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THUKELA WATER PROJECT FEASIBILITY STUDY

WATER RESOURCE EVALUATION AND SYSTEMS ANALYSIS TASK

MAIN REPORT

MARCH 2001

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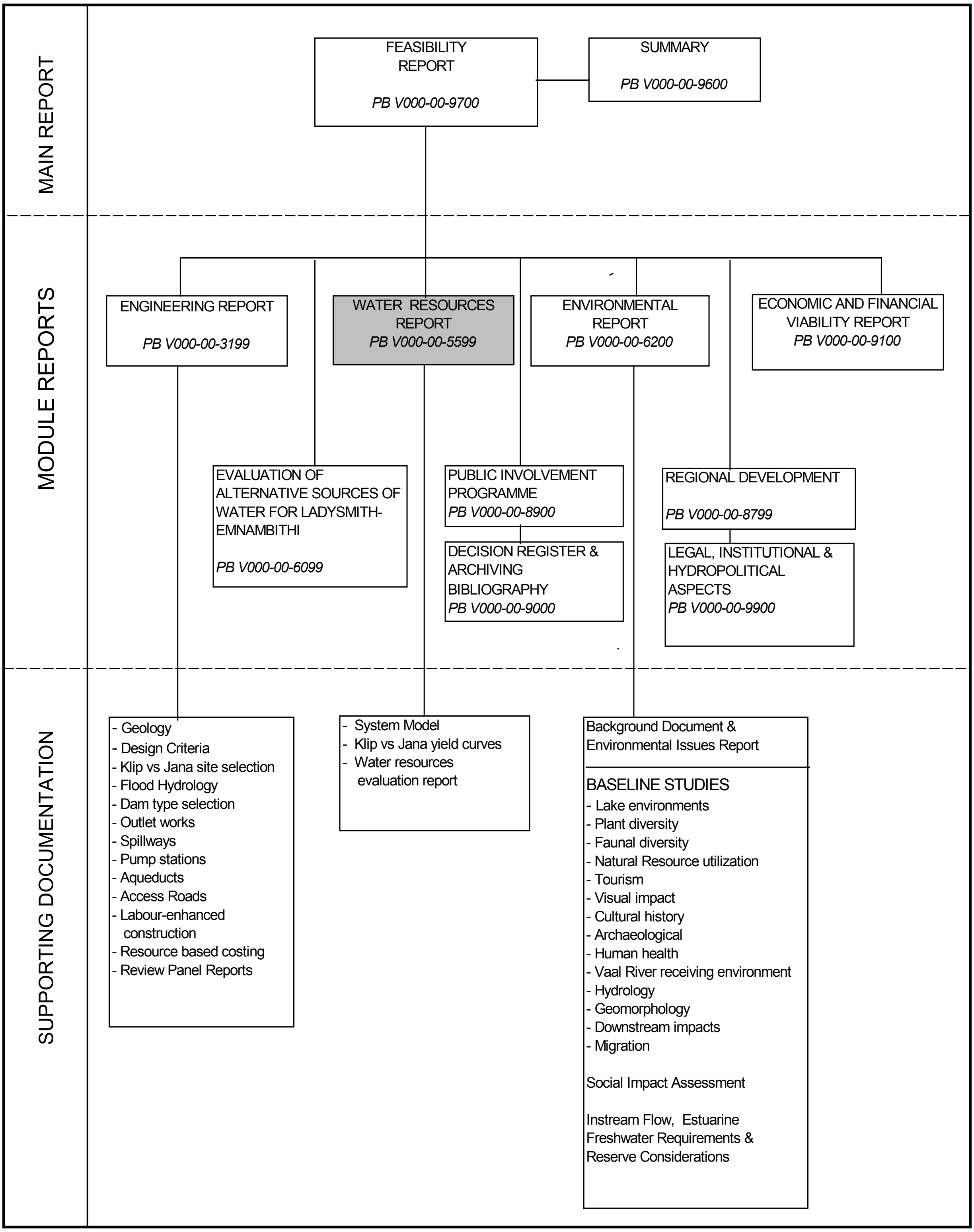

THUKELA WATER PROJECT : FEASIBILITY STUDY
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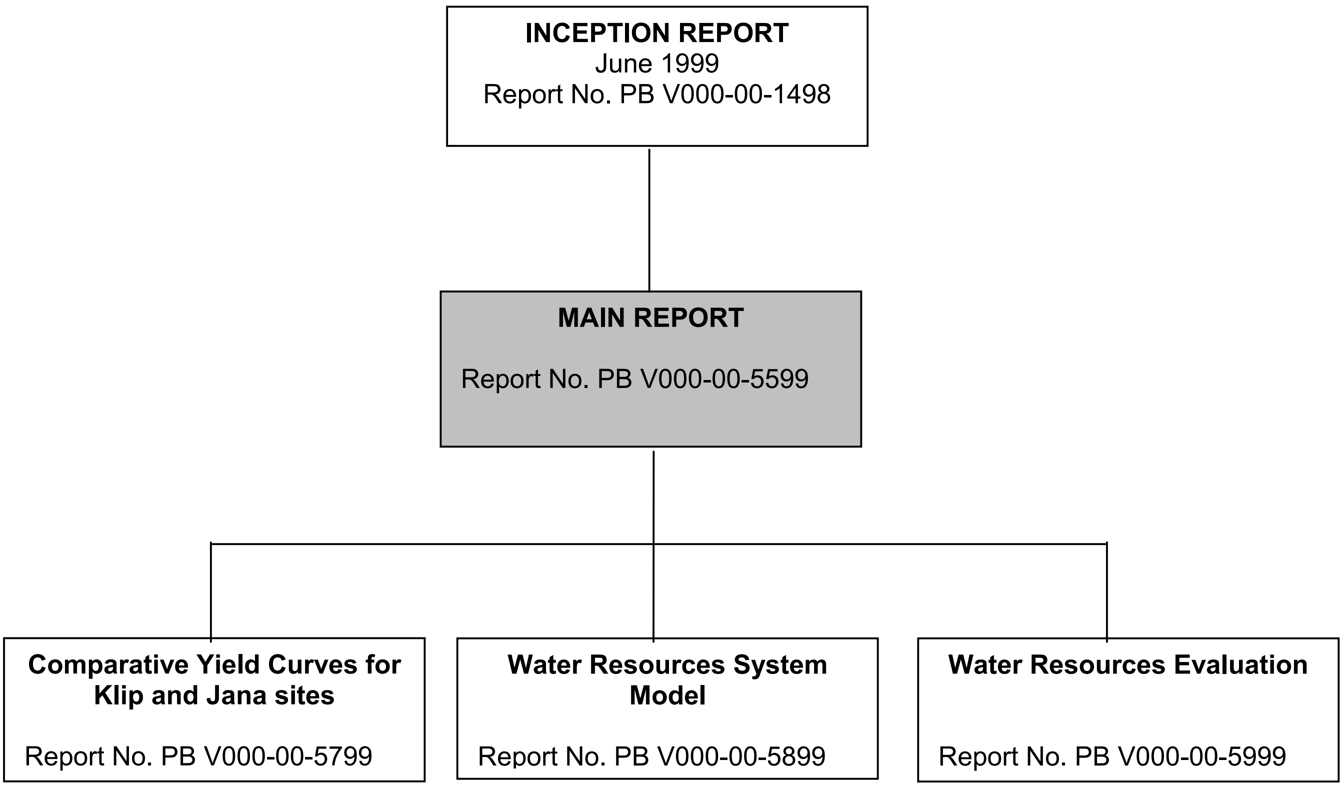
REPORT STRUCTURE

The following reports form part of the documentation produced during the Water Resource Evaluation and Systems Analysis Task. The shaded block depicts this report.



THUKELA WATER PROJECT FEASIBILITY STUDY

TBC CONSORTIUM MARCH 2001

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PREFACE

This Module Report on the Water Resource Evaluation and Systems Analysis associated with the Thukela Water Project proposals emanating from the Feasibility Studies was prepared by the Thukela Basin Consultants consortium. The authors were appointed to undertake one of 15 modules in the Feasibility Study and obtained information from and liased, inter alia, investigating teams assigned to the other modules. The report was prepared under the direction of the Project Management Team.

The report has been accepted as representing the outcome of the terms of reference assigned to the Thukela Basin Consultants and has been used as an important source document for the preparation of a Main Feasibility Report on the Thukela Water Project. All the views, findings, interpretations and recommendations of the authors may not necessarily have been included in full in the Main Feasibility Report. Deviations from this report are noted in the Main Feasibility Report.

THUKELA WATER PROJECT: FEASIBILITY STUDY
WATER RESOURCE EVALUATION AND SYSTEMS ANALYSIS TASK

SUMMARY

1. INTRODUCTION

This summary gives an overview of the water resources evaluation and systems analysis task as described in this report and three supporting technical reports.

The Thukela-Vaal Transfer Scheme (TVTS) reconnaissance, pre-feasibility and interim studies served to eliminate a large number of potential dam sites in the Thukela and its tributaries and to narrow development proposals down to two possible schemes, one in the upper Thukela and the southern tributaries, the other in the northern tributaries. The pre-feasibility study proposed a series of dams in the southern tributaries, however, one of the main dams, Deeldrift, on the Little Thukela River, was ruled out primarily for environmental reasons. The interim study proposed two dams, one at Mielietuin on the Bushmans River and one at either the Klip or Jana site on the Thukela River. These proposals were examined in more detail in the Thukela Water Project (TWP) Feasibility Study. The purpose of the feasibility phase water resources study was to accurately determine the size of the two dams required to deliver water at a rate of 15 m^3/s (up to 473 million m^3 /annum), the rate at which Eskom have indicated they can pump additional water up to Sterkfontein Dam and hence into the Vaal catchment.

The Water Resources Yield Model (WRYM) was used for the Pre-feasibility and Interim study. Although an attempt to account for the Instream Flow Requirements (IFRs) was made during the Interim Study, the version of WRYM available at that stage did not have a facility to model IFR releases realistically. The results obtained during the Interim Phase nevertheless indicated that supplying IFRs would reduce yields from storage significantly. Using the updated WRYM (Mark 5) which caters for IFR releases, IFRs and the Estuarine Flow Requirement (EFR) were incorporated in the feasibility phase system model.

2. FEASIBILITY PHASE

2.1 Water Resources System Model

The supporting report "Water Resources System Model" describes the various revisions to the system model including updating hydrology, improvements to the system model, particularly in the modelling releases for Instream Flow Requirements (IFRs) and increased system complexity, refinement of demands and elevation – area – storage data and revision of priorities for supplying demands. The Mooi River was modelled in more detail in a separate study, the Mgeni River Augmentation Planning Study. This system was therefore included as an input channel to the Thukela system. Two dummy dams, Uitkyk in the Sundays and Buffelshoek in the Buffalo, were included in the system model and sized to supply demands in the tributary catchments including IFR's down to their confluences with the Thukela. These revisions are summarised in this report and described in detail in the "Water Resources System Model" supporting report. The current natural runoff, demands, transfers, return flows and IFR details are summarised in this report and the comparative tables are given in the "Water Resources System Model" report.

2.2 Comparative yield curves for Klip and Jana sites

Storage-yield curves for the Klip and Jana sites were required early in the study to facilitate the selection between the two mutually exclusive sites. Development of these curves is described in the supporting report "Comparative Yield Curves for Klip and Jana Sites". The two sites are situated close to one another in the Thukela so the effect of the rest of the Thukela system on the yields from the two dams is taken to be similar. Therefore it was possible to use the pre-feasibility system model, updated to include the extended hydrology time series, the IFRs and the EFR.

The yield from storage at these sites was found to be very similar for equivalent dam sizes and therefore did not influence the preference for one site over the other.

2.3 Water Resource Evaluation

2.3.1 Introduction

The "Water Resources Evaluation" supporting report describes the effect of changes in demands, IFRs and operating rules on yield from the proposed dams, determination of historic and stochastic yields and estimation of filling times for Mielietuin and Jana Dams.

These analyses showed that small changes to the IFR patterns could significantly increase yield from the Mielietuin and Jana Dams. Accordingly, proposals were made to the IFR specialist team, which resulted in adjustments being made to the IFR recommendations.

2.3.2 Operating rules

The yield model was set up to supply water to the various consumer user sectors at different priorities. The order of priority of supply was as follows:

a) IFRs (and EFR) to meet the ecological Reserve
b) In-basin water requirements for industrial and domestic use, projected to the year 2030.
c) In-basin irrigation requirements, projected to the year 2030 but then reduced by 75% to allow for a smaller assurance of supply. The reasoning behind this is that irrigators should not receive a higher

assurance of supply following the construction of the Jana and Mielietuin Dams than they receive currently.

d) The remaining water is assumed to be available for transfer to the Vaal River System.

Operation of the system was set up so that the transferable yield from Mielietuin would be maximised. This is because Mielietuin Dam, situated at a higher elevation than Jana, provides a lower unit cost of water than Jana Dam.

The existing transfer scheme was assumed to operate essentially as it has in the past except that IFRs, not currently released from either the Driel Barrage or the Spioenkop Dam, were provided in the yield analyses at a higher priority than transfers to the Vaal River System.

In setting up the system model it was assumed that water would be pumped at a constant rate equivalent to the yields of Jana and Mielietuin Dams. No allowance was made for downtime for maintenance purposes. This aspect needs to be addressed in detail during the design phase of the project.

2.3.3 Instream Flow Requirements

IFRs, which are estimates of the minimum flow requirements to maintain the riverine ecology in an acceptable state, were determined at various points in the Thukela system by a team of specialists. Initially IFRs were only modelled in the main stream of the Thukela and Bushmans River but it was found that this drastically reduced the transferable yield of the Jana Dam. Based on the reasoning that sufficient water would have to be released down the tributaries of the Thukela, especially the Sundays, Buffalo and Mooi Rivers, to meet the IFRs on these rivers, these flows were also modelled. In the case of the Sundays and Buffalo Rivers, it was found that storage will be required on these rivers in future if the in-basin requirements up to the year 2030 are to be met, together with the IFRs. These hypothetical dams were included in the yield model.

It was found that inclusion of IFRs downstream of Driel Barrage and Spioenkop Dam reduces the amount of water that can currently be transferred through the existing Thukela-Vaal Scheme. However, while the IFRs downstream of the proposed new developments can be determined with fairly high confidence, it was not possible to determine the IFR required below the existing transfer scheme with the same certainty. The reason for this is that while IFRs below new dam sites will normally be set to maintain the river in its current ecological management class (EMC), an EMC of the river downstream of the existing scheme must be negotiated to be acceptable to all stakeholders. On the other hand, in-basin stakeholders will require a high EMC to support recreation and agricultural activities while water users in the Vaal River System will strive to maximise the amount of transferable water at minimum cost with a concomitant lower EMC. This could not be negotiated in the Feasibility Study but will be addressed in a separate study in which the Reserve is determined for the whole Thukela basin. To cope with this uncertainty, a realistic upper and lower bound was set to the IFR and the scheme configuration and transferable yields determined for these two possible extremes. This range of uncertainty only affects the yield from the Jana Dam and not the yield from Mielietuin Dam. It is expected that the actual Reserve will lie somewhere between the two extremes.

2.3.4 Yield estimates

Yields were determined for both a high and low IFR scenario as described in section 3.3.3 and a wide range of dam sizes at Mielietuin and Jana using historic inflow time series. The results of these historic yield analyses are summarised in Tables S1 to S3.

For the low and high IFR scenarios, the transfers possible from the existing Thukela-Vaal Scheme reduce from 527 million m^3/a to 448 million m^3/annum and 357 million m^3/annum respectively. Water released from Driel Barrage and Spioenkop Dam to supply IFRs will, however, be available for transfer from Jana and it was found that the total average transfer from the combined existing Drakensberg scheme and Jana Dam is the same for both high and low IFR scenario (see Figure S1). In other words, the amount of water, which can be transferred from the Thukela basin to the Vaal River System, is essentially the same whether it is pumped from Jana Dam or the Driel Barrage. However, there is a pumping cost implication because Jana Dam is, at a much lower elevation than the Driel barrage. The aqueduct capacity from the Jana/Mielietuin system would also have to be greater for the high IFR scenario.

Table S1: Transferable yield from Mielietuin Dam (Historic analysis)

Full supply level (m amsl)	Working storage (million m^3)	Transferable yield (million m^3/a)
1010	206	105
1015	250	114
1020	297	123
1025	352	129
1030	417	137
1033	464	141
1035	498	143

Table S2: Transferable yield from Jana Dam (Historic analysis)

(Low IFR below existing transfer scheme)

Full supply level (m amsl)	Working storage (million m^3)	Transferable yield (million m^3/a)
800	364	204
820	630	271
840	991	322
850	1213	335
860	1469	351
870	1763	368
880	2177	393
890	2639	422

TableS3: Transferable yield from Jana Dam (Historic analysis)

(High IFR below existing transfer scheme)

Full supply level (m amsl)	Working storage (million m^3)	Transferable yield (million m^3/a)
800	364	253
820	630	347
840	991	416
850	1213	431
860	1469	446
870	1763	464
880	2177	489
890	2639	517

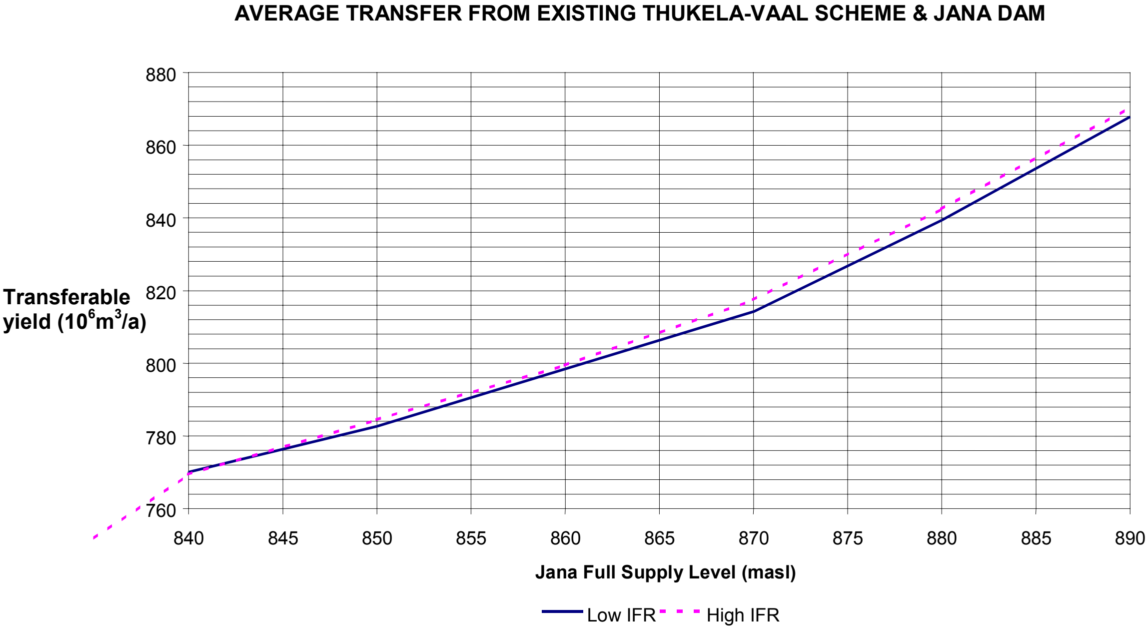

Figure S1: Average transferable yield from the existing Thukela-Vaal Scheme and the Jana Dam

2.3.5 Stochastic analyses

Once all modifications and enhancements to the feasibility study system model had been incorporated and thoroughly tested using a single historic inflow time series, yield analyses were carried out using stochastic inflow time series so as determine the assurance of supply of the proposed scheme (see Table S4 to S6).

Table S4: Transferable yield from Mielietuin Dam (Stochastic analysis)

Reservoir FSL (m amsl)	Transferable yield at an assurance of: (million m^3/a)		
	95%	98%	99%
1015	125	108	99
1025	136	120	112
1033	147	129	122

Table S5: Transferable yield from Jana – low IFR scenario (Stochastic analysis)

Reservoir FSL (m amsl)	Transferable yield at an assurance of: (million m^3/a)		
	95%	98%	99%
810	300	260	235
840	390	338	315
860	435	390	355
890	520	455	420

Table S6: Transferable yield from Jana – high IFR scenario (Stochastic analysis)

Reservoir FSL (m amsl)	Transferable yield at an assurance of: (million m^3/a)		
	95%	98%	99%
810	380	340	310
840	490	435	400
860	530	485	450
890	610	545	520

The Engineering module of the Feasibility Study identified a scheme comprising a dam with FSL at 860m at the Jana site and a dam with FSL at 1025 at the Mielietuin site as the preferred layout.

Note that the contribution from the existing transfer scheme has not been included in this analysis. This is because the water is supplied from Driel Barrage to Kilburn at well beyond this system's firm yield and is therefore not comparable with the high assurance supply from the TWP. In order to determine the assurance of supply of the combined scheme, the storage available in the Vaal River System must also be taken into account. An analysis of the combined Vaal and Thukela systems is currently being carried out under a separate contract in order to determine total yield and hence the incremental yield and its assurance as perceived in the Vaal River System.

The required aqueduct capacities necessary for the proposed TWP scheme layout to deliver water at an assurance of 98% are shown in Table S7. A larger capacity will almost certainly be required to cater for downtime and aqueduct losses.

Table 9: Aqueduct capacities required to deliver water at a 98% level of assurance

IFR Scenario	Mielietuin aqueduct capacity (m^3/s)	Jana aqueduct capacity (m^3/s)
High IFR	3.8	15.4
Low IFR	3.8	12.4

2.3.6 Filling times

Filling times were assessed by simulation using 201 stochastic inflow time series and starting with the dams empty. Downstream IFRs and in-basin demands were supplied during filling. It was assumed that when filling commenced for Jana Dam, Mielietuin Dam would be fully operative. The simulation results were presented graphically in the form of boxplots showing projected water levels in the dam.

These results are included in Appendix A of the "Water Resources Evaluation" supporting report. The number of years required to fill the dams at an assurance of 95%, to 100%, 75%, 50% and 25% of working storage are summarised in Table S8.

Table S8: Reservoir filling times (with 95% confidence)

Full supply level (m)	Years to fill dam to (at assurance of 95%)			
	25%	50%	75%	100%
Mielietuin				
1033	3	4	5	6
1025	2	3	4	5
1020	2	3	4	5
Jana: Low IFR scenario				
890	4	6	8	10
875	3	5	6	9
860	3	4	5	8
835	2	3	3	5
Jana: High IFR scenario				
890	3	5	6	8
875	3	4	5	6
860	3	4	5	6
835	2	3	3	5

2.3.7 Water Quality

The Thukela and Klip rivers that will feed Jana carry good quality water with regard to inorganic constituent concentrations and will not affect any user detrimentally. Water that will flow into Mielietuin will show the effects of pollution from Estcourt as raised conductivity levels (but still low) and associated ion concentrations. Elevated phosphate-P concentrations will stimulate algal growth, possibly resulting in mesotrophic conditions.

Possible problems with manganese, iron and ammonia are anticipated, as are low temperature releases form bottom outlets. Maximum temperature differences between surface and bottom water of about 10°C are expected to occur in January/February and this could cause considerable shock to the ecosystem when monthly bottom water releases introduce much colder water to the rivers. Temperature changes in the river immediately downstream of the dam should not exceed a few °C if serious impacts on the aquatic environment are to be avoided. Dissolved oxygen concentrations could also be depleted below 4 mg/l (lower limit for aquatic life) and the great depths of Jana and Mielietuin may prevent mixing and resulting in bottom water releases being anoxic the whole year round.

Most of the detrimental water quality effects could be minimised by ensuring that as much surface water as possible is released when monthly bottom water releases are made and by providing dilution in tailponds before overflow to the rivers. Spraying of water into tailponds will be necessary to rapidly re-oxygenate the water before it enters the rivers.

3. CONCLUSIONS

- The system analysis model of the Thukela system developed during the feasibility study adequately simulates operation of the system, including supplying water demands and IFR's.

- IFRs downstream of the proposed Jana and Mielietuin Dams significantly reduce the transferable yield from these dams. Dummy dams were included in the Sundays and Buffalo rivers to supply water requirements in these catchments as well as IFR's down to the confluence with the Thukela. These tributary IFRs contribute to the IFRs in the lower Thukela River as well as the EFR and reduce the releases that would otherwise be required from Jana Dam and hence increase the transferable yield from the TWP.

- IFRs, which will in future be required below Driel Barrage and Spioenkop Dam, will reduce the transfers from the Thukela-Vaal Scheme. However, these IFRs will also increase flow into the Jana Dam resulting in increased transferable yield from Jana. The net result is that these IFRs will not significantly influence the total transferable yield from the combined scheme. Dams sized at the preferred FSLs (Mielietuin 1025 m amsl and Jana 860m amsl) will be able to deliver additional flows of 3.8 m^3/s (Mielietuin) and between 12.4 m^3/s and 15.4 m^3/s (Jana) at an assurance of 98%. The impact of the TWP on the yield of the Vaal River System is being investigated under a separate contract.

- The reduction in transfers from the Thukela-Vaal Scheme due to IFR releases from Driel Barrage and Spioenkop Dam must be taken into consideration when sizing components of the proposed scheme. The size of Jana Dam is not affected by these IFRs but the capacity of the aqueduct from Jana to Kilburn Dam is.

- Both proposed dams are large relative to MAR and will take 6 to 10 years to fill.

- Most of the detrimental water quality effects could be minimised by ensuring that as much surface water as possible is included in monthly bottom water releases. Spraying of water into tailponds will be necessary to rapidly re-oxygenate the water before it enters the river. The quality of the transferred water should be good, since this would consist mostly of surface water.

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ABBREVIATIONS

DSL	Dead Storage Level
DWAF	Department of Water Affairs and Forestry
EFR	Estuarine Flow Requirement
FSL	Full Supply Level
IFR	Instream Flow Requirement
MAR	Mean Annual Runoff
M AMSL	Metres Above Mean Sea Level
PMT	Project Management Team
ToR	Terms of Reference
TVTS	Thukela-Vaal Transfer Scheme
TWP	Thukela Water Project
VAPS	Vaal Augmentation Planning Study
WRYM	Water Resources Yield Model

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1 INTRODUCTION

The previous Thukela-Vaal Transfer Scheme (TVTS) pre-feasibility and interim studies served to eliminate a large number of potential dam sites in the Thukela and its tributaries and to narrow development proposals to two layouts, one in the upper Thukela and the southern tributaries and one in the northern tributaries. The Thukela Water Project (TWP) Feasibility Study focuses primarily on the proposed development in the upper Thukela and the southern tributaries. The interim study defined the project as comprising Mielietuin in the Bushmans River and either Klip or Jana in the Thukela. The proposed location of the dams is shown in Drawing W1.

The Water Resources Yield Model (WRYM) was used for the system analysis in the pre-feasibility study. An interim study then was undertaken in order to incorporate into the system analysis model Instream Flow Requirements (IFR's). However, at that stage WRYM did not have a facility to model IFR releases properly and, consequently, the results of the analysis were inconclusive. The results did, however, indicate that supply of the IFR's would reduce yield from the reservoirs. Channels to model IFR's and the estuarine flow requirement (EFR) have since been added to the WRYM model and IFR's and the EFR could be properly modelled in the system model for the feasibility study.

2 STUDY OBJECTIVES

The main objectives of the study were to provide the following information:

- comparative storage-yield curves for the Klip and Jana sites to facilitate selection between the two sites.
- an assessment of the transferable yields using historic inflow time series from the proposed dams with due allowance to meet all projected in-basin demands including environmental requirements and existing and planned inter-basin transfers.
- the yield-assurance relationships for the dams using long-term stochastic inflow time series.
- estimated filling times for the proposed dams from the results of simulations using multiple stochastic inflow time series.

3 REVISIONS TO THE SYSTEM MODEL

The report "Water Resources System Model" describes the various revisions to the system model.

3.1 Implementation of first phase revisions

3.1.1 Hydrology update

The hydrological database used in the interim study spanned the period 1920 to 1992 (hydrological years). Subsequently these time series of natural streamflow, afforestation and irrigation usage were extended by two years to the end of the 1994 hydrological year (i.e. to September 1995). This coincides with the end of the 90's drought. When, for the sake of compatibility with analyses done for the Mooi-Mgeni transfer, the Mooi-Mgeni system model was used to generate an inflow time series for the Mooi River, the period of the hydrology data files was changed to the period used in the Mooi-Mgeni study (1925 to 1994).

3.1.2 Replacement of minimum flow channels

In the Mark 3 version of WRYM, there was a restriction on the number of general flow channels and minimum flow channels and a minimum flow of zero had to be used. The maximum number of general flow channels was increased in the current Mark 5 version of WRYM and therefore minimum flow channels could be replaced with general flow channels.

3.1.3 Updating of elevation-area-storage data

More detailed elevation-area-storage data for Mielietuin, Jana and Klip dams was supplied by DWAF and used in the model.

3.1.4 Implementation of IFR channels

The IFR channels introduced in the Mark 5 version of WRYM enabled the IFR's and the EFR to be effectively modelled. Flow requirements were specified for five IFR sites and the EFR that are shown in Drawing W5. These sites are:

IFR A Thukela River, downstream of Spioenkop Dam
IFR B Klip River, downstream of Qedusizi Dam
IFR 2 Thukela River, downstream of proposed Jana/Klip Dam
IFR 3 Bushmans River, downstream of proposed Mielietuin
IFR 5 Thukela River, upstream of Mooi river confluence
EFR Thukela River estuary

IFR data is entered in a new input datafile (F14 file). In this file the IFR requirement is specified as a function of the inflow at up to ten nodes (reference nodes) having incremental inflow. The in-house program "RANKGRAF" was written to rank and plot, for each calendar month, the IFR flows and also to combine, rank and plot the reference node inflows. This information was used to prepare the data for the F14 datafiles. The IFR channel is a special case of the min-max channel and will not pass more than the specified flow, therefore a general flow channel was placed in parallel to the IFR channel to allow floods to pass. Full details are given in the "Water Resources System Model Report".

3.2 Implementation of second phase revisions

3.2.1 Renumbering of nodes and channels

Due to the addition of nodes and channels primarily for the IFR's, it became necessary to renumber the nodes and channels to make the system more ordered and to facilitate checking and further revisions.

3.2.2 Review and revision of priorities and penalties for supplying demands

To refine and optimise the system operation, certain penalties were revised, the number of operating zones in the dams was increased to allow for the possible inclusion of restrictions based on water level in the reservoirs and the prioritisation of supplying demands was revised.

In-basin demands and existing and planned transfers must be supplied in preference to the new transfers to the Vaal. In accordance with this rule the following priority for supplying users was adopted:

- IFR's and the EFR
- primary demands – industry, urban and rural,
- inter basin transfers both existing and planned,
- irrigation,
- proposed Thukela Vaal transfer.

It should be noted that IFR's should receive priority of supply but that actual penalty values allocated were not the highest. However, as all in-basin demands must be supplied before water can be allocated to the proposed transfer scheme, the IFR penalties were not of significance. Furthermore checks were made to ensure that the IFR's were fully supplied which in turn showed that the other demands would also be fully supplied.

The order of supplying demands from reservoirs was set as listed below.

- Chelmsford
- Craigieburn
- Zaaihoek
- Mearns (dummy dam in the Mooi system that was included to model the Mooi-Mgeni transfer before the system was modified to utilise an inflow time series from the Mooi-Mgeni system model).
- Jana
- Spioenkop
- Mielietuin
- Wagendrift

The order of prioritising reservoirs was selected so that in-basin demands would be supplied in preference from storage that could not supply water to the proposed transfer scheme.

The WRYM system model utilises a system of penalties to decide which demands should be supplied in preference and from which storage demands can be supplied. As the model developed changes had to be made to the penalty system to ensure correct operation of the system. These changes are described in detail in the "Water Resources System Model" report.

3.3 Implementation of third phase revisions

3.3.1 Farm dams

There are many farm dams in the tributaries of the Thukela River and water stored in these dams is not available to supply downstream demands. Individually these dams are small but together have a combined capacity of some $338x10^6m^3$. The Mark 3 version of WRYM limited the number of dams that could be modelled and in addition to the major dams only two dams could be included to represent groups of farm dams. The Mark 5 version of WRYM relaxed this restriction and an additional five dummy dams were included in the system model. The total storage in dummy dams is only two thirds of the total storage in farm dams. This is because the location of the other dams did not permit them to be logically included in the system model without introducing an unrealistic level of detail. The effect of ignoring these dams will, however, be negligible.

3.3.2 Irrigation demands

In times of drought, restrictions will be applied to irrigators. It was agreed that rigorous modelling of irrigation supply, incorporating restrictions dependent on water level in the reservoirs, was not warranted and that a suitable compromise would be to supply 75% of the average irrigation demand on a firm basis. Accordingly the irrigation datafiles were adjusted to reflect only 75% of irrigation demand.

3.3.3 Mooi River system

To ensure that the Mooi River was operated as postulated in the Mooi-Mgeni study, it was requested that the system model utilised by the Mooi-Mgeni study consultants be incorporated in the Thukela system model. This proved to be unrealistic as incorporating the significantly more detailed Mooi-Mgeni system into the Thukela system model would have resulted in a very large, cumbersome model. Accordingly it was agreed to generate a time series of inflow from the Mooi River to the Thukela using the Mooi-Mgeni system model. The hydrological time series for the Mooi-Mgeni system starts in 1925 and ends in 1994. As the critical period is not at the beginning of the time series, it was decided to shorten the Thukela hydrology to also start in 1925 rather than extend the Mooi River hydrology. This would have no effect on the historical analyses but would affect stochastic generation of time series. However, the effect would more than likely be conservative because the years being removed are better than average.

3.3.4 Zaaihoek hydrology

During the study the hydrology for the Zaaihoek Dam catchment was revised. The revisions had a knock-on effect on the TM26 and TM31 catchments so the time series for these catchments were also revised. The combined mean annual runoffs for the revised inflow time series dropped by $28x10^6m^3/a$. In addition, the Zaaihoek Dam transfer to Majuba Power Station was reduced by about $20x10^6m^3/a$ for 2030 development levels (more recent information from Eskom).

3.3.5 Buffalo urban demands

Following recent trends in water use for Newcastle, the combined Newcastle, Madedeni and Osizweni urban demand in the Buffalo catchment was reduced by about $55x10^6m^3/a$ for the 2030 development level resulting in an increase in transferable yield from Jana.

3.3.6 Uitkyk and Buffelshoek Dams

Growth in water demands in the Sundays and Buffalo rivers will reduce the contribution from these catchments towards supplying IFR's. For these projected growths to be realised, further development of water resources in these catchments would also have to take place. IFR's downstream of these developments would ensure that the contribution to supplying IFR's in the Thukela would be maintained and that the burden would not fall unrealistically on Jana Dam. Two dummy dams, Uitkyk in the Sundays and Buffelshoek in the Buffalo, were included in the system model and sized to supply demands in the tributary catchments including IFR's down to their confluences with the Thukela. The more realistic approach to modelling these tributaries resulted in significantly more water being available for transfer from Jana Dam.

These assumptions will have to be tested with and without these dummy dams during the Decision Support Phase of the study in order to provide decision-makers with indication of the relative impacts on the transfer to the Vaal River System.

3.4 Miscellaneous system changes

3.4.1 System renumbering

As for the second phase revisions, it became necessary to renumber the nodes and channels following further additions and modifications to the system.

3.4.2 Ladysmith demand

At times a portion of Ladysmith's demand is supplied directly from Spioenkop Dam. In the initial model the entire demand was abstracted from the Thukela upstream of the Klip confluence. When the IFR downstream of Spioenkop was introduced this was no longer acceptable because flow past the IFR site would incorrectly include the portion of the demand supplied directly from the dam. Accordingly the model was modified to include the direct supply to Ladysmith so that flow past the IFR site could be properly checked.

3.4.3 Revised instream flow requirements

During the study it was decided, based on the outcome of a detailed investigation that storage would not be provided at Qedusizi Dam. Without storage, supply of the IFR in the Klip River cannot be controlled. Accordingly, IFR B in the Klip River was removed. At a workshop held in November 1998, IFR2 and IFR5 were modified to take account of improved measurement of the cross-sections at the sites.

The primary task of this workshop was to define the requirements at IFR A downstream of Spioenkop Dam. The requirements for IFR A were significantly higher than determined using the “Rapid Assessment” method and now could not be fully supplied from Spioenkop Dam only. To supply IFR A fully the penalties were modified to allow water to be released from Woodstock Dam as well.

IFR 2 and IFR 5 were revised and a new IFR A was generated at the November 1998 workshop. IFR A is dealt with in detail in the supporting report “Water Resources Evaluation”. It is important to note that IFR A is now able to draw on Woodstock Dam in preference to everything else in the system. These assumptions will be tested during the Reserve Determination scheduled for the Decision Support Phase.

The EFR was revised by the EFR team but had no impact on the transferable yield from Jana.

3.4.4 Elevation-area-storage revisions

DWAF improved the elevation-storage-area data for both Mielietuin and Jana dams. For Jana these differences were negligible. Accurate surveys are only available up to 870m for Jana but have been extrapolated to 890m. For Mielietuin the changes were quite significant and resulted in a decrease in transferable yield for a given storage capacity. The elevation-area-storage data is listed in Tables 3.9 and 3.10 in section 3.5.8 of this report. It is essential that if a dam with a FSL of greater than 870m at the Jana site is selected that the elevation-storage-area data above this level be determined accurately.

3.4.5 General changes

The source of supply for the Klip River urban and rural demand and irrigation at Nondlolothi was moved from the Thukela River to a postulated dam at Uitkyk in the Sundays River. The working storage of Uitkyk Dam was set so that these demands together with the IFR could be fully supplied.

There was some further revision of penalties to ensure that water was supplied according to the priorities for supply

A buffer level was included in Woodstock Dam to reserve water for IFR A, the Ladysmith demand (that portion abstracted from Spioenkop) and demands between Woodstock and Spioenkop Dams because with IFR A in place these demands cannot be supplied from Spioenkop alone. The penalty for drawing water from the buffer zone was set so that the existing Drakensberg transfer scheme would not have access to this water.

3.4.6 Driel IFR

Late in the study an IFR was introduced downstream of Driel Barrage to ensure the environmental integrity of the stretch of river between Driel Barrage and Spioenkop Dam. No IFR was considered downstream of Woodstock Dam because the water level in Driel Barrage is such that it backs up almost to the toe of Woodstock Dam with the result that there is no riverine environment in this reach. The IFR specialist team investigated the river reach between Driel Barrage and Spioenkop Dam in order to determine the current ecological management class. This IFR was therefore determined as a D and B class using the “Desktop” method.

3.5 The Feasibility System Model

During the Feasibility study the system model was developed as described in the previous sections. This section summarises the data and information that is used in the Feasibility system analysis model shown in Drawing W5.

The Mooi River system is included as an inflow time series. For this reason, details of the runoff time series, demands and return flows from the Mooi catchment are not included in the tabulated data. These details are, however, included in the “Water Resources Evaluation” supporting report.

3.5.1 Inflow time series

The 32 sub-catchments used in the pre-feasibility and interim studies were retained for the feasibility study. The Mooi catchment was input to the model as a streamflow time series at the Mooi-Thukela confluence. This time series was generated using the Mooi-Mgeni system model. Accordingly the four Mooi River inflows in the original Thukela system model are excluded in the feasibility study model. The inflow time series together with the MAR’s for the period 1925 to 1994 are listed in Table 3.1 below.

Table 3.1: Sub-catchment runoff time series

Catchment name	Natural MAR ($10^6m^3/a$)	Catchment name	Natural MAR ($10^6m^3/a$)
TM01.INC	73.24	TM15.INC	110.47
TM02.INC	357.59	TM16.INC	79.82
TM03.INC	19.24	TM17.INC	32.42
TM04.INC	217.90	TM18.INC	25.64
TM05.INC	87.40	TM19.INC	203.75
TM06.INC	30.68	TM24.INC	106.97
TM07.INC	15.07	TM25.INC	133.88
TM08.INC	300.83	TM26.INC	97.07
TM09.INC	6.77	TM27.INC	151.21
TM10.INC	87.95	TM28.INC	214.14
TM11.INC	226.63	TM29.INC	191.50
TM12.INC	35.33	TM30.INC	195.54
TM13.INC	19.63	TM31.INC	140.78
TM14.INC	82.84	TM32.INC	157.91
		Total	3402.20

The MAR of the four Mooi River sub-catchments in the original system model totals $298.22x10^6m^3/a$. Adding this to the 3402.12 $x10^6m^3/a$ gives a total natural MAR for the Thukela of $3700.42x10^6m^3/a$.

The average inflow for the Mooi system was $93.84x10^6m^3/a$.

3.5.2 Water usage by afforestation and dryland sugar cane

The afforestation and dry land sugar cane demands for 1995 and projected to 2030 are listed in Table 3.2.

Table 3.2: Mean annual afforestation and dry land sugar cane water requirements

Catchment Name	Afforestation and dry land sugar usage ($10^6m^3/a$)		Catchment Name	Afforestation and dry land sugar usage ($10^6m^3/a$)	
	1995	2030		1995	2030
TM01.AFF	0	0	TM15.AFF	0	0
TM02.AFF	0	0	TM16.AFF	0	0
TM03.AFF	0	0	TM17.AFF	0	0
TM04.AFF	1.19	2.86	TM18.AFF	2.66	4.80
TM05.AFF	0	0	TM19.AFF	0	0
TM06.AFF	0	0	TM24.AFF	0.34	2.00
TM07.AFF	0	0	TM25.AFF	0.84	4.86
TM08.AFF	0	0	TM26.AFF	0	0
TM09.AFF	0	0	TM27.AFF	1.74	6.38
TM10.AFF	0	0	TM28.AFF	1.74	6.38
TM11.AFF	0	0	TM29.AFF	1.46	2.54
TM12.AFF	3.08	5.89	TM30.AFF	2.54	2.94
TM13.AFF	2.89	5.23	TM31.AFF	0.95	5.41
TM14.AFF	0	0	TM32.AFF	2.47	2.87
			Total	21.91	52.18

Note: The pre-feasibility TM20, TM21, TM22 and TM23 annual afforestation and sugar cane usage totalling 3.78 and 6.60 $x10^6m^3/a$ for 1995 and 2030 respectively is in the Mooi system

3.5.3 Irrigation usage

Irrigation demands are not supplied at the same assurance as primary demands. To avoid unnecessarily complicating the system model irrigation demands were set at 75% of full requirement rather than implement a system of restricted supply based on water levels in the dams. Irrigation requirements were determined as time series using WRSM90. In some months the requirements exceeded available runoff from the catchments. Accordingly irrigation supply time series were generated by taking 75% of the demand with the maximum for each month being the available runoff. These irrigation time series are listed in Table 3.3. All pre-feasibility ".IRR" data files have been converted to ".IRD" data files.

Table 3.3 : Irrigation usage (full development assumed by 2010)

Irrigation demand name	Annual demand ($10^6m^3/a$)		Irrigation demand name	Annual demand ($10^6m^3/a$)	
	1995	2030		1995	2030
CHELD75.IRD	1.28	1.88	TM0275.IRD	1.32	1.67
KLIP75A.IRD	2.40	3.80	TM0675.IRD	6.76	8.35
KLIP75B.IRD	10.94	17.33	TM0875A.IRD	2.38	2.76
LOCHS75.IRD	7.79	12.02	TM0875B.IRD	6.44	7.48
MAND75.IRD	4.70	11.03	TM1175A.IRD	2.09	3.70
MHL75.IRD	4.49	13.94	TM1175B.IRD	4.07	7.19
MNGWEN75.IRD	11.51	17.80	TM1275.IRD	1.02	1.60
MUNGU75B.IRD	2.38	4.18	TM1475B.IRD	7.57	8.53
NON75.IRD	2.81	4.54	TM14_MUN.IRD	6.23	7.49
RORK75B.IRD	4.64	8.70	TM2475.IRD	5.58	6.53
THDRIE75.IRD	1. 40	1.76	TM2675.IRD	2.16	2.29
THLTUG75.IRD	19.85	23.00	V375B.IRD	9.89	18.06
THSKDS75.IRD	2.40	3.01	V3_RORK.IRD	2.70	5.05
THSKOP75.IRD	26.81	33.71	WAG75.IRD	0.83	1.28
THWOOD75.IRD	2.96	3.73	ZAAID75.IRD	5.38	7.62
			Total	170.77*	250.03*

Note: The pre-feasibility HARL75.IRD, MEARNS.IRD and MFUN.IRD mean annual irrigation demands totalling $39.18x10^6m^3/a$ for 2030 are now included in the Mooi system

3.5.4 Urban, rural and industrial demand

Urban, rural and industrial demands are summarised in Table 3.4.

3.5.5 Return flows

Return flows were taken from the report by Simonis “Water demands in the UVW catchments” prepared in 1991 for the Water Research Commission study to update “Surface Water Resources of South Africa”. Return flows were projected in relation to the estimated growth rates of contributing demands to give the values listed in Table 3.5. Return flows from irrigation were estimated to range between 10 and 15% but were not included in the analysis. Table 3.5 lists average annual return flows for various time horizons.

Table 3.4: Urban, rural and industrial water demands

Demand Name	Demand Type	Annual demand ($10^6m^3/a$)				Description
		1995	2010	2020	2030	
DEM1	Urban	0.23	2.37	4.29	4.39	Bergville, Emmaus
DEM2	Rural	0.83	8.87	12.02	12.24	Community water supply
DEM3	Urban	0.00	0.00	2.27	6.22	Ladysmith (part)
DEM3b	Urban	1.38	6.25	7.89	7.89	Ladysmith (drawing from Spioenkop Dam)
DEM4	Urban	6.23	28.15	45.19	62.77	Ezhakeni, Pieters industry
DEM5	Urban/rural	0.54	2.43	3.16	4.39	Driefontein, Peacetown
DEM6	Urban	0.54	9.63	14.23	14.55	Winterton, Loskop
DEM7	Urban/rural	0.89	1.96	2.78	3.50	Colenso, Nkanyezi
DEM10	Urban	22.69	42.92	61.79	95.68	Newcastle, Madedeni, Osizweni
DEM11	Urban	5.26	8.77	12.56	23.32	Dundee, Glencoe, Utrecht
DEM12	Rural	2.83	12.18	21.46	32.63	Community water supply
DEM13	Urban/ind.	9.85	12.81	19.28	25.25	Mandini area
DEM14	Urban/rural	7.05	20.58	32.69	46.33	Klipriver area
DEM15	Urban/ind.	2.27	6.628	10.26	14.52	Tugela Ferry
DEM16	Urban	22.11	24.93	28.81	35.19	Estcourt area
DEM17	Urban	1.48	1.67	3.79	4.61	Weenen, Noodkamp
DEM18	Urban/rural	2.66	3.00	3.95	4.83	Kwadamini, KwaMazel, Sobabili
DEM19	Urban	0.14	0.32	0.73	1.07	Wakkerstroom, Esizamelani
DEM20	Urban	1.04	2.46	4.20	6.22	Volksrust, Charlestown
DEM21	Urban/ind.	1.06	2.53	4.61	6.82	Durnacol, Dannhauser
TOTAL		89.08	258.11	295.96	412.42	

Note: The pre-feasibility DEM8 and DEM9 mean annual urban demands totalling $7.39x10^6m^3/a$ for 2030 were included in the Mooi system

Table 3.5: Return flows

Return flow name	Annual return flow ($10^6m^3/a$)				Description
	1995	2010	2020	2030	
LADY	3.15	14.22	22.20	30.57	Ladysmith
UTREC	0.74	1.23	1.73	2.24	Utrecht
DUND	1.77	2.95	4.55	5.87	Dundee
VOLKS	16.42	38.89	53.29	78.92	Newcastle, Volksrust
DURN	0.61	1.46	2.30	3.42	Durnacol
ESCRT	8.07	9.10	14.41	17.74	Estcourt
TOTAL	30.76	67.85	98.48	138.76	

Note: The pre-feasibility MOOI.RET mean annual return flows of 0.16, 0.43, 0.58 and $0.77x10^6m^3/a$ for 1995, 2010, 2020 and 2030 respectively are included in the Mooi system

3.5.6 Inter-basin transfers

There are two current schemes to transfer water from the Thukela basin to the Vaal. The largest is the Thukela-Vaal Scheme that diverts water primarily at Driel Barrage with inflow regulated by Woodstock dam. The design capacity of the combined scheme is $23m^3/s$ but this is not available on a firm basis and the scheme is normally operated to transfer at a maximum rate of $20m^3/s$. The average transfer rate achievable by this scheme is $17.3m^3/s$. The second scheme is the transfer of $28x10^6m^3/a$ from Zaaihoek dam (2030 requirement) for Majuba power station.

It is proposed to transfer $250x10^6m^3/a$ from the lower Thukela at Middledrift to the Mhlathuze catchment. This scheme is currently transferring $34x10^6m^3/a$ and is expected to reach full capacity by 2010.

A Mooi-Mgeni transfer scheme is planned and is expected to be in operation in the near future. The capacity of this scheme will be $120x10^6m^3/a$ but delivery will depend on water levels in the Mgeni dams. This transfer is included in the detailed Mooi system model that is used to provide the inflow time series for the Thukela system model.

The average inter-basin transfers used in the system model are summarised in Table 3.6.

***Table 3.6**: Mean annual inter-basin transfers from the Thukela system*

Transfer Name	Transfer ($10^6m^3/a$)		Description
	1995	2010, 2020 & 2030	
Thukela-Vaal	631.15	631.15	Existing Drakensberg transfer to Vaal
Zaaihoek	1.99	47.34	Existing Zaaihoek transfer to Vaal
Mhlathuze	0.00	252.46	Proposed Middledrift transfer to Mhlathuze
TOTAL	633.14	930.95	

Note: The MOOI-MGENI scheme transfers up to $120x10^6m^3/a$ and is included in the Mooi system

3.5.7 Instream and estuarine flow requirements.

The IFR and the EFR sites are listed in Table 3.7.

Table 3.7: IFR and the EFR sites

IFR name	Location
IFR 2	Thukela downstream of Jana Dam
IFR 3	Bushmans downstream of Mielietuin Dam
IFR 5	Thukela downstream of the , Bushmans and Sundays confluences
EFR	Thukela estuary
IFR A	Thukela downstream of Spioenkop Dam
IFR BUF	Buffels at Thukela confluence
IFR SUN	Sundays at Thukela confluence
IFR C	Thukela downstream of Driel Barrage

Note: IFR's for the Mooi River are included in the Mooi system

The IFR specialists defined drought, maintenance flows and floods for the IFR's. These requirements were used as input to specialist software to generate an IFR time series. These time series were used together with the reference node time series to derive the data for the WRYM datafile. This data gives the relationship between inflow at the reference node(s) and IFR for each calendar month. These are included in Appendix M of the "Water Resources System Model" supporting report. The maximum, minimum and average requirement for each IFR over the 70-year simulation period is listed in Table 3.8. It should be noted that the values given in Table 3.8 are based on the monthly IFR requirements. Actual flows at the IFR sites will often exceed the requirement because of water released for downstream users and because of the upstream reservoir spilling.

Table 3.8: **Maximum, Minimum and Average IFR requirements**

IFR site	Maximum (m^3/s)	Minimum (m^3/s)	Average (m^3/s)
IFR A ("low" IFR scenario)	21.26	0.65	3.47
IFR A ("high" IFR scenario)	27.60	1.24	7.04
IFR C ("low" IFR scenario)	19.49	0.63	4.01
IFR C ("high" IFR scenario)	33.04	0.77	7.79
IFR 2	40.59	1.00	8.18
IFR 3	8.60	0.40	2.17
IFR 5	56.22	1.40	12.08
IFR SUN	3.04	0.78	1.75
IFR BUF	4.47	0.19	1.13
EFR	10.00	1.00	5.88

3.5.8 Elevation-storage-area data of Jana and Mielietuin

The elevation-area-storage relationship used for Jana and Mielietuin dams are listed in Tables 3.9 and 3.10 respectively.

Table 3.9: Elevation-area-storage relationship for Jana Dam

Elevation (m)	Area (km^2)	Storage ($10^6 m^3$)	Elevation (m)	Area (km^2)	Storage ($10^6 m^3$)
704	0.00	0.23	830	17.84	812.06
720	0.25	3.68	840	20.40	1004.29
740	1.60	22.98	850	23.89	1226.14
760	4.21	82.23	860	27.44	1482.56
780	7.06	197.57	870	31.27	1776.62
800	10.89	377.15	880	36.04	2190.00
810	13.17	498.31	890	41.27	2652.00
820	15.57	643.71			

Table 3.10: Elevation-area-storage relationship for Mielietuin Dam

Elevation (m)	Area (km^2)	Storage ($10^6 m^3$)	Elevation (m)	Area (km^2)	Storage ($10^6 m^3$)
938	0.00	0.00	1002	6.84	150.45
950	0.09	0.32	1010	7.99	209.58
960	0.61	3.42	1018	9.57	279.27
970	1.71	14.57	1024	11.68	342.20
978	2.83	32.53	1030	14.58	420.57
986	4.30	60.86	1034	16.67	482.89
994	5.66	100.44	1040	20.34	594.07

3.5.9 Dummy farm dams

Seven dummy dams were used in the system model to represent the numerous farm dams in the catchment. The location and capacities of these dummy dams are listed in the Table 3.11.

Table 3.11: Dummy dams

Dummy dam No.	Catchment description	Storage ($10^6 m^3$)
1	Upstream of Woodstock Dam	14.14
2	Downstream of Driel and upstream of Spioenkop Dam	32.38
3	Upper reaches of the Little Thukela river	36.16
4	Upper reaches of the Klip river	48.86
5	Between the confluence of the Klip with the Thukela rivers, and Jana, but not on the Thukela river	41.75
6	Upper reaches of the Sundays river	28.19
7	Between V3 and Rork irrigation of the Buffels river, but not on the Buffels river	38.18
	Total storage in dummy dams	239.66

4 COMPARATIVE YIELD CURVES FOR KLIP AND JANA SITES

4.1 Yield analyses

The relationship between storage at full supply level and yield for the two proposed dams (Klip and Jana) was required early in the study as important information in the selection of the preferred site for storage in the Thukela River. As the two sites are situated close to one another on the same river, the catchments are virtually the same and the effect of the rest of the Thukela system on the yields from the two proposed dams would be the same. It was therefore appropriate to use the pre-feasibility system model suitably revised to include IFR channels, updated elevation-area-storage data for the proposed reservoirs and the extended hydrology for the comparative analyses.

Historic firm yields from a range of storage sizes for Klip and Jana were determined for the following four scenarios:

- Total firm yield
- Transferable yield
- Transferable yield without IFR's and the EFR supplied
- Transferable yield with IFR's but without the EFR supplied

These scenarios were necessary to assess the worth and cost effectiveness of both sites from a national and project perspective as well as the impact of IFR's and the EFR on system yield.

4.2 Historic storage-yield

The yield for a range of FSL's at each site are given in section 4 of the supporting report "Comparative Yield Curves for Klip and Jana Sites". The results showed that 10% to 15% of the total yield from Jana or Klip Dam would be required for downstream demands and transfers, 40% to 50% for IFR's and only 40% to 50% would be available for additional transfer to the Vaal.

It should be noted that the yield estimates presented in section 4 of the above-mentioned report are for comparison between the Jana and Klip sites only and should not be used to assess transferable yield from the sites.

The estimates analyses show that for equal storage, yield from the two dams would be equal. Accordingly, selection between the two sites will not be a function of the hydrology. Importantly, much larger storage could be provided at Jana as the FSL at Klip is limited by the proximity of Colenso Town.

After a comparative evaluation of the two sites taking all aspects into account, Jana site was selected for further consideration. Accordingly the rest of the Water Resources study focussed only on the Jana Site and no further reference is made to storage at Klip.

5 WATER RESOURCES EVALUATION

The "Water Resources Evaluation" supporting report describes the analyses that were done to determine the effect of changes in demands and operating rules on yield from the proposed dams, final historic and stochastic transferable yields and to estimate filling times for Mielietuin and Jana dams.

5.1 Sensitivity analyses

The Thukela system is large and extremely complex and it is not always easy to envisage how changes to one part of the system may affect the functioning of the rest of the system. Analyses were done to assess the effect on transferable yield of the following:

- System sensitivity to IFR's and the EFR
- Effect of the size of Mielietuin Dam on the transferable yield from Jana Dam
- Irrigation upstream of Spioenkop Dam
- The current system
- 2010, 2020 and 2030 demand scenarios
- Effect of Mhlathuze transfer on yield from Jana
- Transferable yield curves for Uitkyk and Buffelshoek Dams
- Mielietuin and Jana dams storage-transferable yield curves

These issues are briefly described in what follows.

5.1.1 Sensitivity of yield to changes in the IFR's and the EFR

Analyses were done to assess the effect of changes in the IFR and the EFR on transferable yield. These changes included reducing the maintenance and drought flows by 10% and increasing the frequency of drought flows. The results showed that a significant increase in transferable yield could be achieved, from a water resources perspective, with small changes in the IFR's. These findings were presented to the IFR specialists at the November 1998 workshop. The reductions in maintenance and drought flows, even by as little as 10%, were regarded as unacceptable by the specialists. They did, however, propose changes that effectively extended the period of transition between drought and maintenance flows. This philosophy was used in re-defining all IFR's in the Thukela.

5.1.2 Effect of the size of Mielietuin Dam on the transferable yield from Jana.

Analyses to determine the effect on the transferable yield from Jana Dam of changing the size of Mielietuin Dam showed that the yield from Jana is not affected as long as the firm transferable yield is abstracted at Mielietuin. This is because, when the firm yield from Mielietuin is being abstracted, the dam will only spill during very wet periods when there is plenty of water available from the rest of the system to supply the downstream demands without releases being made from Jana.

5.1.3 Irrigation upstream of Spioenkop Dam

Some concern was raised as to the likelihood of irrigation areas upstream of Spioenkop Dam increasing as projected. Analyses showed that there was no difference in the transferable yield from Jana whether the irrigation area stayed at its present level or increased as projected. However, with less irrigation the average transfer through the existing Drakensberg Pumped Storage Scheme would increase slightly.

5.1.4 The current system

A present day analysis was done to gain an understanding of the current system and to assess the effect that IFR's would have on supplying present day demands. Analysis showed that only the transfers from the existing Thukela-Vaal scheme would reduce if IFR's were implemented. This is because IFR A has to draw on Woodstock Dam to be fully supplied i.e. under present day conditions only the reach of river downstream of Spioenkop has lower flows than required by the IFR's.

5.1.5 2010, 2020 and 2030 demand scenarios

Comparative assessment was required for 2010, 2020 and 2030 demand scenarios to assess future trends in demand and identify possible water shortages and the need for future planning within the Thukela Basin. All proposed dams and transfers were included in the analyses. Supply of in-basin demands for the three scenarios were not affected but transferable yield from Jana and Mielietuin dams decreased over time.

5.1.6 Effect of Mhlathuze transfer on yield from Jana

The transferable yield from Jana was determined with the Mhlathuze transfer set to 34, 85 and $250x10^6m^3/a$. In all cases the same yield was obtained at Jana Dam. This shows that the Mhlathuze transfer is supported from the Buffalo River (Chelmsford Dam) and Mooi River and does not need to be supplied from Jana Dam. This finding confirms the conclusions drawn in the Mhlathuze Basin augmentation feasibility study (DWAF) done some years ago.

5.2 Assessment of changes to the system model on transferable yield

Numerous historic yield analyses have been carried out on Jana and Mielietuin as a result of new and updated information as well as enhancements to the system model. Detailed checks on the system were carried out at each stage of the revisions to the model and any shortfalls in supply were investigated and explained. Some changes resulted in an increase and others in a decrease in transferable yield as follows:

5.2.1 Revised assessment of water demands

In line with the requirement that all in-basin demands should be fully supplied before water is transferred, full irrigation demands were included at a high security of supply. This is clearly unrealistic, as irrigators do not require the same assurance of supply as primary users. Restricting supply to irrigators during droughts was considered but regarded as too complex to implement in the Thukela system model at this stage. It was agreed that supplying irrigators with 75% of their demand at the same assurance as primary users would be a more practical way of allowing for reduced supply to irrigators in the system model. This approach will have to be refined in the next phase of the project cycle. Reducing irrigation increased the water that could be transferred.

The assessment of transferable yield also increased after the Newcastle, Madedeni and Osizweni urban demand in the Buffalo catchment was revised. This demand was significantly reduced from the original 2030 projection in a re-evaluation of projected demands. The decrease of about $55x10^6m^3$ (2030 development level) resulted in an increase in transferable yield from Jana.

Transfers from Zaaihoek for Majuba Power Station were also reduced in accordance with the latest information received from Eskom and resulted in an increase in transferable yield from Jana.

5.2.2 Incorporation of additional farm dams

The inclusion of additional farm dams made possible using the Mark 5 version of WRYM resulted in more water being available for irrigators. This reduces flow in the rivers resulting in lower inflow to Jana and a greater dependency on Jana from downstream demands causing a reduction in transferable yield.

5.2.3 Revision to Zaaihoek hydrology

Inflow time series in the upper reaches of the Buffalo catchment were revised. The revision affected two of the system model inflow time series and resulted in a net decrease in inflow. This caused a reduction in the transferable yield.

5.2.4 Revision to IFR’s and addition of new IFR’s

Small changes made to IFR2, IFR3 and IFR5 had a negligible effect on transferable yield. The inclusion of new IFR’s had a more significant effect. Inclusion of IFR’s in the Sundays and Buffalo rivers reduced the burden on Jana Dam to release water for IFR5 and the EFR. This addition increased transferable yield from Jana Dam. The two new IFR’s upstream of Jana Dam cause an increase in inflow to the dam. This causes the transferable yield to increase, however, to fully supply these IFR’s, releases have to be made from Woodstock and Spioenkop Dams. This reduces transfers by the existing Thukela-Vaal Scheme. Overall transferable yield from the Thukela-Vaal scheme and the Jana Dam reduces when the FSL in Jana is less than 840m amsl because some of the water released from Woodstock for the IFR’s is spilled at Jana. Above 840m amsl losses from the Thukela-Vaal scheme are made up by increases in transfers from Jana albeit at much increased cost as a result of the higher pumping and enlarged infrastructure that would be required.

5.2.5 Revised period of inflow time series

The period of the streamflow time series was changed from 1920 to 1994 to 1925 to 1994 to be compatible with the Mooi River inflow time series generated using the detailed Mooi-Mgeni system model. In the historic analyses yields were not affected by the shorter simulation period because the discarded years do not affect the critical period in the seventies. This shortened time series will affect generation of stochastic time series but because the discarded years are above average, yields determined using the stochastic time series will be conservative.

5.2.6 Uitkyk and Buffelshoek Dams

Including Uitkyk and Buffelshoek dams together with their IFR's in the system model increased transferable yield from Jana by $1.5m^3/s$. Should development of these dams to supply local demands and IFR's on the Sundays and Buffalo Rivers, be delayed or not implemented, the transferable yield from Jana would decrease because the burden of meeting the IFR of the lower Thukela would become the responsibility of Jana Dam.

5.3 Feasibility yield analyses

The feasibility study transferable yields were determined using the system model shown in Drawing W5 with inflow time series, data and information as described in Section 3.5 of this report.

5.3.1 Historic yield analyses

The transferable yield from Mielietuin Dam depends on requirements in the Bushmans River catchment only since it was assumed that Jana Dam would release water for demands downstream of the Bushmans-Thukela confluence. Also the transferable yield from Jana Dam was shown to be independent of the size of Mielietuin Dam as long as the firm transferable yield was abstracted from Mielietuin. Accordingly the system model was used to determine the transferable yield from Mielietuin Dam for a range of dam sizes and then the corresponding transferable yields for Jana Dam were determined by simulation with Mielietuin Dam transferring at capacity. The transferable yield from Jana Dam is affected by the upstream IFR's (Woodstock and Spioenkop). The uncertainty relating to the IFR below the existing transfer scheme could not be resolved during the feasibility study but will be resolved in a separate study in which the Reserve is determined for the whole Thukela basin. To cope with this uncertainty, an upper and lower likely bound was set to the IFR and the scheme configuration and transferable yields determined for these two possible extremes. This range of uncertainty only affects the yield from the Jana Dam and not the yield from Mielietuin Dam. It is expected that the actual Reserve will lie somewhere in between the two extremes. The historical yield analysis results for the Mielietuin and the "low" and "high" IFR scenarios for Jana are summarised in Tables 5.1 to 5.3.

Table 5.1: Transferable yield from Mielietuin Dam

Full supply level (m amsl)	Working storage (10^6m^3)	Transferable yield (10^6m^3/a)
1010	206	105
1015	250	114
1020	297	123
1025	352	129
1030	417	137
1033	464	141
1035	498	143

Table 5.2: Transferable yield from Jana Dam – "low" IFR

Full supply level (m amsl)	Working storage (10^6m^3)	Transferable yield (10^6m^3/a)
800	364	204
820	630	271
840	991	322
850	1213	335
860	1469	351
870	1763	368
880	2177	393
890	2639	422

Table 5.3: Transferable yield from Jana Dam – "high" IFR

Full supply level (m amsl)	Working storage (10^6m^3)	Transferable yield (10^6m^3/a)
800	364	253
820	630	347
840	991	416
850	1213	431
860	1469	446
870	1763	464
880	2177	489
890	2639	517

For the low and high IFR scenarios, the transfers possible from the existing Thukela-Vaal Scheme transfer reduce from the 527 million m^3/a which is currently possible (using 2030 in-basin demands) to 448 million m^3/annum and 357 million m^3/annum respectively. Water released from Driel Barrage and Spioenkop Dam to supply IFRs will, however, make more water available for transfer from Jana and it was found that the total transferable yield from the combined transfer schemes (existing plus Jana and Mielietuin Dams) is the same for both high and low IFR scenario (see Figure 5.1). In other words, the amount of water which can be transferred from the Thukela basin to the Vaal

River System is essentially the same whether it is pumped from Jana Dam or the Driel Barrage. However, there is a cost implication since the cost of pumping from the Jana Dam, at a much lower elevation than the Driel barrage, will be higher. The aqueduct capacity from the Jana/Mielietuin system would have also have to be greater for the high IFR scenario.

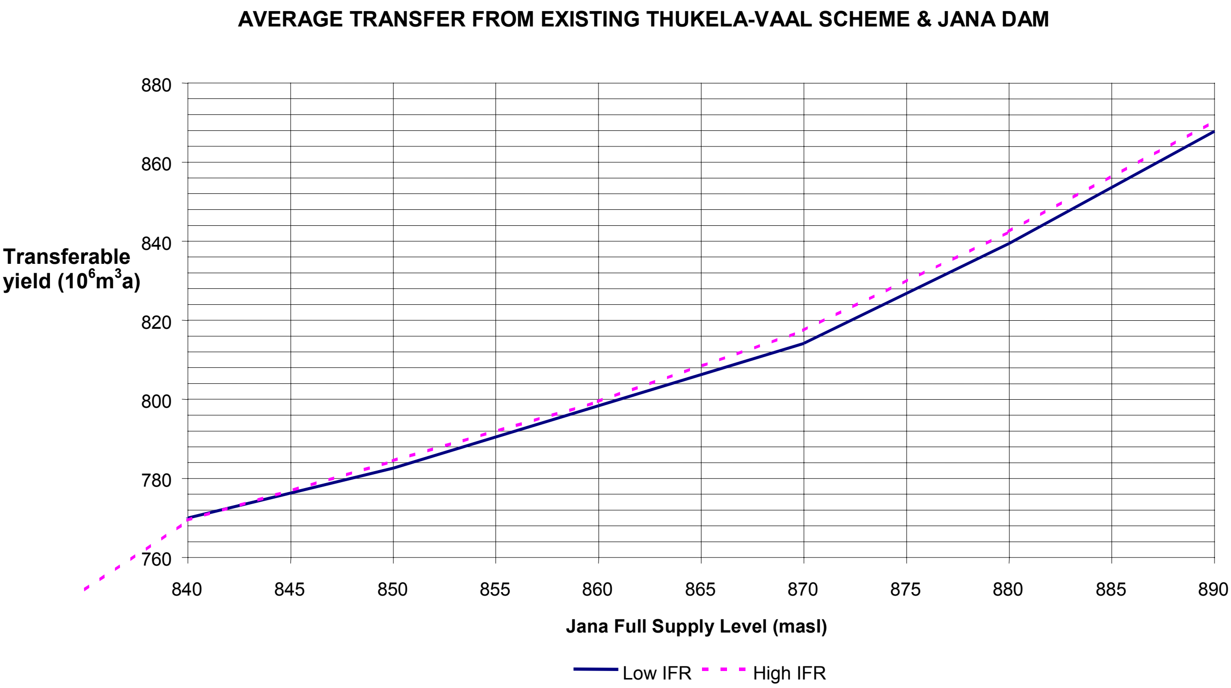

Figure 5.1: Average transferable yield from the existing Drakensberg scheme and the Jana Dam

The target of the TWP is to transfer an additional 15m^3/s to the Vaal River System. At the time of preparing the ToR for the study it was not envisaged that operating policy in the Thukela would affect the existing transfer scheme. Simulations show that under current operating rules and 2030 in-basin demands the average transfer rate for this scheme is 16.7m^3/s. Thus the combined target delivery of the existing and proposed schemes would be 31.7m^3/s. Subsequently changes in operating strategies result in water being released from Woodstock Dam to supply IFR's. Water released from Woodstock Dam cause the average transfer via the existing Thukela-Vaal Scheme to reduce. However, as the water flows into Jana it can be transferred from there. To preserve the total target transfer of 31.7m^3/s the proposed scheme should transfer 15m^3/s plus the reduction in transfer via the existing scheme. These operating rules must be optimised during the next phase of the project cycle. It also should be noted that if Jana is not built, IFRs would still have to be released from the upper catchment storage units.

Transmission losses between the proposed dams at Mielietuin and Jana and Kilburn are expected to be approximately 0.5m^3/s for canal aqueducts and close to zero for pipelines. This should also be included in transferable yields from the proposed dams.

5.4 Long-term stochastic analysis

The historic yield analysis gives no indication of the assurance of yield. In order to determine assurance, long-term stochastic analyses were done using 201 stochastic inflow sequences each 70-years long. The yield assurance relationships for Jana and Mielietuin were analysed for a range of sizes for each dam. The system operates so that Jana and not Mielietuin would supply demands downstream of the confluence of the Bushmans and Thukela Rivers. Thus the transferable yield from Mielietuin is independent of the rest of the system. For Jana, water spilled from Mielietuin will be available to users downstream of the Bushmans-Thukela confluence and could therefore reduce demands on Jana. Thus theoretically the transferable yield from Jana will depend on the size and draft on Mielietuin. However, both the historic and stochastic analyses showed that as long as the draft from Mielietuin equalled it's firm yield for the desired assurance, the size of Mielietuin did not affect the transferable yield from Jana.

Due to the fact that the IFR's below Driel Barrage and Spioenkop Dam affects the transferable yield at Jana, results have been shown for the two IFR scenarios ("low" and "high") between which the final IFR's for these sites is expected to fall. The "low" scenario relates to reaches below Driel Barrage and Spioenkop Dam being both class "D" rivers and the "high" scenario relates to a class "B/C" below Driel Barrage and a class "B" below Spioenkop Dam. Tables 5.4 to 5.6 show the results of the stochastic analyses for Mielietuin and Jana for levels of assurance of 95, 98 and 99 percent. The results show that for the "high" IFR scenario, the transferable yield from Jana is 2.5 to $3m^3/s$ more than for the "low" scenario. Additional yield is available because Woodstock and Spioenkop dams have to release more water to satisfy the "high" IFR scenario. Both the "low" and "high" IFR scenarios reduce the average transfer to the Vaal from the existing Drakensberg scheme.

Table 5.4 : Transferable yield from Mielietuin (Stochastic analysis)

Reservoir FSL (m amsl)	Transferable yield at assurance of		
	95%	98%	99%
	$10^6m^3/a$	$10^6m^3/a$	$10^6m^3/a$
1015	125	108	99
1025	136	120	112
1033	147	129	122

Table 5.5: Transferable yield from Jana – "low" IFR[1]

Reservoir FSL (m amsl)	Transferable yield at assurance of		
	95%	98%	99%
	$10^6m^3/a$	$10^6m^3/a$	$10^6m^3/a$
810	300	260	235
840	390	338	315
860	435	390	355
890	520	455	420

Table 5.6: Transferable yield from Jana – "high" IFR[1]

Reservoir FSL (m amsl)	Transferable yield at assurance of		
	95%	98%	99%
	$10^6m^3/a$	$10^6m^3/a$	$10^6m^3/a$
810	380	340	310
840	490	435	400
860	530	485	450
890	610	545	520

Note 1: Yields quoted for Jana Dam are correct only when abstraction at Mielietuin is at the same assurance.

5.5 Reservoir filling time analysis

The time required to fill the proposed dams will affect the timing of the program for design and construction so that the dams can be commissioned in time to supply demands. Filling times were assessed by simulation using 201 stochastic inflow time series and starting with the dams empty. Demands were set to 2010 levels except for existing and planned transfers and the Mooi system, which were left at 2030 level, both of which should have a minimal impact. Filling times for Mielietuin Dam were determined with no TWP transfers. For the Jana analysis, the level of Mielietuin was set at 1020m and the 1:20 year transferable yield (i.e. 95 % level of assurance) was abstracted from the dam. No TWP transfers were imposed on Jana Dam for the analysis. The analyses results were processed using the in-house program PLOTANL. This program presented as a function of time "box and whiskers" plots of the water levels in the dams. The number of wet seasons to fill the dams at an assurance of 95 percent to 25, 75 and 100 percent of working storage was read off the plots and are summarised in Table 5.7. Analyses were done for Jana Dam with both the "low" and "high" IFR scenarios.

Table 5.7: Reservoir filling times (with 95% confidence)

Full supply level (m)	Wet seasons to fill dam at assurance of 95% to			
	25%	50%	75%	100%
Mielietuin				
1033	3	4	5	6
1025	2	3	4	5
1020	2	3	4	5
Jana "low" IFR scenario				
890	4	6	8	10
875	3	5	6	9
860	3	4	5	8
835	2	3	3	5
Jana "high" IFR scenario				
890	3	5	6	8
875	3	4	5	6
860	3	4	5	6
835	2	3	3	5

5.6 Short term yield analyses

It is intended that first delivery of water to the transfer scheme should commence before the dams are full. How full the dams need to be before transfers commence depends on the accepted risk of shortfalls occurring in the short term. Accordingly analyses were done to assess the risk of shortfalls if the full transfers were commenced when the dams were 25, 50 and 75% full. Only the preferred dam sizes at Mielietuin and Jana of 1025 m amsl and 860m amsl respectively were analysed.

The feasibility system model was used in the analyses with 201 stochastic inflow sequences each 5-years long and demands set at 2010 levels. The results showed that the short-term risk of failure to supply the target draft would not be worse than 1:20 years.

6 WATER QUALITY

Consideration of water quality was limited to that pertaining to IFR releases and transferable yield. This summary was taken from the report "Specialist Study on the Impacts Relating to the creation of Impoundment's for the Thukela Water Project on Water Quality and the Water Quality that will be released" undertaken by the Integrated Environmental Module of TWP Feasibility Study.

The Thukela and Klip rivers that will feed Jana show good water quality with regard to inorganic constituent concentrations that will not affect any user detrimentally. Water that will flow into Mielietuin will show the effects of pollution from Estcourt as raised (but still low) conductivity levels and associated ion concentrations. Elevated phosphate-P concentrations will stimulate algal growth, possibly resulting in mesotrophic conditions.

Regarding the water quality in Jana and Mielietuin and the likely quality of downstream releases, three components were evaluated as follows:

- Inflow to the dams
- dam surface water
- water at the bottom of the dam

Due to settlement of sediment, bottom water releases will be turbid and hence increase the turbidity in the relevant rivers whereas surface water spills will result in far lower turbidity in the rivers than normal. Iron and manganese concentrations in downstream rivers would be reduced by a factor of about two when surface water is spilled whereas when bottom water is released, high concentrations of reduced dissolved iron and manganese could have harmful environmental effects. E. *coli* levels should drop drastically in the dams and in spilled and released water. The pH of surface water spills should not affect the rivers much but bottom water releases are likely to have lower pH values by about 0.5 to 1.0 pH units, which are potentially harmful to the ecosystem (although the overall pH is generally within tolerable limits). Total ammonia concentrations are much higher in bottom water and about 45% of bottom water releases could be harmful to the ecosystem due to the toxic free ammonia content.

Changes in temperature of the rivers below the dams will depend on the level the water is released from and the time of year. Maximum temperature differences between surface and bottom water of about 10°C should occur in January/February and could cause considerable shock to the ecosystem when monthly bottom water releases introduce much colder water to the rivers. Temperature changes for aquatic considerations should generally not exceed 2°C. Dissolved oxygen concentrations could be depleted below 4 mg/l (lower limit for aquatic life) and the great depths of Jana and Mielietuin may prevent mixing and as a result bottom water releases would be anoxic the whole year round. These effects should be confined to a relatively short length of river below the dams and could be mitigated by storage in tailponds.

7 CONCLUSIONS

A system analysis model of the Thukela River System was developed during the Feasibility Study that adequately simulates operation of the whole Thukela system including supplying water demands both inside and outside of the basin and Instream Flow Requirements (IFR's).

As can be expected, IFR's downstream of the proposed Jana and Mielietuin dams significantly reduce the transferable yield from these dams. Dummy dams were included in the Sundays and Buffalo rivers to supply local water demands in these catchments (assuming significant growth in irrigation water demand) as well as IFR's at their confluences with the Thukela. These dummy dams are to be either local developments or will later form part of a possible Northern Tributaries Transfer Development. Either way the dams will not form part of the configuration of the currently proposed scheme. This reduced the burden on Jana dam to supply IFR's in the Thukela upstream of the Mooi confluence and the EFR allowing more water to be transferred. This assumption needs to be reviewed in the Decision Support Phase.

IFR's upstream of Jana Dam increase flow into the dam resulting in increased transferable yield from Jana. However, transfers via the existing Thukela-Vaal Scheme are reduced because releases have to be made from Woodstock and Spioenkop to supply the IFR's. The reduction in transfers via the existing Drakensberg Pumped Storage Scheme due to releases from Woodstock to supply IFR's as well as transmission losses must be taken into consideration when sizing components of the proposed scheme. Releases from Woodstock to supply the IFR's will not affect the size of Jana Dam, but will affect the capacity of the aqueduct from Jana. Based on the results of simulation analyses to determine transferable yields from Mielietuin and Jana, a combination of dam sizes at the two sites could be selected to achieve the desired delivery at Kilburn.

The preferred FSL's for the dam are Mielietuin 1025 m amsl and Jana 860m amsl. The transferable yields for this option for the "low" and "high" IFR scenarios for the Woodstock and Spioenkop IFR's are shown in Table 7.1 .

Table 7.1 : Summary of Mielietuin (1025 MSL) and Jana (860mSL) option

IFR scenario	Assurance of transfer (%)	Average transfer from existing Drakensberg (m^3/s)	Transferable yield from Mielietuin (m^3/s)	Transferable yield from Jana (m^3/s)
"low" IFR	95	14.4	4.3	13.8
	98	14.4	3.8	12.4
	99	14.4	3.6	11.3
"high" IFR	95	11.5	4.3	16.8
	98	11.5	3.8	15.4
	99	11.5	3.6	14.3

The storages behind both the proposed dams are relatively large in terms of the catchment MAR at those points in the river system and therefore are expected to take between 6 and 10 years to fill.

Most of the detrimental water quality effects downstream of the proposed dams could be minimised by ensuring that as much surface water is released as possible when monthly releases are made and that there is sufficient dilution in the dam tailponds. Spraying of water into tailponds is required to rapidly re-oxygenate the water before entering the rivers. The effects of varying water quality should be further investigated in time. The quality of the transferred water should be good, since this would comprise essentially surface water. Potential aggressiveness towards concrete needs to be investigated.