Water, Households
& Rural Livelihoods

Modelling scenarios for water resources management in the Sand River Catchment, South Africa

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Research promoting access of the poor to sustainable water supplies for domestic and productive uses in areas of water scarcity

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Preliminary results of research for
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PREFACE

This working paper was prepared as a contribution to a joint Indian, South African and UK research project on Water, Households and Rural Livelihoods (WHiRL). This project is focused on research to promote better water security for rural water supply.

The paper can be downloaded from the project website at www.nri.org/whirl. The author may be contacted at smits@irc.nl.

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1 INTRODUCTION

Currently, in South Africa, there are various initiatives to look at water resources and water demand on a catchment scale. Many of these studies investigate water availability for the Basic Human Needs Reserve, Ecological Reserve and for licensing for other uses (see Pollard et al, 2002). Indispensably, computer models are being used for these studies.

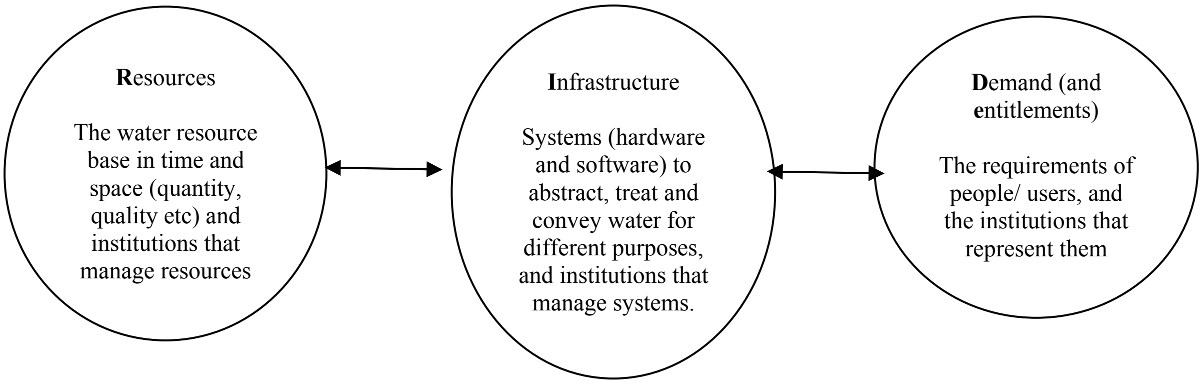
A component of the WHiRL project in South Africa included looking at the integration of water services with catchment level water resources and infrastructure planning. As part of that work, the Resources, Infrastructure, Demand and Entitlement (RIDe) methodology was developed and applied (Moriarty *et al*, 2004).

This paper discusses use of water resources modelling tools as part of the application of the RIDe methodology, in order to assess possible management scenarios for water resources in the Sand River Catchment, South Africa.

2 METHODOLOGY

The Resource, Infrastructure, Demand and entitlement (RIDe) is a simple framework with generic application. It is based on the understanding that water resources are linked to people by supply (and disposal) infrastructure, and that each of these three system elements (resources, infrastructure, users) normally has its own set of institutions, boundaries and other characteristics (Moriarty *et al*., 2004).

Figure 1 the RIDe framework



When applying the RIDe framework, a range of computer based modelling tools (from spreadsheets to complex mass balance models) can be useful in managing the typically large amount of data collected. In the WHiRL project, an MS-Excel spreadsheet model was developed to carry out the initial analysis for the Sand River Catchment. This model was based on quaternary catchments, and a limitation of this approach was the lack of fine spatial dissagregation between demand and resources. The Sand catchment is characterised by large and complex bulk supply and irrigation networks, meaning that water users often inhabit a different part of the catchment than the source from which their supply is drawn. In some cases, water from the Sand is used to supply communities living outside the catchment boundary. The MS-EXCEL model could not adequately capture these kinds of relationships as it simply lumped resource availability and demand at a quaternary catchment level, without explicitly modelling the infrastructural link between the two.

Nonetheless, the spreadsheet model was useful in identifying the broad outlines and trends in the water balance of the Sand. For example, it showed that the catchments resources are (unsurprisingly for a semi-arid river) insufficient to meet demand in parts of the year, with supply for both irrigation and domestic relying on impounded water from a number of dams. More seriously it suggested that current use was incompatible with the requirement to ensure sufficient water for the proper ecological functioning of the river (see Pollard et al, 2002).

Based on this analysis, and the need to look in greater detail at both the water resources, and the degree to which domestic water entitlements were being met, the Aquator (Oxford Scientific Software, 2003) software package was selected for a more precise modelling of water resources, infrastructure and use of the Sand River Catchment. Aquator is a mass balance model with a graphical interface that allows explicit modelling of water resources (ground and surface), supply infrastructure, and demand centres.

A wide range of data sources were used to parameterise the model for the Sand River Catchment. These include mainly "grey" literature and information from DWAF on infrastructure in the catchment and abstractions by different uses.

- **For surface water**, the national WR90 dataset was used. This is a national dataset containing naturalised monthly run-off data for every quartenary catchment in the country; that is, the theoretical run-off under virgin catchment conditions.
- **Groundwater** availability was not explicitly modelled, as that would have required detailed hydro-geological information. Instead, groundwater availability was estimated based on a range of different recharge scenarios.
- For several key parameters, such as **agricultural** and **domestic water use**, little concrete data exists, and what does is often incomplete, unreliable or contradictory. As a result, wide use was made of proxies and estimates. These were discussed during a series of meetings with stakeholders in Thulamahashe, Timbavathi and Polokwane, and datasets adjusted accordingly to ensure reliability and fit with best available knowledge.

3 DESCRIPTION OF THE CATCHMENT

The Sand River Catchment, which forms part of the Sabie Catchment, lies in the eastern region of South Africa, straddling Mpumalanga and Limpopo provinces. The total area of the catchment is 1910 km^2, sub-divided into 9 quaternary catchments. The headwaters of the catchment lie in the hills at the edge of the Drakensberg escarpment, and receive an average of 1800 mm/yr of rainfall. However, the bulk of the catchment lies in the dry lowveld, with a mean annual rainfall of only 500 mm/yr (Pollard and Walker, 2000). Figure 2 shows a GIS map of the catchment, showing main population centres, irrigation schemes and forestry plantations; as well as the outlines of the nine quaternary catchments and channels of the main tributaries of the Sand.

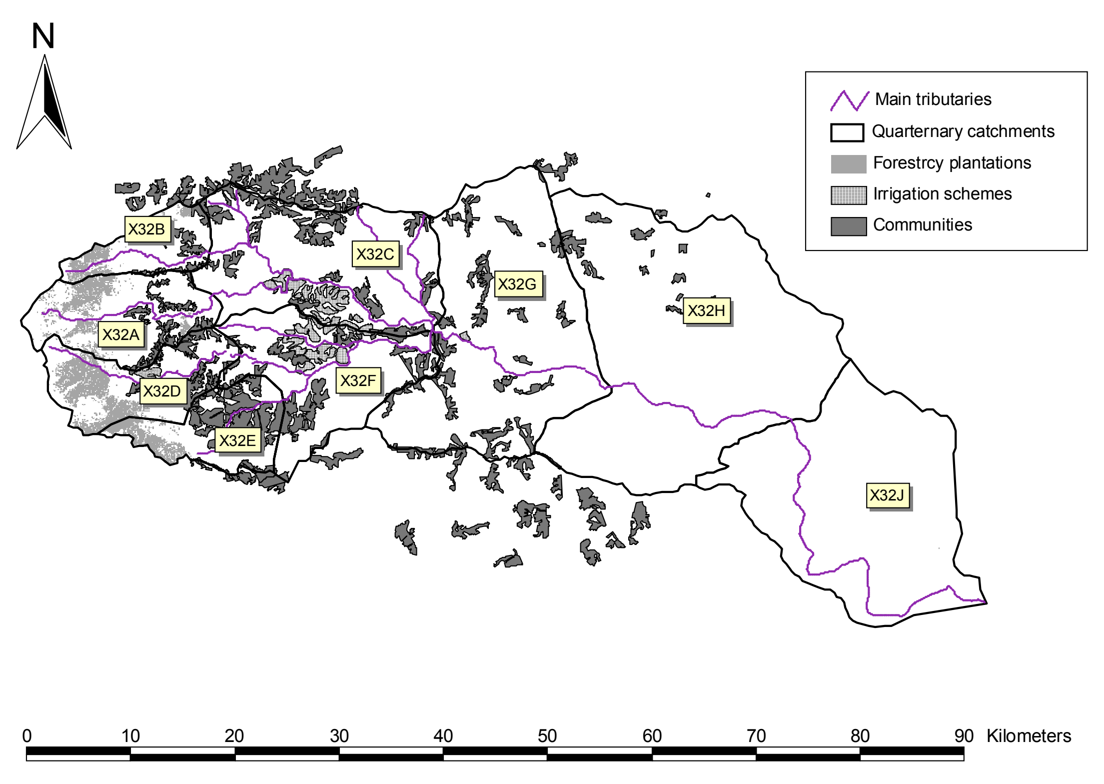


Figure 2 Map of the Sand river catchment and quaternary catchments

3.1 Water resources

The sand catchment is primarily semi-arid, and shows the typical variability associated with such regions in terms of surface water availability both within and between years. Figure 3 shows a flow duration curve[1] for annual runoff from the unaltered catchment, based on the national WR90 dataset (Midgely *et al*, 1994). The steep rise at the lower end of the graph shows the impact of wetter years, and indicates the highly skewed flow distribution, with an average annual flow of 136 Mm^3/yr, as compared to median and lower annual flows of 75.7 Mm^3/yr[2] and 49.8 Mm^3/yr. Median runoff from the catchment is equivalent to 40mm if shared equally across the entire catchment areas, or less than 10% of rainfall. However, this obscures the fact that the bulk of runoff (80% of the median) is generated in the four westerly quaternaries that lie in the higher rainfall zone at the edge of the escarpment (see Table 1).

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[1] A flow duration curve shows the cumulative probability of a given flow quantity being met or exceeded

[2] Throughout the document various units are used for water availability of demand, depending on which is the most appropriate one. For yearly figures we use Mm^3/yr. Monthly data have been averaged out to daily figures and are expressed as Ml/d. To give the reader a more "visual" sense of the order of magnitude these data have also been expressed as m^3/s or even as mm for the whole catchment.

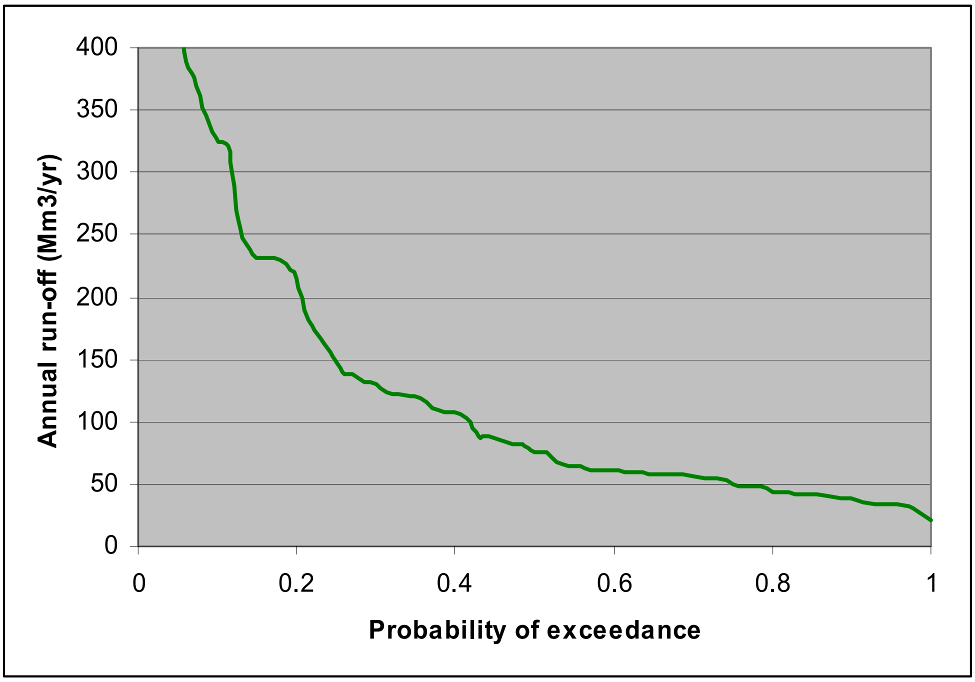

Figure 3: WR90 derived flow duration curve for annual run-off (Mm^3/yr)

Not only is there a large variability across the years but also within any year, between the wet and dry season. Figure 4 shows daily runoff values for each month of the year (in m^3/s) at the catchment outlet under 'virgin' conditions, at different levels of occurrence. This shows that the variability in flows in the Sand River is especially high in summer and much less so in winter. This means that between years there is relatively a large difference in how "wet" the summer is. The winters are all more or less equally dry.

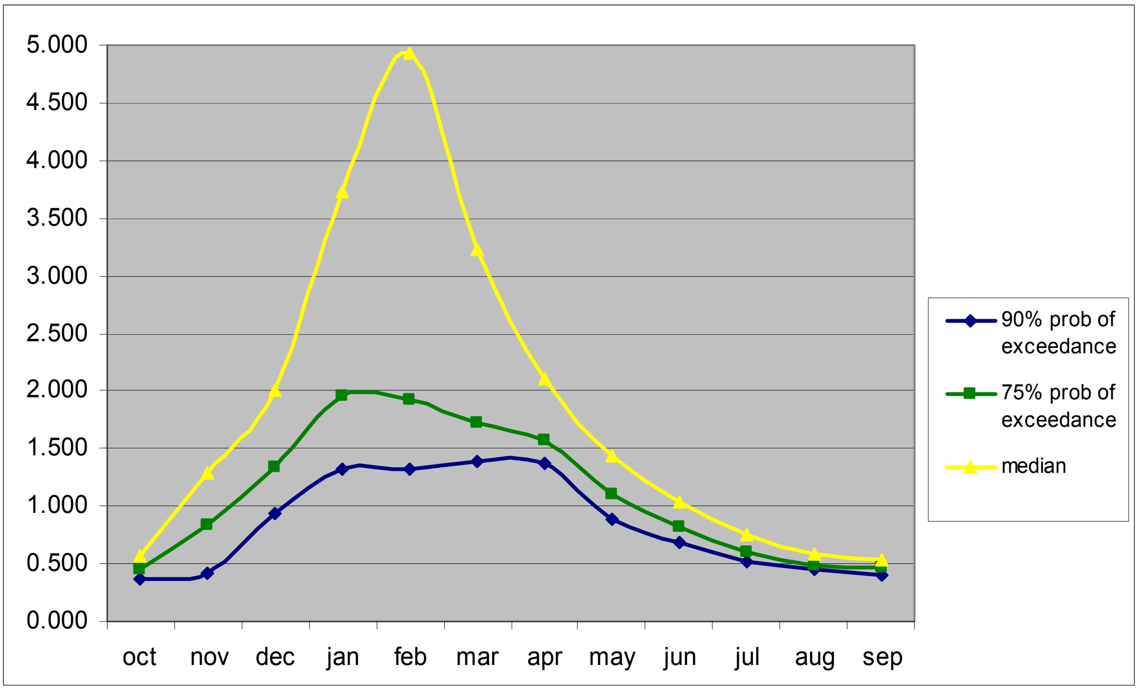

Figure 4: Cachment flow (m^3/s) at different levels of probability of exceedance

Table 1 shows the spatial variability of run-off by quaternary catchment for different levels of occurrence. The quaternaries X32A and X32D generate together about half of the run-off.

Table 1: internally generated annual run-off for all quaternaries

	Internally generated annual run-off (Mm^3/yr)								
	X32A	X32B	X32C	X32D	X32E	X32F	X32G	X32H	X32J
50% of exceedance	20.2	7.9	5.0	20.9	9.6	3.0	2.1	2.5	1.2
75% of exceedance	14.0	5.9	2.7	14.0	7.4	1.6	0.5	0.6	0.3

Detailed data on groundwater was not available (or was deemed unreliable). A simple calculation of recharge to groundwater as a percentage of annual rainfall was used. This was done for ‘low’, ‘medium’ and ‘high’ recharge scenarios of 2%, 5%, and 10% of long-term average rainfall respectively (sourced from the WR90 dataset). This resulted in estimated recharge of 31 Mm^3/yr, 77 Mm^3/yr and 155 Mm^3/yr respectively (Moriarty et al, 2004).

3.2 Infrastructure and demand

Domestic water supply infrastructure: The water resources of the catchment serve an estimated population of approximately 330,000, of whom about 270,000 live inside the boundaries of the catchment. As can be seen from the map, much of this demand is met by a network of highly interconnected bulk water supply networks, drawing water from a number of off-takes both along the river and from storage dams.

In theory, 61 of the 96 communities lying within, or drawing domestic water from, the Sand catchment are served at least partially by bulk schemes; several are served by more than one. However, in reality many of these schemes function erratically, if at all, due to poor maintenance and widespread unregistered connections. The other principal source of drinking water for catchment communities is groundwater, with most communities having (again in theory) one or more boreholes installed. However, in reality many boreholes aren’t equipped with pumps or those they have do not function.

Despite the anomalies between the (often contradictory) data available on coverage with water supply infrastructure, for water resources modelling purposes it was assumed that all schemes function optimally and that communities make best use of the different sources that are available to them. This means that the model results show a theoretical situation, analysing whether available resources and installed infrastructure have the capacity to meet the BHNR and ER if functioning optimally.

Total demand for domestic water was difficult to determine because different sources of information showed different numbers of inhabitants in the catchment. Finally, it was agreed that there are about 350.000 inhabitants being served by water from the catchment. As will be discussed later, domestic demand is between 25 and 80 l/p/d, with the latter being the most realistic *gross* demand. This means that the total domestic demand for the entire catchment is between 9 and 28 Ml/d (equivalent to between approximately 3 and 10 Mm^3/yr). This demand is assumed to be more or less constant throughout the year. In reality there will be slight seasonal variations in demand, especially when people have small backyard gardens. This level of detail in changes in demand could not be determined, so it has not been analysed as such.

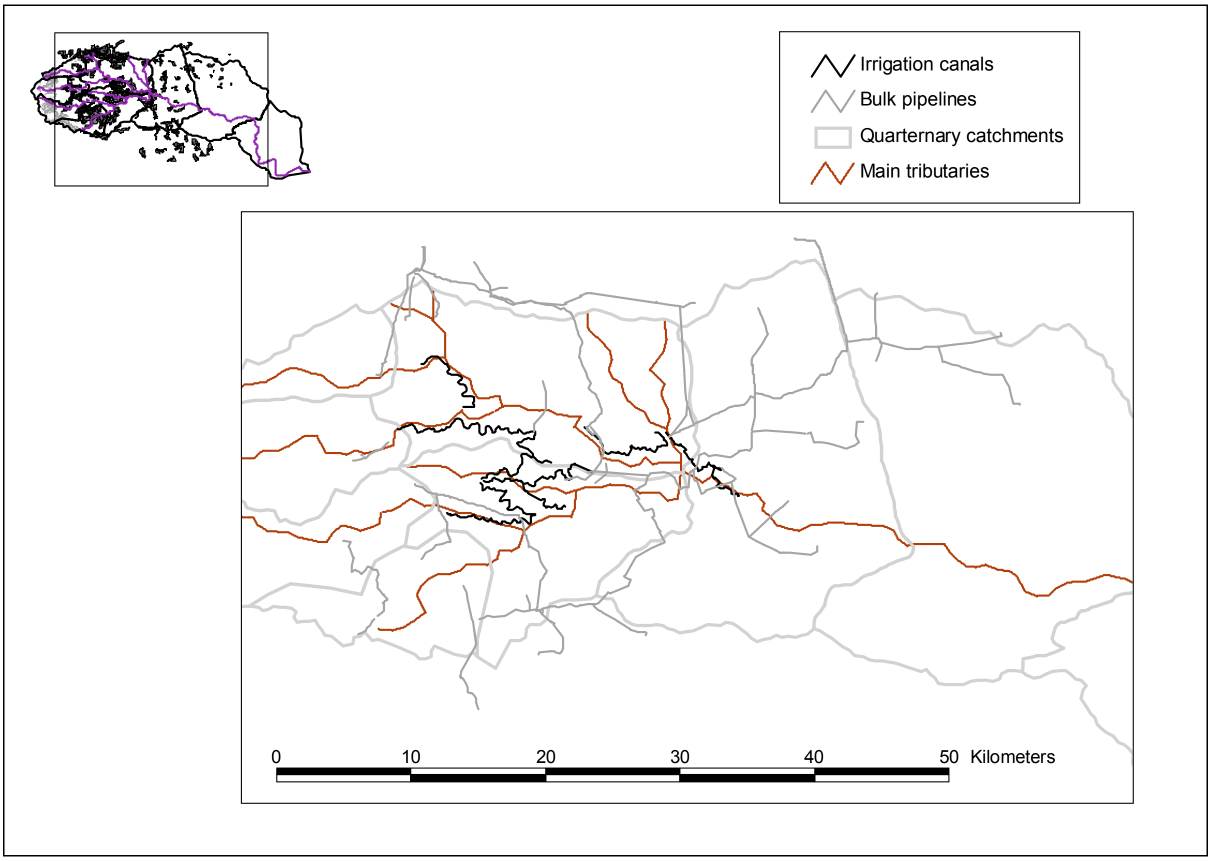

Figure 5 Map of main domestic and agricultural water supply infrastructure, with an inset showing the entire Sand catchment

Irrigation infrastructure: The upper and middle reaches of the catchment have approximately 1,500 ha or land under irrigation of one form or another, with a total annual demand of approximately 12 Mm^3/yr. Monthly variations in irrigation demand are shown in Table 2. The infrastructure to supply water to these schemes is, like the domestic water system, highly interconnected, and the two systems are themselves also interconnected in some places. The exact lay-out of the three large schemes in the central catchment (Orinoco, Dingleydale and New Forest) was not known so, so in the model it was treated as a single scheme. It is expected that this has lead to minor errors in the results. In addition to the three main schemes, a fourth, currently non-functioning scheme exists in the upper catchment (quaternary X32D). This scheme, called Zoeknog, was originally developed for coffee, but has fallen into disuse. There are now plans to revitalise the scheme to grow bananas, although the final decisions has yet to be taken. The potential impact of starting irrigation again formed the basis of one of the scenarios examined.

Table 2: Monthly total irrigation demand

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Irrigation demand (Ml/d)	43	54	56	35	22	18	18	37	37	33	33	21

Storage infrastructure: Combined storage capacity in the catchment is 7.9Mm^3, shared between four major dams (Casteel, Orinoco, Edinburgh, Acornhoek), of these two are used solely for irrigation, and one for drinking water. For modelling purposes it was assumed that the dams can be operated adequately and that they release water upon downstream water demands. In reality these dams are not equipped with operation infrastructure, such as gates.

Inter-basin transfer: A major inter-basin transfer from the Injaka dam is coming on line, and is currently supplying between 6 and 8 Ml/d into the Sand. There are plans to increase this amount, and to link it directly into the bulk supply infrastructure over the next 10 years. This in fact has been included as one of the scenarios. The other transfers from outside the catchment are via Moreli Spruit and Hoxane Water Works.

Forestry plantations: Forestry plantations are an important user of water in the catchment. As can be seen in the map (Figure 2) these plantations are all located in the upper (wet) part of the catchment. Although forestry does not "abstract" water from the rivers, trees consume soil water or shallow groundwater and hence lead to Stream Flow Reduction (SFR), as less water is available for run-off. The SFR is calculated based on the extra demands of plantation forestry over naturally occurring vegetation. While forest demand will clearly vary with water availability, no information with this level of detail was available, so it has been assumed that demand of forestry does not alter between wet and dry years, only within years. The monthly demand for all forestry in the catchment is given below.

Table 3: Monthly total forestry demand

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Forestry demand (Ml/d)	40	39	31	14	5	3	4	3	8	15	29	35

Environmental demand: The last major water demand of water is "the environment". Identifying the impact of current and planned water needs on the ecological reserve (ER) (see Pollard *et al*, 2002, for an explanation of this and other terms related to South African water legislation). This is currently being implemented by the identification of so-called Environmental Flow Requirement (EFR) for rivers or stretches of rivers. The EFR (previously referred to as in-stream flow requirements or IFR) is a flow regime that needs to be guaranteed to maintain the river ecology and the goods and services that it provides. IFRs were determined for three so-called IFR sites along the Sand River (DWAF 1998), although currently only site (IFR 7 near the Exeter gauging weir) is being used to set operating rules.

The establishment of IFRs requires advanced methods (e.g. Hughes *et al.*, 1998), and turning the IFRs into operating rules is a subject of ongoing work. For the case of the Sand River Catchment, the current understanding is that the ER is expressed in the form of monthly flow duration curves (FDCs). So far, these curves have only been determined for the control point at the exit of the X32H quaternary catchment. For the other quaternaries the IFR has not been determined as a FDC, however new operating rules (yet to be implemented in terms of new abstraction or monitoring infrastructure) seek to limit the proportion of total flow that major abstractors like irrigation schemes can take.

Despite no figure for the annual ecological demand having been derived in the EFR process, a figure can be arrived at by summing the monthly requirements at a given level of probability of exceedence. This gives figures of 12.3 Mm^3/yr and 38.6 Mm/yr for the 90% and 50% probability of exceedance respectively. The monthly figures are presented in Section 5 when they are compared to scenario results.

4 DEFINITION OF SCENARIOS

For a specific description of the current situation and issues around water resources, infrastructure and demands and entitlements in the Sand River Catchment, see Pollard *et al.* (2002). Based on the former paper, as well as on discussions with stakeholders about possible future developments of water resources, infrastructure and demand, a number of key scenarios describing possible future water use within the catchment were defined. The starting point for all scenarios was an assumption that the water resources of the catchment should, in line with legislation, be safeguarded first for domestic and environmental requirements. Working from this assumption both existing and potential future use was examined, as were changes in land management. The process was highly iterative, with initial analysis showing the need for further data, or development of the model. The list below therefore represents only the final scenarios that were tested.

Virgin catchment: the catchment as it would be without abstractions or commercial forestry. This scenario serves as a baseline for maximum water resources availability, against which subsequent scenarios can be evaluated.
Meeting the BHNR: The second scenario was based upon meeting the minimum domestic entitlement - (i.e. RDP minimum standards of 25 l/p/d). In other words, the catchments ability to meet the basic human needs reserve while maintaining current patterns of use in agriculture and forestry.
Current use: This scenario was based upon current domestic demands, which are believed to be in the order of magnitude of 80 l/p/d. This level reflects current actual *gross* demand, including, water lost in the pipelines and due to illegal connections.
Removal of forestry: This scenario looked that the likely impact on water resources of removing forestry in the upper catchment.
Irrigation at Zoeknog: This scenario looked at the likely impacts of starting irrigation up at the disused Zoeknog scheme
Injaka transfer: This final scenario looked at the likely impacts of the Injaka transfer operating at full planned potential.

The AQUATOR model was used to test each of the above scenarios using a ten year set of runoff figures from the WR-90 dataset. Much of Southern Africa experiences, in addition to strong inter-annual variability, a longer term trend of periods of above and below average rainfall. The run-off data used to test the scenarios were those for the 1980s, as this was one of the driest decades in the 70 years covered by WR90. Because storage potential in the catchment is currently low, there is no significant opportunity to benefit from wetter decades (or indeed years). Given the objective of using modelling to test the suitability and sustainability of current and future water use, it seemed sensible to use a drier rather than wetter period to test the different scenarios.

In the next section more details are given for each of these scenarios, together with the main findings. The results for each scenario are presented as aggregate values for demand for all consumptive uses of water (domestic uses, irrigation and forestry), as well as total supply in terms of available surface water resources. The results for the non-consumptive demand (the Ecological Reserve) are presented at the end of the paper, where the different scenarios can also be compared to each other.

5 RESULTS

When looking at the results for aggregated anthropogenic demand presented in the following sections, it is important to bear in mind that on top of this, the ER will also have to be met. However, because of the lack of clarity as to how to turn the FDCs in which the ER is currently expressed in to clear operating rules (volumes to be met at a given time), we have chosen to avoid confusion by presenting them in a separate table at the end of this section. To help in interpreting the results for demand, it is useful to consider that median total annual surface water production (under virgin condition) for the ten years examined was 121 Mm^3, although as Table 4 shows this was highly variable.

Table 4 Total annual runoff (Mm^3) for the years used for scenario testing (source WR90)

Year	**1970**	**1971**	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**
Total annual runoff (Mm3)	119	322	41	255	121	376	122	215	34	48

5.1 Scenario 1: Meeting the BHNR - minimum domestic entitlements with no system losses.

5.1.1 Assumptions and input data

In this scenario we look at whether the Basic Human Needs Reserve (BHNR) can be supplied under current conditions. Pollard *et al.* (2002) state that the BHNR should be a stock sufficient to supply the entitlement of 25 l/p/d *at the tap*. The following conditions were assumed, and input data used:

Domestic

- Domestic demand is set equal to the RDP minimum domestic entitlement of 25 l/p/d.
- It is assumed that there are no infrastructural losses or illegal connections that affect this demand. Hence, scenario 1 is really a sub-BHNR scenario because it does not allow for losses.
- In order to meet this demand, the model uses the infrastructure that is now in place, both the existing bulk schemes and the groundwater sources.
- It is assumed that under this scenario, people give preference to water supplied through bulk schemes, as this is provided for free, whereas they often would have to pay for groundwater sources (through purchasing diesel). Hence the model will only take water from groundwater when the bulk scheme cannot provide 25 l/p/d.
- When running the model, those communities that cannot get the required amount from one or both of these sources, will appear to receive nothing. In practice, they might get water directly from the rivers or springs. This abstraction is not included in the model, as these are relatively small amounts.

Irrigation

- Irrigation demand is set to current values, but does not include the planned irrigation system at Zoeknog.
- The model uses the operation rules by the DWAF office in Nelspruit for the amounts of water that the irrigation systems should leave in the rivers, although it is realised that in practice the infrastructure is not in place to regulate how much water is taken in at the irrigation weirs and how much left in the river. The results thus give an indication of the situation best operation practices.

- Some irrigation systems use water from various abstraction points. By assigning "relative weightings" to these, we have tried to simulate realistic priority settings in abstraction practices.

Transfer

- This scenario uses the 8.6 Ml/d of water that is currently being pumped via the temporary pumping station at Injaka. The operational procedures for the temporary pumping station are geared towards meeting environmental demands and the domestic demands of one community only, although this latter remains uncertain.

Storage infrastructure

- Dam operation rules are set as such that they will release water upon demands from downstream abstraction points for domestic use and for irrigation. For the latter, demand also includes the amounts of water that should be passed downstream by the irrigation systems. It is realised that the dams often lack the infrastructural requirements for such releases. Again, the results give an indication of the situation under idealised operating practices.

5.1.2 Results and implications

The resulting catchment level annual water balance for the different uses of water is as follows.

Table 5: Demand and consumption for the different water uses under scenario 1

	Demand (Mm^3/yr)	Consumption or SFR (Mm^3/yr)	% of demand met
Forestry	6.8	6.8	100
Irrigation	11.4	11.1	97
Domestic	3.1	2.5	82
Total	**21.3**	**20.4**	**96**

Domestic

- The communities that do not achieve their minimum entitlement are those ones not linked to a bulk scheme and without sufficient groundwater pumping capacity installed. Under this definition, only 82% of domestic entitlement can be met. However, all communities linked to a bulk scheme always get sufficient water. This means that meeting the BHNR under this scenario depends on whether sufficient and adequate infrastructure is in place and not (yet) on overall resource availability.
- Under this scenario, according to the model 0.5 Mm^3/yr, gets abstracted from groundwater and 3.3 Mm^3/yr comes in via transfers from other catchments (mainly from Injaka). The main reason for that is that in the model preference was set of use of surface water over these other sources of water.

Irrigation

- Some irrigation systems can only meet their demands part of the time. The design supply for the systems is a 95% assurance of supply. Only Dingleydale irrigation scheme was estimated to get a supply slightly below that design norm. This was during two prolonged droughts. The possible impact on crop production has not been calculated.

Forestry

- The demand for forestry is met in its totality.

Storage

- The resulting patterns of change in storage differ from dam to dam. In general during wet years the dams fill up quickly and then stay filled up more or less the whole time as there is no need for their water. In dry years, on the other hand, the dams run dry very quickly as their storage capacity is limited. The dams that show this pattern most clearly are Casteel dam and Acornhoek dam. It is difficult to get details about the functioning of

Orinoco dam, as it is not clear which part of the Orinoco/New Forest scheme is effectively upstream and which part downstream of the dam. The Edinburgh dam is the one that has the largest storage capacity, but with the least downstream abstraction. This is the dam that makes least efficient use of its capacity. In times when other dams are dry and irrigation systems are not able to meet their requirements, water remains in Edinburgh, but without the infrastructure to convey it to where it is needed.

5.2 Scenario 2: Current use

5.2.1 Assumptions and input data

This scenario uses the same input data as the scenario above, but with two changes:

Domestic

- The demand for water for domestic purposes is set to 80 l/p/d. This is close to the nominal supply capacity of installed infrastructure and therefore, in terms of demand on water resources, gives a more realistic reflection than does the previous scenario. However, only in an ideal system would this scenario result in 80l/p/d reaching each person in the catchment.
- In reality how this higher supply is currently broken down village by village and system by system is not known. Nor is the portion of the 80 l/p/d that actually is consumed by the inhabitants after losses in pipelines, illegal connections and, higher actual demand for water by those at the head of the system is taken into account.
- It is assumed that under this scenario people will make full use of the installed groundwater pumping capacity, as there is likely to be more stress in the bulk schemes. So the model was run giving priority to groundwater.

This scenario is therefore a close approximation to the current reality in the catchment, particularly in terms of demands on the resource base.

5.2.2 Results

The resulting water balance for the different uses of water is as follows.

Table 6: Demand and consumption for the different water uses under scenario 2

	Demand (Mm^3/yr)	Consumption or SFR (Mm^3/yr)	% of demand met
Forestry	6.8	6.8	100
Irrigation	11.4	11.1	97
Domestic	9.9	7.2	73
Total	**28.1**	**25.0**	**89**

Domestic

- Nearly all bulk schemes can provide water for this higher demand. The two exceptions being: the communities that depend on the Sand River Treatment Plant and the ones that depend on the Thulamahashe Treatment Works. This is caused by under-design of the intake works with respect to the design population served. None of the other bulk schemes face water resources problems even under drought conditions.
- Communities that only depend on groundwater have even greater difficulties in meeting the higher demand than under the previous scenario.
- Under this scenario groundwater (at 3.3 Mm^3/yr), meets about 30% of domestic demand. While not directly tested using the model, estimates of likely groundwater availability suggest that almost all domestic water needs could be met from groundwater sources if sufficient pumping capacity were installed; the exceptions are the more densely populated parts of the catchment, where local demand might exceed local groundwater potential.

Irrigation

- The irrigation systems remain unaffected by the increased domestic demand.

Storage

- The dams now have to make full use of their storage capacity to overcome dry periods. Both Casteel and Acornhoek dam run totally dry during prolonged dry periods, while Edinburgh continues to remain partially full due to lack of links to other infrastructure.

5.3 Scenario 3: Removal of forestry

5.3.1 Assumptions and input data

This scenario was developed using the same input data as in the previous scenario (2), with the only difference that plantation forestry was removed, and assumedly replaced by natural vegetation; with the result that no SFR took place. This means that the 6.8 Mm^3/yr of surface water that forestry used to take became available further downstream in the catchment.

5.3.2 Results

Although this '*working for water*' scenario does have an impact on total water resources availability in the catchment, it has no impact on increasing the fulfilment of domestic demands. The communities that could not meet their demands under the previous scenario are limited by the available infrastructure, not the available water resources. Making more water available does not make a difference until the infrastructure needed to capture the water and convey it to the communities is put in place. Removal of forestry has a small positive impact on irrigation at Dingleydale and Champagne, as there is now more water available to fill the Casteel dam. Both schemes were had their full demand met to above the required assurance level.

5.4 Scenario 4: Irrigation at Zoeknog

5.4.1 Assumptions and input data

This scenario builds upon the previous one, with the difference that the planned Zoeknog irrigation system was implemented, resulting in more water being abstracted from the river. The total demand for irrigation under this scenario increases from 12Mm^3/yr to about 13 Mm^3/yr.

5.4.2 Results

This scenario only has an impact on total catchment water availability, but not significantly on any of the individual demands. The intakes for irrigation and domestic use that are downstream from Zoeknog are unaffected by the reduction in flow as there is still enough water in the river to meet their demand.

To some extent, under this scenario, the new irrigation scheme replaces the demand of one of the forestry plantations that used to be in the same quaternary catchment, although the timing of the peaks in demands of the irrigation scheme and the previous forestry plantations differ. Whereas forestry's peak demand is during the period of high water availability from December until February, irrigation has its peak demand in March-April and August-September when water availability is lower.

5.5 Scenario 5: Full Injaka transfer

5.5.1 Assumptions and input data

This scenario differs significantly from the previous ones. The Injaka transfer is meant to support domestic use and downstream ecological flows in the Sand River Catchment, as described in section 3.

How the Injaka transfer will actually operate is not yet clear. It has been assumed that it will replace the need for abstractions from smaller intakes (like Thulamahashe Treatment Plant and the Sand River Treatment plant). It is also assumed that users will continue to use groundwater to the maximum installed pumping capacity and only then use water from Injaka to supplement their supplies.

5.5.2 Results

- As can be seen in the table below, all communities can meet their domestic demands (defined as 80 l/p/d including losses) all the time, *as this scenario assumes extra infrastructure is in place to meet these demands*. The Injaka transfer basically takes over the supply to the communities that depend on Thulamashe Treatment Works and Sand River Treatment Plant.
- Irrigation needs are fully met

Table 7: Demand and supply of different water uses under scenario 5

	Demand (Mm^3/yr)	Consumption (Mm^3/yr)	% of demand met
Sub-total irrigation	13.1	13.0	99.6
Sub-total domestic	9.9	9.9	100
Total	**23.0**	**23.0**	**100**

5.6 Comparison between the scenarios with regard to the Ecological Reserve

Table 8 below summarises the differences between the different scenarios in terms of the overall water balance (total supply minus total demand). These are compared to both the virgin catchment, and the requirements of the ecological reserve. The comparison is carried out at two levels of certainty of exceeding an instream flow 50% and 90%. This is compared to the median and 90 percentile values for the model output in the relevant month.

The results clearly indicate that the ER cannot be met most of the time (the shaded cells indicate when the ER cannot be met), at least for this dry decade (the 1980s). The following points give some indication of the implications of these numbers:

- For the dry decade modelled, the median flow in the virgin catchment is more or less equivalent to the median ER in the winter months. That would mean that no non-impounded surface water can be extracted during these months without breaking the ER.
- For the month of January, at the 90% confidence level, about 26 Ml/d can be extracted from the run-off, which would be equivalent to actual domestic demand of 80 l/p/d, if that were the only use.
- As 50% of forestry demand and consumption comes from December until February, it means that during these months, in dry years, forestry already consumes so much that the ER can not be met.

- As modelled, filling up of dams contributes to not meeting the ER in the summer months. However, if they were not allowed to fill, irrigation and domestic water would suffer during winter months.

It is once again important to underline that in wetter decades the results would obviously be better. Nonetheless, working with the levels of uncertainty linked to the available data, and the need to apply a reasonable interpretation of the precautionary principles, it can be assumed that even in wetter periods the situation will remain critical.

Finally, special mention should be made on the full Injaka transfer scenario. Under this scenario the flow at the IFR point is even higher than under the virgin catchment scenario. This transfer therefore has the potential to significantly alter the natural rhythm and functioning of the catchment.

Table 8: Comparison between Ecological Reserve and flow for different scenarios

	Probability of occurrence	**Average daily flow (Ml)**						
		ER	**Virgin catchment**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
Jan	90	**50**	76	29	25	44	42	94
	50	**163**	213	125	121	158	158	210
Feb	90	**56**	84	30	26	46	45	97
	50	**187**	225	190	186	235	232	285
Mar	90	**52**	67	36	32	40	39	92
	50	**196**	240	143	139	182	179	232
Apr	90	**36**	79	48	45	55	51	103
	50	**123**	173	133	129	146	143	196
May	90	**27**	82	53	50	61	53	105
	50	**90**	104	82	78	83	75	127
Jun	90	**24**	67	44	40	49	38	90
	50	**76**	81	57	53	56	45	97
Jul	90	**21**	53	37	33	38	27	80
	50	**67**	63	44	40	44	33	86
Aug	90	**18**	42	29	25	29	28	80
	50	**57**	51	33	30	30	30	82
Sep	90	**15**	40	28	24	27	27	79
	50	**48**	**48**	**32**	**28**	**30**	**30**	82
Oct	90	**25**	47	**22**	**18**	28	28	80
	50	**48**	52	**30**	**26**	**30**	**30**	82
Nov	**90**	**35**	**52**	**17**	**14**	**29**	**28**	80
	50	**83**	**101**	**40**	**37**	**67**	**62**	114
Dec	**90**	**50**	**57**	**18**	**12**	**41**	**35**	88
	50	**149**	104	64	60	107	92	154

6 CONCLUSIONS

- An extensive modelling exercise using AQUATOR was carried out in order to confirm and refine previous results from spreadsheet modelling. The main conclusions from both exercises are similar. The added value of the AQUATOR model lies in the greater degree of spatial dissagregation it brings. This was particularly important with regard to understanding the water supply problems of individual communities and water supply systems.

Water supply infrastructure

- The lay-out of infrastructure within the catchment is chaotic, reflecting the political and developmental history of the catchment (see Pollard et al, 2002). Both bulk and irrigation schemes are highly interconnected making their operation highly complex. When the Injaka transfer materialises, the lay-out of infrastructure is likely to become even more complex as, to meet its declared function of securing domestic water supply, it will required even more conveyance infrastructure. On the other hand, at that time some satellite abstraction points may be taken out of operation, and existing pipelines be removed.
- Current dam storage capacity is limited, and essentially lacks the ability to provide security against inter-annual variability – such as drought periods. Dam operation is complicated by the high degree of inter-connection between systems, and by the lack of required infrastructure to carry out effective operation and releases from the dam.

Meeting domestic needs

- Under the current circumstances (low transfer, forestry, no irrigation scheme at Zoeknog), water use is such that the RDP entitlement of 25 l/p/d can *theoretically* be met in most communities. Those communities where the RDP entitlement cannot be met, are those that are not connected to a bulk scheme and without sufficient groundwater pumping capacity installed. The model shows clearly that providing the minimum domestic water entitlement is an infrastructure (hardware and management) issue and not (yet) a resource availability issue. This remains the case even when additional resources are allowed for to meet losses in conveying the BHNR entitlement of 25 l/p/d to the tap.
- The actual *gross* demand for domestic water is estimated to average about 80 l/p/d across the catchment. This includes unauthorised connections and losses. Sufficient water resources exist to meet this demand. However, as for the lower 25l/p/d entitlement, those communities without sufficient supply infrastructure continue to be un-served, as do those relying on two of the bulk schemes (Thulamahashe Water Works and Sand River Water Works), whose intake capacity is under-designed. Again, the reality of supplying 80l/p/d (or anything like it) to catchment communities would require wholesale upgrading and maintenance of the system to reduce unaccounted for water. Meeting the actual domestic demand is therefore again an infrastructure (both hardware and management) issue and not a resource issue.
- At the full Injaka transfer of 25 Mm^3/yr, all communities can meet a demand of 80 l/p/d. However, as the current inflow point is downstream of *all* domestic abstraction points, this will require significant additional investments in conveyance infrastructure.
- Groundwater extraction is underdeveloped. In addition it is highly erratic, with some communities having significantly greater access than others, and many having significant (theoretical) excess capacity. However, this surplus water cannot be accessed by other communities without investment in new conveyance infrastructure. At the moment, theoretically installed capacity can supply about 30% of the domestic water demand at 3.5

Mm^3/yr. However initial estimates suggest that this could be significantly increased as the estimated groundwater availability is between 31-77 Mm^3/yr under conservative scenarios.

- In conclusion, it can be said that lack of access to domestic water supply is not primarily caused by a lack of sufficient water resources, but rather by the lack of properly functioning conveyance infrastructure. We have constantly had to qualify statements about access to domestic water with words such as ‘theoretically available’. This reflects the current situation of very high unaccounted for water from poorly maintained systems and widespread unsanctioned connections. When we argue that bottlenecks in domestic water supply are cause primarily by infrastructure, it is primarily the *management* (operation and maintenance) of already existing infrastructure that is at the root of current domestic water supply problems. This implies that to deliver the benefits of catchment management programmes to the catchment communities it will be essential to address the problems of water supply infrastructure and its management.

Meeting environmental needs

- Under most scenarios the ER cannot be met most of the time for the decade that was studied. Analysing data for a longer time period might show a somewhat more optimistic situation, but it is clear that current use of water within the catchment is incompatible with meeting environmental objectives. For the decade modelled, water availability over and above the reserve (ER and BHNR) is very limited and in most cases far below what is needed for forestry and irrigation.
- At the other end of the spectrum, concerns exist around the Injaka transfer. Its operation rules seem to suggest that a set amount of water would be supplied to the catchment throughout the year to support downstream flows. Without careful management, the transfer has the capacity to seriously disrupt the natural flow regime of the lower catchment, by providing too much water. The planned quantity targeted at meeting domestic demand is about twice the current domestic demand of about 80 l/p/d, and it is not clear whether this surplus water will be used to augment downstream flows.

Irrigation and forestry

- Current forestry and irrigation demand can be met most of the time in absolute terms. Under drought conditions some irrigation demand cannot be met, but this is not dramatic. Dingleydale is the only irrigation system that has an assured supply that is slightly below recommended standards.
- *However,* meeting current irrigation demand implies breaking the ER most of the time. Current irrigation and forestry use is therefore incompatible with meeting the reserve, and while the situation will be improved by removing forestry the amount of water released will still be less than irrigation demands. What is more, peak forest water consumption is from December until February, when water availability is also highest. Irrigation peak demand is in March-April and in September-August when water availability is significantly lower.
- It is therefore clearly not feasible to develop additional irrigation if the reserve is to be met. And certainly not the proposed Zoeknog scheme which would use a similar amount of water to one of the forestry plantations.

Communication with non-specialist stakeholders

- The modelling of the catchment confirms the high variability of the natural system. Surface water availability varies greatly both within and between years, and as such is typical of the functioning of a semi-arid river system. Great care is needed, particularly when dealing with non-specialist stakeholders, in using concepts such as ‘average’ flows, or aggregated annual availability. If a single value is to be used, we recommend that it is the median, or indeed lower quartile (if properly explained), and that attention is always drawn to the naturally variable flow regime.

7 RECOMMENDATIONS FOR FUTURE WORK

It is clear from the analysis above that improvements in domestic water supply infrastructure are needed. However, there are many ways in which this can be done. Different alternatives for improvement will need to be analysed in terms of advantages, disadvantages, costs, operation and maintenance requirements and management options, so that informed decisions on future investments in infrastructure can be made. Specific alternatives that will need to be researched further would include greater use of groundwater and bulk scheme refurbishments accompanying the Injaka transfer.

- For the borehole systems some baseline information is available, but is full of inconsistencies. Updating and understanding this information would be a first step. Additional research will need to be done on investment and operation and maintenance costs of these systems.
- For the refurbishment of bulk schemes, preliminary investment costs are available and these seem to be extremely high. There is also a lack of information on O&M costs.
- For both types of systems, an analysis will need to be done on the necessary level (and potential effectiveness) of the necessary management systems. Borehole systems can typically be managed (to a large extent) by communities themselves, whereas bulk schemes typically need a larger organisation to run them. Community management of systems often turns out to be more effective and efficient than management by larger institutions. Understanding this in the context of the Sand River Catchment will be crucial.

If groundwater is to be considered as an important resource for the future water development of the region, then a more detailed understanding of its potential is needed. Special attention should be given to issues such as groundwater recharge in different sub-areas of the catchment and the links between the surface and groundwater system. Linked to this, assumptions about the relationship between forestry and SFR as used in this exercise were highly simplistic and will need to be modified to have a true understanding of the potential impact of the removal of plantation forestry on the river system.

In the area of irrigation infrastructure there is also scope for further work. These systems seem to have infrastructure that does not allow for effective operation of abstractions and regulation of flows through the river. Also the distribution of water between the systems seems complicated. We feel there is great potential for improving the infrastructure and the management of it.

Although dam storage capacity is limited, dams still can play some role in regulating and managing the flows in the catchment. Understanding and possibly improving the management and control infrastructure at these dams should be examined.

The Ecological Reserve as a demand is probably the issue that has generated most conceptual difficulty during this work. The understanding and application of the Ecological Reserve is still evolving, and it is critical that this work be continued so as to come to practical rules for its implementation within the Sand River Catchment.

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