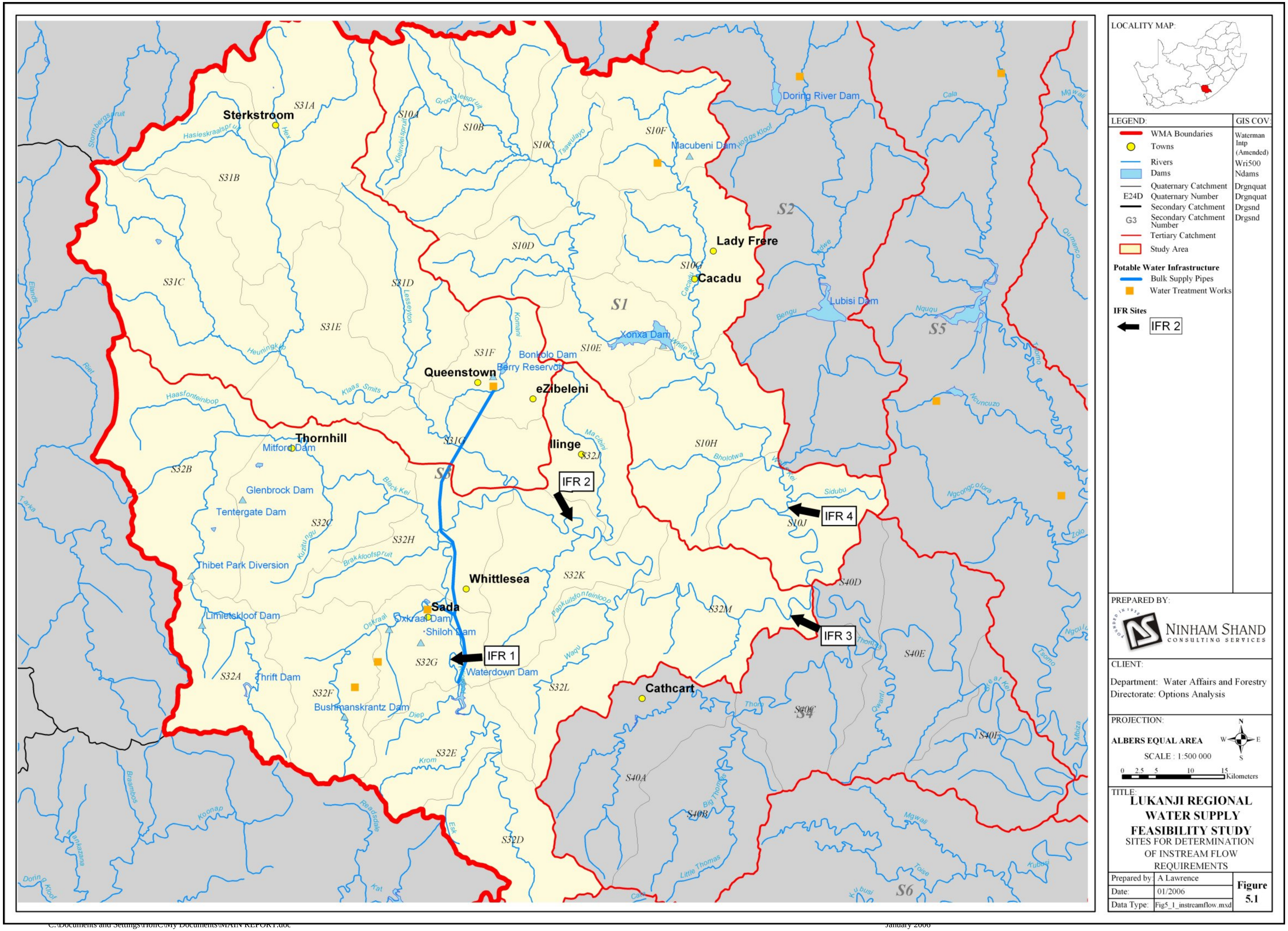
In this study, the Intermediate Ecological Reserve Method (IERM) for rivers was followed because the available data were generally appropriate for this level of determination.

5.2.2 Instream Flow Requirements

The environmental flow requirements of rivers are commonly referred to as "instream flow requirements" for which the acronym IFR is used. This terminology is used in this report for the quantity component of the Ecological Reserve for Rivers.

IFRs were determined at the four sites shown in Figure 5.1. Three sites were selected at points downstream of Waterdown and Oxkraal Dams, and one downstream of Xonxa Dam.

The Flow-Stress-Response method (FS-R) (O'Keeffe et al, 2002) was used to determine low flows, and a method adjusted from the standard Building Block Methodology (King and Louw, 1998) and the Downstream Response to Imposed Flow Transformation (DRIFT) Methodology (Brown and King, 2001) was followed to set high flows at each site and for a range of Ecological categories which will include the PES and the REC. Thereafter, a scenario meeting of the specialist team was held, at which modifications to the IFR were considered and their probable effectiveness, relative to the desirable IFR, was assessed.



LOCALITY MAP:
LEGEND:
GIS COV:
WMA Boundaries
Towns
Rivers
Dams
Quaternary Catchment
E24D Quaternary Number
Secondary Catchment
G3 Secondary Catchment Number
Tertiary Catchment
Study Area
Waterman Intp (Amended)
Wri500
Ndams
Drgnquat
Drgnquat
Drgsnd
Drgsnd
Potable Water Infrastructure
Bulk Supply Pipes
Water Treatment Works
IFR Sites
IFR 2
PREPARED BY:
NINHAM SHAND
CONSULTING SERVICES
CLIENT:
Department: Water Affairs and Forestry
Directorate: Options Analysis
PROJECTION:
ALBERS EQUAL AREA
SCALE : 1:500 000
0 2.5 5 10 15 Kilometers
N
S
W
E
TITLE:
LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY
SITES FOR DETERMINATION OF INSTREAM FLOW REQUIREMENTS
Prepared by: A Lawrence
Date: 01/2006
Data Type: Fig5_1_instreamflow.mxd
Figure 5.1
Sterkstroom
Queenstown
eZibeleni
Ilinge
Thornhill
Whittlesea
Sada
Lady Frere
Cacadu
Cathcart
IFR 1
IFR 2
IFR 3
IFR 4
Doring River Dam
Macubeni Dam
Lubisi Dam
Xonxa Dam
Bonkolo Dam
Berry Reservoir
Mitford Dam
Glenbrock Dam
Tentergate Dam
Thibet Park Diversion
Limietskloof Dam
Oxkraal Dam
Shiloh Dam
Waterdown Dam
Thrift Dam
Bushmanskrantz Dam
S1
S2
S4
S5
S6
S31A
S31B
S31C
S31D
S31E
S31F
S31G
S32A
S32B
S32C
S32D
S32E
S32F
S32G
S32H
S32J
S32K
S32L
S32M
S10A
S10B
S10C
S10D
S10E
S10F
S10G
S10H
S10J
S40A
S40B
S40C
S40D
S40E
S40F

5.3 DELINEATION OF THE RESOURCE

The choice of the sites at which the IFRs were determined was influenced by ease of access and numerous other factors, which include :

- Locality of gauging weirs with good quality hydrological data.
- Locality of proposed and existing developments.
- Locality and characteristics of tributaries.
- Present status defined by the Intermediate Habitat Integrity of the different river reaches.
- Level II ecotypes and/or stream classification.
- Reaches where social communities depend on a healthy river ecosystem.
- Suitability of the sites for follow-up monitoring.
- **Habitat diversity and cues for setting flow requirements for aquatic organisms, marginal and riparian vegetation.**
- **Suitability of the sites for accurate hydraulic modelling over a range of flows, but particularly low flows.**
- **Accessibility of the sites.**
- **Areas or sites that could be critical for ecosystem functioning. These are often represented by riffle units, where low flow conditions or the cessation of flow constitutes a break in the functioning of the river, and consequently, the biota dependent on this habitat and/or perennial flow are adversely affected. Pools are not considered critical habitats since they are still able to function as an ecosystem or at least maintain life during periods of no flow.**
- Locality of geomorphologically representative sites based on stream classification.

The criteria in bold above carry more weight than the other criteria.

The positions of the sites are shown on the map on Figure 5.1. The sites and the river reaches in which they are situated are described below.

Site 1 : The Klipplaat River 8 km downstream of Waterdown Dam for the reach of river between Waterdown Dam and the Black Kei River.

Site 2 : The Black Kei River about 13 km downstream of its confluence with the Klaas Smits River as being representative of the Upper Black Kei River.

Site 3 : The Black Kei River about 5 km upstream of its confluence with the White Kei River as being representative of the Lower Black Kei River.

Site 4 : The White Kei River some 35 km downstream of Xonxa Dam for the river reach between Xonxa Dam and the confluence with the Black Kei River.

5.4 ECOCLASSIFICATION

Information on the past and present ecological status of the resource at the selected sites was gathered by the specialist team from existing published data and from field investigations. Categories in which data was collected are :

- Habitat integrity
- Fish
- Aquatic invertebrates
- Riparian vegetation
- Fluvial geomorphology
- Hydrology
- Hydraulics
- Water quality

Using these data, the Present Ecological Status (PES) was determined at each site, and Recommended Ecological Classes (RECs) were proposed. Details of the data and the procedures followed are recorded in Appendices 2 and 3 of this report.

The PES and recommended REC for each site are shown in Table 5.1, as well as the expected classifications in 5 years and 20 years time if the present flow and land-use patterns are maintained. The latter show whether the PES is stable or will continue to deteriorate under existing conditions. The alternative ecological categories considered are also shown.

TABLE 5.1 ECOCLASSIFICATION OF IFR SITES

RIVER AND SITE	PRESENT ECOLOGICAL STATE (PES)	ECOSTATUS TRAJECTORY WITH EXISTING CONDITIONS		ECOLOGICAL IMPORTANCE AND SENSITIVITY (EIS)	RECOMMENDED ECOLOGICAL CLASS (REC)	LOWER ALTERNATIVE EC SCENARIO	HIGHER ALTERNATIVE EC SCENARIO
		SHORT TERM (5 YEARS)	LONG TERM (20 YEARS)				
Klipplaat : IFR 1	C	C	C	Moderate	C	D	B/C
Upper Black Kei : IFR 2	D	D	D	Moderate	D	*	C
Lower Black Kei : IFR 3	C/D	D	C/D	Moderate	C/D	D	B/C
White Kei : IFR 4	C/D	C/D	C/D	Moderate	C/D	D	B/C

* No scenario considered because an ecological class of lower than D is not acceptable.

Generic descriptions of the categories used in the classification system are shown in Table 5.2.

TABLE 5.2 DEFINITIONS OF GENERIC RIVER CLASSIFICATION CATEGORIES

CATEGORY	DESCRIPTION
A	Natural : ▪ The resource base has not been decreased; ▪ The resource capability has not been exploited.
B	Largely natural with few modifications : ▪ The resource base has been decreased to a small extent; ▪ A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.
C	Moderately modified : ▪ The resource base has been decreased to a moderate extent; ▪ A change of natural habitat and biota has occurred, but the basic ecosystem functions are still predominantly unchanged.
D	Largely modified : ▪ The resource base has been decreased to a large extent; ▪ Large changes in natural habitat, biota and basic ecosystem functions have occurred.
E	Seriously modified : ▪ The resource base has been seriously decreased; ▪ The loss of natural habitat, biota and basic ecosystem functions is extensive.
F	Critically modified : ▪ The resource base has been critically decreased; ▪ Modifications have reached a critical level and the resource has been modified completely with an almost total loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.

It can be concluded from consideration of Tables 5.1 and 5.2 that the rivers of the study area are moderately to largely modified throughout. The major causes of these modifications are the following :

- ***Klipplaat River downstream of Waterdown Dam :*** The change in the natural flow patterns resulting from the construction of Waterdown Dam has resulted in a PES of a Category C. The lower reaches could be affected by the discharge of treated sewage effluent from Sada-Whittlesea.

- ***Upper Black Kei River :*** A changed flow regime caused by the upstream dams and poor water quality caused by agricultural activities.

- ***Lower Black Kei River :*** A changed flow regime caused by the upstream dams and poor water quality caused by agricultural activities and the discharge of treated sewage effluent from Queenstown and Sada-Whittlesea have resulted in a PES category of C/D. The PES is slightly better than that of the Upper Kei River because the state of the invertebrates and the riparian vegetation is slightly better.

- ***White Kei River downstream of Xonxa Dam :*** A changed flow regime caused by the upstream dams has resulted in changes in geomorphology and riparian vegetation. Riparian vegetation has also deteriorated as a result of grazing and vegetation removal. These factors have resulted in a PES category of C/D.

5.5 DETERMINATION OF IFRs

In the procedure for quantifying the IFR, flows are determined for maintenance (those flows that will maintain the system in the target ecological class during years other than drought years) and for drought periods (flows that will only allow for survival of the most critical components of the ecosystem). The flow determinations are done at a meeting of the specialist team. Data on a defined set of components of the river ecosystem are used in the procedure, and the study team includes a specialist on each of these components. The components are :

- Geomorphology
- Riparian vegetation
- Fish
- Aquatic invertebrates
- Water quality

Support is provided by a hydraulician and an IFR hydrologist.

A standard set of procedures for quantifying the IFR is followed, as described in Chapter 4 of Appendix 2.

At each site, IFRs are determined for each of the three scenarios for which ecological categories are shown in Table 5.1, i.e. flows that will maintain the REC, flows that will maintain a lower ecological category, and flows that will maintain a higher ecological category.

Detailed information on the IFR at each site is provided in Appendix 2. A summary of this information is shown in Table 5.3, where the recommended IFRs are expressed as percentages of the virgin mean annual runoff (MAR) at each site. The virgin MAR is the average annual volume of flow at the site as it is estimated to have been before flow in the rivers was modified by human activities.

TABLE 5.3 SUMMARY OF PROPOSED IFRs

IFR SITE	REC	IFR AS % OF PRESENT MAR	ALTERNATIVE SCENARIO (UP)	IFR AS % OF PRESENT MAR	ALTERNATIVE SCENARIO (DOWN)	IFR AS % OF PRESENT MAR
IFR 1	C	24,8	B/C	29,2	D	17,5
IFR 2	D	9,2	C	14,7	-	-
IFR 3	C/D	11,2	B/C	20,1	D	7,8
IFR 4	C/D	20,7	B/C	30,4	D	16,0

The confidence specialists have in their data and their recommendations in general varied from medium-low to medium-high.

The Reserve determinations included a water quality component which is discussed in Section 5.6.

The IFRs shown in Table 5.3 are the desirable minimum requirements in the opinion of the specialist team. These results however only represent one scenario that can achieve the RECs. Due to many constraints such as small outlet pipes from dams and insufficient water for releases, additional flow scenarios based on modifications of the IFRs must be tested. Spills and additional flows from tributaries can often make up for the lack of flow releases due to operational constraints. It is therefore attempted to design an optimised flow scenario that has minimum impact on the users and on the ecology. A second meeting was therefore held during which specialists considered the implications for the river ecosystems of modifying the ecological flow releases from the dams to suit their outlet capacities. The conclusions reached are discussed in Section 5.7.

5.6 WATER QUALITY REQUIREMENTS

Six water quality resource units were identified within the study area. Details of these are shown in Table 5.4.

TABLE 5.4 WATER QUALITY RESOURCE UNITS

NO	WATER QUALITY RESOURCE UNIT	IFR SITE	JUSTIFICATION
1	Upper Black Kei upstream of the Klaas Smits River confluence	-	The upper Black Kei River is a catchment where the dominant land-use is subsistence agriculture and rural settlements.
2	Black Kei from the Klaas Smits confluence to the White Kei confluence	IFR 2 IFR 3	The Klaas Smits is affected by Queenstown Sewage Works discharges that can modify the Black Kei River quality quite substantially. It is also close to the ecoregion boundary between the Great Escarpment Mountains ecoregion and the Eastern Uplands ecoregion.
3	Klipplaat River downstream of Waterdown Dam to the confluence with the Black Kei River.	IFR 1	Insufficient water quality data to further subdivide this reach.
4	Oxkraal River from the Oxkraal Dam to the confluence with the Klipplaat River.	-	To match an initially proposed IFR reach
5	Lower Klaas Smits River	-	Largely affected by Queenstown effluent (nutrients) and catchment processes (total suspended solids and total dissolved solids)
6	White Kei River from Xonxa Dam to the confluence with the Kei River.	IFR 4	No water quality data to justify further subdivision of this river reach.

For each resource unit, a monitoring point was identified where water quality data was available to characterise the present water quality state and reference conditions. The monitoring sites selected are shown in Table 5.5.

TABLE 5.5 MONITORING SITES USED AS SOURCES OF WATER QUALITY DATA

NO.	WATER QUALITY RESOURCE UNIT	IFR SITE	REFERENCE SITE	PRESENT STATE SITE
1	Upper Black Kei upstream of the Klaas Smits River confluence	-	S3R001Q01	S3H004Q01 : Black Kei River at Cathcart's Gift/Endwell
2	Black Kei from the Klaas Smits confluence to the White Kei confluence	IFR 2 IFR 3	--	No water quality monitoring points in this resource unit. Water quality assessment was based on on-site observations and extrapolation of data from upstream points and major tributaries.
3	Klipplaat River downstream of Waterdown Dam to the confluence with the Black Kei River.	IFR 1	S3R001Q01	S3R001Q01 : Waterdown Dam on Klipplaat River : near dam wall
4	Oxkraal River from the Oxkraal Dam to the confluence with the Klipplaat River.	-	S3R001Q01	S3H005Q01 : Oxkraal River at Sada-Whittlesea
5	Lower Klaas Smits River	-	S3R001Q01	S3H006Q01 : Klaas Smits River at Weltevrede/Queenstown
6	White Kei River from Xonxa Dam to the confluence with the Kei River.	IFR 4	S3R001Q01	S1R001Q01 – Xonxa Dam on the White Kei River: Near the dam wall

The present water quality status was assessed and then classified. The water quality categories for the different resource units are summarised below in Table 5.6.

TABLE 5.6 PRESENT WATER QUALITY STATUS

NO.	WATER QUALITY RESOURCE UNIT	IFR SITE	PRESENT WATER QUALITY STATUS				
			OVERALL	INORGANIC SALTS	NUTRIENTS	PHYSICAL VARIABLES	RESPONSE VARIABLES
1	Upper Black Kei	-	Poor (D/E)	Poor (E/F)	Fair (A/C)	Good (A/B)	Not done
2	Lower Black Kei	IFR 2 IFR 3	Fair (C/D)	Fair (C/D)	Fair (C/D)	Fair (C/D)	Poor (C/D)
3	Klipplaat River*	IFR 1	Natural (A/B)	Natural (A/B)	Good (B/C)	Good (B/C)	Good/Fair
4	Oxkraal River	-	Poor (D/E)	Poor (E/F)	Fair (C/D)	Good (A/B)	Not done
5	Lower Klaas Smits River	-	Fair (D)	Poor (E/F)	Fair (A/C)	Good (A/B)	Not done
6	Lower White Kei River	IFR 4	Good (B)	Good (B)	Good (B)	Good (A/B)	Fair (C/D)

* Status of the river reach upstream of the Oxkraal River confluence

The data shown in Table 5.6 indicate that water quality in the Black Kei River deteriorates in a downstream direction up to the confluence with the Klipplaat River, largely the result of increasing salinity. The Klipplaat River, and some of the smaller tributaries downstream of the Klaas Smits confluence, appeared to improve the quality of the lower Black Kei River upstream of the White Kei confluence. This conclusion was based on field observations by fish and invertebrate specialists. There were no routine water quality monitoring points in the lower Black Kei River to confirm the conclusion and it is strongly recommended that a routine water quality monitoring point be established in the lower Black Kei River because future water supply developments for Queenstown might affect quality in this river reach. Development options that affect the quality in the Klaas Smits, Klipplaat and smaller tributaries would need to consider carefully the quality impacts in the main stream Black Kei River.

The main water quality issues are :

- **Point sources**

There are only two wastewater treatment works of note in the study area, one at Queenstown and one at Sada-Whittlesea. The Queenstown WWTW discharges into the Komani River from where water is abstracted for irrigation. Not all the treated effluent is abstracted for irrigation. Some treated effluent therefore flows into the Black Kei River via the Klaas Smits River when there is a low demand for irrigation water (Wilcock, pers. comm., 2005). The works complied with the general effluent standard but the nutrient budget of the Komani and lower Klaas Smits Rivers were dominated by the effluent discharge. At Sada-Whittlesea, domestic effluent is treated and discharged into the Klipplaat River downstream of the Oxkraal confluence. On average, the effluent complies with the general effluent standards. Other centres rely on oxidation ponds, septic tanks and pit latrines for waste disposal.

- **Non-point sources**

It was found that non-point sources and catchment processes controlled the TDS and TSS concentrations in the rivers but that that point sources dominated the phosphorus budget in the Kei River downstream of Queenstown. Stormwater runoff from rural settlements may also affect water quality in the rivers, especially in those catchments with a high concentration of dense settlements.

The determination of the water quality Reserve is recorded in detail in Appendix 3. A summary is given in Table 5.7. It can be seen from comparison of Table 5.7 with Table 5.1 that the RECs for water quality differ in some instances from those shown in Table 5.1. The reason is that Table 5.1 shows averages for the four individual components of the river ecosystem used in the IFR determinations (see Section 5.3.2), and water quality is only one of these components.

TABLE 5.7 SUMMARY OF THE WATER QUALITY RESERVE

RESOURCE UNIT	PRESENT STATUS CATEGORY	RECOMMENDED ECOLOGICAL CATEGORY	WATER QUALITY ISSUES OF CONCERN
Upper Black Kei upstream of the Klaas Smits River confluence	D/E Poor	D Fair	Natural elevated salt concentrations aggravated by degradation of catchment due to erosion and poor land-use practices
Notes : Land-use practices need to be addressed to achieve the REC			
Lower Black Kei River from Klaas Smits confluence to the White Kei confluence	C/D Fair	D Fair	Nutrient enrichment from the Klaas Smits River
Notes : Improve to a class D by addressing point source loads from Sada-Whittlesea and Queenstown sewage treatment works and implement IFR releases from Waterdown Dam to dilute salt concentrations			
Klipplaat River downstream of Waterdown Dam to Black Kei River	B Good	B Good	Point source loads from Sada – Whittlesea sewage treatment works
Notes : Maintain present status			
Oxkraal River from Oxkraal Dam to the Klipplaat River	D/E Poor	D Fair	High salinity and high nitrogen concentrations
Notes : Identify sources of salt and nitrogen concentrations			
Lower Klaas Smits River	D Fair	D Fair	Effluent from Queenstown Sewage Treatment Works
Notes : Maintain present status			
White Kei River from Xonxa Dam to the confluence with the Black Kei River	B Good	B Good	Improved data required for monitoring
Notes : Maintain present status			

5.7 ECOLOGICAL CONSEQUENCES OF FLOW SCENARIOS

As explained in Section 5.5, modifications to the desirable IFRs to accommodate operational constraints were considered by the specialist team. Several scenarios were considered, as described below :

Scenario 1 : IFRs demand for an EC lower than the REC, i.e. the "Alternative Scenario (down)" of Table 5.3.

Scenario 2 : IFRs to achieve and maintain the REC, i.e. the REC Scenarios of Table 5.3.

Scenario 3 : IFRs demand for a higher EC than the REC, i.e. the "Alternative Scenario (up)" of Table 5.3.

Scenario 4 : This is a modified version of Scenario 2 to achieve the REC. The desirable floods specified for release from Waterdown and Xonxa Dams were reduced to suit the capacities of the outlet works of the dams. In the case of Waterdown

Dam a 5 m^3/s flood replaced an 18 m^3/s event and, in the case of Xonxa Dam, a desirable 45 m^3/s flood was reduced to 10 m^3/s to suit the outlet works.

Scenario 5 : Scenario 1 with changes as described for Scenario 4.

In addition, a scenario with no IFR and expected future water use was evaluated.

The ability of the flow scenarios to meet the REC is summarised in Table 5.8. It must be noted that an explicit IFR demand lower than the REC could still meet the REC if sufficient unregulated flows from the explicit IFR spills and/or inflow from tributaries augment demand.

TABLE 5.8 SUMMARY OF THE ECOLOGICAL CONSEQUENCES INDICATING THE NUMBER OF IFR SITES WHERE THE RECOMMENDED ECOLOGICAL CATEGORY (REC) CAN BE MET

Y = yes; N = no.

	PES	REC	SC1	SC2	SC3	SC4	SC5	NO IFR
IFR 1	C	C	Y	Y	Y	Y	Y	N (?)
IFR 2	D	D	Y	Y	Y	Y	Y	N
IFR 3	C/D	C/D	Y	Y	Y	Y	Y (?)	
IFR 4	C/D	C/D	N	Y	Y	Y (?)	N	N
Number of IFR sites where ecological objectives are achieved.			3Y 1N	4Y	4Y	4Y (?)	3Y 1N	4N

The 'N' under Scenario 1 at IFR Site 4 means that if the 'Alternative Scenario (down)' IFR is enforced explicitly at Site 4, then this is insufficient to meet the recommended ecological requirements (REC) at Site 4. The unregulated contributions from spills/tributaries are insufficient to increase the streamflows of the alternative scenario to the 'recommended' category.

Scenario 4, 5 and No IFR are the only practical scenarios to assess as they consider existing constraints. Of these scenarios, Scenario 4 has the least ecological impact as it meets the ecological objectives at all the IFR sites (the question mark indicates some uncertainty around IFR 4). The 'No IFR' scenario is not an acceptable scenario from an ecological point of view as it does not meet the REC at any site.

The Scenario 5 has the least impact on yield but cannot meet the REC at IFR 4 on the White Kei. For the Black Kei and Klipplaat River, Scenario 5 would be acceptable. A decision should be made after comparing the socio-economic value and importance of the White Kei system compared to the Ecological Importance. Other factors such as the present use of goods and services as part of resource economics and the potential impact on this if the river is allowed to degrade, as well as the confidence in the IFR 4 assessment and the ecological consequences assessments should be considered to aid in the decision.

It is not within the scope of this study to make such decisions as the required procedures for doing so include extensive public consultation and participation in the process, as well as possibly refining the Environmental Water Requirement (EWR) in cases of uncertainty, activities which are not within the terms of reference of this study.

With regard to refining the EWR, some comments regarding the relationship between EWR releases and irrigation releases, which arose from detailed modelling of these releases in the Water Resources Yield Model are included hereunder for future reference.

5.8 IRRIGATION RELEASES AND EWR RELEASES

The information presented in this section, and in more detail in Appendix 4, is provided to assist in any refinement of the recommended EWR releases that may occur before the Reserve is implemented.

It may be feasible to construct an ecological release sequence that takes advantage of the modified flow regime introduced by the irrigation releases, possibly optimising both the irrigation and EWR release regimes. Historically, the irrigation releases have been made as slugs of water with a higher initial release rate of a period of 9 to 10 days and this may also help to simulate flood releases (see Annexure E of Appendix 4).

Figure 5.2 shows the average monthly distribution of the natural inflows (solid red line), the EWR (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.

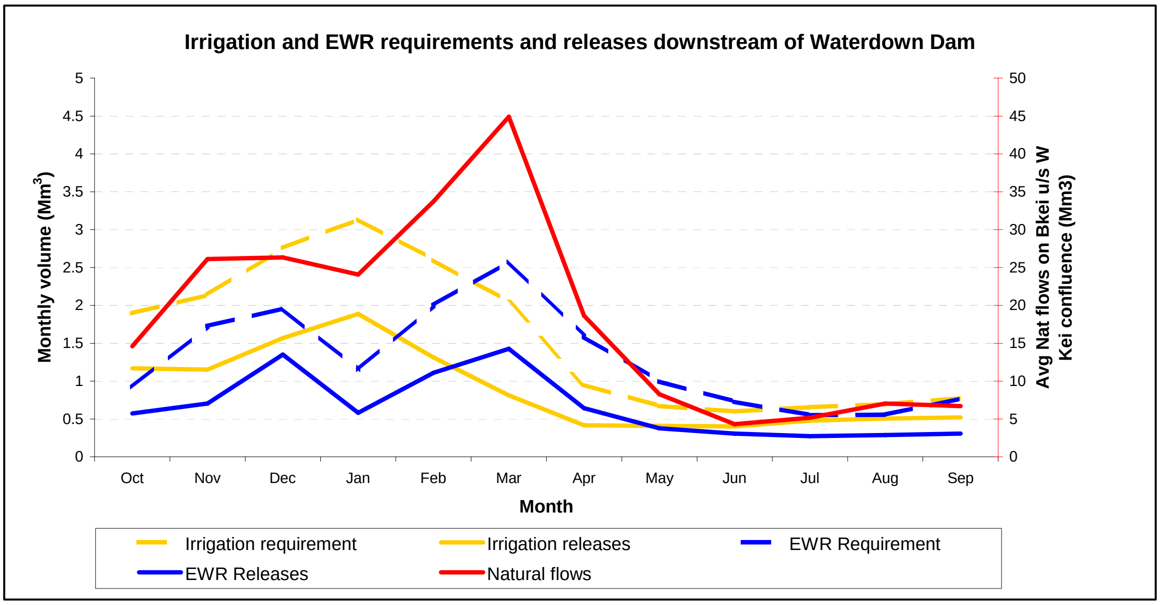


Figure 5.2 Average EWR and irrigation requirements downstream of Waterdown and Oxkraal Dams

Figure 5.3 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 that the sum of the areas is the total release made for EWR and irrigation. For interest, the EWR requirements at IFR Site 1 downstream of Waterdown Dam have also been shown (solid red line).

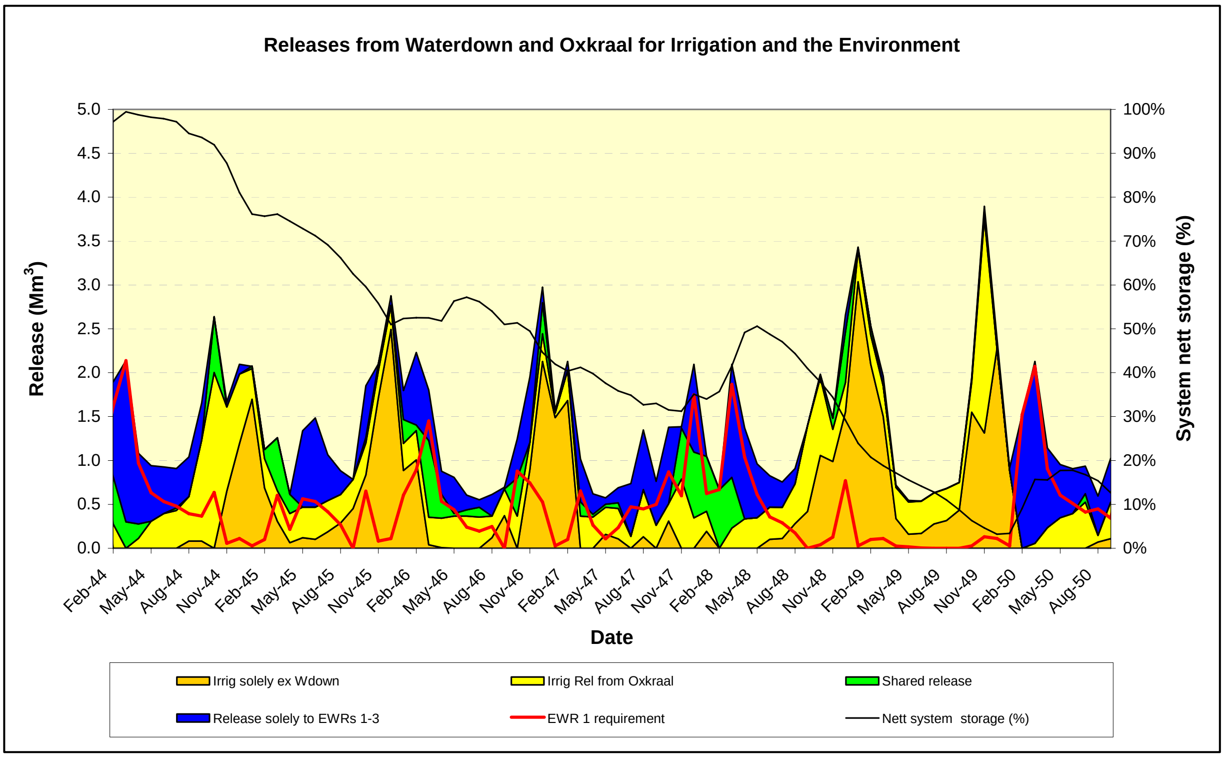


Figure 5.3 Comparison of EWR flows at IFR Site 1 with releases for EWR and irrigators

6. WATER REQUIREMENTS

6.1 GENERAL

The water requirements that affect the Lukanji Water Resources System are :

- Urban and rural domestic requirements supplied from the dams of the System or from run-of-river flow.
- Irrigation requirements, supplied from the dams, run-of-river abstractions and boreholes.
- Afforestation, to the extent that it reduces natural runoff and, hence, the quantity of water available for other users.
- Invasive alien vegetation which has the same effect as afforestation.

Each of these categories of water requirements is discussed below in the context of its implications for possible schemes to augment the water supply to Queenstown.

6.2 URBAN AND RURAL DOMESTIC

For the purpose of this investigation, the water requirement projections described below for Queenstown and Sada-Whittlesea, as well as rural villages that are also likely to be supplied from the urban water supply scheme, were used.

6.2.1 Queenstown

The population growth rate assumed for Queenstown in the QRWSFS was 3,5% p.a. The more recent demographic studies for the development of the National Water Resource Strategy (DWAF, 2000) have estimated a growth rate for Queenstown of 1,61% p.a. from 1995 to 2005, followed by a growth of 0,87% p.a. from 2005 to 2015 and subsequently a growth rate of 0,61% from 2015 to 2025. The metered raw water-use in 2002 was 7,3 Mm^3/a. At the end of 2002, a large low cost housing scheme was completed which is estimated by the Town Engineer of Queenstown to have increased water requirements by 0,3 Mm^3/a to 7,6 Mm^3/a. Using the estimates of future population growth rates given above, and assuming the growth rate between 2025 and 2045 to remain at 0,61% p.a., gives a water requirement in 2045 of 10,3 Mm^3/a.

6.2.2 Sada-Whittlesea

The QRWSFS predicted that the water requirements of Sada-Whittlesea would grow at 3,36% from 2,03 Mm^3/a in 1995 to 2,42 Mm^3/a in 2000. Thereafter, the growth rate was predicted to decrease to 2,73% p.a., to give a water requirement in 2005 of 2,77 Mm^3/a. It appears that the actual water use in 2003 was 2,4 Mm^3/a. This value was obtained from the Town Engineer of Queenstown. A rough check was performed by subtracting the quantity of water supplied from Waterdown Dam to Queenstown from the total quantity released from the dam into the pipelines to Sada-Whittlesea and Queenstown between October 2002 and September 2003. This showed a water use of 2,01 Mm^3 in that twelve month period, which is in reasonable agreement with the value of 2,4 Mm^3 assumed for the 2003 calendar year.

The demographic studies commissioned by DWAF for the development of the National Water Resource Strategy (DWAF, 2000) predicted that the population of Sada-Whittlesea would grow at 0,3% p.a. to 2020, and would remain virtually static thereafter. For the purposes of considering possible water augmentation schemes, it has been assumed that the future increases in water requirements will follow these predicted population growth rates. On this basis, water requirements will increase to 2,52 Mm^3/a by 2020, and then remain almost static. However, the village of Zulukama and other rural villages in the vicinity of Sada-Whittlesea are likely to be connected to the Sada water supply in the future. Therefore, in consultation with the Town Engineer of Queenstown, a water requirement of 2,40 Mm^3/a in 2003, increasing to 2,50 Mm^3/a by 2020, and 3,0 Mm^3/a by 2045, was assumed.

6.2.3 Ilinge

The small town of Ilinge, situated some 8 km south-east of Queenstown, had a water requirement of 1,38 Mm^3/a in 2002, according to the Town Engineer of Queenstown. This is expected to increase to 1,44 Mm^3/a by 2005, and remain static thereafter.

6.2.4 Rural Villages

The water requirements of rural villages in the immediate vicinities of Ilinge are of interest in this study as the villages are likely to be connected to the urban water supply scheme. If a pipeline were constructed between Xonxa Dam and Queenstown, the possibility of supplying villages along the route with raw water from the pipeline could also be considered.

Estimates of the future water requirements of rural villages in the area vary significantly, as discussed below.

The demographic study conducted for the National Water Resource Strategy indicates rural population growth rates of 0,37% p.a. up to 2005, followed by a negative growth rate of 0,4% p.a. from 2005 to 2015 and a negative growth of 0,85% p.a. from 2015 to 2025. If these rates are used for projecting the water requirements of the rural villages (Macibini Villages) that are situated close to Ilinge, a water quantity of 0,74 Mm^3/a in 2002 decreasing to 0,55 Mm^3/a in 2025 is obtained. Based on recent population figures, a population growth rate of 1,5% p.a. was used for the latest study of the Xonxa Dam Transfer Scheme (Stewart Scott, 2003), and the water requirements of the Macibini Villages were predicted to be about 1,49 Mm^3/a in 2045, based on 1997 water requirements of 0,73 Mm^3/a. For purposes of this study, it has been assumed that the requirements will grow to 0,76 Mm^3/a by 2005 and then remain static.

The QRWSFS predicted that the rural water requirements that could be supplied from the Xonxa pipeline along its route would grow from a negligible quantity in 1990 to 1,22 Mm^3/a in 2045. Uhlmann, Withaus and Prins (1996) forecast a rural demand of about 0,8 Mm^3/a in 2015, which would increase to 3,5 Mm^3/a in 2045.

It has been proposed (Stewart Scott, 2003) that Ilinge and the Macibini Villages be supplied from the Queenstown Water Treatment Works. The requirements of the other villages in the vicinity of the proposed Xonxa pipeline route have not been included in the analysis of possible augmentation schemes because it is unlikely that they would be supplied from the Xonxa pipeline (see Section 8.7.4).

6.2.5 Total Urban and Rural Domestic Requirements

The total projected potable water requirements from the urban water supply scheme are summarised in Table 6.1. It can be seen that the requirements are expected to increase from 12,46 Mm^3/a in 2005 to 15,5 Mm^3/a in 2045.

TABLE 6.1 PROJECTED WATER REQUIREMENTS FOR QUEENSTOWN AND RURAL VILLAGES

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

6.2.6 Potential for Water Conservation and Demand Management

It can be seen from Table 6.1 that the growth in the water requirements of the Queenstown Complex did not increase between 1995 and 2003. In fact, water use decreased in the intervening years to a low of 5,96 Mm^3/a in 2000 but has increased again as low cost housing schemes have been implemented. The decrease between 1995 and 2000 is attributed to the effects of water demand management.

According to figures supplied by the company that operates the Queenstown potable water supply scheme, water losses are about 22% of raw water requirements. Most of the losses occur in the potable water distribution system.

The above statistics suggest that there is little scope for reducing water consumption further by water demand management, but that significant savings could be made by reducing losses. However, this is likely to be a long-term process because of the difficulties of repairing old water reticulation systems. Therefore, any savings that could be achieved have not been allowed for in the estimates of future water requirements shown in Table 6.1.

6.3 IRRIGATION

The irrigation developments that rely on water from the Lukanji Water Resources System have been described in Chapter 4. In terms of their water requirements they may be categorised as :

- Schemes supplied with water from dams that are also existing or potential sources of urban supplies.
- Irrigation developments in the catchment areas of the main dams.
- Other irrigation developments.

The present and expected future water requirements of the schemes in each of these categories are described below, together with water requirements for opportunistic irrigation, both in the catchments of the dams and in other areas.

6.3.1 Schemes Supplied from Dams with Potential for Urban Water Supply

The dams with potential for urban water supply and the irrigation schemes that they supply are :

- Waterdown Dam which supplies the Klipplaat River Government Water Scheme;
- Oxkraal Dam which was constructed to supply the Oxkraal Irrigation Scheme, but can also release water to the river channel to supply the Klipplaat River Government Water Scheme;
- Shiloh Dam which was also constructed to supply a portion of the Oxkraal Irrigation Scheme;
- Bushmanskrantz Dam, which is located upstream of Oxkraal Dam on the same river, and which was built to supply the Zweledinga Irrigation Scheme. Water can be transferred from Bushmanskrantz Dam to Oxkraal Dam by means of river channel releases.

The irrigation schemes and their water requirements have been described in Chapter 4. For purposes of considering ways in which the urban water supply can be augmented it has been assumed that :

- The total scheduled area irrigated under the Klipplaat River Irrigation Scheme will, in the near future, be increased to 1 924 ha as a result of the development of an additional 394 ha of land between Waterdown Dam and Oxkraal River. The total irrigation water requirement from Waterdown Dam will then be 14,68 Mm^3/a, including an allowance for conveyance losses of 25% of the allocation.

- An area of 541 ha of land will in the near future be developed for irrigation from Oxkraal Dam as part of the Oxkraal Irrigation Scheme. The quantity of water required from Oxkraal Dam to supply this area will be 4,13 Mm^3/a, including an allowance of 25% of the allocation for conveyance losses.

- As part of the Oxkraal Irrigation Scheme, an additional area of 25 ha of land will, in the near future, be developed for irrigation by means of water supplied from Shiloh Dam. The quantity of water required will be 0,19 Mm^3/a, including an allowance for conveyance losses of 25% of the allocation.

- No water will be required from Bushmanskrantz Dam for the foreseeable future for the defunct Zweledinga Irrigation Scheme. (This assumption is made for purposes of considering alternative operating rules, but in no way precludes the possibility of reviving irrigation below the dam at any time in the future).

- The area of irrigated land to be supplied with water from Xonxa Dam is unlikely to exceed 1 000 ha at any time in the future. The quantity of water required from Xonxa Dam to irrigate 1 000 ha of land would be 11,25 Mm^3/a, including an allowance of 25% of the allocation for conveyance losses.

The assumed quantities of water to be supplied for irrigation from the dams that are possible sources of additional urban water supply are summarised in Table 6.2.

TABLE 6.2 ASSUMED IRRIGATION WATER REQUIREMENTS FROM DAMS THAT ARE POSSIBLE SOURCES OF ADDITIONAL URBAN WATER SUPPLY

SCHEME	DAM	ASSUMED AREA IRRIGATED (ha)	QUOTA (m^3/ha/a)	ALLOWANCE FOR CONVEYANCE LOSSES (m^3/ha/a)	WATER REQUIREMENTS (Mm^3/a)
Klipplaat River Government Water Scheme	Waterdown	1 924	6 100	1 525	14,7
Oxkraal Irrigation Scheme	Oxkraal Shiloh	541 25	6 100 6 100	1 525 1 525	4,1 0,2
Zweledinga	Bushmanskrantz	0	-	-	0
TOTALS IN CATCHMENT OF BLACK KEI RIVER		**2 490**	**-**	**-**	**19,0**
Xonxa Irrigation Scheme	Xonxa	1 000	9 000	2 250	11,3

6.3.2 Irrigation Water Requirements in the Catchment Areas of the Main Dams

Irrigation developments in the catchment areas of the main dams reduce the runoff into the dams, and hence, the yields of the dams. Developments falling into this category are :

- The Upper Klipplaat Irrigation Scheme (see Section 4.3), which is situated in the catchment of Waterdown Dam, and which, for purposes of calculating the yield of Waterdown Dam, has been assumed to abstract 5,1 Mm^3/a by means of farm dams and pumping from rivers.

- Irrigation in the catchment of the Bonkolo River upstream of Bonkolo Dam is assumed to use 0,68 Mm^3/a from surface water resources and 0,5 Mm^3/a from groundwater (see Section 4.8). The effect of the groundwater use on streamflow has been assumed to be negligible. In terms of a Water Court Order, surface water use upstream of Bonkolo Dam can be restricted whenever Bonkolo Dam is subjected to drought. It is uncertain how this restriction is applied in practice.

- Diffuse irrigation along the Upper White Kei River upstream of Xonxa Dam was estimated in the QRWSFS to take place on 557 ha of land and to have a water requirement of 5 Mm^3/a. These values were accepted for the current study. (The Water Resources Situation Assessment Report (DWAF, 2002) gives a water use of 3,67 Mm^3/a, but the higher value given in the QRWSFS is considered more appropriate for this study as it reduces the risk of over-estimating the yield of Xonxa Dam).

The assumed water requirements for irrigation in the catchments are summarised in Table 6.3.

TABLE 6.3 IRRIGATION WATER REQUIREMENTS IN THE CATCHMENTS OF THE MAIN DAMS

IRRIGATION DEVELOPMENT	DAM CATCHMENT AREA	ASSUMED WATER REQUIREMENT (Mm^3/a)
Upper Klipplaat	Waterdown Dam	5,1
Bonkolo River	Bonkolo Dam	1,2 *
Upper White Kei	Xonxa Dam	5,0
Total irrigation water requirement		**11,3**

* 0,5 Mm^3/a is supplied from groundwater.

6.3.3 Other Irrigation Schemes

Other irrigation developments that are of relevance to this study are those along the upper reaches of the Black Kei River, in the catchment of the Klaas Smits River, and opportunistic irrigation in the catchment of the Black Kei River downstream of its confluence with the Klipplaat River. The significance of these developments is that they reduce the quantity of water available from run-of-river flow that can be used on irrigated land that is scheduled under the Klipplaat River Government Water Scheme. As mentioned previously, the quota supplied from Waterdown Dam is less than the optimum for irrigation. When the scheme was first established, the water from the dam supplemented water abstracted from run-of-river flow (DWAF, 1993), but, with the development of additional dams on the Oxkraal River and in the upper reaches of the Black Kei River, the reliability at which the required quantity of water can be abstracted may have decreased. If this were the case, it would be reasonable when considering the future apportionment of water from Waterdown and Oxkraaal Dams, to take into account the possible need to increase the quota for irrigation. This is addressed in Chapter 7.

The assumptions made in this study on the water requirements of the various developments are the following :

- The Ntabethemba and associated schemes along the Black Kei River upstream of its confluence with the Klipplaat River (see Section 4.7) are estimated to require 2,16 Mm^3/a of water in their current state (290 ha of irrigated land). In the past, about 1 200 ha of land has been under irrigation, but there has been a drastic decline in irrigation farming, possibly because insufficient water is available at reasonable assurance for the original areas of irrigation. It was estimated in a previous study (DWAF 1993) that, after allowing for about 700 ha of diffuse irrigation from minor tributaries, the 1:10 year yield of the existing dams and the remaining run-of-river flow combined is about 2,5 Mm^3/a. This is sufficient to irrigate about 380 ha of land. However, for purposes of this study, it has been conservatively assumed that irrigation of the previously irrigated land might be re-instated. If that were to occur, the water requirement for irrigation would be about 12,6 Mm^3/a for 1 900 ha (including the 700 ha of diffuse irrigation at an average field edge requirement of 6 600 m^3/ha/a (DWAF, 1993)). This conservative approach to estimating the water use in this area was adopted because any increase in the area of irrigated land would affect the run-of-river yield available to the Klipplaat River Government Water Scheme.

- Opportunistic irrigation in the catchment of the Klaas Smits River is estimated (see Section 4.8) to take place on about 5 250 ha of land, of which 990 ha is irrigated from groundwater. The average water requirement is approximately 5 600 m^3/ha/a (DWAF, 1993), giving a water requirement of 29,4 Mm^3/a. Of this, an estimated 5,5 Mm^3/a is supplied from groundwater and 23,9 Mm^3/a from surface water. Part of this requirement (0,7 Mm^3/a from surface water and 0,5 Mm^3/a from groundwater) is in the catchment of Bonkolo Dam (see Section 6.3.2). Therefore, the irrigation water requirements in the Klaas Smits River catchment, excluding the catchment of Bonkolo Dam, are estimated to be 23,2 Mm^3/a from surface water and 5,0 Mm^3/a from groundwater.

- Opportunistic irrigation in the catchment of the Black Kei River downstream of its confluence with the Klipplaat River occurs along small tributaries in areas remote from the Black Kei River itself. It is estimated (DWAF, 1993) that some 440 ha of land is irrigated in this way, and that the field edge requirement of the crops grown is approximately 5 400 m^3/ha/a, giving a total water requirement of 2,4 Mm^3/a.

The irrigation water requirements assumed in this study for developments that do not affect the yields of the main dams are summarised in Table 6.4.

TABLE 6.4 IRRIGATION WATER REQUIREMENTS THAT DO NOT AFFECT THE YIELDS OF THE MAIN DAMS

IRRIGATION DEVELOPMENT	LOCATION	ASSUMED WATER REQUIREMENT	
		FROM SURFACE WATER (Mm^3/a)	FROM GROUNDWATER (Mm^3/a)
Ntabethemba and associated schemes	Black Kei River catchment upstream of Klipplaat River confluence	12,6	Negligible
Opportunistic irrigation in catchment of Klaas Smits River	Catchment of Klaas Smits River excluding catchment of Bonkolo Dam	23,2	5,0
Opportunistic irrigation in the Lower Black Kei River catchment	Black Kei River catchment downstream of Klipplaat River confluence	2,4	Negligible
Total water requirements		**38,2**	**5,0**

6.3.4 Optimum Irrigation Water Requirements of the Klipplaat River Government Water Scheme

The optimum field edge water requirement of the mix of crops grown on the scheduled land under the Klipplaat River Government Water Scheme has been calculated (DWAF, 1993) to be approximately 7 500 m^3/ha/a along the Klipplaat River and 7 000 m^3/ha/a along the Black Kei River, while the quota supplied from Waterdown Dam is 6 100 m^3/ha/a. Thus, there is a shortfall of 1 400 m^3/ha/a and 900 m^3/ha/a in the quantity of water supplied to the respective areas.

There is normally insufficient water in the Klipplaat River downstream of the dams for the irrigated lands along its banks to be supplied with significant quantities of water from run-of-river flow. Therefore the additional water, if supplied, would have to come from Waterdown Dam or Oxkraal Dam (if supplied from Oxkraal Dam, the water would have to be piped to the 600 ha of land that is located along the Klipplaat River upstream of the Oxkraal/Klipplaat River confluence). The additional water required along the Black Kei River could be abstracted from run-of-river flow in that river at an assurance of at least 1:10 years (see Chapter 7). The quantities of additional water required are shown in Table 6.5.

TABLE 6.5 IRRIGATION WATER REQUIREMENTS OF THE KLIPPLAAT RIVER GOVERNMENT WATER SCHEME IN EXCESS OF THE ALLOCATION FROM WATERDOWN DAM

SECTION OF SCHEME	ALLOCATION (m^3/ha/a)	ADDITIONAL WATER REQUIREMENT (m^3/ha/a)	SCHEDULED AREA (ha)	TOTAL WATER REQUIREMENT (Mm^3/a)
Klipplaat River	6 100	1 400	915	1,3
Black Kei River	6 100	900	1 009	0,9
Total additional water requirement				**2,2**

6.3.5 Summary of Water Requirements for Irrigation

The irrigation requirements from the various categories of sources of supply are summarised in Table 6.6 where it can be seen that the total field edge water requirement is some 77 Mm^3/a, of which 30 Mm^3/a are supplied from dams which are potential sources of additional urban water supply, and approximately 11 Mm^3/a is abstracted from surface water sources in the catchment areas of the same dams.

TABLE 6.6 SUMMARY OF FIELD EDGE WATER REQUIREMENTS FOR IRRIGATION

SOURCE OF SUPPLY	FIELD EDGE WATER REQUIREMENT (Mm^3/a)
Dams with potential for urban water supply	30,3
Surface water in catchments of dams with potential for urban supply	10,8
Dams not used for urban supply and run-of-river flow not affecting main dams	40,4 *
Groundwater	5,5
Total requirement	**87,0**

* Includes 38,2 Mm^3/a from Table 6.4 and 2,2 Mm^3/a from Table 6.5 that could be supplied from dams.

6.4 STREAMFLOW REDUCTION BY AFFORESTATION

There is little indigenous forest in the study area and less than 7 km^2 of the study area is covered by commercial timber plantations (DWAF, 1996). Most of this is along the Amatola mountain range in the catchment of the Klipplaat River. The total reduction in streamflow caused by afforestation is estimated to be 1,24 Mm^3/a, from plantations located as shown in Table 6.7.

TABLE 6.7 ANNUAL WATER REQUIREMENTS FOR AFFORESTATION

RIVER CATCHMENT	AFFORESTED AREA (ha)	WATER REQUIREMENT (Mm^3/a)
Upper Klipplaat River	474	1,01
Middle Klipplaat River	20	0,02
Lower Klipplaat River	7	-
Upper Oxkraal River	146	0,21
Lower Oxkraal River	1	-
Total	**648**	**1,24**

6.5 INVASIVE ALIEN VEGETATION

According to the Water Resources Situation Assessment Report (DWAF, 2002), the main occurrence of alien vegetation is in the catchment of Waterdown Dam where there is reported to be a consolidated area of 5,5 km^2 of mainly black wattle which is estimated to reduce streamflow by about 0,8 Mm^3/a.

7. WATER AVAILABILITY

7.1 DETERMINATION OF THE YIELD OF THE SYSTEM

In order to determine the quantities of water available to meet the water requirements described in Chapter 6, the yields of various components of the Lukanji Water Resources Systems were determined using the Water Resources Yield Model configured to represent the System. The model used was originally developed for the QRWSFS and covers the whole of the Upper Kei Basin, i.e. the catchments of the Black Kei River and the White Kei River upstream of the point at which they join to become the Great Kei River (see Figure 2.1). Consequently, the model includes the Doring River Dam and the Lubisi Dam in addition to the dams that are of interest in this study. As the configuration of the original system model is described in detail in the reports on the QRWSFS (DWAF, 1997), the description is not repeated in this document.

For the present study, some modifications were made to the original model to take account of changes in irrigated areas, to model environmental releases from dams, and to facilitate determining the assurances at which various quantities of run-of-river flow could be abstracted from the Black Kei River. In addition, estimates of the probable loss in capacities of the main dams by the year 2020 as a result of sediment accumulation were made using the results of the most recent basin surveys carried out by DWAF. The results of this exercise were used to determine the yields of the dams in the year 2020 for use in considering alternative possibilities for augmenting the urban water supply.

Finally, stochastic flow sequences were developed and long-term and short-term yield characteristic curves were derived for the main dams of the system in order to obtain the reliabilities of the yields.

The changes made to the model and the results of the yield analyses are described in detail in Appendix 4 to this report, while the results of the yield analyses are summarised in the remainder of this chapter. It should be noted that the modelled water requirement values for irrigation, afforestation and alien vegetation differ slightly from the values given in Chapter 6 because the latter are estimated from assumed average annual requirements, whilst the modelled values are calculated from monthly rainfall sequences covering a 74 year period.

7.2 YIELDS OF DAMS

The estimated yields for conditions in 2020 of those dams that are existing or potential future sources of urban water supply are shown in Table 7.1. Land-use in the catchments of the dams was assumed to remain as it is at present (2005).

TABLE 7.1 ESTIMATED YIELDS OF MAIN DAMS FOR CONDITIONS IN 2020

DAM	NATURAL MAR (Mm^3/a)	MAR IN 2020 (Mm^3/a)	LIVE STORAGE IN 2020 (Mm^3/a)	YIELDS					
				HISTORICAL FIRM YIELD (Mm^3/a)	1:10 year (Mm^3/a)	1:20 year (Mm^3/a)	1:50 year (Mm^3/a)	1:100 year (Mm^3/a)	1:200 year (Mm^3/a)
Waterdown Dam	45,7	36,7	36,07	16,8	24,5	23,3	20,3	18,8	17,6
Bushmanskrantz and Oxkraal Dams	17,9	17,9	15,60	6,2	8,6	8,0	7,0	6,2	5,7
Bonkolo Dam	3,20	2,5	5,94	0,7	1,2	1,1	0,9	0,8	0,7
Xonxa Dam	47,87	42,8	110,4	20,6	29,6	27,2	23,0	20,7	19,0

The combined yields of Bushmanskrantz and Oxkraal Dams were calculated because it was assumed, for the purpose of considering possible augmentation schemes, that the Zweledinga Irrigation Scheme will not be brought back into use.

The historical firm yields for catchment conditions in 2005 and estimated live storage in 2005 are shown for the same dams in Table 7.2 for comparison with Table 7.1.

TABLE 7.2 HISTORICAL FIRM YIELDS OF MAIN DAMS FOR CONDITIONS IN 2005

DAM	NATURAL MAR (Mm^3/a)	MAR IN 2005 (Mm^3/a)	LIVE STORAGE (Mm^3)	HISTORICAL FIRM YIELD (Mm^3/a)
Waterdown Dam	45,7	36,7	36,07	16,8
Bushmanskrantz and Oxkraal Dams	17,9	17,9	16,33	6,7
Bonkolo Dam	3,20	2,5	5,96	0,8
Xonxa Dam	47,87	42,8	117,9	21,6

The historical firm yields for conditions in 2005 of the dams in the upper reaches of the Black Kei River, namely Thrift, Limietskloof, Tentergate, Glenbrock and Mitford Dams, and the small Shiloh Dam on a tributary of the Oxkraal River, are shown in Table 7.3. The historical firm yields of Thrift and Limietskloof Dams were calculated using the system model. The other dams are not included in the system model and the historical firm yields shown in Table 7.3 are those derived in the Upper Kei Basin Study (DWAF, 1993) for conditions in 1992. The yields at the various reliabilities shown in the table were calculated form the historical firm yields using ratios derived for the equivalent reliabilities for Bushmanskrantz and Oxkraal Dams. The yields at various reliabilities for the latter were derived from stochastic analyses using the system model.

The ratios are considered to be applicable to the yields of the other dams because their catchments experience similar climatic conditions.

TABLE 7.3 YIELDS OF SMALLER DAMS FOR CONDITIONS IN 2005

DAM	NATURAL MAR (Mm^3/a)	MAR IN 2005 Mm^3/a	LIVE STORAGE Mm^3	YIELDS				
				HISTORICAL FIRM YIELD (Mm^3/a)	1:10 year (Mm^3/a)	1:50 year (Mm^3/a)	1:100 year (Mm^3/a)	1:200 year (Mm^3/a)
Thrift Dam	4,3	3,3	2,6	0,31	0,43	0,40	0,31	0,28
Limietskloof Dam	1,4	0,6	0,78	0,01	0,01	0,01	0,01	0,01
Tentergate Dam		0,6	1,72	0,26	0,36	0,33	0,26	0,24
Glenbrock Dam	0,34	0,34	0,41	0,12	0,17	0,15	0,12	0,11
Mitford Dam	0,53	0,39	0,89	0,05	0,07	0,06	0,05	0,04
Shiloh Dam	0,89	0,89	0,26	0,25	0,35	0,28	0,25	0,23

All the dams, with the exceptions of Glenbrock and Shiloh, have opportunistic irrigation in their catchment areas, and this reduces their yields significantly.

7.3 RUN-OF-RIVER YIELDS

Run-of-river flows at various reliabilities were derived using the system model, for the Klipplaat River between Waterdown Dam and the Black Kei River confluence, and for the Black Kei River between its confluences with the Klipplaat River and the White Kei River. The estimated quantities of water available are shown in Table 7.4. As the quantities include flood flows, the quantities of water that could be abstracted for run-of-river irrigation would be less than those shown in the table.

TABLE 7.4 ESTIMATED RUN-OF-RIVER FLOWS

RIVER REACH	YIELDS			
	1:10 year (Mm^3/a)	1:50 year (Mm^3/a)	1:100 year (Mm^3/a)	1:200 year (Mm^3/a)
Black Kei between Klipplaat and White Kei	0,43	0,40	0,31	0,28
Klipplaat downstream of Waterdown Dam	0,01	0,01	0,01	0,01

7.4 RIVER CHANNEL LOSSES

When flow in the river channels is low and releases are made from dams to provide water for irrigation or the environment, substantial losses occur as a result of filling of pools in the river bed and evapotranspiration by vegetation along the edges of the channel. Dummy dams were included in the system model as a means of simulating these losses. The river channel losses estimated in this way are shown in Table 7.5. The quantities shown are the average annual losses incurred by irrigation releases made from Waterdown and Oxkraal Dams.

TABLE 7.5 ESTIMATED RIVER CHANNEL LOSSES INCURRED BY IRRIGATION WATER RELEASES

RIVER	REACH	km	LOSS (Mm^3/a)	LOSS/km $Mm^3/a/km$
Klipplaat	Waterdown to Oxkraal	9	0,3	0,04
Oxkraal	Oxkraal Dam to Kliplaat confluence	7	0,1	0,02
Klipplaat	Oxkraal confluence to Black Kei	10	0,4	0,04
Black Kei	Klipplaat to Klaas Smits	24	0,6	0,02
Black Kei	Klaas Smits to White Kei	14 15	1,6 3,4	0,11 0,22
TOTALS		**80,1**	**6,5**	**0,08**

7.5 EFFECTS OF ENVIRONMENTAL FLOW REQUIREMENTS ON YIELDS

The impacts of environmental flow requirements described in Chapter 5 on the yields of the dams from which the environmental releases would be made were analysed in detail by means of the system model. These analyses are described in Appendix 4. The dams concerned are Waterdown and Xonxa. The impacts that releases made in accordance with the various environmental flow scenarios would have on their yields are shown in Table 7.6.

TABLE 7.6 IMPACTS OF ALTERNATIVE ENVIRONMENTAL FLOW SCENARIOS ON YIELDS OF DAMS

IFR SCENARIO	EFFECT ON YIELD OF WATERDOWN DAM (Mm^3/a)	EFFECT ON YIELD OF XONXA DAM (Mm^3/a)
1	- 4,1	- 4,0
2	- 5,4	- 5,4
3	- 6,9	- 8,3
4	- 3,7	- 3,1
5	- 2,4	- 1,8

8. POTENTIAL AUGMENTATION SCHEMES

8.1 URBAN WATER REQUIREMENTS AND AVAILABILITY

The existing urban water supply scheme is described in Section 4.2 and present and expected future water requirements are discussed in Chapter 6. It is apparent from the description of the scheme that it consists of three components, namely :

- the supply to Queenstown, which is provided from Bonkolo Dam and Waterdown Dam;
- the supply to Sada-Whittlesea and adjacent rural villages, which is provided from Waterdown Dam, and
- the supply to Ilinge, which is currently provided from boreholes.

The present (2005) and expected future water requirements of these components of the scheme are shown in Table 8.1, together with the capacities at 1:50 year assurance of the raw water supplies. (The capacity of the Ilinge borehole supply is assumed to be at 1:50 year assurance, but the actual assurance of supply is not known.).

TABLE 8.1 URBAN WATER REQUIREMENTS AND PRESENT CAPACITY OF RAW WATER SUPPLY SCHEMES

SCHEME COMPONENT	WATER REQUIREMENTS (Mm^3/a) IN THE YEAR			CAPACITY OF EXISTING RAW WATER SUPPLY AT 1:50 YEAR ASSURANCE (Mm^3/a)
	2005	2020	2045	
Queenstown	7,85	8,80	10,30	5,9
Sada-Whittlesea and rural villages	2,41	2,50	3,00	2,5
Ilinge and, after 2005, Macibini Villages	1,44	2,20	2,20	1,3

The water supply to Queenstown from Waterdown Dam is limited by the capacity of the pipeline. The difference of 2,85 Mm^3/a between the 5 Mm^3/a that can be supplied through the pipeline and the current requirement of 7,85 Mm^3/a is provided from Bonkolo Dam. As Bonkolo Dam can provide this amount of water at only very low assurance, this is not a sustainable situation and it is clear that an augmentation scheme is urgently required.

It is also apparent from Table 8.1 that the water supply to Sada-Whittlesea will be adequate for some years to come, but the supply to Ilinge is in urgent need of augmentation.

The supply to Ilinge, which is provided by six boreholes, is reported to have experienced operational difficulties for several years. Because of this, the Water Services Provider for the area, which is the Chris Hani District Municipality, plans to link Ilinge and the nearby Macibini Villages to the Queenstown water supply, so that potable water can be provided from the

Queenstown Water Treatment Works. If this were done, the current requirement from the water treatment works would increase from 7,85 Mm^3/a to 9,29 Mm^3/a (see Table 8.1), and the requirements in 2020 and 2045 would be 11,0 Mm^3/a and 12,5 Mm^3/a, respectively.

The simplest way of increasing the supply to Queenstown would be to increase the capacity of the pipeline between Waterdown Dam and Queenstown. This could be done by providing a booster pump station on the branch line to Sada-Whittlesea (see Section 4.2 for the reasons for this) and an additional booster pump station on the main pipeline. The extent to which the capacity could be increased is governed by the maximum water pressure that the pipeline can safely be subjected to. On this basis, the maximum capacity of the pipeline has been determined (DWAF, 1996) to be 27 Mℓ/day. If it is assumed that the pipeline might be taken out of operation for maintenance for 10% of the time in any year, it would be able to deliver 27 Mℓ/day for, say 330 days per year, which would amount to 8,9 Mm^3/a. Adding the 1:50 year yield of Bonkolo Dam of 0,9 Mm^3/a to this would bring the total supply, assuming that sufficient water were available from Waterdown Dam, to 9,8 Mm^3/a. (The implications of seasonal variation in the water requirements of Queenstown need to be taken into account, but these are addressed later.) A supply of 9,8 Mm^3/a would meet the requirements of Queenstown alone to about the year 2037, and of Queenstown, Ilinge, and the Macibini Villages to 2010 if the existing boreholes were abandoned, or to 2020 if they were retained.

The other factor to be considered is the availability of raw water from Waterdown Dam. Apart from the urban requirements, Waterdown Dam supplies water to irrigated lands scheduled under the Klipplaat River Government Water Scheme. This requirement (see Table 6.2) is 14,7 Mm^3/a, and it is assumed that it is supplied at 1 in 10 year assurance. For purposes of comparing this requirement with the urban requirement, which is assumed to be supplied at 1 in 50 year assurance, it is convenient to convert the irrigation requirement to an equivalent quantity at 1:50 year assurance. The 1 in 50 year yield of Waterdown Dam is about 83% of the 1 in 10 year yield. Therefore, it can be assumed that the equivalent irrigation water requirement at 1 in 50 year assurance is 83% of the 1 in 10 year requirement of 14,7 Mm^3/a, i.e. 12,2 Mm^3/a at 1 in 50 year assurance. On this basis, the total equivalent future requirement from Waterdown Dam with the existing pipeline to Queenstown boosted to its maximum capacity would be 24,1 Mm^3/a. This is made up as follows :

Requirement for Queenstown (determined by maximum capacity of pipeline) at 1:50 year assurance	:	8,9 Mm^3/a
Requirement of Sada-Whittlesea (to 2045) at 1:50 year assurance	:	3,0 Mm^3/a
Equivalent irrigation requirement at 1:50 year assurance	:	12,2 Mm^3/a
Total equivalent requirement at 1:50 year assurance	:	24,1 Mm^3/a

The 1:50 year yield of Waterdown Dam is 20,3 Mm^3/a, which is 3,8 Mm^3/a less than the above requirement. A further consideration is that releases for the Reserve, which have not been made

in the past, may be required in the future. Desirable patterns of releases for the ecological Reserve have been determined in this study (see Chapter 5). It seems likely that these releases, when implemented, will reduce the yield of Waterdown Dam available for other purposes by up to 3,7 Mm^3/a. In this situation, the available yield would be 7,5 Mm^3/a less than the requirements.

The yields of Bushmanskrantz, Oxkraal and Shiloh Dams are not fully utilised at present, and they could, therefore, be used to provide some of the water for irrigation, which would otherwise need to be provided from Waterdown Dam. Additional areas of land may be prepared in the near future for irrigation from these dams. The requirement for this land plus the requirement from Waterdown Dam will bring the total quantity of irrigation water to be supplied from the four dams to 19,0 Mm^3/a at 1:10 year assurance (see Table 6.2). This is equivalent to 15,8 Mm^3/a at 1:50 year assurance. However, until such time as the additional land is developed for irrigation, the water requirement for irrigation will remain at its current level of 14,7 Mm^3/a at 1:10 year assurance, which is equivalent to 12,2 Mm^3/a at 1:50 year assurance. The combined 1:50 year yields of the four dams total 27,6 Mm^3/a, made up as follows :

1:50 year yield of	:	Waterdown Dam	20,3 Mm^3/a
		Bushmanskrantz and Oxkraal Dams	7,0 Mm^3/a
		Shiloh Dam	0,3 Mm^3/a
		TOTAL	27,6 Mm^3/a

With the combined use of the four dams there would still be a shortfall in available yield relative to future requirements of 3,8 Mm^3/a, calculated as follows :

Combined 1:50 year yield of dams	27,6 Mm^3/a
Less present 1:50 year equivalent irrigation requirements	12,2 Mm^3/a
Water available for urban supplies	15,5 Mm^3/a
Less Sada and villages to 2045	3,0 Mm^3/a
Less maximum capacity of Queenstown pipeline	8,9 Mm^3/a
Less provision for ecological Reserve	3,7 Mm^3/a
Balance in 2005 (after allowing for Reserve and future requirements of Sada-Whittlesea)	- 0,2 Mm^3/a
Less 1:50 year equivalent irrigation requirements for Oxkraal Irrigation Scheme	3,6 Mm^3/a
Future balance	- 3,8 Mm^3/a

If it were accepted that the Reserve releases would not be implemented in the near future, Waterdown Dam, supported by the other three dams, could meet the urban water supply requirements to 2010 if the Ilinge boreholes were abandoned, and to 2020 if they were retained. Alternatively, a decision not to implement the additional irrigation would have the same effect.

An additional source of raw water would be required to meet the urban requirements to 2045. The required additional quantity would be 1,4 Mm^3/a if the Ilinge boreholes were retained and the ecological Reserve were not implemented, and 5,1 Mm^3/a if it were implemented. If the Reserve releases were implemented and the Ilinge boreholes were abandoned, the total requirement would be 6,6 Mm^3/a.

For purposes of an initial comparison of the costs of possible augmentation schemes an additional raw water requirement of 6,6 Mm^3/a was assumed. The implications for the costs of augmentation schemes of retaining the Ilinge boreholes are considered later (see Section 8.7.5). The implementation of the ecological Reserve is a legal requirement. Therefore, even though the timing of such implementation is uncertain, it has been assumed in this study that it will be implemented and that the impact of this on the available yield of the dams must be provided for when considering the yield available for augmenting the urban supply. The potential sources of additional raw water that were considered are described in the next section.

8.2 POTENTIAL SOURCES OF ADDITIONAL RAW WATER

The estimated current and future raw water requirements at the Queenstown Water Treatment Works are compared with the available yields from the present sources of raw water in Table 8.2. The available yields are the 1:50 year yields after allowing for the impact of the ecological Reserve and subtracting the estimated future (2045) requirements of Sada of 3,0 Mm^3/a, the current yield of the Waterdown pipeline of 5,0 Mm^3/a, and the equivalent 1:50 year irrigation requirements in 2005 of 12,2 Mm^3/a (i.e. making no allowance for additional irrigation), assuming that the full yields of Oxkraal, Bushmanskrantz and Shiloh Dams will be used to provide part of the allocations to irrigation from Waterdown Dam,
(i.e. 27,6 Mm^3/a - 3,7 Mm^3/a - 3,0 Mm^3/a - 5,0 Mm^3/a - 12,2 Mm^3/a = 3,7 Mm^3/a).

TABLE 8.2 ESTIMATED URBAN WATER REQUIREMENTS AND YIELD AVAILABLE FROM EXISTING RAW WATER SOURCES

ITEM	YEAR		
	2005	2020	2045
	(Mm^3/a)	(Mm^3/a)	(Mm^3/a)
Queenstown water requirements	10,05	11,00	12,50
Less existing 1:50 year yield of Bonkolo Dam	0,90	0,90	0,90
Less yield of existing Waterdown Pipeline	5,00	5,00	5,00
Additional yield required	4,15	5,10	6,60
Potentially utilisable 1:50 year yield of Waterdown, Oxkraal and Shiloh Dams	3,70	3,70	3,70
Yield required from other sources	0,45	1,40	2,90

The table shows that additional yield of 4,15 Mm^3/a is required in 2005, increasing to 6,6 Mm^3/a by 2045 if the maximum delivery through the Waterdown Pipeline is assumed to remain at 5,0 Mm^3/a. If it were decided not to develop additional land for irrigation below Oxkraal and Shiloh Dams, but to use the water instead for the future requirements of Sada-Whittlesea and Queenstown, an additional 3,7 Mm^3/a would be available from Waterdown Dam. Even if the conveyance capacity between Waterdown Dam and Queenstown were increased accordingly, additional water would still be required. The quantity would increase from 0,45 Mm^3/a in 2005 to 2,90 Mm^3/a in 2045. Therefore, it is necessary to consider other sources. Some of these sources would not be sufficient to meet the full expected water requirements in 2045. In these cases it has been assumed, purely for purposes of investigating the cost of additional water from Waterdown Dam for urban supplies relative to the costs of water from other sources, that up to 3,7 Mm^3/a would be made available from Waterdown, Oxkraal, Bushmanskrantz and Shiloh Dams (i.e. the water that is likely to in fact be used for future irrigation development).

Potential sources of additional surface water are discussed in detail in the reports on the QRWSFS (DWAF, 1996). The most favourable of these for the size of supply now envisaged are listed in Table 8.3 and described below, as are potential groundwater sources identified in the current study.

TABLE 8.3 POTENTIAL SOURCES OF ADDITIONAL YIELD

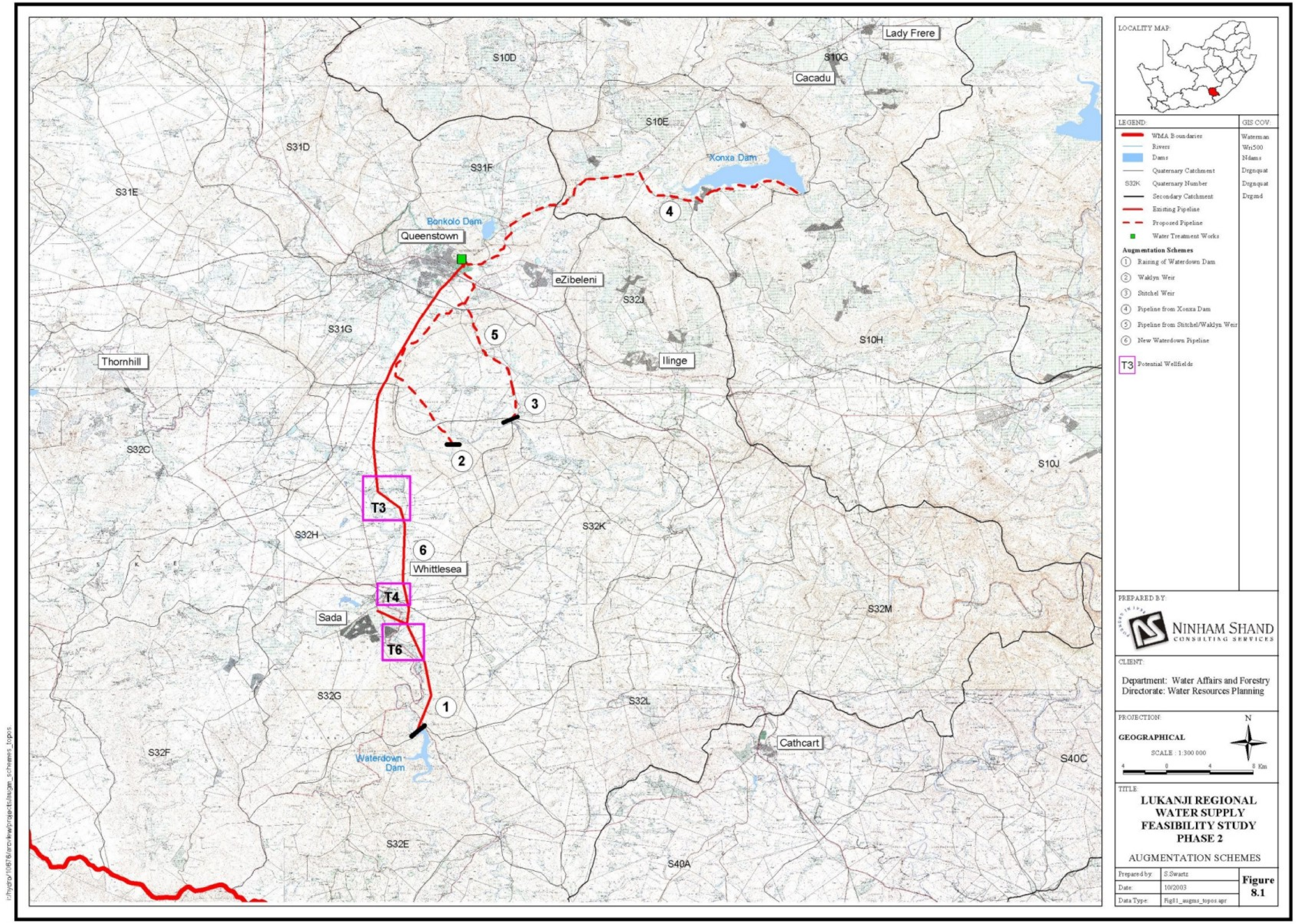
SOURCE	YIELD AT 1:50 YEAR ASSURANCE
Raising of Waterdown Dam	4,3 Mm^3/a
A weir on the Black Kei River at Waklyn	Up to 5,7 Mm^3/a
A weir on the Black Kei River at Stitchel	Up to 7 Mm^3/a
Xonxa Dam	11,1 Mm^3/a
Groundwater in the vicinity of Sada-Whittlesea	Between 3 Mm^3/a and 6 Mm^3/a

The localities of the sources of water listed in Table 8.2 are shown on Figure 8.1.

For purposes of comparing possible augmentation schemes based on these sources, pipelines have been sized to have a capacity of 1,5 times the annual quantity of water that they are required to deliver. This has been done to accommodate seasonal variations in water requirements and periods when the pipeline is shut down for maintenance. In practice, it may be more economical to size the pipelines to pump at a constant rate, storing excess water in Bonkolo Dam during periods when water requirements are less than the rate of delivery through the pipeline, and providing additional water from Bonkolo Dam when requirements exceed the capacity of the pipeline.

Bonkolo Dam can be used in this way because its capacity is very large in comparison to the MAR at the dam. A disadvantage of such an arrangement is that it would complicate the operation of the scheme and that water that has been pumped, and is therefore expensive, is lost by evaporation and may be lost by spillage. Therefore, for purposes of comparing possible augmentation schemes it was considered to be acceptable to omit this possibility. It is, nevertheless, discussed further in Section 8.7 in relation to the preferred augmentation options.

Descriptions of each source and the type of infrastructure required to deliver water to Queenstown follow.


Lady Frere
S10D
S10G
Cacadu
S10E
S31D
S31F
Xonxa Dam
S31E
4
Bonkolo Dam
Queenstown
eZibeleni
S32J
S31G
5
S10H
Thornhill
Ilinge
3
S32C
2
S10J
T3
S32K
S32H
6
Whittlesea
T4
Sada
S32M
T6
S32G
S32L
1
Cathcart
S32F
Waterdown Dam
S40C
S32E
S40A
LOCALITY MAP:
LEGEND:
WMA Boundaries
Rivers
Dams
Quaternary Catchment
S32K Quaternary Number
Secondary Catchment
Existing Pipeline
Proposed Pipeline
Water Treatment Works
Augmentation Schemes
1 Raising of Waterdown Dam
2 Waklyn Weir
3 Stitchel Weir
4 Pipeline from Xonxa Dam
5 Pipeline from Stitchel/Waklyn Weir
6 New Waterdown Pipeline
T3 Potential Wellfields
GIS COV:
Waterman
Wri500
Ndams
Drgnquat
Drgnquat
Drgsnd
PREPARED BY:
NINHAM SHAND
CONSULTING SERVICES
CLIENT:
Department: Water Affairs and Forestry
Directorate: Water Resources Planning
PROJECTION:
GEOGRAPHICAL
N
SCALE : 1:300 000
4 0 4 8 Km
TITLE:
LUKANJI REGIONAL WATER SUPPLY FEASIBILITY STUDY PHASE 2
AUGMENTATION SCHEMES
Prepared by: S.Swartz
Date: 10/2003
Data Type: Fig81_augms_topos.apr
Figure 8.1

8.2.1 Raising of Waterdown Dam

Waterdown Dam was originally designed to be raised by 7,0 m, thus increasing the capacity from 21 Mm^3 to 59 Mm^3. This would make additional water available for supplying Queenstown or irrigators. It was calculated in the QRWSFS that an increase in firm yield of 3,6 Mm^3/a could be obtained by such a raising of the dam. The ratio of 1 in 50 year yield to firm yield for Waterdown Dam at its existing capacity has been determined to be 1,2:1 (see Table 7.1). Thus, multiplying an increase in firm yield of 3,6 Mm^3/a by a factor of 1,2 gives an equivalent increase in 1 in 50 year yield of 4,3 Mm^3/a.

It can be seen from Table 8.2 that an additional supply of 4,3 Mm^3/a would meet the water requirements of Queenstown to well beyond 2045 if the existing spare yield were utilised as well, but to only just beyond the year 2005 if the spare yield were allocated to irrigation instead. In the latter case, an additional source of supply would be required to meet requirements beyond 2005.

In order to deliver the additional water to Queenstown if the dam were raised, the water transfer capacity would have to be upgraded from the existing 5 Mm^3/a to 9,3 Mm^3/a. As discussed previously, the existing pipeline has a design capacity of 23 Mℓ/day but can deliver a maximum of only 13,7 Mℓ/day while supplying Sada-Whittlesea at the same time. According to the QRWSFS, the capacity of the pipeline could be increased by 20% to 27 Mℓ/day by installing an additional pump station. (A booster pump station on the line to Sada would also be required if this were done.). At a capacity of 27 Mℓ/day and a peak factor of 1,5, the average quantity of water delivered would be 6,6 Mm^3/a. The balance of 3,3 Mm^3/a would have to be supplied through a new second pipeline. Alternatively, the existing pipeline could remain as it is, and the new pipeline could be designed to deliver the full additional quantity of water.

A further consideration is that the existing pipeline is forty-five years old and can, therefore, be expected to require refurbishment in the near future. In view of this, it might be economical to abandon the existing pipeline and replace it with a new one that will convey the full 9,3 Mm^3/a of water.

In order to identify the optimum way of augmenting the water supply to Queenstown it is necessary to consider all three of the above options in conjunction with the potential schemes for providing water from other sources that are listed in Table 8.3 and are described below.

8.2.2 A Weir on the Black Kei River at Waklyn

One of the possibilities investigated in the QRWSFS was a storage dam or a diversion weir at Waklyn on the Black Kei River, some 21 km south of Queenstown and upstream of the Klaas Smits River confluence. The present day mean annual runoff at the site is 51 Mm^3/a (QRWSFS), and for the quantity of water required for the Queenstown supply, a diversion weir with a small volume of storage would be more economical than a large storage dam. An analysis carried out for the QRWSFS showed that for a pump station and pipeline capacity of 1,5 m^3/s, a firm yield of about 3,6 Mm^3/a could be obtained if negligible storage were provided by the diversion weir. Alternatively, if 1 Mm^3 of storage were provided by the weir, a yield of 5,7 Mm^3/a could be obtained for a pipeline capacity of 0,5 m^3/s.

The scheme would require a diversion weir, a single pump station, and a 22 km long pipeline to deliver water to the Berry Reservoir in Queenstown.

In the current study, a weir with a storage capacity of 1 Mm^3 was considered in conjunction with a range of pipeline capacities to suit the various schemes in which combinations of water from various sources were considered. These are described in detail in Appendix 6. Amongst the possibilities considered was a scheme in which the existing Waterdown Dam to Queenstown pipeline would be abandoned and water from Waterdown Dam would be released into the river to be intercepted at the Waklyn weir and pumped to Queenstown.

8.2.3 A Weir on the Black Kei River at Stitchel

The feasibility of a storage dam or a weir at Stitchel on the Black Kei River some 17 km south of Queenstown was also investigated in the QRWSFS. This site is downstream of the Klaas Smits River confluence and the present day mean annual runoff is 98 Mm^3/a. According to the QRWSFS, a firm yield of about 7 Mm^3/a could be obtained if a weir with negligible storage were provided, together with a pump station and pipeline of 2 m^3/s capacity. Lower abstraction capacities would be required for the same yield if storage of 1 Mm^3 were provided. As in the case of the Waklyn Weir, the costs of alternative schemes consisting of a weir providing 1 Mm^3 of storage and various different pipeline capacities were investigated (see Appendix 6).

The advantage of this site relative to the Waklyn site is that lower pumping rates are required for the same yield, because of the higher runoff. A disadvantage is the high silt load that is introduced by the Klaas Smits River. A 15,5 m high weir with large radial scour gates to deal with the silt would be required. The pipeline to Queenstown would be 18 km long and two pump stations would be required to accommodate the lift, which is higher than that at the Waklyn site.

8.2.4 Xonxa Dam

Xonxa Dam lies to the east of Queenstown and has sufficient unutilised yield to provide an additional 6,6 Mm^3/a at 1 in 50 year assurance. A pipeline between the dam and the Berry Reservoir would be 32 km long, and would pass over Nonesi's Nek, some 10 km east of Queenstown, which would entail pumping against a static head of 430 m by means of two pump stations, one at the dam and one about 19 km from the dam. (In terms of pumping costs, it is of interest to compare this with the Waterdown Dam to Queenstown pipeline which is 48 km long, but has no static head.).

As in the cases of the other sources of supply, a number of schemes incorporating varying quantities of water from Xonxa Dam were costed and compared (see Appendix 6).

8.2.5 Groundwater in the Vicinity of Sada-Whittlesea

In a review of the groundwater potential of the area, described in detail in Appendix 5, five target areas for the development of wellfields were identified in the vicinity of Sada-Whittlesea. Hydrogeological structures are considered to be more favourable in this area than in areas closer to Queenstown. It was estimated that each of these areas could provide sustained yields of 0,9 Mm^3/a, giving a combined yield of 4,5 Mm^3/a.

In considering possible augmentation schemes for Queenstown, this groundwater source was considered as an alternative to raising Waterdown Dam as a source of water, in conjunction with the existing Waterdown, Oxkraal and Shiloh Dams, to meet the full estimated additional requirements of Queenstown to 2045.

8.3 PRELIMINARY COMPARISON OF ALTERNATIVE AUGMENTATION SCHEMES

Early in the study, before the magnitudes of the water requirements shown in Table 8.2 had been finalised, a preliminary comparison of the estimated costs of augmentation schemes (excluding the groundwater option) was carried on the basis of providing additional quantities of water of 2,83 Mm^3/a in 2005 and 1,27 Mm^3/a in 2020, i.e. a total increase in the supply of 4,1 Mm^3/a compared to the final estimated water requirement in 2045 of an additional 6,6 Mm^3/a. Even though the estimates of water requirements have increased, the preliminary analysis served the purpose of identifying those alternatives that merit further consideration. The analysis is described in detail in Appendix 6 of this report and the results are, therefore, only summarised here.

Sixteen different scheme development options were considered, as outlined in Table 8.4. In Options 1 to 8, it was assumed that the existing Waterdown to Queenstown pipeline would remain in use indefinitely, while Options 9 to 16 assumed that the existing pipeline would be replaced by the first phase of the new scheme. Both the phased implementation of schemes and the initial construction of augmentation schemes to the ultimately required capacity were considered.

TABLE 8.4 SCHEME DEVELOPMENT OPTIONS INVESTIGATED IN THE PRELIMINARY ANALYSIS

OPTION	YEAR		TOTAL CAPITAL COST (R Million)	NPV AT 6% (R Million)
	2005	2020		
1	Construct Stitchel weir and pipeline (2,83 Mm^3/a)	Construct 2nd Stitchel pipeline (1,27 Mm^3/a)	81	80,06
2	Construct Xonxa pipeline (2,83 Mm^3/a)	Construct Stitchel weir and pipeline (1,27 Mm^3/a)	87	67,57
3	Construct Stitchel weir and pipeline (2,83 Mm^3/a)	Construct Xonxa pipeline (1,27 Mm^3/a)	89	105,66
4	Construct Xonxa pipeline (4,1 Mm^3/a)		34	46,49
5	Construct Waklyn weir and Waklyn pipeline (2,83 Mm^3/a)	Construct 2nd Waklyn pipeline (1,27 Mm^3/a)	87	89,12
6	Boost existing Waterdown pipeline (additional 1,15 Mm^3/a) and construct Xonxa pipeline (2,95 Mm^3/a)		28,6	40,57
7	Construct Xonxa pipeline (2,83 Mm^3/a)	Construct Waklyn weir and Waklyn pipeline (1,27 Mm^3/a)	92	69,57
8	Construct Xonxa pipeline (2,83 Mm^3/a)	Construct Xonxa pipeline (1,27 Mm^3/a)	45	41,97
9	Construct Stitchel weir and pipeline (7,83 Mm^3/a) and decommission Waterdown pipeline	Construct 2nd Stitchel pipeline (1,27 Mm^3/a)	94	116,95
10	Construct Xonxa pipeline (7,83 Mm^3/a) and decommission Waterdown pipeline	Construct Stitchel weir and pipeline (1,27 Mm^3/a)	112	117,57
11	Construct Stitchel weir and pipeline (7,83 Mm^3/a) and decommission Waterdown pipeline	Construct Xonxa pipeline (1,27 Mm^3/a)	97	114,03
12	Construct Xonxa pipeline (9,1 Mm^3/a) and decommission Waterdown pipeline		60	94,24
13	Construct Waklyn weir and Waklyn pipeline (7,83 Mm^3/a) and decommission Waterdown pipeline	Construct 2nd Waklyn pipeline (1,27 Mm^3/a)	99	111,26
14	Raise Waterdown Dam and construct new pipeline (9,1 Mm^3/a) and decommission Waterdown pipeline		118	135,33
15	Construct Xonxa pipeline (7,83 Mm^3/a) and decommission Waterdown pipeline	Construct Waklyn weir and Waklyn pipeline (1,27 Mm^3/a)	117	121,83
16	Construct Xonxa pipeline (7,83 Mm^3/a) and decommission Waterdown pipeline	Construct Xonxa pipeline (1,27 Mm^3/a)	70	100,60

The net present values (NPVs) at discount rates of 3%, 6% and 9% were calculated for each option, taking into account estimated capital, maintenance and running costs. The NPVs at 6%, which is considered to be an appropriate discount rate for present economic circumstances, are shown in the last column of Table 8.4.

Options 1 to 8 all provide the same quantity of water, and their NPVs are, therefore, directly comparable. Options 9 to 16 provide, in addition, the quantity of water that is currently provided by the existing Waterdown pipeline. Consequently, their NPVs are directly comparable with one another, but not with those for Options 1 to 8.

The results of this preliminary analysis show that, for schemes where it is assumed that the existing Waterdown Pipeline will remain in operation indefinitely, Options 6 and 8 are the most economic for augmenting the water supply to Queenstown. The cost of Option 6 is marginally less than that of Option 8 at 6% discount rate. Option 4 is slightly more expensive than both Options 6 and 8, while the other options are significantly more expensive.

Option 6 would entail boosting of the existing Waterdown Pipeline and constructing a single Xonxa pipeline of 300 mm diameter in 2004. Option 8 would entail the phased construction of two Xonxa pipelines, while Option 4 is the construction of a single Xonxa pipeline in place of the two smaller ones of Option 8.

The differences between the NPVs of the three options are small and more detailed investigation was carried out, as described later in this report, to determine the most favourable option.

For the options that entail the decommissioning of the existing Waterdown pipeline when the first scheme comes into operation, Option 12 proves to be the most economical. This is a single 600 mm diameter Xonxa pipeline constructed in 2004, that would supply the water requirements until 2045. At the discount rate of 6%, Option 16 (two phased pipelines from Xonxa Dam to Queenstown) proves to be just slightly more expensive than the single Xonxa pipeline. The other options are all significantly more expensive.

It can be seen from Table 8.4 that the costs of the more economical schemes in which the Waterdown Pipeline is replaced are more than twice the cost of the equivalent schemes in which it is assumed that the pipeline will continue in use indefinitely. This demonstrates the high value of the existing pipeline. It appears from discussion with the Town Engineer of Queenstown that the existing pipeline is reliable and shows no signs of serious deterioration. Therefore, in further investigations of the more favourable schemes, it was assumed that the existing pipeline would remain in operation indefinitely.

When comparing the schemes involving the replacement of the existing Waterdown Pipeline, the NPV of Scheme 14, which involves raising Waterdown Dam and constructing a new 9,1 Mm^3/a capacity pipeline between the dam and Queenstown, is much higher than that of Scheme 12 involving the construction of a single pipeline of equivalent capacity between Xonxa Dam and Queenstown. However, analysis of the costs of individual components of Scheme 14 shows (see Appendix 6) that 35% of the NPV is attributable to the capital cost of raising Waterdown Dam.

Thus, the NPV of the capital and operating costs of the pipeline from Waterdown Dam is approximately 65% of the total NPV of Scheme 14 of R135,33 million, which amounts to R88 million. Comparing this value with the NPV of R94,24 million for Scheme 12 for the equivalent pipeline from Xonxa Dam, suggests that a second pipeline from Waterdown Dam might be more economical if additional water could be made available at a significantly lower cost than that of raising the dam. Therefore, various alternatives were considered, as described below.

8.4 POSSIBILITIES FOR INCREASING THE SUPPLY TO QUEENSTOWN FROM WATERDOWN DAM

The estimated water requirement of Queenstown in 2045 is 6,60 Mm^3/a higher than the capacity of the present supply, as shown in Table 8.2. The supply would be required at 1:50 year assurance.

An extra 3,6 Mm^3/a of water could be made available to Queenstown from Waterdown Dam if irrigation supplies were limited to the requirements in 2005. The additional requirement of 3,0 Mm^3/a might be obtained by :

(i) purchasing allocations of irrigation water, or
(ii) developing a groundwater supply for Sada.

8.4.1 Purchase of Irrigation Allocations

The potential for purchasing water allocations from farmers supplied from Waterdown Dam was investigated. The farmers, through their representatives, were consulted on their willingness to sell water allocations at about R7 000/ha. The amount was calculated, as shown in Table 8.5, from the difference in estimated costs between a Xonxa Scheme and a Waterdown Scheme with no raising of the dam, and the number of hectares worth of water allocations that would be required to obtain the additional quantity of water required. The farmers did not want to sell at that price. Without the purchase of water allocations, there will be insufficient water available from Waterdown Dam to meet the future requirements of Queenstown without augmentation from another source.

TABLE 8.5 ECONOMIC PRICE FOR PURCHASE OF WATER ALLOCATIONS

NPV at 6% of Scheme 12 (Xonxa) is R94 243 602
NPV at 6% of Scheme 14 without raising Waterdown Dam is R90 487 948

Thus, if Waterdown Dam is not raised, there will be a saving in cost of approximately R4 million, but an additional 4,1 Mm^3/a of water will need to be obtained by purchasing water allocations.

Water allocations are assumed to be 6 100 m^3/ha/a + 25% allowance for river losses = 7 625 m^3/ha/a at 1:10 year assurance.

Equivalent quantity at 1:50 year assurance = 7 625 x 0,83 = 6 328 m^3/ha/a.

No. of ha of allocations to be purchased = $\frac{4100000}{6328}$ = 648 ha

= R6 153/ha

8.4.2 Groundwater Supply for Sada-Whittlesea

In a review of the groundwater potential of the area, described in detail in Chapter 3, five target areas for the development of wellfields were identified in the vicinity of Sada. Hydrogeological structures are considered to be more favourable in this area than in areas closer to Queenstown. It was estimated that each of these areas could provide sustained yields of up to 1,2 Mm^3/a by means of eight production boreholes, each delivering 5 ℓ/s for 19 hours per day.

The three most favourable of these, in terms of costs of development and favourable hydrogeological conditions are situated close to Sada. These three target areas are designated T4, T5 and T6 on Figure 8.1, and could provide the 3 Mm^3/a of water that it is estimated that Sada will require by 2045. In that case, the allocation of 3,0 Mm^3/a from Waterdown Dam to Sada could be transferred to Queenstown. This, together with the 3,6 Mm^3/a of potential additional yield available from Waterdown Dam (see Table 8.2), would make 6,6 Mm^3/a of yield available for Queenstown, and would meet its estimated requirements to 2045. In view of this, a scheme with a groundwater component was one of the alternatives included in the final comparison of potential augmentation schemes.

8.5 FINAL COMPARISON OF AUGMENTATION OPTIONS

For the reasons discussed in Section 8.3, where the preliminary comparison of augmentation schemes was described, schemes in which the existing Waterdown to Queenstown pipeline would be abandoned were not considered further, and, because of their high cost, neither were schemes that would require the construction of a diversion weir on the Black Kei River. Thus, all the options that were considered involved retaining the existing supplies from Waterdown and Bonkolo Dams with augmentation from either Waterdown or Xonxa Dams, or both. In addition, the possibility was considered of supplying Sada with groundwater and thereby making more water from Waterdown Dam available for the supply to Queenstown.

The principal details of the options considered are shown in Table 8.6.

Option A allows for a new 400 mm diameter pipeline from Waterdown Dam to Queenstown to deliver the additional 3,6 Mm^3/a of water that is available from Waterdown Dam if it is assumed that the allocation of water to irrigation will not be increased in future, or, alternatively, that additional irrigation water will be supplied, but the Reserve will not be implemented. This would bring the assured supply to Queenstown to 9,5 Mm^3/a. An additional 0,6 Mm^3/a from another source would be required to bring the available supply at 1:50 year assurance to the requirement in 2005 of 10,1 Mm^3/a. (This quantity includes 2,2 Mm^3/a to replace the existing borehole supplies to Ilinge and the Macibini Villages).

TABLE 8.6 PRINCIPAL DETAILS OF FINAL AUGMENTATION OPTIONS CONSIDERED

Options	Component	Capacity (Mm^3/a) in Year					Capital Cost (R million)	Annual Operating Cost at Full Capacity (R million)	Net Present Value at 6% (R million)	Unit Reference Value (R/m^3)
		2005	2015	2020	2030	2045				
A	Bonkolo Pipeline	0,9	0,9	0,9	0,9	0,9	*	*	*	*
	Existing Waterdown Pipeline	5,0	5,0	5,0	5,0	5,0	*	*	*	*
	Second Waterdown Pipeline	3,6	3,6	3,6	3,6	3,6	79,85	1,06		
	Xonxa Pipeline (300 mm dia)	1,2	1,2	1,2	1,2	1,2	47,33	0,78		
	Second Xonxa Pipeline (300 mm dia)	--	1,8	1,8	1,8	1,8	47,80	1,35		
	Total Scheme Capacity	10,7	12,5	12,5	12,5	12,5	174,98	3,19	176	1,08
	Water requirements	10,1	10,7	11,0	11,6	12,5				
B	Bonkolo Pipeline	0,9	0,9	0,9	0,9	0,9	*	*	*	*
	Existing Waterdown Pipeline	5,0	5,0	5,0	5,0	5,0	*	*	*	*
	Second Waterdown Pipeline	3,6	3,6	3,6	3,6	3,6	79,85	1,06		
	Xonxa Pipeline (400/300 dia)	1,2	1,2	1,2	1,2	1,2	50,95	0,79		
	Xonxa Pipeline boosted	--	1,0	1,0	1,0	1,0	1,02	0,82		
	Xonxa Pipeline boosted	--	--	--	0,8	0,8	1,58	1,00		
	Total scheme capacity	10,7	11,7	11,7	12,5	12,5	133,40	3,67	156	1,00
	Water requirements	10,1	10,7	11,0	11,6	12,5				
C	Bonkolo Pipeline	0,9	0,9	0,9	0,9	0,9	*	*	*	*
	Existing Waterdown Pipeline	5,0	5,0	5,0	5,0	5,0	*	*	*	*
Wellfields	Existing Waterdown boosted	1,15	1,15	1,15	1,15	1,15	0,35	0,18		
T4 & T6	Groundwater to Sada-Whittlesea (2,5 Mm^3/a in 2 equal phases in 2007 and 2022)	**		**			20,85	0,72		
	Second Waterdown Pipeline (in 2007)	3,65	3,65	3,65	3,65	3,65	90,58	1,04		
	Second pipeline boosted	--	1,0	1,0	1,0	1,0	1,62	0,86		
Wellfield	Second pipeline further boosted	--	--	--	0,8	0,8	1,54	1,18		
T3 + pipeline	Third groundwater scheme for Sada-Whittlesea (0,5 Mm^3/a in 2040)				**		7,35	0,12		
	Total Queenstown Scheme capacity	10,7	12,0	12,0	12,5	12,5	122,29	4,10	127	0,78
	Queenstown water requirements	10,1	10,7	11,0	11,6	12,5				

* Costs are not included as these components are common to all the schemes

** Yields are not included in the totals because the wellfields supply Sada-Whittlesea, thereby making more water available to Queenstown from Waterdown Dam.

*** Design flow rates for proposed pipelines are 1,5 times the capacities quoted.

TABLE CONTINUED OVERLEAF

TABLE 8.6 CONTINUED

Options	Component	Capacity (Mm^3/a) in Year					Capital Cost (R million)	Annual Operating Cost at Full Capacity (R million)	Net Present Value at 6% (R million)	Unit Reference Value (R/m^3)
		2005	2015	2020	2030	2045				
D	Bonkolo Pipeline	0,9	0,9	0,9	0,9	0,9	*	*	*	*
	Existing Waterdown Pipeline	5,0	5,0	5,0	5,0	5,0	*	*	*	*
	Xonxa Pipeline (400 mm dia.)	4,8	4,8	4,8	4,8	4,8	67,35	3,80		
	Second Xonxa Pipeline (300 mm dia.)	--	1,8	1,8	1,8	1,8	47,80	1,36		
	Total Scheme Capacity	10,7	12,5	12,5	12,5	12,5	115,15	5,16	148	0,90
	Water requirements	10,1	10,7	11,0	11,6	12,5				
E	Bonkolo Pipeline	0,9	0,9	0,9	0,9	0,9	*	*	*	*
	Existing Waterdown Pipeline	5,0	5,0	5,0	5,0	5,0	*	*	*	*
	Xonxa Pipeline (500/400 mm dia.)	4,8	4,8	4,8	4,8	4,8	68,00	3,55		
	Xonxa Pipeline boosted	--	1,0	1,0	1,0	1,0	1,37	1,15		
	Xonxa Pipeline further boosted	--	--	--	0,8	0,8	1,50	0,81		
	Total Scheme Capacity	10,7	11,7	11,7	12,5	12,5	70,87	5,51	122	0,74
	Water requirements	10,1	10,7	11,0	11,6	12,5				

In order to meet this requirement and the expected growth in requirements to the year 2015, a 300 mm diameter pipeline, with pumps to deliver 1,2 Mm^3/a, to be constructed in 2005 between Xonxa Dam and Queenstown, has been allowed for. Thereafter, the construction in 2015 of a second 300 mm diameter pipeline, also from Xonxa Dam, but with pumps sized to deliver 1,8 Mm^3/a, has been allowed for to meet the water requirements to the year 2045.

The net present value of this scheme is estimated to be R176 million, and the unit reference value for water provided R1-08/m^3, both at discount rates of 6% per annum.

Option B is a variation on Option A in which a pipeline of sufficient diameter (500/400 mm) to convey the 2045 water requirement from Xonxa Dam is constructed in 2005, and pumping capacity is boosted in further phases in 2015 and 2030.

This approach, with a net present value of R156 million Rand, and a unit reference value of R1-00/m^3, is more economical than Option A, which would entail the phased construction of two separate pipelines from Xonxa Dam to Queenstown.

Option C allows for the water supply to be augmented from Waterdown Dam only. The water requirement in 2045 of 2,9 Mm^3/a that is additional to the 8,6 Mm^3/a that is currently available to Queenstown from Waterdown Dam would be obtained by the phased development of wellfields to supply Sada-Whittlesea, thereby making the water that would otherwise be supplied to it from Waterdown Dam available for the Queenstown supply. The first phase of construction, assumed for purposes of the financial comparison to occur in 2004, would entail :

- boosting of the existing Waterdown to Queenstown pipeline to deliver an extra 1,15 Mm^3/a (the maximum obtainable without exceeding the pressure rating of the pipeline);
- constructing a second pipeline between Waterdown Dam and Queenstown with pump stations initially sized to deliver 3,65 Mm^3/a, but designed to be boosted in two phases to a maximum capacity of 5,4 Mm^3/a.

The intention to develop a wellfield to supply Sada-Whittlesea would allow the 0,59 Mm^3/a of the yield of Waterdown Dam, which was assumed in the analysis in Section 8.1 to be allocated to the future requirements of Sada, to be used for the Queenstown supply immediately. Consequently, taking account of the predicted growth in the water requirements of both Queenstown and Sada-Whittlesea, delivery from the proposed wellfield will only be required from 2008 onwards. The requirement from the wellfield is expected to be 0,02 Mm^3/a in 2008, increasing to 2,53 Mm^3/a by 2041, and 2,88 Mm^3/a by 2045. Therefore, for purposes of this analysis, it has been assumed that a wellfield with a sustained yield of 1,25 Mm^3/a would be commissioned in 2007 (in target area T6 as described in Chapter 3) with a second wellfield with a sustained yield of 1,25 Mm^3/a being developed in 2022 (target area T4) and a third, with a yield of 0,5 Mm^3/a being commissioned in 2040 (assumed to be in target area T3).

The delivery of the second pipeline between Waterdown Dam and Queenstown would be increased in stages by increasing the pumping capacity in 2015 and 2030 to increase the capacity to 5,4 Mm^3/a.

This scheme would have a net present value of R127 million and a unit reference value of R0-78/m^3.

Options D and E allow for all augmentation of the Queenstown water supply to be from Xonxa Dam, i.e. the supply from Waterdown Dam would be fixed at the present 5 Mm^3/a. Option D allows for the construction of a 400 mm diameter pipeline between Xonxa Dam and Queenstown in 2005, followed by a second pipeline of 300 mm diameter in 2015. Option E allows for a 500 mm/400 mm diameter pipeline to be constructed in 2005 with pumping capacity boosted in 2015 and again in 2032.

Option E is the more economical of the two, with a net present value of R126 million and a unit reference value of R0-77/m^3.

The bases for the design of the conceptual schemes and the cost estimates are described in Appendix 6. Tables showing the calculation of net present values are contained in Addendum 6.3 of Appendix 6.

8.6 PREFERRED AUGMENTATION OPTION

It was shown in the preliminary comparison of augmentation schemes, described in Section 8.3, that the existing pipeline between Waterdown Dam and Queenstown is of high economic value. Therefore, it is likely to remain in service for the foreseeable future, even though it is now forty-five years old, as it is reported to still be in good condition. The preliminary comparison also showed that augmentation of the Queenstown water supply from a new dam or diversion weir to be constructed on the Black Kei River would be considerably more costly than augmentation from the existing Xonxa Dam, or from the existing Waterdown Dam, if sufficient water could be made available.

The investigations carried out for this study have shown that there is sufficient unallocated water available from Xonxa Dam to meet the expected increase in the water requirements of Queenstown to beyond the year 2045.

With the availability of water from Oxkraal Dam to provide some of the water for irrigation previously provided from Waterdown Dam, there is currently (2005) unutilised yield from Waterdown Dam that could be used to augment the water supply to Queenstown. However, the quantity is insufficient to meet the expected increase in the requirements of Queenstown to the year 2045, and a supplementary source would be required to do so. The preliminary assessment of possible augmentation schemes has shown that it would not be economical to supplement the raw water supply by raising Waterdown Dam. However, a pre-feasibility level desktop assessment of groundwater potential in the area has shown good prospects for the development of wellfields in the vicinity of Sada-Whittlesea. Therefore, the possibility was considered of increasing the quantity of water that could be supplied to Queenstown from Waterdown Dam by developing a groundwater supply for Sada-Whittlesea, and thereby making available for the Queenstown supply the water currently supplied to Sada-Whittlesea from Waterdown Dam.

The results of financial comparisons of schemes to augment the Queenstown supply from this potential groundwater source with schemes to augment it from Xonxa Dam are shown in Table 8.1. It can be concluded from the information presented in the table that:

- it would be more economical to construct a pipeline between Xonxa Dam and Queenstown sized initially to convey the full quantity of water required in the year 2045 than to construct two smaller pipelines in phases (Options A and B and Options D and E);
- in terms of the unit reference values for water supplied over the period from 2005 to 2045, there would be little difference between augmentation from Waterdown Dam, with a new groundwater supply included (Option C), and augmentation entirely from Xonxa Dam;
- augmentation partially from Waterdown Dam, (without groundwater supply) and partially from Xonxa Dam (Option B) would cost about 30% more, in terms of unit reference values, than augmentation exclusively from either of the sources (Option C or Option E).

In view of the above, it is necessary to make a choice between augmentation from Waterdown Dam (Option C) and augmentation from Xonxa Dam (Option E). The choice is made easier by certain advantages which are apparent in the Xonxa Dam option, namely:

(i) The raw water source already exists, whereas the groundwater source for the Waterdown Dam option has still to be proved in the field, and the cost of developing it may be significantly higher than estimated.

(ii) The initial capital cost of the Xonxa Pipeline, estimated to be R68 million, is considerably lower than the estimated R90 million for the Waterdown Pipeline, and it would, therefore, be easier to finance. (The disadvantage is that the Xonxa Pipeline pumping costs would be higher than those from Waterdown Dam).

(iii) A supply from Xonxa Dam would be from a completely separate source, which would reduce the risk of complete disruption of the supply in the event of a natural disaster.

(iv) There is unutilised yield available from Xonxa Dam, whereas the additional water that would be used from Waterdown Dam could also be beneficially used for irrigation by small scale farmers.

(v) Xonxa Dam lies in a region with different hydrological characteristics to the region in which Waterdown Dam is situated. Droughts in the two regions do not have a high correlation, a factor which has benefits for the operation of the system.

For the above reasons, augmentation from Xonxa Dam is preferred to augmentation from Waterdown Dam.

8.7 OTHER FACTORS CONSIDERED

In the course of the investigations certain factors were considered that were not taken into account in the comparison of possible augmentation schemes because they did not significantly affect the relevant costs. Nevertheless, some of them merit consideration when carrying out the detailed design of the first phase of the augmentation scheme. The factors are:

- The possibility of supplying the Sada Water Treatment Works with raw water from Oxkraal Dam.
- Constructing a booster pump station on the existing pipeline to Sada-Whittlesea.
- Using Bonkolo Dam as balancing storage to reduce the rate of pumping from Xonxa or Waterdown Dams.
- Supplying rural villages along the route of the pipeline from Xonxa Dam to Queenstown.
- Retaining the existing borehole supply to Ilinge and possibly augmenting it with additional boreholes.

Each of these factors is discussed briefly below.

8.7.1 Supply to Sada-Whittlesea from Oxkraal Dam

The Sada Water Treatment Works is about 15 m above the full supply level of Oxkraal Dam. Therefore, while it would be feasible to supply water from Oxkraal Dam, the whole supply would have to be pumped, and a new pump station and 4 km long pipeline would have to be constructed. The full supply level of Waterdown Dam, on the other hand, is about 30 m above the level of the water treatment works, so that, even though a new pump station is required on the existing pipeline, water could be supplied by gravity alone for part of the time and pumping costs would be lower. In addition, no new pipeline would be required. Finally, as Oxkraal and Waterdown Dams both supply irrigation water to the same areas via releases into the river channel, there would be no benefit, in terms of increasing the available yield, in supplying the treatment works from Oxkraal Dam.

It is concluded from the above that there would be no advantage in supplying the Sada Water Treatment Works from Oxkraal Dam. It would be more economical to construct a booster pump station on the existing branch from the Waterdown Dam to Queenstown Pipeline.

8.7.2 Booster Pump Station on the Existing Pipeline to Sada-Whittlesea

The cost of a booster pump station on the Sada pipeline has not been investigated in this study because in the alternative augmentation schemes considered, the existing supply to Sada-Whittlesea was assumed to be replaced by a groundwater supply, with the result that a booster pump station was not required. However, if, as seems probable, it is decided to augment the supply to Queenstown from Xonxa Dam, the implications of providing a booster pump station on the pipeline to Sada-Whittlesea should be considered when optimising the detailed design of the augmentation scheme. Factors to consider are:

(i) As the water requirements of Sada-Whittlesea increase, it may be necessary to provide a booster pump station in order to be able to maintain the current level of supply to Queenstown. Alternatively, it might be more economical to continue to supply Sada-Whittlesea without boosting and to decrease the supply from Waterdown Dam to Queenstown slightly, while compensating for this by supplying slightly more water from Xonxa Dam.

(ii) Conversely, because pumping costs from Xonxa Dam would be about 40% higher than from Waterdown Dam, it might be economical to provide booster pump stations on both of the existing Sada and Waterdown Dam to Queenstown pipelines and reduce the quantity of water pumped from Xonxa Dam.

8.7.3 Using Bonkolo Dam as Balancing Storage to Reduce the Rate of Pumping from Xonxa and Waterdown Dams

The capacity of Bonkolo Dam is more than twice the present day mean annual runoff into the dam. As the route of the proposed pipeline from Xonxa Dam to Queenstown would pass close to Bonkolo Dam, it may be feasible to use Bonkolo Dam as balancing storage for the water transferred from Xonxa Dam. This would allow water to be pumped from Xonxa Dam at a lower peak factor and would reduce pumping costs and, probably, the capital cost of the pipeline.

The quantity of water that could be pumped into Bonkolo Dam without significantly increasing the risk of losing more water through spillage of the dam, is addressed in Chapter 9 on system operating rules. The evaluation of the possible financial benefits of adopting this approach should be part of the optimisation of the detailed design, if it is decided to implement an augmentation scheme from Xonxa Dam.

Similarly, by means of a cross-connection from the Waterdown pipeline to the pipeline between Bonkolo Dam and the Queenstown Water Treatment Works, excess flow in the pipeline could be diverted into Bonkolo Dam for storage, to be fed back to the treatment works during times of peak demand. As discussed in Section 8.1, by boosting the existing pipeline and the branch to Sada, the delivery through the existing pipeline could be increased from the present 5,0 Mm^3/a to 8,9 Mm^3/a by operating the pipeline continuously at full capacity. The delivery of 8,9 Mm^3/a might be reduced to 8,7 Mm^3/a by the availability of water from Waterdown Dam (the 3,7 Mm^3/a that is not used for irrigation at present). A supply of 8,7 Mm^3/a would still require the implementation of an additional augmentation scheme in 2005. However, as in the case of the Xonxa pipeline discussed above, this approach would reduce the required capacity of the augmentation scheme.

The indications from discussions held with the Department of Agriculture and the Chris Hani District Municipality during the course of this study were that it is highly likely that the lands for which Bushmanskrantz and Shiloh Dams were built to provide water for irrigation are highly likely to be developed in the near future. Consequently, no additional water to the 5,0 Mm^3/a currently used from Waterdown Dam is likely to be available to Queenstown from this source in future. Therefore, the possibilities, discussed above, of boosting the existing Waterdown pipeline and storing water from the pipeline in Bonkolo Dam are unlikely to be practical.

8.7.4 Supplying Rural Villages along the Route of a Pipeline from Xonxa Dam to Queenstown

The possibility of supplying rural villages in the vicinity of Xonxa Dam from a pipeline between Xonxa Dam and Queenstown was considered. Disadvantages of such an arrangement would be that the offtakes for the villages would add to the complexity of the pipeline design and operation, and several small water treatment works would be required to provide potable water to the villages.

It is understood that, as a result of a separate study commissioned by Chris Hani District Municipality, it is likely that these villages will be supplied from groundwater sources. The results of the investigation into supplying the villages from the proposed pipeline are, nevertheless, recorded below for future reference.

Xonxa Dam is situated in a valley surrounded by steep hills that limit the number of rural villages upstream of the dam wall that it might be feasible to supply from the dam to fourteen in number. The total number of people living in the villages is about 40 000 according to the figures provided by the National Demographic Study commissioned by DWAF in 2000. Five of these villages to the north of Xonxa Dam are supplied or intended to be supplied by the Cacadu Regional Water Supply Scheme. The feasibility of supplying the other villages from the proposed Xonxa Dam to Queenstown pipeline was investigated in detail in 1996 by UWP in a study commissioned by DWAF. The estimated costs of supplying the villages from the proposed pipeline were compared with the estimated costs of groundwater supplies. It was found feasible to supply the six villages listed in Table 8.9, which also shows predicted future populations and estimated water requirements, including those of livestock.

TABLE 8.7 RURAL VILLAGES THAT COULD BE SUPPLIED WITH RAW WATER FROM THE XONXA PIPELINE

VILLAGE NAME	CODE	POPULATION IN YEAR			LIVESTOCK (ELSU)*	WATER REQUIREMENTS** (kℓ/d)		
		1995	2005	2015		1995	2005	2015
Xonxa	E011	7 810	9 384	10 050	4 510	363	406	424
Hatini	E010	1 469	1 765	1 890	1 716	96	104	108
Egcibhala	E012	2 198	2 641	2 828	1 270	102	115	120
Gandu	E013	1 266	1 521	1 629	732	59	66	69
North of Ndenxe	E008	4 348	5 224	5 595	796	146	170	180
Ndenxe	E009	1 068	1 283	1 374	848	58	63	66
Totals		18 159	21 818	23 366	9 872	824	924	967

* ELSU = equivalent large stock unit. Water requirement assumed to be 30 ℓ/d/unit plus 10% losses.

** Human requirement assumed to be 25 ℓ/person/day plus 10% losses.

The village populations in 1995 were taken from the UWP report as they agreed approximately with the values given by the National Demographic Study which were correlated with the 1996 Census figures. Growth in population after 1995 was calculated using the growth rates predicted in the National Demographic Study. Equivalent large stock units were taken from the UWP report and assumed to remain constant, as the area is fully stocked.

It is assumed that water requirements will remain constant after 2015. The requirement of 967 kℓ/day equates to 0,35 Mm^3/a. For pipeline design purposes, a capacity of 970 kℓ/day at a peak factor of 1,5 has been assumed. Thus the additional capacity required in the Xonxa pipeline to serve the rural villages would be a maximum of 16,8 ℓ/s. This requirement would reduce in stages along the pipeline as offtakes for groups of villages were reached.

8.7.5 Retaining the Existing Borehole Supply to Ilinge

In carrying out the comparison of augmentation options, it was assumed that the groundwater supply to Ilinge would no longer be used. However, this scheme, with an estimated capacity of 1,3 Mm^3/a, is a valuable asset. (It is estimated (see Section 3.9) that the development of a groundwater supply of similar capacity in the vicinity of Sada-Whittlesea would cost at least R10 million). Therefore, it would be preferable to identify the causes of the operational difficulties that have been experienced with the scheme and, if possible, to remedy these.

If the existing Ilinge supply were retained, the additional capacity required for the Queenstown supply, shown in Table 8.2, would reduce to 2,85 Mm^3/a in 2005 and 3,8 Mm^3/a in 2020. If the Waterdown Pipeline were boosted to its full possible capacity and water were stored in Bonkolo Dam when the delivery of the pipeline exceeded requirements, an additional augmentation scheme, which would probably be a pipeline from Xonxa Dam, would not be required until the year 2017.

This approach would be considerably more economical than the immediate construction of a pipeline from Xonxa Dam. However, it would depend upon the availability of the 3,7 Mm^3/a portion of the yield of Waterdown, Bushmanskrantz, Oxkraal and Shiloh Dams that is currently unused, but is intended for irrigation, being made available for urban water supply. It appears, for the reasons given in Section 8.7.3, that the additional water is unlikely to be available for the urban supply. In that case, augmentation from Xonxa Dam will be required immediately and a decision on whether or not to retain the Ilinge boreholes will affect only the design capacity of the pipeline.

8.8 SUMMARY OF FINDINGS

The findings of this investigation of alternative potential augmentation schemes may be summarised as follows :

1. The preferred augmentation scheme is a pipeline from Xonxa Dam to Queenstown.

2. The required capacity of the pipeline and the date when it will need to be commissioned depend upon :

   - the extent to which the capacity of the existing pipeline from Waterdown Dam to Queenstown can be increased, and
   - the assured yield of the wellfield that currently supplies Ilinge and whether it is intended to maintain this supply or abandon it.

3. The indications from discussions held with the Department of Agriculture and the Chris Hani District Municipality during the course of this study were that the currently unutilised portion of the combined yields of Bushmanskrantz, Oxkraal and Shiloh Dams is likely to be required in the near future for the irrigation of lands to be developed for small scale farmers. Therefore, it is concluded that no additional water to the 5 Mm^3/a currently obtained through the Waterdown Pipeline will be available to Queenstown from Waterdown Dam. Consequently, a new pipeline to convey water form Xonxa Dam to Queenstown is required immediately.

4. The future of the Ilinge groundwater supply should be determined by those responsible for managing the water supplies. A decision on this needs to be made before the design of the Xonxa pipeline can be optimised.

9. SYSTEM OPERATING RULES

9.1 DEVELOPMENT OF SYSTEM OPERATING RULES

Short-term yield characteristic curves derived from stochastic analysis were used to determine operating rules for Waterdown, Bushmanskrantz, Oxkraal, and Xonxa Dams. The operating rules determined in this way were simulated in the system model to verify that they would be satisfactory.

The short-term yield characteristic curves are contained in Appendix 4 to this report.

Ideally, the system should be operated in an integrated manner to draw down the dams in a systematic way that minimises spills and maximises the security of supply to the consumers. Fully integrated operation is dependent on the ability to shift demands from one dam to another. In the Lukanji System, the only demand that can be switched between the Xonxa/Bonkolo sub-system and the Waterdown/Oxkraal sub-system is that of Queenstown (including Ilinge and the Macibini Villages). This demand is not sufficient to enable fully integrated operation of the system and ensure a balanced drawdown of the dams.

This is illustrated in Figure 9.1 which shows simulated volumes of water in Waterdown and Xonxa Dams for the period from 1927 to 1953 with releases for the ecological Reserve implemented and urban and irrigation water requirements at estimated levels for the year 2020. The capacity of the pipeline from Waterdown Dam to Queenstown is assumed to be the existing 5 Mm^3/a, and that from Xonxa Dam 13 Mm^3/a. In the late 1930s in the simulation, Waterdown Dam appears to receive adequate inflows and remains relatively full, while Xonxa Dam is drawn down to empty. In the late 1940s, the situation is different : Waterdown Dam is drawn down to empty while some water remains unused in Xonxa Dam. If the capacity of the Waterdown Pipeline had been bigger, more water could have been taken from Waterdown Dam in the 1930s so as to prevent Xonxa Dam from emptying. The converse does not apply to the 1940s situation, as the pipeline from Xonxa Dam was modelled with sufficient capacity to supply the full estimated requirements of Queenstown in 2020.

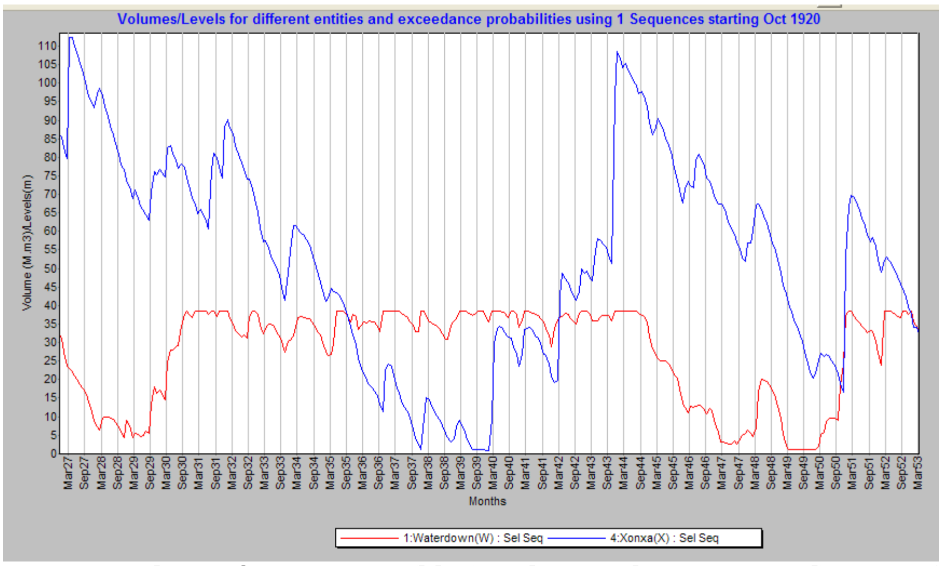


Figure 9.1 Drawdown of Xonxa Dam (blue) and Waterdown Dam (red) (Scenario AD)

Because it is not possible to operate the dams in a fully integrated manner, a semi-integrated operating rule was adopted. To determine rules for the curtailment of the irrigation supplies, the system was divided into two sub-systems : the Waterdown/Oxkraal sub-system and the Xonxa/Bonkolo sub-system. Queenstown can obtain water from both sub-systems, and each of the sub-systems was managed to provide a portion of the urban requirements. The exact proportion supplied from each sub-system can vary. If one sub-system has a surplus relative to the other, and if this surplus can be used to support the sub-system with a shortfall, then curtailments in supply that would otherwise be applied, can be relaxed.

The capacity of the pipelines between the dams and the urban areas that they supply has already been mentioned as a factor that affects system operating rules. This, and several other factors that need to be taken into account when developing system operating rules are discussed in the next section. Thereafter, the recommended system operating rules are described.

9.2 FACTORS THAT INFLUENCE SYSTEM OPERATING RULES

Factors that can influence the operation of the system in such a way as to optimise its yield are :

- relative evaporation losses from dams for the same volume of water stored;
- relative risks of loss of water as a result of dams overflowing;
- desired reliability of supply to urban consumers and to irrigators;
- capacities of pipelines for urban supplies.

Each of these factors is discussed below.

9.2.1 Relative Evaporation Losses from Dams

The capacity v surface area curves for the dams of the System are shown in Figure 9.2, where it can be seen that the surface area of Waterdown Dam, for a given volume of water in storage, is significantly lower than the surface areas of the other dams. For instance, for a storage volume of 36 Mm^3, the surface area of Waterdown Dam is less than half of that of Xonxa Dam.

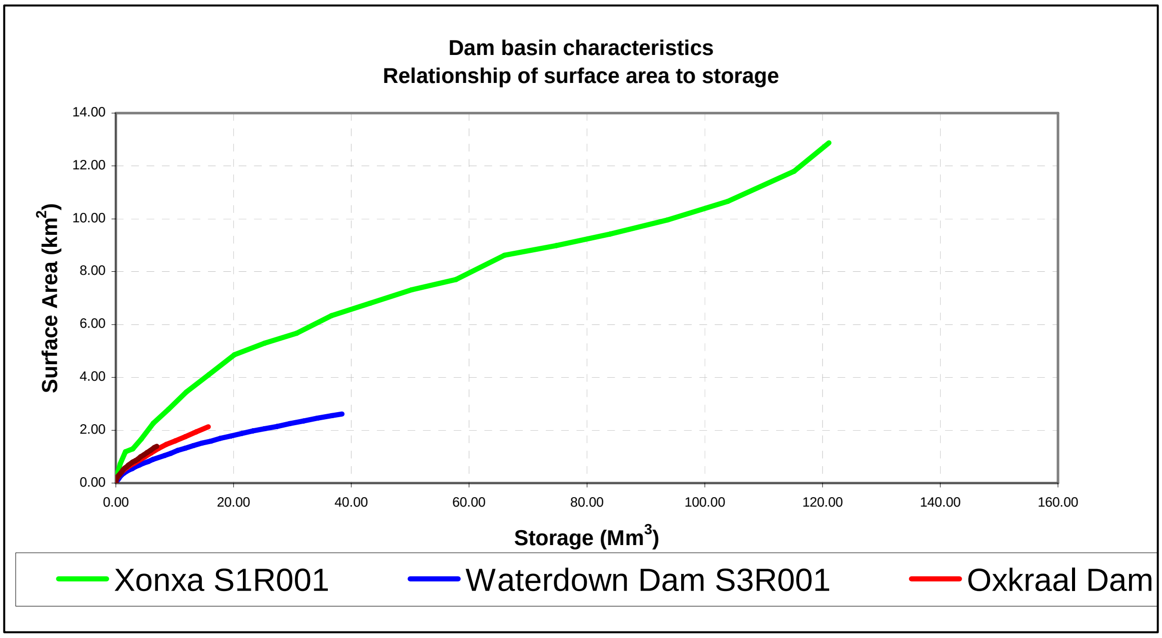


Figure 9.2 Relationship of surface area to storage for the major dams of the Upper Kei Basin

It can also be seen from Table 9.1, that the gross mean annual evaporation at Waterdown Dam is lower than it is at the other dams. Consequently, during prolonged periods of drought, it is advantageous to store water in Waterdown Dam in preference to the other dams because the quantity lost to evaporation is far less.

TABLE 9.1 EVAPORATION FROM THE MAJOR DAMS

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

9.2.2 Relative Risks of Dams Overflowing

The higher the ratio of storage capacity to MAR, the less frequently a dam is likely to overflow. The ratios of storage to MAR for the main dams in the Lukanji System are shown in Table 9.2. It can be seen from the table that the capacities of Xonxa and Bonkolo Dams are more than double the MARs at their sites, whereas the capacities of the other dams (Waterdown, Oxkraal and Bushmanskrantz) are equal to one MAR or less.

TABLE 9.2 RATIO OF DAM STORAGE CAPACITY TO MAR

DAM	GROSS STORAGE	DEAD STORAGE	NETT STORAGE	MAR	RATIO OF NETT STORAGE TO MAR
	(Mm^3/a)	(Mm^3/a)	(Mm^3/a)	(Mm^3/a)	(Mm^3/a)
Xonxa	112,3	1,22	111,1	42,8	2,6
Waterdown	38,39	1,08	37,31	38,6	0,97
Oxkraal	15,68	4,78	10,9	15,3	0,71
Bonkolo	6,95	1,01	5,94	2,57	2,31
Bushmanskrantz	4,72	0	4,72	4,69	1,01

In order to maximise the yield of the system, the quantity of water that overflows from the dams should be limited to as little as possible. Testing by means of the System Model has shown that the risk of Xonxa and Bonkolo Dams overflowing is low when their water levels are at 90% of their full supply capacities, whereas Waterdown, Bushmanskrantz and Oxkraal Dams need to be at 80% or less of their full supply capacities for the risk of overflowing to be equally low.

9.2.3 Desired Reliability of Supply to Urban Consumers and to Irrigators

Statistics on water use by various categories of consumers, derived from data provided by the Town Engineer of Queenstown for 2001, are shown in Table 9.3 for Queenstown and Table 9.4 for Sada.

TABLE 9.3 WATER USE BY CONSUMER CATEGORIES IN QUEENSTOWN IN 2005

CONSUMER CATEGORY	NUMBER OF ERVEN	AVERAGE WATER USE (kℓ/month)	TOTAL USE (ROUNDED) (kℓ/month)	PORTION OF TOTAL (%)
Low cost housing	14 728	16,3	240 000	36,9
Medium cost housing	2 282	22,8	52 000	8,0
High cost housing	1 272	45,6	58 000	8,9
Total residential	**18 282**	**19,1**	**350 000**	**53,8**
Commercial	861	87,1	75 000	11,5
General Industrial	121	173,5	21 000	3,2
Other	285	42,1	12 000	1,8
Bottler and Abattoir	2	25 000	50 000	7,7
Total metered	**19 551**	**26,0**	**508 000**	**78,0**
Unaccounted for water			143 000	22,0
Totals			**651 000**	**100**

TABLE 9.4 ESTIMATED WATER USE BY CONSUMER CATEGORIES IN SADA-WHITTLESEA

CONSUMER CATEGORY	NUMBER OF ERVEN	AVERAGE WATER USE (kℓ/month)	TOTAL USE (ROUNDED) (kℓ/month)	PORTION OF TOTAL (%)
Commercial	44	170,5	8 000	4
Low cost housing	8 490	17,8	151 000	74
Unaccounted for water			45 000	22
Totals			204 000	100

In some towns in South Africa, restrictions on garden watering, which is usually associated with high cost housing, provide a convenient means of imposing light water restrictions. However, it can be seen from Tables 9.3 and 9.4 that, in the cases of Queenstown and Sada-Whittlesea, water consumption by high cost housing constitutes less than 9% of the water requirements of Queenstown and a negligible quantity in Sada-Whittlesea. Consequently, even light water restrictions will have to be imposed on other consumer categories in addition to high cost housing in order to achieve any significant reduction in water consumption.

For the purpose of deriving system operating rules, it has been assumed that during dry periods, when the volumes of water stored in the dams fall below certain pre-determined levels, supplies to consumers will be restricted in order to prevent, as far as possible, the water supply from failing completely. In this approach, increasingly severe water restrictions would be applied as storage volumes in the dams decreased. It is envisaged that four levels of restrictions, as shown in Table 9.6 would be applied to urban consumers.

The proposed restrictions are aimed at limiting water use for individual households to 20 kℓ/month for "Level 1 and 2" restrictions, which typically would be imposed at a frequency of 1 in 10 years, 13 kℓ/month for "Level 3" restrictions, typically occurring at a frequency of 1 in 100 years, and 10 kℓ/month and 5kℓ/month, respectively for "Level 4" and "crisis" restrictions occurring at frequencies of 1 in 200 years or more.

Concurrently, commercial and industrial supplies would be restricted to the percentages of normal supplies shown in Table 9.5.

TABLE 9.5 BASIS FOR URBAN WATER RESTRICTIONS

CONSUMER CATEGORY	MAXIMUM QUANTITY OF WATER ALLOWABLE FOR RESTRICTION LEVELS			
	LEVEL 1 AND 2	LEVEL 3	LEVEL 4	CRISIS
Domestic (kℓ/month)	20	13	10	5
Commercial (% normal supply)	90%	80%	70%	50%
Industrial (% normal supply)	95%	90%	85%	80%
Overall reduction (% normal supply)	93%	75%	60%	40%

On this basis, the probability that restrictions would be imposed on low cost housing would be 1 in 100 years. The calculation of the expected overall reductions in water use at the various restriction levels is shown in Appendix A4.

As the crops grown under irrigation in the areas supplied from Waterdown and Xonxa Dams are generally cash crops rather than high value permanent crops such as fruit orchards, it is advantageous to supply irrigation water at 1 in 5 year to 1 in 10 year assurance in preference to the higher assurances that would be appropriate for orchards, as a greater average quantity of water can be supplied in this way. Therefore, for purposes of developing system operating rules, it has been assumed that irrigation supplies would be curtailed more frequently with "Level 1" restrictions in which irrigation supplies would be reduced to 50% of normal occurring once every five years on average, and "Level 2" restrictions, which would require irrigation releases to be stopped completely, would occur at about 1 in 10 year intervals. The assumed percentages of normal water requirements supplied during restrictions of varying severity are shown on Table 9.6, where the proposed urban restrictions are also shown for ease of comparison.

TABLE 9.6 PERCENTAGE OF NORMAL WATER REQUIREMENTS SUPPLIED DURING RESTRICTIONS OF VARYING SEVERITY

SUPPLY CATEGORY	PERCENTAGE OF NORMAL SUPPLY AT RESTRICTION LEVEL				
	LEVEL 1	LEVEL 2	LEVEL 3	HEAVY	CRISIS
Urban	90%	90%	75%	60%	40%
Irrigation	50%	0%	0%	0%	0%
Probable frequency of restrictions	1 in 5 years	1 in 20 years	1 in 100 years	1 in 200 years	Exceeds 1 in 200 years

It should be noted that, in a crisis situation, it would be prudent to consider temporarily reducing releases for environmental water requirements.

9.2.4 The Influence of the Capacity of the Xonxa and Waterdown Pipelines on the Reliability of Supply

The reliability of supply from the dams used for the urban water requirements can be estimated by deducting the water requirements from the long-term yields of the dams, as shown in Table 9.7. In the table, the anticipated water requirements in 2020 are deducted from the yields at various reliabilities, as obtained from the stochastic yield analysis.

The requirements in 2020 were assumed to comprise :

- urban supplies of 13,50 Mm^3/a.
- average annual irrigation and EWR releases from the dams as determined from the system model for the critical period in the flow sequences, which was from August 1944 to January 1950.

TABLE 9.7 USING THE RESULTS OF THE STOCHASTIC YIELD ANALYSIS TO ESTIMATE THE AVAILABLE YIELD

DAM NAME	YIELDS UNDER 2020 CONDITIONS (Mm³/a)					
	HISTORIC AL 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 and Bushmanskrantz 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						
Urban	- 13,5	- 13,5	- 13,5	-13,5	- 13,5	- 13,5
Irrigation and EWR releases	- 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						
Urban	0,0	0,0	0,0	0,0	0,0	0,0
Irrigation and EWR releases	- 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

It can be seen from Table 9.7 that, if the full urban demand is imposed on Waterdown Dam, the spare yield at the 1 in 10 year risk of failure is -1,9 Mm^3 (i.e. a shortfall of 1,9 Mm^3/a) 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/a at the 1 in 100 year risk of failure (bottom row of Table 9.7). The quantity of yield from Xonxa Dam that can be utilised will depend on the capacity of the pipeline from Xonxa Dam to Queenstown.

Table 9.8 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 100 year risk of failure.

TABLE 9.8 USING THE RESULTS OF THE STOCHASTIC YIELD ANALYSIS 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 and Bushmanskrantz Dams	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						
Urban	- 3,5	- 3,5	- 3,5	- 3,5	- 3,5	- 3,5
Irrigation and EWR releases	- 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	- 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

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 9.1). 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 9.9. Case 8 x 7 - 80%, in which the inflows to Xonxa Dam were reduced by 20%, was modelled to test the sensitivity of the yields to the uncertainty of the hydrology for Xonxa Dam.

TABLE 9.9 IMPACT OF THE CAPACITY OF THE XONXA PIPELINE ON THE RELIABILITY OF SUPPLY (FOR ESTIMATED WATER DEMANDS IN 2045)

SCENARIO		PIPELINE CAPACITIES				DEMANDS					FACTORED WHITE KEI INFLOWS	SUPPLY							SCENARIO SHOWN ON FIGURES
												IRRIGATION				URBAN			
												WATERDOWN		XONXA					
IDENTIFIER	DESCRIPTION	WATERDOWN TO QUEENSTOWN	XONXA TO BONKOLO	WATERDOWN TO QUEENSTOWN *PLUS* SADA	XONXA TO BONKOLO	15,5 Mm^3/a TO SADA AND QUEENSTOWN	IRRIGATION ALLOCATIONS (INCL 25% LOSSES)	SUPPLY ALL EWRS	LOSSES : LAST 20 KM OF BLACK KEI UPSTREAM OF WHITE KEI	LOSSES : REMAINING DOWNSTREAM WATERDOWN/OXKRAAL		AVERAGE IRRIGATION SUPPLY OVER 75 YEARS	YEARS WITH SHORTFALLS	IRRIGATION SUPPLY	YEARS WITH SHORTFALLS	AVERAGE URBAN SUPPLY OVER 75 YEARS	YEARS WITH SHORTFALLS	MINIMUM ANNUAL SUPPLY	
		m^3/s		Mm^3/a								%	%	%	%	%	%	%	
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 (1)	0,00	999 (1)	0,0	Y	Y	Y	N	Y	N/A	79	50	100	0	92	27	39	**15x0**
R2	Only Sada supplied from Waterdown	N/A	0,40	N/A	15,0	Y	Y	Y	N	Y	100	92	39	81	36	96	31	57	**3x15**
R3	Existing Waterdown plus up to 7,5 Mm^3/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 Mm^3/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 Mm^3/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	**8x7-80%**
R6	Existing Waterdown plus up to 10 Mm^3/a from Xonxa	0,16	0,32	8	10,0	Y	Y	Y	N	Y	100	87	44	95	14	99	9	82	**8x10**

(1) Unlimited capacity
N/A = not applicable

In all cases :

- The target demand supplied to Sada-Whittlesea 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 Table 6.2, i.e. 19 Mm^3/a supplied from Waterdown and Oxkraal Dams and 11,3 Mm^3/a from Xonxa Dam.
- 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 would be avoided by stopping the 0,3 Mm^3/a irrigation supply required in that section.

Figures 9.3, 9.4 and 9.5 show the curtailment in supply with decreasing active storage for the Waterdown, Xonxa/Bonkolo and the Oxkraal systems. The scenario numbers (15 x 0, 8 x 7, etc) correspond to those shown in column t of Table 9.9. If the urban supply from Waterdown (Figure 9.3) plus Xonxa/Bonkolo (Figure 9.4) exceeds the required demand then the surplus may be supplied from either Waterdown or Xonxa/Bonkolo. For a given system storage Figure 9.6 shows the assumed relative storage of the individual dams. Ideally, the surplus should be provided from the dam that is furthest above its recommended operating storage, but, for the reasons given in Section 9.1, this is not always possible.

The percentage of the irrigation allocation supplied from the Waterdown/Oxkraal sub-system decreased from about 92% through 87% to 79% as the urban demand on Waterdown increased from 3 through 7,5 to 15,5 Mm^3/a (column m in Table 9.9).

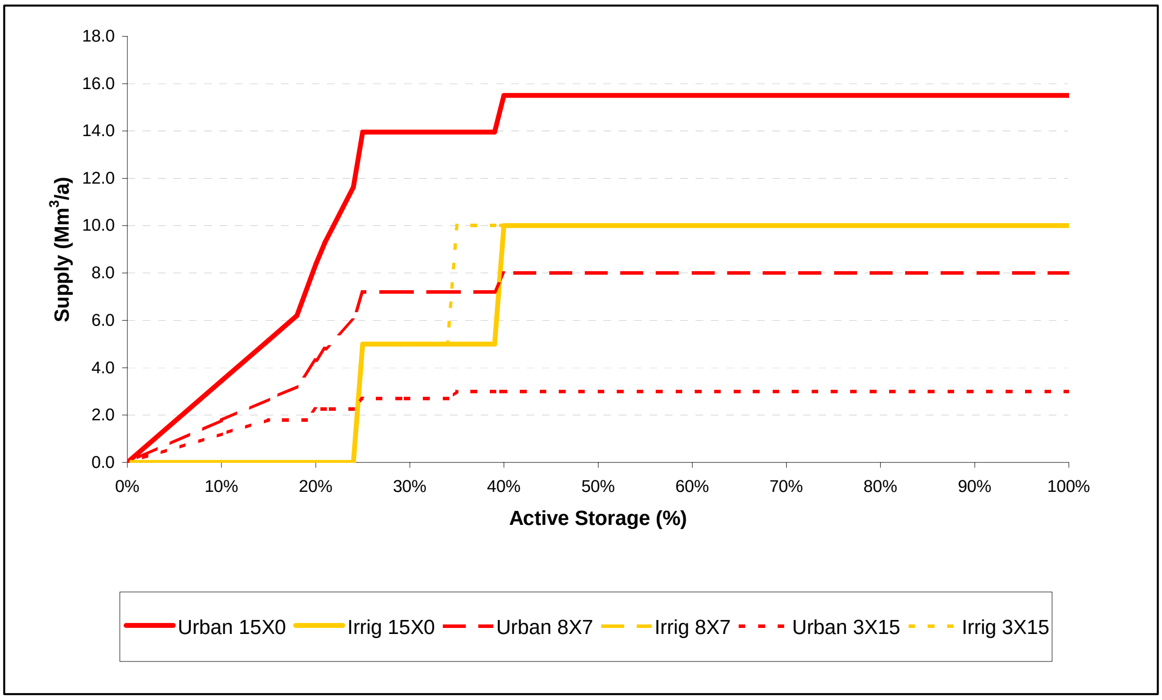


Figure 9.3 Curtailment of supply from Waterdown Dam

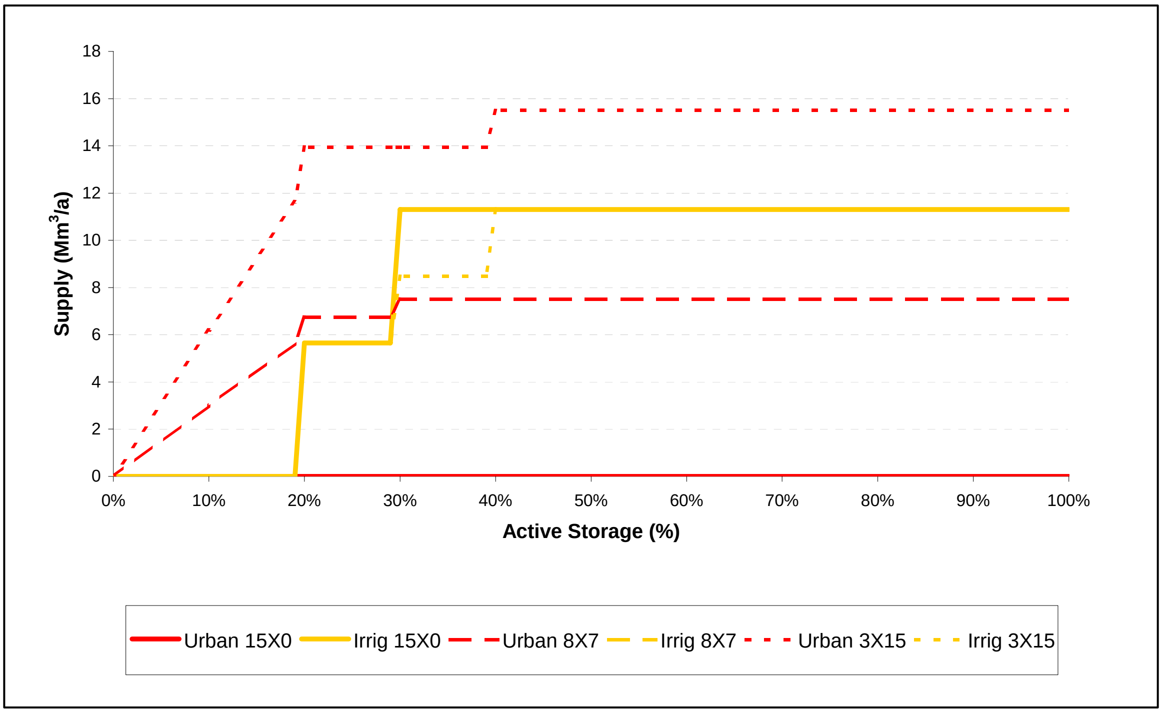


Figure 9.4 Curtailment of supply from Xonxa and Bonkolo Dams

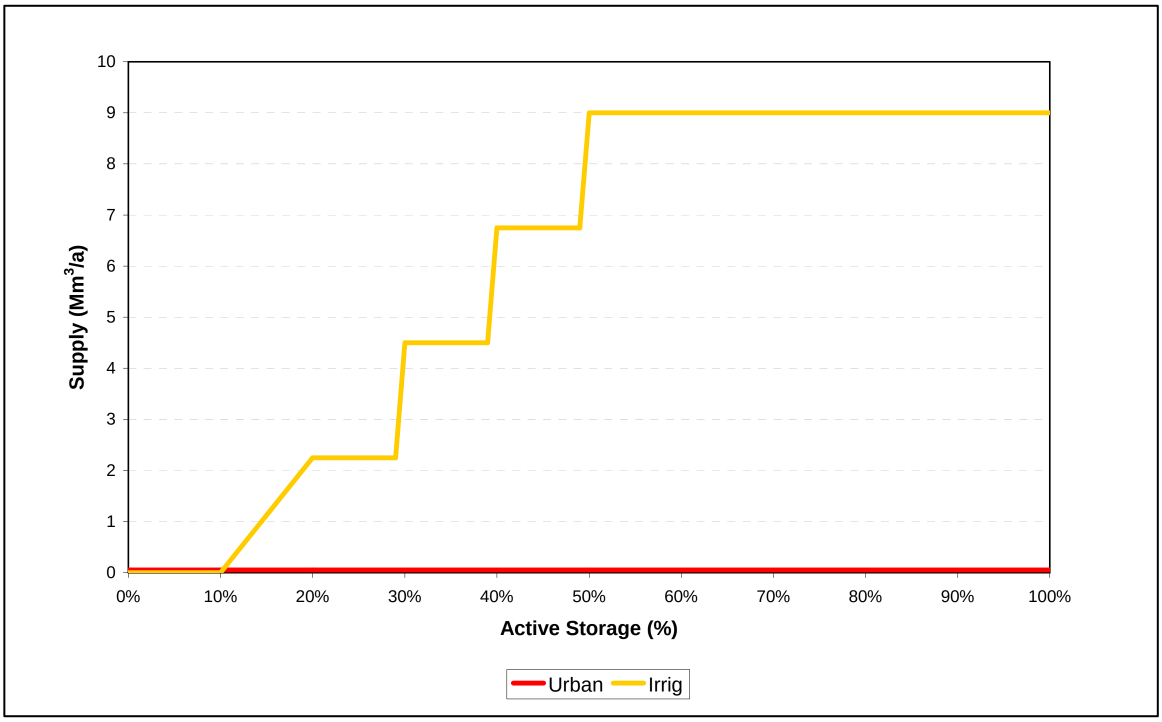


Figure 9.5 Curtailment of supply from Oxkraal/Bushmanskrantz Dams

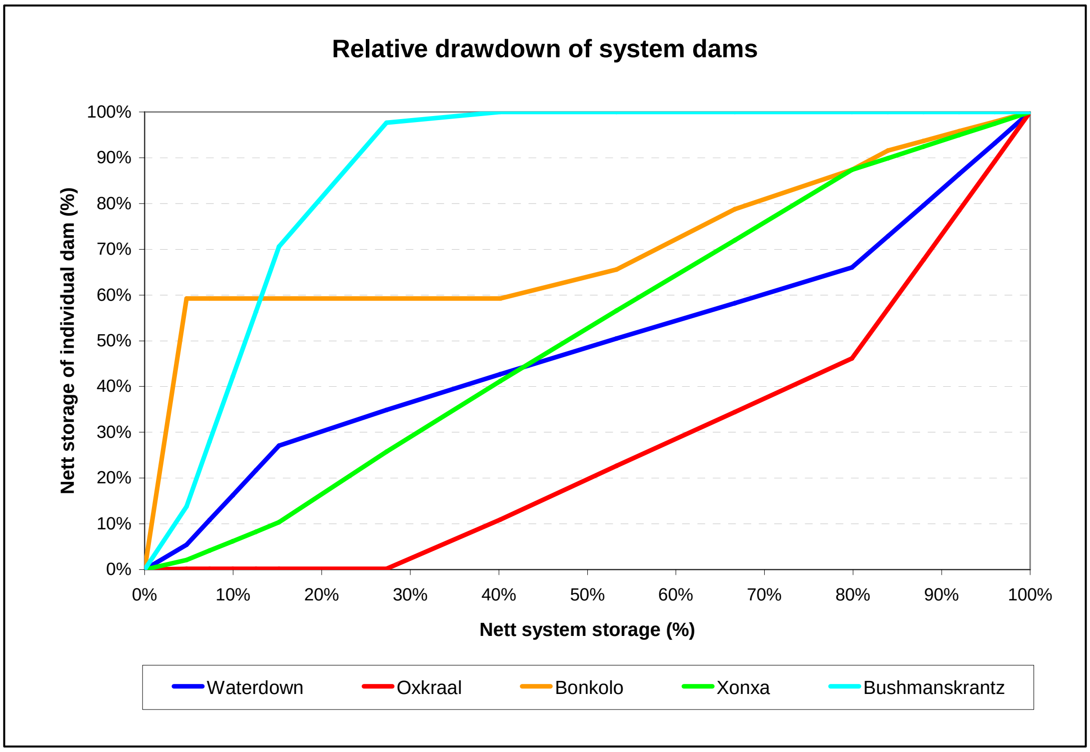


Figure 9.6 Approximate relative drawdown of the system dams

Figure 9.7 shows the reliability of the urban supply from Waterdown and Xonxa Dams combined, and Figure 9.8 the reliability of irrigation releases from Waterdown Dam for the various scenarios (see the scenario numbers in Table 9.9). Note how slight curtailments of the irrigation supplies 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.

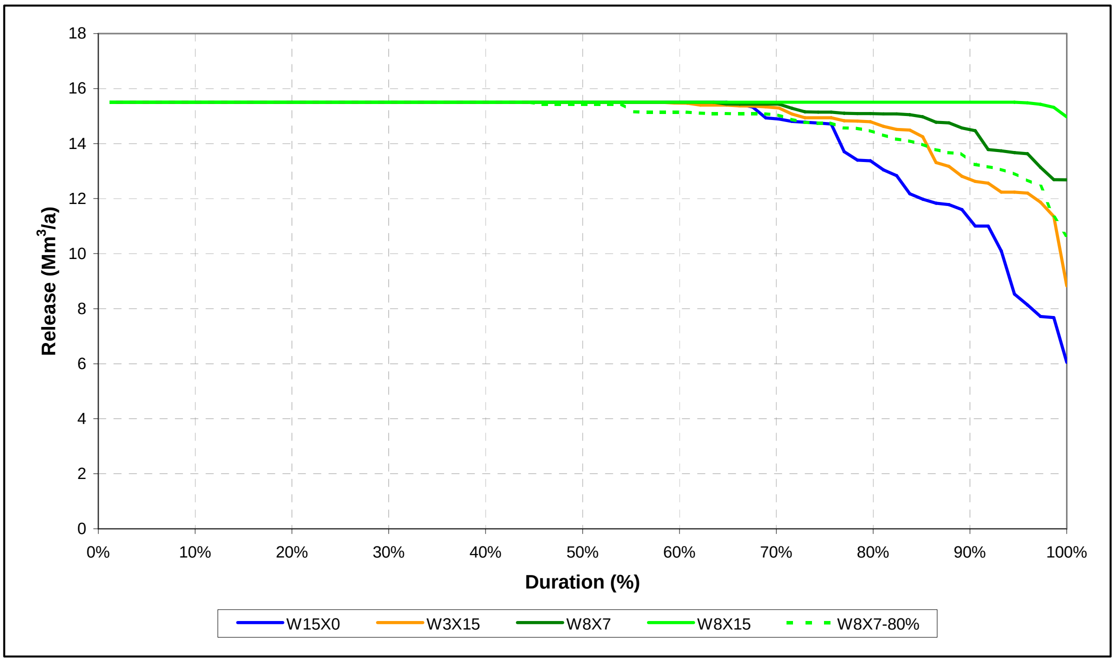


Figure 9.7 Reliability of urban supply

As the urban supply from Waterdown Dam increased, so the urban supply from Xonxa Dam decreased and the water available from Xonxa Dam for irrigation increased (see Figure 9.9). If Waterdown Dam attempts to supply all th
e urban requirements then 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.

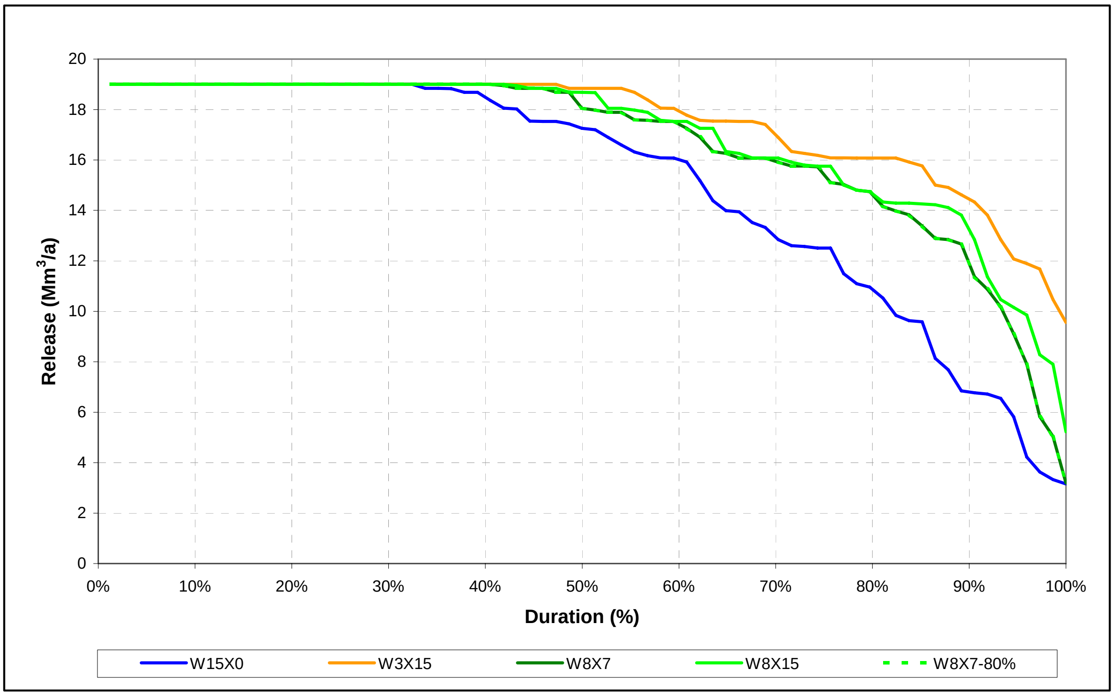


Figure 9.8 Reliability of irrigation releases from Waterdown/Oxkraal

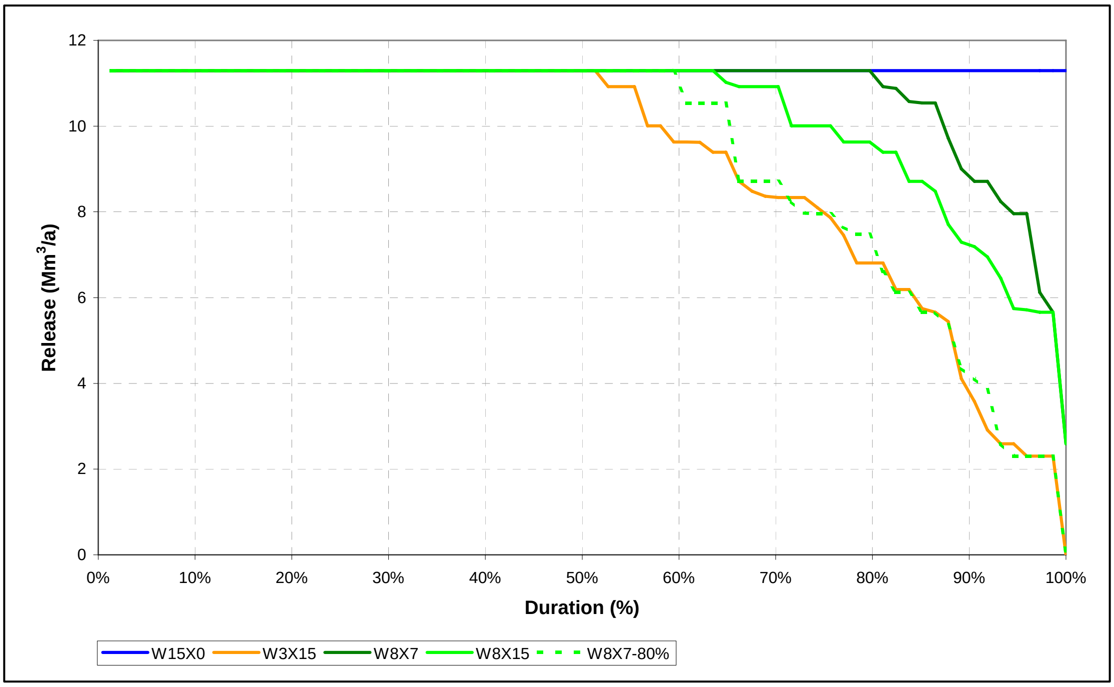


Figure 9.9 Reliability of irrigation releases from Xonxa Dam

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 from 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% of the total requirement of 15,5 Mm^3/a in both cases (see column s of Table 9.9). If water is supplied from both systems then the minimum annual supply rises to above 80% and, on average over the 75 years of record, above 98% of the urban demand is supplied (see column q of Table 9.9).

During droughts, the releases to irrigation are curtailed and very little water may be available for extended periods. This is illustrated in Figure 9.10 where the releases from Waterdown do not exceed half of the allocation for the five year period from 1932 to 1935 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.

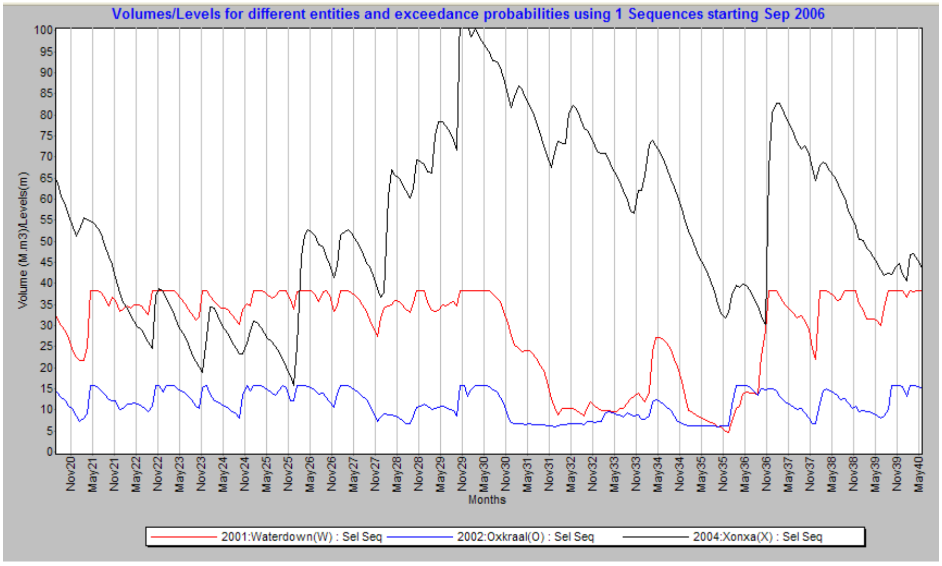


Figure 9.10 (a) **Storage volumes in Waterdown, Oxkraal and Xonxa Dams (1920 – 1940)**

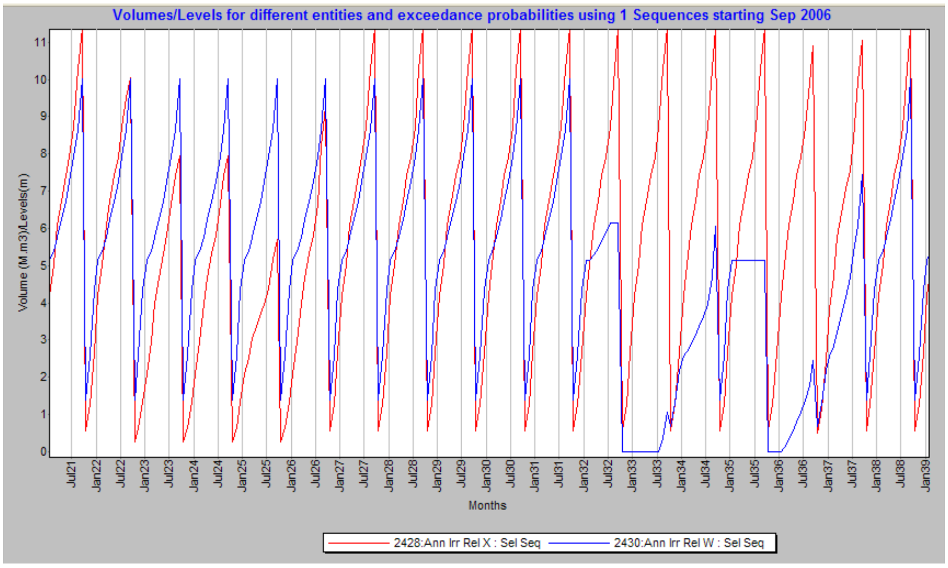


Figure 10 (b) **Irrigation water supplied from Xonxa and Waterdown Dams (1920 – 1939)**

The analysis described above leads to the following conclusions regarding the influence of pipeline capacity on the reliability of supply from the Lukanji System :

(i) Even if sufficient pipeline conveyance capacity were provided between Waterdown Dam and Queenstown, the existing water supply sources, comprising Waterdown, Bonkolo, Bushmanskrantz and Oxkraal Dams, after making allowance for releases for environmental water requirements, could supply the expected irrigation and urban water requirements in 2020 at an assurance of less than 1 in 10 years (see Table 9.7).

(ii) If Xonxa Dam were added to the system and a pipeline capable of conveying 10 Mm^3/a of water per annum, with adequate provision for seasonal variations in demand, were provided between Xonxa Dam and Queenstown, there would be sufficient water available to make the required releases for environmental flow requirements and to meet the expected urban requirements in 2020 and the irrigation requirements supplied from Xonxa Dam at an assurance of approximately 1 in 100 years. The irrigation requirements from Waterdown Dam would be met at slightly less than 1 in 100 year assurance.

(iii) In practice, supplies would probably be restricted at intervals of considerably less than 100 years because the severity of a drought is not known until it is over, and restrictions would, therefore, be applied at an early stage of the drought period in order to ensure that at least a portion of the urban supply could be provided at high reliability.

(iv) The design period considered in the study for augmentation schemes was to the year 2045. By that time the urban water requirements are expected to have increased from the 13,5 Mm^3/a estimated for 2020 to 15,5 Mm^3/a. The irrigation requirements are expected to remain at the 2020 levels of 19,0 Mm^3/a from Waterdown and Oxkraal Dams and 10,1 Mm^3/a from Xonxa Dam. It can be deduced from Table 9.8 that the requirements in 2045 could be supplied at less than 1 in 100 year assurance, but more than 1 in 50 year assurance if a pipeline able to deliver 10 Mm^3/a between Xonxa Dam and Queenstown were provided, and the pipeline had sufficient spare capacity to accommodate seasonal variations in demand.

(v) Testing of the proposed operating rules in the system model showed that for expected water requirements in 2045, the existing pipeline between Waterdown Dam and Queenstown and a pipeline from Xonxa Dam to Queenstown with an average capacity, after allowing for seasonal variations in demand, of 7,5 Mm^3/a, would be able to supply an average of 98% of the urban requirements with a minimum of 82%. Restrictions would be required once every three years on average, but the restrictions would, at times, probably be necessary for periods of more than one year, with the result that periods between restrictions would generally be greater than three years.

Irrigation releases from Waterdown and Oxkraal Dams would be restricted for nearly 60% of time, giving an average supply of 87% of the full requirement over the 75 year period that was simulated (Table 9.9). The supply would be less than 90% of the full requirement for 40% of the time, less than 80% for 15% of the time, and less than 50% for 5% of the time (see Figure 9.8).

Irrigation releases from Xonxa Dam would be restricted once every five years, on average, and 95% of the full requirement would be supplied over the 75 year period simulated (see Figure 9.9).

(vi) If the capacity of the Xonxa pipeline was increased from 7,5 Mm^3/a to 15,5 Mm^3/a, and other conditions remained as described for (v) above, restrictions on the urban supply would be required at intervals of 1 in 20 years. There would be no significant change in the assurance of the irrigation supply from Waterdown and Oxkraal Dams, but the average frequency of restrictions on the irrigation supply from Xonxa Dam would increase from 1 in 5 years to 1 in 3 years.

(vii) It is concluded from the above that a pipeline with a capacity of about 7,5 Mm^3/a from Xonxa Dam to Queenstown would enable an acceptable assurance of supply to be provided to close to the year 2045. Reference to Figure 9.7 shows that the estimated urban requirement in 2020 of 13,5 Mm^3/a, which is 87% of the estimated requirement in 2045, could be supplied for more than 95% of the time, which is an acceptable level of assurance.

(viii) The assurance of urban supply provided by a pipeline from Xonxa Dam to Queenstown with a capacity of 15 Mm^3/a would be desirable, but uneconomical because of the high cost of the pipeline. Therefore a smaller capacity pipeline needs to be considered for the 2045 situation.

In view of (viii) above, and the information in Table 9.8, which indicates that a Xonxa pipeline with a capacity of 10 Mm^3/a would be adequate for the 2045 situation, a scenario with a 7,5 Mm^3/a capacity pipeline from Waterdown Dam and a 10,0 Mm^3/a capacity pipeline from Xonxa Dam was tested in the system model (Scenario 8 x 10 in Table 9.9). The results showed that restrictions on the urban supply would be required at intervals of about 1 in 8 years on average, and that the minimum quantity supplied would be 82% of the full requirement, and the average quantity supplied over the 75 year period simulated would be 99% of the full urban requirement.

This is considered to be a satisfactory level of assurance in terms of the criteria for water restrictions discussed in Section 9.2.3. Therefore, it is recommended that a pipeline be provided between Xonxa Dam and Queenstown with an initial capacity of 7,5 Mm^3/a, to meet the expected requirements to the year 2020, but designed to be boosted to a capacity of 10,0 Mm^3/a to meet requirements to the year 2045. In both cases, the pipeline should have sufficient spare capacity to accommodate seasonal variations in demand. As discussed in Section 8.7.3, the possibility of using Bonkolo Dam as balancing storage in order to reduce the peak factor required for the pipeline as well as allowing pumping to take place in Eskom off-peak periods should be considered.

The pipeline capacities referred to above are based on the assumption that the Ilinge groundwater supply will be discontinued. If that supply were retained, the design capacities of the Xonxa pipeline could be reduced. The amended design capacities would depend upon the firm yield of the groundwater supply, which has not yet been reliably established.

9.3 OTHER FACTORS AFFECTING SYSTEM OPERATING RULES

Other factors, in addition to those already mentioned in this chapter, that should be taken into account when determining system operating rules are :

- The cost of conveying water from Waterdown Dam to Queenstown is less than that of conveying it from Xonxa Dam to Queenstown because the pumping head is considerably lower.
- With the infrastructure as it is at present, Sada-Whittlesea can only be supplied from Waterdown Dam.
- Irrigated areas along the Klipplaat River between Waterdown Dam and the Oxkraal River confluence can only be supplied from Waterdown Dam.
- The environmental water requirements of the Klipplaat River between Waterdown Dam and the Oxkraal River confluence can only be supplied from Waterdown Dam.
- The Oxkraal Irrigation Scheme, once the land has been developed for irrigation, will be able to be supplied only from Oxkraal and Shiloh Dams.
- It has been assumed that the Zweledinga Irrigation Scheme below Bushmanskrantz Dam will remain out of use for the foreseeable future. If it is rejuvenated, the operating rules for Bushmanskrantz Dam will need to be amended.

9.4 PROPOSED SYSTEM OPERATING RULES

Taking into account the above factors and the other factors referred to earlier in this chapter, the following operating rules are proposed for the system comprising Waterdown, Bushmanskrantz, Oxkraal, Shiloh and Xonxa Dams when the total volume of water stored in the system is above 40% of total capacity :

- When the dams are full, they should, in order to minimise water losses through spillage, be drawn down equally until they are all at 90% of full supply capacity.
- Thereafter, in order to minimise pumping costs, urban supplies should be drawn from Waterdown and Bonkolo Dams in preference to Xonxa Dam until the levels in the two dams fall to 75% of their full supply capacity.
- As long as Waterdown and Bonkolo Dams are below 75% of their capacities, preference should be given to Xonxa Dam as a source of supply for Queenstown, with the shortfall in the supply from Xonxa Dam provided from Bonkolo Dam and Waterdown Dams in that order. (This operating rule is intended to minimise evaporation losses from the dams when inflow to the dams is below average.)

- For those areas of irrigation that can be supplied from either Waterdown Dam or Oxkraal and Shiloh Dams, preference should be given to supplying from Oxkraal and Shiloh Dams until they are drawn down to 50% of their total capacity when releases should be limited to 6,5 Mm^3/a. At 40% of capacity, releases should be limited to 4,5 Mm^3/a and, at 30% capacity, to 2,5 Mm^3/a.
- Until the level of Oxkraal Dam has fallen to 10% of its full supply capacity, no irrigation releases should be made from Bushmanskrantz Dam. Thereafter, Bushmanskrantz Dam should be drawn down by making releases to Oxkraal Dam via the river channel. The reason for not releasing water from Bushmanskrantz Dam sooner is to reduce the risk of loss of water through spillage. Sufficient water should be retained in Bushmanskrantz Dam for the preservation of fish and to meet the requirements for the next twelve month period of the two villages that are supplied from the dam (assuming that the Zweledinga Irrigation Scheme remains unutilised).
- If the storage volume in Bonkolo Dam falls to below 50% of its full supply capacity, water should be transferred by pipeline from Xonxa Dam to Bonkolo Dam until Bonkolo Dam reaches 60% of its capacity again. (When Bonkolo Dam is at 60% or less of its capacity the risk of it overflowing during the next six months is negligible).

The following operating rules are proposed for the Waterdown sub-system when storage is below 40% of full supply capacity :

- When storage in Waterdown Dam is between 40% and 25% of total capacity, supplies to Sada-Whittlesea should be restricted to 90% of the normal quantity and supplies to Queenstown to 90% of 5 Mm^3/a, i.e. 4,5 Mm^3/a, and irrigation supplies should be reduced to 50% of the full allocation plus the allowance for river losses.
- When storage is between 25% and 20% of total capacity, urban supplies should be reduced to not more than 75% of normal and less if more water can be supplied from Xonxa Dam in accordance with its operating rule (e.g. if Xonxa is above 20% full supply 90% of Sada requirement from Waterdown and 90% of Queenstown requirement from Xonxa Dam). Irrigation supplies should stop completely.
- When storage is between 20% and 15% of total capacity urban supplies should be reduced to not more than 60% of normal and less if sufficient water to provide 60% or more of the urban requirement can be supplied from Xonxa Dam in terms of its operating rules. No irrigation releases should be made.
- When storage is between 10% and 15% of total, urban supplies should be determined in relation to the quantity available from Xonxa Dam, no irrigation water should be released, and consideration should be given to reducing releases for environmental water requirements.
- If storage falls below 10%, alternative emergency sources for urban supplies should be investigated.

Equivalent operating rules for the Xonxa/Bonkolo sub-system under drought conditions are as follows :

- When storage is between 30% and 20% of total capacity, restrict the urban supply to Queenstown to 90% of the normal quantity and releases for irrigation to 50% of the normal quantity.
- When storage is between 20% and 15% of total capacity, reduce the supply to Queenstown to 75% of normal (i.e. 75% of the total requirement of Queenstown minus the 5 Mm^3/a supplied from Waterdown Dam) and stop the irrigation releases completely.
- When storage falls to 15% of total capacity, reduce the urban supply to not more than 40% of normal, or less if more water can be supplied from Waterdown Dam in terms of its operating rules, so as to make up at least 40% of the total urban demand. Make no irrigation releases and consider reducing releases for environmental water requirements as well.
- If the volume of water in storage continues to decrease below 15% of total capacity, alternative emergency sources of urban supplies should be investigated.

The operating rule for the Xonxa/Bonkolo sub-system is more conservative than that for the Waterdown/Oxkraal sub-system because there is greater uncertainty about the effects of silt accumulation on the capacity of Xonxa Dam at low water surface elevations (i.e. the actual capacity might be considerably less than the assumed value). Therefore, the dam should be surveyed regularly to reassess its capacity.

10. CONCLUSIONS AND RECOMMENDATIONS

The main objectives of this study were :

- 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-Whittlesea, and
- to propose system operating rules for the existing water supply scheme 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.

With regard to the next augmentation scheme it was concluded that :

- The urban water requirements in the areas supplied by the existing schemes were 11,7 Mm^3/a in 2005 and are expected to increase to 13,5 Mm^3/a by 2020 and 15,5 Mm^3/a by 2045.
- The capacity of the existing raw water supplies to these schemes is 9,7 Mm^3/a at 1:50 year assurance, of which 7,5 Mm^3/a is provided from Waterdown Dam, 0,9 Mm^3/a from Bonkolo Dam and 1,3 Mm^3/a from boreholes at Ilinge.
- Because the water requirements exceed the 1:50 year assured yields of the water sources, water is currently provided at a low assurance of supply. This is not a desirable situation and an augmentation scheme is urgently required.
- With the availability of water from Oxkraal Dam to provide some of the water for irrigation previously provided from Waterdown Dam, there is currently (2005) an additional 3,7 Mm^3/a of water available from Waterdown Dam if it is assumed that the allocation of water to irrigation will not be increased in the future or, alternatively, that additional irrigation water will be supplied, but the Reserve will not be implemented in the near future. However, the quantity is insufficient to meet the expected increase in the requirements of Queenstown to the year 2045, and a supplementary source would be required to do so. Also, even though the additional water is available in Waterdown Dam, it is not possible to supply it through the existing pipeline arangement.
- After evaluation of a number of alternative augmentation schemes, a pipeline from Xonxa Dam to Queenstown was identified as the preferred scheme.
- There would be some scope for boosting the capacity of the existing Waterdown to Queenstown pipeline at relatively low cost, thereby postponing the date when the pipeline from Xonxa Dam will be required, if the currently unutilised yield available from Waterdown Dam could be allocated to urban supplies. However, it appears from

discussions held with the Department of Agriculture and the Chris Hani District Municipality that the water will be required in the near future for irrigation.

- There is also uncertainty as to whether the existing groundwater supply to Ilinge will continue in use or be shut down when a planned supply from the Queenstown Water Treatment Works becomes available to Ilinge and the Macibini Villages.

- Irrespective of the decision made in respect of the future of the Ilinge boreholes, the augmentation scheme from Xonxa Dam is required immediately. However, the decision on the Ilinge boreholes will affect the design capacity of the pipeline and should, therefore, be made as soon as possible.

With regard to the development of system operating rules it was concluded that :

- Waterdown Dam and Xonxa Dam do not always experience critical droughts at the same time. Therefore, supplying Queenstown with water from both dams would increase the security of supply in comparison to that achieved by using Waterdown Dam alone, even if there were sufficient water available from it.

- In order to achieve the maximum benefit, in terms of security of supply, of using the two dams, the pipeline from Xonxa Dam should have sufficient capacity to convey at least 65% of the full annual water requirement of Queenstown, Ilinge and the Macibini Villages, with allowance made for seasonal and operational variations in demand, until such time as the requirement reaches 11,5 Mm^3/a. When the requirement increases to between 11,5 Mm^3/a and 12,5 Mm^3/a, the capacity of the pipeline should be increased to 80% of the requirement. In order to minimise the require pipeline peak factor, the pipeline should be designed so that water can be delivered into Bonkolo Dam for storage when necessary.

The above conclusions lead to the recommendations set out below.

1. The portions of the yields of Oxkraal, Bushmanskrantz and Shiloh Dams that are not used for supplying local irrigation schemes should be used to supply irrigation water for the Klipplaat Government Water Scheme that would otherwise be supplied from Waterdown Dam.
2. The next augmentation scheme should be a pipeline from Xonxa Dam to Queenstown with a facility for also discharging water into Bonkolo Dam.
3. The required capacity of the pipeline will depend upon whether it is intended to retain or abandon the existing groundwater supply to Ilinge. Therefore, the future of the Ilinge groundwater supply should be decided as soon as possible by those responsible for managing the water supplies, and, if it is decided to retain it, its assured yield should be determined.
4. The size of the pipeline from Xonxa Dam should be determined as part of the detailed design. In order to maximise the assurance of supply of the augmented water supply scheme, the pipeline should be sized so as to at least be able to deliver 65% of the total

estimated annual demand of Queenstown, Ilinge and the Macibini Villages, with adequate allowance made for seasonal and operational variations in demand, up to a design demand of 11,5 Mm^3/a. For higher design demands, the pipeline capacity should be increased to at least 80% of the demand.

5. System operating rules, as proposed in Section 9.4 of this document, should be implemented.

A further objective of this study was to make a recommendation on how Thrift and Limietskloof Dams, which are located close to the headwaters of the White Kei River should be used. These dams were originally intended to be used to expand the Ntabethemba Irrigation Scheme (described in Section 4.7), but this has not been done, apparently because of the high capital cost that would be involved. Consequently, the dams are unused at present. The combined 1:10 year yield of the dams is only 1,25 Mm^3/a. It is recommended that the present owners of the farms on which the dams are located be approached to find out if they are interested in buying the dams with a view to re-establishing irrigated lands in the area that was originally supplied from the dams, or that the Government acquire and develop the land for resource poor farmers.

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