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KROMME/SEEKOEI CATCHMENTS RESERVE DETERMINATION STUDY

TECHNICAL COMPONENT

HYDROLOGY AND SYSTEM ANALYSIS REPORT

Coastal & Environmental Services

KROMME/SEEKOEI CATCHMENTS RESERVE DETERMINATION STUDY – TECHNICAL COMPONENT

HYDROLOGY AND SYSTEM ANALYSIS REPORT: FINAL

November 2005

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KROMME/SEEKOEI CATCHMENTS RESERVE DETERMINATION STUDY – TECHNICAL COMPONENT
HYDROLOGY AND SYSTEM ANALYSIS REPORT: FINAL

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EXECUTIVE SUMMARY

This report summarises the hydrology and systems analysis tasks undertaken in support of the Kromme / Seekoei Catchments Reserve Determination Study.

The Hydrology task used earlier Pitman calibrations to generate natural and present day flow sequences at specified riverine sites in the Kromme (AWRSA (1994) calibration) and the Seekoei / Swart (WRSM90 calibration) rivers. Ecologists used these flow sequences to determine the Ecological Water Requirements (EWR) that would be necessary to maintain the river at different levels of degradation, corresponding to different ecological categories.

The Systems analysis task determined the water available for the environment and urban and agricultural consumers for scenarios in which the following were varied:

- EWR flows supplied at selected sites
- Infrastructure (lumped farm dam size and irrigation abstraction)
- Urban / agricultural development levels

For each of these scenarios the stream flow entering the estuary was also determined to provide a wide range of estuarine flows scenarios for assessment by the estuarine specialists. These specialists determined the impact of these scenarios on the ecological integrity of the estuary.

Due to the Kromme catchment being such a strategic component of the water supply to the Nelson Mandela Metropolitan Municipality (NMMM), a chapter has been included to describe this system together with its operational and planning considerations. This chapter indicates that the system may require augmentation in the near future to meet the growing urban demand, even if the environmental releases are not increased.

A specialist workshop was held on 23 - 25 February 2005 to determine the estuarine release to meet the Recommended Ecological Category (REC). During normal years the requirement is 16 Mm^3/a, which reduces to a “damage control” volume of 2 Mm^3/a in drought periods. If the drought Estuarine Flow Requirement (EFR) is maintained without gaps for the approximately nine years when the system is drawn down below 60% storage, then the reduction in yield is limited to 4.7 Mm^3/a. However, if the “damage control” releases cannot be maintained for such a long period then the yield of the system will be reduced. For shorter drawdown periods the impact of the high EWR releases will be larger and this impact would need to be determined using stochastic analyses.

An alternative scenario was also developed with a reduced release of about 12 Mm^3/a during normal years, but was not scored at the workshop. The releases also reduced to a “damage control” volume of 2 Mm^3/a in drought periods. If the “damage control” releases are maintained without gaps for the approximately nine years when the system is drawn down below 60% storage, then the reduction in yield is limited to 3.9 Mm^3/a. This scenario was generated to test how sensitive the yield was to estuarine flow requirements, as the difference between the two scenarios are only about 0.8 Mm^3/a and potentially can reduce the biodiversity in the system.

At present about half of the natural stream-flow of the Seekoei / Swart system is intercepted by the farm dams located upstream of the estuary. Many of the inflow scenarios generated for the Seekoei / Swart estuary hypothetically assumed that environmental releases could be made from the farm dams and that the upstream development (i.e. farm dams and irrigated areas) was reduced significantly. For each scenario the table below summarises the releases, farm dam sizes and irrigation demands (columns B to D) as well as the flows reaching the estuary (column H) and the percentage of the current irrigation demand supplied (column J).

Seekoei/Swart River Scenarios

Scenario	River release maintains category	Dummy farm dam size	Irrigation target	Natural inflow	Riverine Release	Spill	Estuary inflows = Release + Spill	Supply to irrigation	% Supply to agriculture	Evaporation losses
A	B	C	D	E	F	G	H	I	J	K
Present day	0- Pday	7.2	8.3	18.4	0.0	9.5	9.5	7.5	100%	1.4
Category D River	D	7.2	8.3	18.4	2.5	7.6	10.1	7.1	95%	1.2
Category C River	C	7.2	8.3	18.4	3.4	7.1	10.4	6.9	91%	1.1
Category B River	B	7.2	8.3	18.4	4.6	6.3	10.9	6.5	86%	1.0
Category B River with 13Mm^3/a to estuary	B	4.3	5.0	18.4	4.6	8.3	12.9	4.5	60%	1.0
Category B River with 15Mm^3/a to estuary	B	2.2	2.5	18.4	4.6	10.5	15.2	2.5	33%	0.8
Category A River with 15Mm^3/a to estuary	A	2.2	2.5	18.4	6.2	9	15.2	2.5	33%	0.8

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TERMINOLOGY AND ACRONYMS

AWRSA	Algoa Water Resources System Analysis
DS	Downstream
EFR	Estuarine Flow Requirement
EWR	Ecological Water Requirements
FSL	Full Supply Level
HFY	Historical Firm Yield
ISP	Internal Strategic Perspective
MAR	Mean Annual Runoff
Mm^3	Million cubic meters
Mm^3/a	Million cubic meters per annum
NMMM	Nelson Mandela Metropolitan Municipality
PMF	Probable Maximum Flood
REC	Recommended Ecological Category
US	Upstream
WDM	Water Demand Management
WTW	Water Treatment Works
WRYM	Water Resource Yield Model
WRSM90	Water Resources Simulation Model 1990

1 INTRODUCTION

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The Systems analysis task determined the water available for the environment and urban and agricultural consumers for scenarios in which the following were varied:

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- Urban / agricultural development levels

For each of these scenarios the stream flow entering the estuary was also determined to provide a wide range of estuarine flow scenarios for assessment by the estuarine specialists. These specialists determined the impact of these scenarios on the ecological integrity of the estuary.

As the Kromme catchment is such a strategic component of the water supply to the Nelson Mandela Metropolitan Municipality (NMMM), a chapter has been included to describe this system together with its operational and planning considerations. This chapter indicates that the system may require augmentation in the near future to meet the growing urban demand, even if the ecological releases are not increased.

Most of the information presented was obtained from the Algoa Water Resources System Analysis Study (DWAF, 1994a-f), Surface Water Resources of South Africa 1990 (WRSM90) (Midgley *et al.*, 1994) and relevant reports from the Tsitsikamma to Coega Internal Strategic Perspective (DWAF, 2003). More recent data have also been obtained from the DWAF Directorate of Hydrology in Pretoria, the regional DWAF office in Cradock and the NMMM, and a report discussing the annual operation of the system in 2004.

2 KROMME RIVER HYDROLOGY

The Kromme River originates at the Heights in the Langkloof, 12km east of Joubertina. The river flows in an easterly direction parallel to the Baviaans and Kouga rivers. Up to Churchill Dam, at the eastern end of the Langkloof, the river has no major tributaries and most of the surface water drains into the main channel *via* numerous small streams. Another major storage dam, the Impofu Dam (previously Charlie Malan Dam), is located on the Kromme River, about 20km downstream of Churchill Dam. The catchment of the Impofu Dam has two major rivers: a short section of the Kromme River downstream of Churchill Dam, which conveys spills and releases from Churchill Dam, and the Diep River, which flows into the Kromme River from a northerly direction between these two dams. Another, much smaller tributary, the Geelhoutboom River, enters the Kromme River about 13km downstream of the Impofu Dam at the Kromme Estuary.

The hydrology of the Kromme River upstream of Impofu Dam was investigated in detail as part of the Algoa Water Resources System Analysis (AWRSA) Study (DWAF, 1994a-e). The Pitman Model was used to define a rainfall – runoff relationship for the catchments upstream of the flow gauging stations K9R001 (Churchill Dam) and K9R002 (Impofu Dam). This entailed calibrating the Pitman Model to generate monthly flow sequences matching the observed flow sequences at these sites. For this Reserve determination study the Pitman parameters determined during the AWRSA study were used to generate long-term stream flow sequences for period from 1927 to 2000.

Relevant hydrological data for the Kromme River IS presented in Table 2-1. The sub-catchments upstream of Churchill Dam are K90A and K90B and those above Impofu Dam are K90C and K90D. Sub-catchment K90F represents the area downstream of Impofu Dam, including the Geelhoutboom River tributary.

The Kromme River and Diep River catchments upstream of Churchill and Impofu dams have a small amount of agriculture reducing river flows. Water is mainly used for the irrigation of pastures and deciduous fruit.

It is important to note that although the town of Kareedouw is located in the Kromme River catchment upstream of Churchill Dam, the town draws water from springs and boreholes and has little effect on the surface runoff in the catchment.

Two issues were highlighted during the AWRSA study, as described below.

The first is that the length of the observed record available for calibrating the inflows into Impofu Dam was only about 8 years long i.e. from 1983 to 1991. Also, because this period coincided with the drought only significant inflow was available for calibration. The last column of Table 2-1 illustrates that the percentage of the rainfall in the Kromme Catchment (K90A and K90B) reaching Churchill Dam is about 20% while that from the Diep Catchment reaching Impofu Dam (K90C and K90D) is only 10%. Recalibrating the Impofu Catchment will help to check this relationship.

The second issue was that the 1983 to 1991 drought was more severe than previous droughts and reduced the Historical Firm Yield of the Churchill / Impofu system from about 56 to 32 Mm^3/a. The demand applied on the two dams affects the amount of spillage that can be expected at the estuary. Many analyses used the stochastic yield corresponding to an annual probability of failure of 1 in 50 years of 44.4 Mm^3/a, which lies about halfway between the two different historical analyses. The simulated records were replaced with the available naturalised observed inflows at Churchill and Impofu dams. The resultant sequence of natural mean annual runoff (MAR) at the Kromme River Estuary was about 88 Mm^3/a as can be seen at the bottom of Table 2-1.

Table 2-1 Hydrological data: Kromme River

Catchment i=incremental c=cumulative	Location	Area	MAP	Natural patched runoff	Afforestation	Irrigation	Farm Dam Caps	Present day incremental	Checking Natural inflows	Nat runoff	Nat runoff / rainfall
		km^2	mm	Mm^3/a	km^2	km^2	Mm^3	Mm^3/a		mm	%
K90A (i) [1]	US Churchill	213	740	33.6	0	2.1[1]	0.39[2]	29.5	30.4[2]	158	22%
K90B (i) [1]	US Churchill	150	740	23.7	2.2[1]	1.4[1]	0.00		K90A+B=57.3[1]	158	22%
K90C (i) [1]	US Impofu	267	596	8.4	0	1.9[1]	2.55[1]	15.8	16.9[1] vs 30.7[2]	31	5%
K90D (i) [1]	US Impofu	215	693	10.3	1.2[1]	1.5[1]				48	7%
K90E (i) [2]	DS Impofu inc Geelhoutboom	176	676	11.9	0	1.5[6]	0.90[5]	10.9	12[2]	67	10%
Cumulative at Kromme Estuary		**1021**	**699**	**87.8**				**34.0[3]**		**86**	**13%**

(1) Algoa Water Resources System Analysis (DWAF, 1994).

(2) WRSM90.

(3) Spills and releases from Impofu Dam assuming a demand with a 1 in 50 year risk of failure is applied to the system.

(4) This represents the naturalized MAR of the incremental catchment as simulated for the period 1927 to 2000. However, this is based on a very short calibration period of 1983 to 1991, which coincided with a severe drought. WRSM90 reports a larger incremental MAR for the area upstream of Impofu Dam of 30.7 Mm^3/a.

(5) Farm dam capacities of 0.9Mm^3 in K90E are based on a volume for the Geelhoutboom River of 0.77Mm^3 (Sinclair and Associates) plus the 0.13 Mm^3 for the Grasmere Dams (WRSM90 Volume V: Appendix 5.1.1).

(6) Irrigation areas in K90E are the sum of an area of 135ha for the Geelhoutboom River (Sinclair and Associates) plus an estimate of 15ha for the 0.13Mm^3 Grasmere Dams.

3 KROMME RIVER SYSTEM

3.1 Existing water supply infrastructure

The Churchill and Impofu dams, which together supply about half of the urban water demand of the NMMM, are located in the Kromme River.

Churchill Dam, which was completed in 1947, is a concrete multiple arch type dam and consists of ten inclined circular arches with spans of 17m. Six of the arches form an ogee overflow spillway; while a gated “Stoney” spillway channel exists on the left flank. The design flood for the dam is 1500m^3/s. Two outlet towers are located immediately upstream of the wall. The one close to the left bank is used as a multiple level draw-off tower and has a 900mm diameter steel scour pipe at the base of the tower, which discharges into the river downstream of the dam wall. The control valve for this pipeline is positioned in the tower. The other tower, which is located near the right bank, is used for scouring and has two 1300mm cement mortar lined cast iron scour pipes from the base of the tower through the dam wall. The 1300mm diameter scour pipes are connected via 1500 mm butterfly valves to 1500 mm Larner Johnson needle valves at the downstream end of the dam wall. Based on the dimensions of the above pipes, hydraulic calculations show that (under Full Supply Level (FSL) conditions) the maximum capacity of each of the 1300mm diameter scour pipes is about 25m^3/s, while the maximum capacity of the 900mm diameter scour pipe is 11m^3/s. These capacities will be less when the level in the dam is below FSL.

Impofu Dam is a 75m high embankment dam with a side channel spillway able to accommodate the Probable Maximum Flood (PMF) of about 5000m^3/s. From the base of the outlet tower, a 1500mm diameter scour pipe runs through a conduit to the downstream face of the dam. A 900mm diameter sleeve valve and a 250mm diameter sleeve valve are fitted to the downstream end of the scour pipe. Compensation water pipework consists of a 1200mm diameter vertical pipe in the tower connected to 4 x 1200mm diameter butterfly valves with bellmouth draw-offs at various levels. This pipework is connected into the scour pipework at the tower base. The small 250mm sleeve valve is intended for normal compensation water flow. When the 900 mm sleeve valve is fully open under full reservoir head, the maximum velocity in the 1500mm diameter pipe will be 10m/s. This corresponds to about 18m^3/s.

Water from Churchill Dam is treated at the Churchill Water Treatment Works (WTW) downstream of the dam. Releases to the treatment works are measured in the supply line to the works. The capacity of the treatment works is 95Ml/d. However, if the dam is less than about 40% full, the water must be pumped to the treatment works, which reduces its capacity to 50 Ml/d. The supply from Churchill Dam is supplemented with water from Impofu Dam, which was completed in 1983. From Impofu Dam, water is pumped to the Elandsjagt Water Treatment Works (capacity 65Ml/d) on the southern bank of the dam. It is planned to increase the capacity of the Elandsjagt Water Treatment Works to 105Ml/d in the near future.

From the Churchill WTW, water gravitates to Port Elizabeth by means of two parallel pipelines. At the Elandsjagt WTW, treated water is injected under gravity into the Churchill supply line, which crosses the Impofu Dam near the treatment works. A booster pump station near the Gamtoos River crossing increases the capacity of the pipelines when required. The pipelines deliver water to four reservoirs in the Metropolitan Area. The Churchill pipeline also supplies water, about 2Mm^3/a in 2003, to local authorities, including Jeffreys Bay, Humansdorp and St Francis Bay, along its route to Port Elizabeth. These towns supplement their own local (mainly borehole) supplies with water from this pipeline. Furthermore, small coastal resorts also draw water directly from this supply line.

Details of the dams, water treatment works and pipelines which from part of this system are summarised in Table 3-1 and Table 3-2 respectively.

Table 3-1 Physical details of existing dams on the Kromme River

Dam	FSL (m)	Gross capacity (Mm^3)	Nett capacity (1) (Mm^3)	Present day (1991) Firm Yield (Mm^3/a)	Release capacity when dam is at FSL (m^3/s)
Churchill	155.5	34.3	34.1	31 (4)	61
Impofu	76.3	106.94	87.03 (2) 99.23 (3)		18

(1) Nett Capacity = Gross capacity – Dead storage.
(2) Normal withdrawal at WTW.
(3) With pumps on barge.
(4) Represents Historical Firm Yield (1927-1991) of Churchill / Impofu system after deduction of the release of an assumed $2Mm^3/a$ from Impofu Dam for the ecology (1:50 year stochastic yield = $44.4Mm^3/a$). This $2Mm^3/a$ ecological allowance was based on an estimate of the evaporation from the estuary by Dr Paul Roberts and will be revised as part of this Reserve determination study. In the Internal Strategic Perspective it was estimated that the alien vegetation upstream of the dam might reduce the yield by a further 3.5 million cubic meters per annum, though this figure is uncertain. (Both figures come from the Algoa Water Resources Stochastic Analysis [AWRSA] , Report 2, Vol 1 pp iii and 25).

Table 3-2 Bulk water supply lines from Churchill and Impofu dams

Description	Origin	Delivery	Diameter (mm)	Length (km)	Capacity (Ml/d)
Churchill Pipelines	Churchill and Elandsjagt WTW	Greenbushes Res. Emerald Hill Res. Airport Res. Glen Dining Res.	1 x 680 to 760 1x 1060 to 1295	105	146 (Boosted) 105 (Gravity)

3.2 System operation

The Churchill and Impofu dams function as part of an integrated water supply system to meet the urban requirements of the NMMM. Other major sources of supply include Kouga Dam *via* Loerie Dam, Groendal Dam and the Orange/Sundays River Scheme via the Scheepersvlakte balancing Dam. There are also various minor sources of supply viz. groundwater and springs, dams on the Bulk, Van Stadens and Sand rivers and some reuse.

Figure 3-1 illustrates the main inflows and feasible demands on the Kromme River System assuming that 36 Mm^3/a is supplied to the Nelson Mandela Metropolitan Municipality (NMMM) / coastal towns and that releases of 11 Mm^3/a are made to the estuary. The inflows to the Churchill

Dam (54 Mm^3/a) are greater than those to the Impofu Dam (16 million m^3 plus 30 Mm^3/a spills from Churchill) so more water (Mm^3/a) can be supplied from the Churchill Dam to the NMMM than from the Impofu Dam (14 Mm^3/a) to reduce pumping costs. In addition to the releases from Impofu Dam, the estuary also receives an additional 19 Mm^3 in spills from Impofu Dam plus about 11 Mm^3/a from the portion of the Kromme River downstream of the Impofu Dam and from the Geelhoutboom River and other tributaries. An agricultural demand of about 2 Mm^3/a is supplied from Impofu Dam.

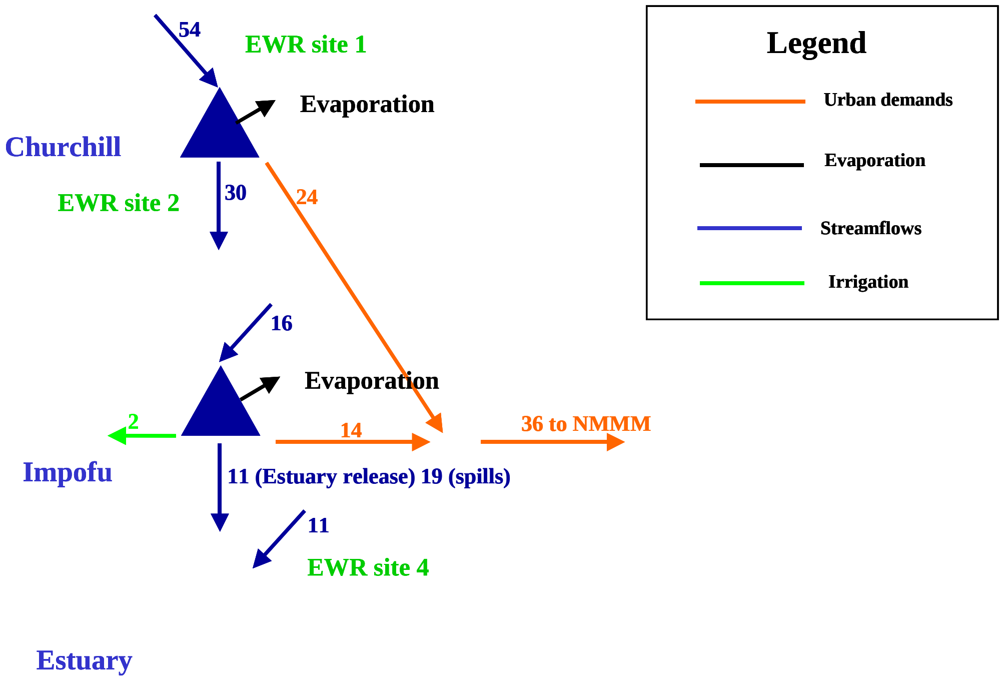

Figure 3-1 Main inflows and demands of the Kromme River System (Mm³/a)

Figure 3-2 displays a historical record of the annual abstraction volumes from the Impofu and Churchill dams.

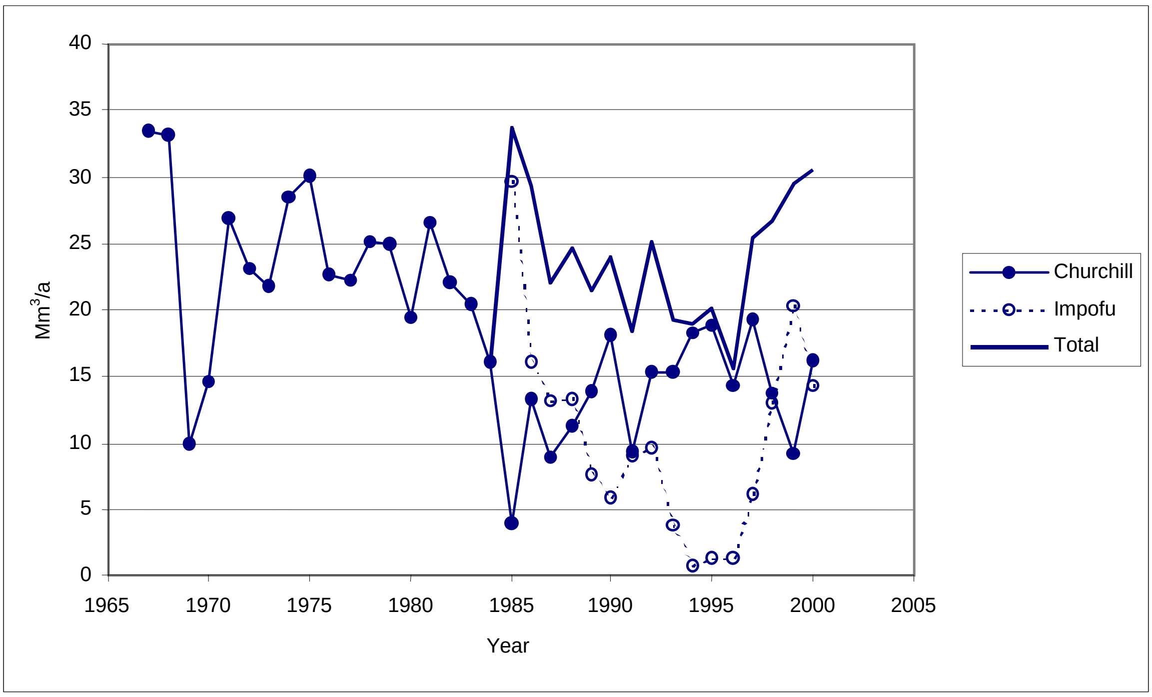

Figure 3-2 Annual abstractions for urban use: Churchill and Impofu dams

In 2002, the Churchill and Impofu dams supplied about 45% of the total urban requirements of the NMMM. In the Internal Strategic Perspective (ISP) for the Tsitsikamma to Coega region the total urban demand of the NMMM and coastal towns in 2002 was estimated at about 72Mm^3/a. Due to the discrepancies in the data it was recommended that a detailed reconciliation of the monthly supply to the WTW and the annual supply be carried out. Preliminary updated data indicates that the raw water demand from July 2003 to June 2004 was about 84 Mm^3/a prior to deducting losses at the WTW. The demand is increasing at about 3 Mm^3/a from the influx of workers attracted to the Coega harbour project.

Figure 3-3 shows the monthly distribution of water demand on the Churchill / Impofu Dam for the period 1997/98 to 2003/04.

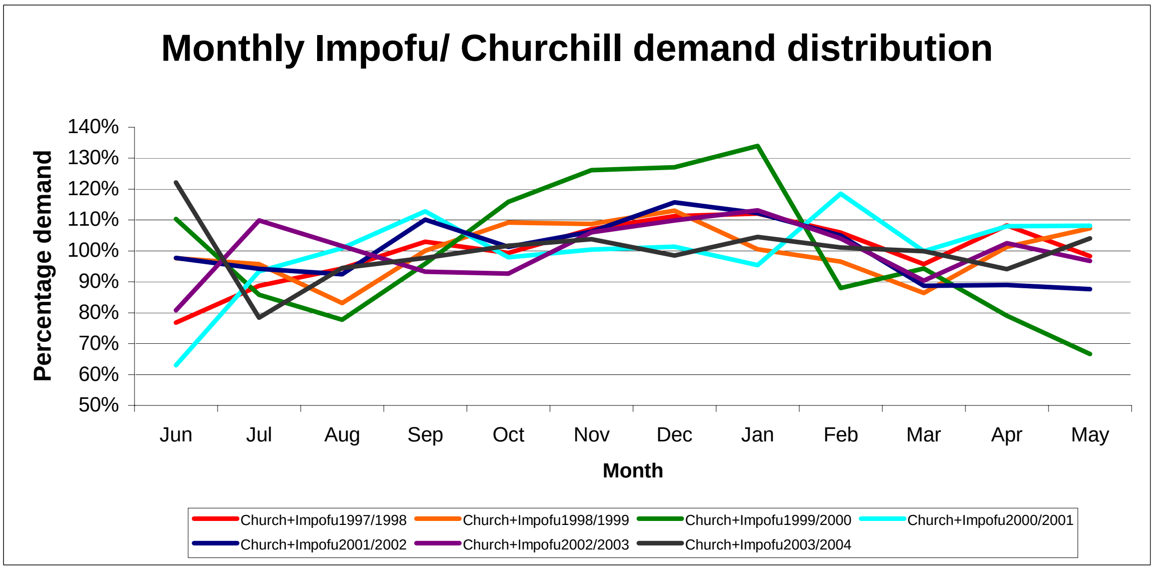

Figure 3-3 Monthly urban demands on the Impofu / Churchill system

The Churchill and Impofu dams are operated as a single system. Due to water from Churchill Dam entering the Churchill Dam WTW under gravity (if the dam is more than 40% full), it is more cost effective to abstract water from Churchill Dam than from Impofu Dam, whence the water has to be pumped to the Elandsjagt WTW. The fact that the amount of water that can be abstracted from Churchill Dam is limited to only 50Ml/d if the dam is less than 40% full, also affects the operation of the system.

Although the main function of the Churchill/Impofu system is to supply water to the NMMM, there are some local demands on the system as indicated in Table 3-3. These include direct abstractions and releases for downstream riparian users from Impofu Dam. According to Mr Raimer of the NMMM, the ecological requirement of 2Mm^3/a that is prescribed for the Kromme Estuary is not released from Impofu Dam. Some of the water that is released for the riparian users downstream of Impofu Dam, however, may reach the estuary, but these releases will probably decrease in future, as one of the main downstream riparian users (Mr. Gutsche) is currently constructing a pipeline to abstract water directly from Impofu Dam. No specific releases for downstream riparian users are currently made from Churchill Dam. However, the backwash water from the WTW located downstream of the dam was historically released into the river though it may now be stored in an off-channel dam.

Table 3-3 Local demands on Impofu Dam

User	Type	Area	Unit demand	Demands	Note
		(ha)	(m^3/ha)	(Mm^3/a)	1, 4
Various	Direct Abstraction	71.1	6000 –9000	0.64	1, 4
Department of Community Development	Direct Abstraction	8	6000 -9500	0.08	1, 4
Mr Esterhuizen	Direct Abstraction	75	6000 -9500	0.71	2, 4
Mr Gutsche (SA Bottling Co)	Release	88	6000 -9500	0.84	3, 4
Ecological release to Kromme Estuary	Release			2	5
Total				4.26	

(1) From a 1988 survey, described in a 1990 report by Murray Biesenbach & Badenhorst Inc.
(2) Mr Esterhuizen's water consumption is being contested.
(3) This is Mr Gutsche's allocation from the dam; he could potentially intercept some of the ecological releases, although such releases are apparently not made.
(4) The allocation in m^3/ha from the dam has not been finalised and could be anywhere between 6000 and 9500 m^3/ha. The upper limit was used to calculate the annual demands.
(5) Release from dam to Kromme River Estuary. Not made at present.
This table is based on a discussion with Flip de Wet of DWAF (048 –881 3005) during May 1999 and reported in the "Report on Algoa System Operation May 1999" by Ninham Shand (see Annexure IV, Appendix A).

As Churchill Dam is much smaller than Impofu Dam, Churchill Dam fills and spills much more often than Impofu Dam, which is evident from the tables in Appendix A, which list monthly river discharges (releases and spills) from these dams.

The Tsitsikamma River, which is situated to the west of the Kromme River, has been identified as a possible source of augmentation for the NMMM. The proximity of the Tsitsikamma catchment to the Kromme River Supply System, together with the spare capacity in the supply infrastructure from the Churchill and Impofu dams, make it feasible to treat raw water from the Tsitsikamma River at the Elandsjagt WTW and to supply this water to the NMMM via the existing pipelines. If required, the capacity of the bulk supply pipelines can be increased by the construction of additional booster pump stations.

3.3 Long and short-term planning

Figure 3-4 compares the projected demand increases assumed for the AWRSA (green line) and the Algoa Prefeasibility Study (black dashed line; see references DWAF 2001a, DWAF 2001b, DWAF 2002a). The red dots on the curves indicate when each study recommended augmentation, and corresponded to NMMM demands of between 88 and 93 Mm^3/a. The demand projections have been revised using the latest available demands represented by the red and blue lines. These revised demand projections indicate that the system could require augmentation in the near future, even without additional environmental releases.

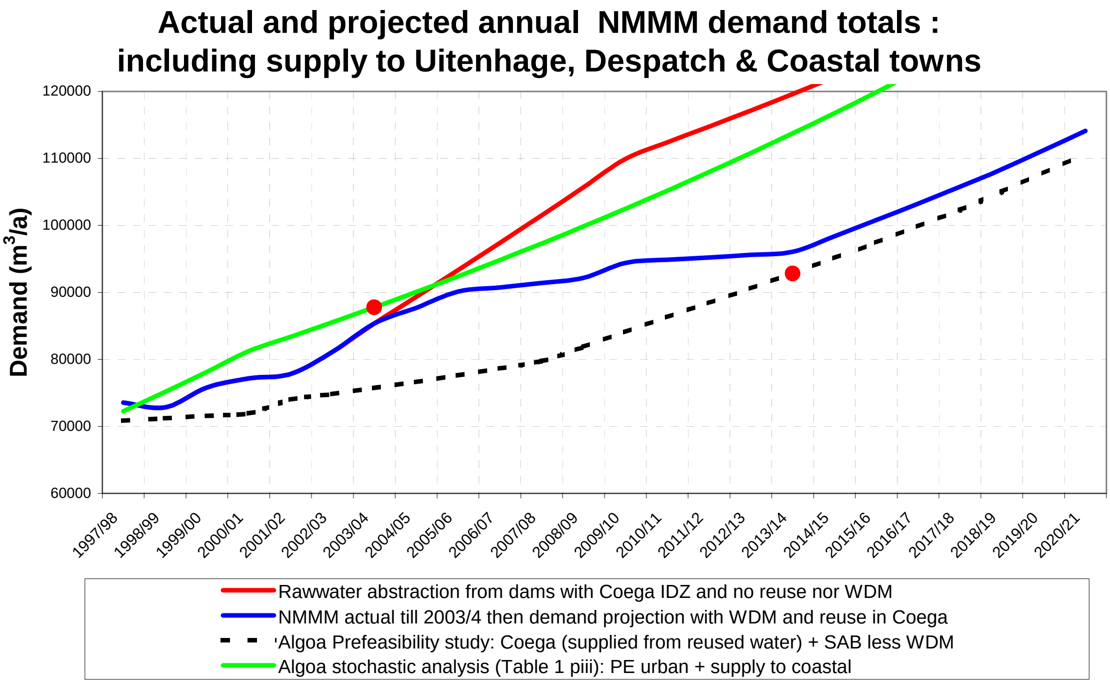

Figure 3-4 Projected NMMM demands compared to the system yield

The long-term water resource planning indicates when augmentation of the water supply is necessary to reduce the risk of restrictions. However, a severe drought may still necessitate the imposition of progressively increasing restrictions to reduce the risk of the dams emptying. Figure 3-5 shows how, during the recent dry period, blue dots representing the total storage in the dams was plotted on a monthly basis on a box and whisker diagram showing the anticipated storage levels from 1 September 2004. The boundary between the shaded and unshaded halves of the box represents the storage anticipated under median inflows. There is a 25% chance of drier inflows, in which case the storage trajectory would follow the bottom of the box. If the storage dropped below the 25% level more severe restrictions would be imposed on or before 1 November 2005. As a guide, the level of restrictions that would be imposed for different system storages has been shown on Figure 3-5.

There is some resilience in the estuarine ecosystem as it was a marine-dominated estuary under the Reference Condition. Therefore releases can be curtailed to 2 Mm^3/a during drought conditions to counteract the development of hyper saline conditions due to evaporation in the estuary which reduces species diversity. For this reason it may be possible to reduce the estuarine releases when the system storage drops and curtailments are imposed on the urban and agricultural consumers, rather than bind the estuarine releases to a gauge in the catchment.

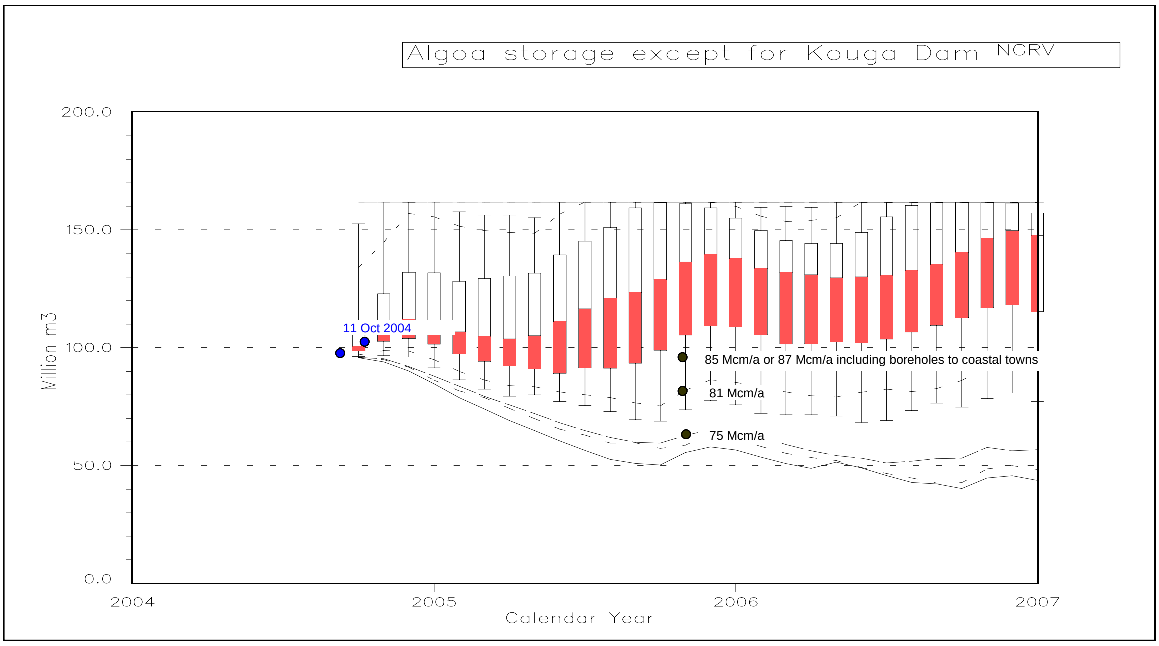

Figure 3-5 Monthly monitoring of restriction risk

4 KROMME RIVER ECOLOGICAL SCENARIOS

4.1 Qualitative discussion of the impact on the yield

This chapter discusses the modelling of ecological scenarios in the Kromme River and their impact on the yield of the system. The required Ecological Water Requirements (EWR) releases will have three different types of impact on the yield and operation of the system depending on the location of the releases in the system, as can be seen in Figure 4-1.

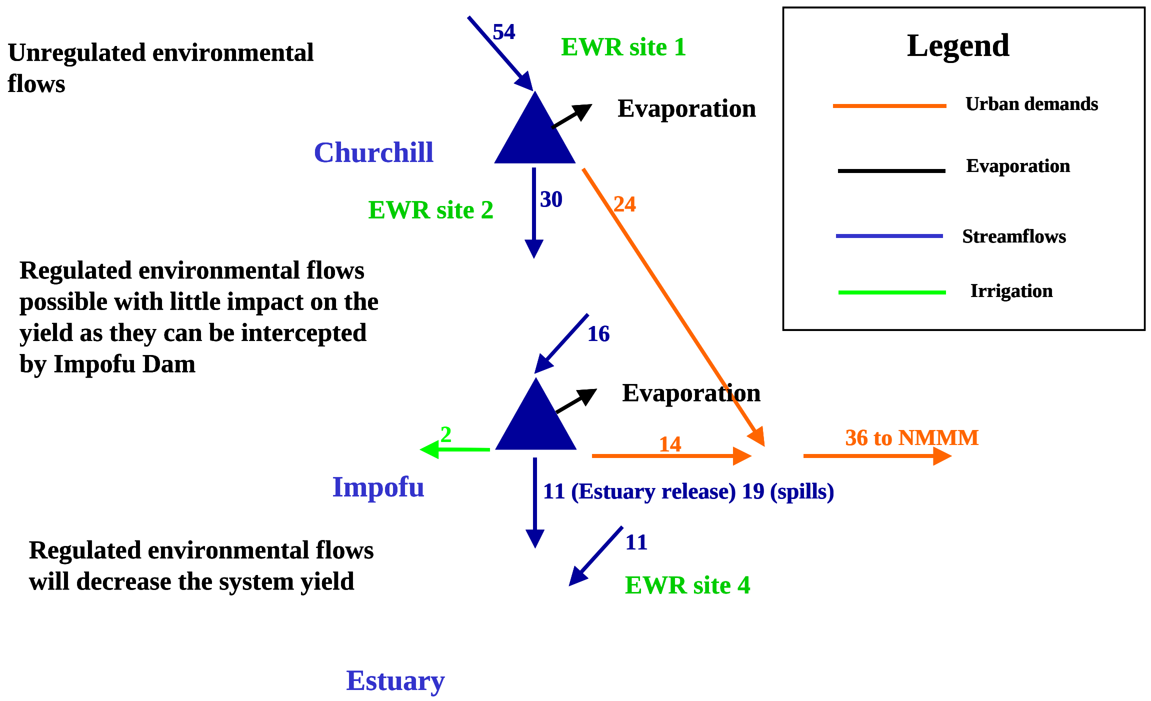

Figure 4-1 Annual abstractions for urban use: Churchill and Impofu dams

The area upstream of the Churchill Dam is largely undeveloped and any future development has been discouraged because it will impact directly on the yield of the Churchill and Impofu dams. Since 1987 portions of the area were declared Government Water Control Areas and in September 1994 no new water works or alterations to existing water works were permitted without obtaining authorization. Nevertheless, to exploit the area some farmers are bulldozing marshlands. There is little opportunity for regulating or providing additional Ecological Water Requirements unless releases are made from private farm dams.

The area between Churchill and Impofu dams can be regulated by making releases from Churchill Dam. The area is relatively undeveloped and additional water works have also required authorization such as the area upstream of Churchill Dam. At present no explicit environmental releases are made (i.e. releases specifically to maintain ecosystem function) from Churchill Dam but one of the outlet valves was leaking and water used to backwash the filters used to flow down the river. However, the leaking valve has been fixed and the backwash water is apparently stored in an off-channel dam. Blended releases of up to 11m^3/s can be made from the intake tower (depending on the storage level) and additional scour releases of up to 50m^3/s are possible from the scour valves. If a D Ecological Category (EC) is maintained below Churchill Dam, between 4.9 Mm^3/a and 7.9 Mm^3/a will need to be released from Churchill Dam. If the larger flood releases are omitted because of the limited outlet capacity of the dam, then there is a chance that spills over the dam will compensate for the reduced flood releases. If this is so then the smaller 4.9 Mm^3/a volume will be adequate to maintain a D EC below Churchill Dam. These releases can be intercepted at Impofu Dam and pumped to NMMM without reducing the yield of the system, though there will be an increase in pumping costs.

The streamflow downstream of Impofu Dam can also be regulated by making releases from the Impofu Dam for the estuary, but any releases will reduce the yield of the system unless they are over-spill. At present the NMMM release is about 30Ml every 10 days, which equates to 1.2 Mm^3/a and is 0.4 Mm^3/a more than Mr Gutsche's annual allocation of 0.8 Mm^3/a. The fate of the additional 0,4 Mm^3 was uncertain, and it could either replenish the environment (possibly also spilling into the estuary) or it could be intercepted before reaching the estuary by "hippo" pools from which water is pumped. DWAF's Regional Office was concerned that additional releases might be intercepted by irrigators and had instructed D Raymer that the present releases from Impofu for Mr. Gutshe would fulfil the requirements for the ecological releases and fill up the hippo pools (Raymer, NMMU, *pers. comm.*)

Mr Gutsche is constructing a pipeline to abstract his allocation of 0.8 Mm^3/a directly from the dam which should be completed by September 2005. The additional 0.4 Mm^3/a will continue to be released from Impofu Dam down the Kromme River for the ecology.

4.2 WRYM Scenarios

A large number of scenarios were analysed using the WRYM to provide inflow sequences for the estuarine workshop. These scenarios can be grouped as follows:

- Natural conditions
- Present Day
- Future developments
- Alternative estuarine releases (indicating additional scenarios identified at; and after the scenarios workshop.)

The scenarios analysed are summarized in Table 4-1. This table describes the EWR, future schemes, infrastructural limitations and demands used for each scenario. The scenarios are also discussed in more detail below.

Natural conditions. The stream flows prepared were originally stream flows simulated using the Pitman Model. Subsequently these flows were patched and the observed stream flow records were incorporated where available. The natural stream flows developed by the AWRSA for the period from 1927 to 1990 were used for the catchments upstream of Impofu Dam.

Present Day. A number of alternative present day scenarios were analysed by varying the following:

- The releases to the estuary from Impofu Dam. The initially proposed release of 2 Mm^3/a has been reduced to about 0.4 Mm^3/a because it may have been intercepted by irrigators downstream. Scenarios using both 2 and 0.4 Mm^3/a releases were analysed.
- Additional abstractions in the Geelhoutboom River. A weir is located in the Geelhoutboom River at the edge of the tidal influence and it was assumed that there might be an additional abstraction of 0.95 Mm^3/a from the weir (Scenarios pp83v and pp2v), Table 4.1.
- The target draft from the Churchill / Impofu system of NMMM and irrigators. Drafts of 30 Mm^3/a, 44 Mm^3/a and 55 Mm^3/a were applied (in addition to releases of 2 Mm^3/a to the estuary) which varied the spill received by the estuary. These drafts correspond to the Historical Firm Yield of the system for the period 1927 to 2000, the 1 in 50 year stochastic target draft (the most likely draft) and the Historical Firm Yield for the period 1927 to 1983, respectively. (Scenarios pp00, pp2 and pp83), Table 4.1.
- No Impofu Dam. To assist ecologists to understand the behaviour of the estuary prior to the construction of the estuary another scenario without the Impofu Dam was analysed (Scenario cp2), Table 4.1.

Future Developments: The following proposed developments were analysed (see Table 4.1 for more details):

- Using the Churchill/Impofu System to supply more of the peak demand from the Sundays and Loerie systems and also increasing the demand on the Churchill / Impofu system by about 3.5 Mm^3/a (peak1 scenario).
- An increased run of river abstraction of 0.8 Mm^3/a upstream of Churchill and of 0.5 Mm^3/a in the incremental catchment upstream between Churchill and Impofu (c1_2 scenario as well as CI00 and CI83).
- An additional dam of 0.95 Mm^3 on the Geelhoutboom River supplying a demand of 0.95 Mm^3/a (Scenario Y1-1). In another case the weir is located in the Geelhoutboom River at the edge of the tidal influence and was assumed to help supply the 0.95 Mm^3/a demand (Scenario Y1-1E). In another scenario the demand of 0.95 Mm^3/a was increased to 1.45 Mm^3/a and was supplied from the new dam and the weir (Scenario Y1-1P).

Alternative estuarine scenarios: Different estuarine releases from the Impofu Dam were coupled with scenarios maintaining different EWR scenarios in the Geelhoutboom River:

Estuarine releases: In the initial analyses the releases tested were 5, 7.5 and 10 Mm^3/a. The Specialist Workshop (23 – 25 February 2005) recommended that a release of 16 Mm^3/a (Estuarine Scenario 6) be analysed and an alternative release of 12 Mm^3/a (Estuarine Scenario 7) was also analysed. The releases were reduced to 2 Mm^3/a when the storage in the system dropped below about 60%. There is some resilience in the estuarine ecosystem as it was a marine dominated estuary under the Reference Condition. Therefore releases can be curtailed to 2 Mm^3/a during drought conditions to counteract the development of hyper saline conditions due to evaporation in the estuary which reduces species diversity. It might therefore be acceptable to link the estuarine releases to the dam storage rather than indicator gauges within the catchment. Of concern is that with an increase in demand, the 60% storage level might be occurring more frequently that at present and therefore not be representative of a drought year. The A/B, B/C and C/D ECs were also considered in the Geelhoutboom River for the 5 Mm^3/a estuarine release (Scenarios 25Yab, 25Ybc, 25Ycd [under the 1 in 50 year target drafts] and i5yab, i5ybc, i5ycd [under the Historical Firm Yields for the 1927 to 1983 period]).

Table 4-1 WRYM Scenarios

Scenario	EWR conditions						Future Devs				Infrastructure			Urb & Agr Dems					Comment
	U/s Churchill	D/s Churchill	Geelhoutboom	Impofu estuary releases	Target estuary release	Omit estuary releases if storage < 60%	RoR u/s Churchill Dam (1)	RoR u/s Impofu Dam (1)	Geelhoutboom R (Ghb) Dam	Dem on exist .08Mm³ weir us estuary	Churchill WTW Cap	Elandsjagt WTW Cap	Pipeline from Chill & Impofu	Firm Yield period ('27-'83) or ('27-'00)?	Historical Firm Yield (HFY) or LTCC draft (eg2% risk) to NMMM		Agric from Impofu Dam	Supply from Boreholes	
				m³x10⁶/a	m³x10⁶/a		m³x10⁶/a	m³x10⁶/a	m³x10⁶	m³x10⁶/a	Ml/d	Ml/d	Ml/d			m³x10⁶/a	m³x10⁶/a	m³x10⁶/a	
Natural																			
np																		na	Replacing simulated stream flows with observed stream flows (patching) reduces flows in '83 drought
Present Day																			
pp83				2	2						u	u	u	83	HFY	53	2	2	
pp00				2	2						100/50	105	u	00	HFY	28	2	2	For period ending '00 patched stream flows have much less yield period ending '83 (i.e. wrt pp83)
pp83w				0.4	0.4						u	u	u	83	HFY	54	2	2	0.4Mm3 estuary releases (i.e. wrt pp83)
pp83v	C	D	C/D	0.4	0.4					0.95	u	u	u	83	HFY	54	2	2	0.4MM3 estuary releases &abstract 0.95Mm3/a from weir u/s of Geelhoutboom R (i.e. wrt pp83)
pp2				2	2						100/50	105	u	-	2%	42	2	2	1 in 50 year yield [AWRSA] Report 2, Vol 1 pp iii and 25
pp2w				0.4	0.4						u	u	u	-	2%	44	2	2	0.4Mm³ estuary release (i.e. wrt pp2)
pp2v				0.4	0.4					0.95	u	u	u	-	2%	44	2	2	0.4Mm³/a estuary releases + abstract 0.95Mm³/a from weir u/s of Geelhoutboom R (i.e. wrt pp2)
cp2				2	0						100	-	u	-	2%	25	2	2	No Impofu; Assume 25 Mm³/a on Churchill Dam
Additional developments																			
Peak demands on Churchill																			
peak1	C	D	C/D	5	5						100/50	105	u	-	2%	43	2	2	Peak on Churchill & Impofu and supply additional 3.5Mm³/a.
Additional development u/s of Churchill & Impofu																			
CI00	C	D	C/D	5	5		0.8	0.5			100/50	105	u	00	HFY	23	2	2	New RoR demands u/s of Churchill & Impofu; 5% reduction in IFR flows and impact on the yield
CI83	C	D	C/D	5	5		0.8	0.5			100/50	105	u	83	HFY	48	2	2	
CI_2	C	D	C/D	5	5		0.8	0.5			100/50	105	u	-	2%	37	2	2	
1 Million m3 dam on Geelhoutboom																			
Y1-1	C	D	-	5	5				0.95		100/50	105	u	-	2%	39	2	2	Geelhoutboom Dam not supplying EWR requirements downstream.
Y1-1E	C	D	C/D	5	5				0.95		100/50	105	u	-	2%	39	2	2	Geelhoutboom Dam supplies EWR requirements downstream.
1 Million m3 dam on Geelhoutboom plus pumping from weir																			
Y1-1p	C	D	C/D	5	5				1	0.47	100/50	105	u	-	2%	39	2	2	Irrig releases from Geelhoutboom Dam to ds weir supply some of IFR site 4
Increase Impofu's estuarine releases and enforce increased EWR in Geelhoutboom River																			
Using draft equal to Historical Firm Yield for the 1920-83 period																			
i5ycd	C	D	C/D	5	5						100/50	u	u	83	HFY	50	2	2	If Ywoods river categories can't be supplied pull water from Ywoods dams. Some shortfalls when Churchill/Impofu Dams empty but in practice the estuary release might also be curtailed when the supply to the urban consumers is curtailed.
i5ybc	C	D	B/C	5	5						100/50	105	u	83	HFY	50	2	2	
i5yab	C	D	A/B	5	5						100/50	105	u	83	HFY	50	2	2	
i7ycd	C	D	C/D	7.5	7.5						100/50	105	u	83	HFY	48	2	2	
iaycd	C	D	C/D	10	10						100/50	105	u	83	HFY	44	2	2	
5ycd2	D	D	C/D	5	5						100/50	105	u	83	HFY	50	2	2	Categories C u/s Churchill only fails because the required IFR base flows > modelled natural stream flow
5ycd3	D	D_{cap}	C/D	5	5						100/50	105	u	83	HFY	50	2	2	Omit 1x7m³/s(avg daily) & 1x15m³/s IFR releases as peak flows > blended outlet capacity (11m³/s)
i5-0	C	D	C/D	5/0	5	Y					100/50	105	u	-	2%	39	2	2	Stop 5Mcm estuary releases when the storage drops below 60%?
Using draft having a 1 in 50 year risk of failure																			
25ycd	C	D	C/D	5	5						100/50	u	u	-	2%	39	2	2	Based on i5ycd with different target draft
25ybc	C	D	B/C	5	5						100/50	105	u	-	2%	39	2	2	Based on i5ybc with different target draft
25yab	C	D	A/B	5	5						100/50	105	u	-	2%	39	2	2	Based on i5yab with different target draft
27ycd	C	D	C/D	7.5	7.5						100/50	105	u	-	2%	37	2	2	Based on i7ycd with different target draft
2aycd	C	D	C/D	10	10						100/50	105	u	-	2%	34	2	2	Based on iaycd with different target draft
Investigate impacts of revised Scenario 1(6) and 2(7) on the Yield																			
i16-2	C	D	C/D	16/2	16	Y					100	105	u	-	2%	39	2	2	Estuarine release reduced to 2Mcm/a when storage < 60%, possibly by specifying the estuary in a demand file.
i12-2	C	D	C/D	12/2	12	Y					100	105	u	-	2%	40	2	2	
i16h2	C	D	C/D	16/2	16	H					100	105	u	-	HFY	26	2	2	
i12h2	C	D	C/D	12/2	12	H					100	105	u	-	HFY	26	2	2	

4.3 Quantitative impact of the releases from the Impofu Dam on the system yield

This analysis investigates the impact of Scenario 6 arising from the estuary workshop, on the yield of the system. Scenario 6 represents the ecological flows required for the Kromme Estuary to meet the Recommended Ecological Category (REC), as identified at the Specialist Workshop (23 – 25 February 2005). To test the sensitivity of the estuarine model to evaporative requirements and drought flows, an additional scenario (Scenario 7) was generated (although not scored by the workshop). This scenario included the required ecological flows for the period October to March (i.e. similar to that of Scenario 6), but allowed for zero flow releases from April to September and in drought periods (see Table 4-2). Scenario 7 was developed to see how much the yield could be increased by reducing the EWR requirements. The difference between the Historical Firm Yields obtained for Scenario 6 and 7 varied from 0.8 (Table 4-5 comparing existing Scenarios 6 and 7 with no gap) to 2.7 (Table 4-5 comparing existing scenarios 6 and 7 with 3 year drought gap) Mm^3/a depending on for how many years the EWR releases from Impofu Dam were reduced to 2 Mm^3/a during droughts. At this stage the impact of reducing the EWR requirements to Scenario 6 were not evaluated in detail.

Table 4-2 Ecological flows for the two scenarios

Month	Scenario 6		Scenario 7		
	Normal Flows	Damage control	Normal Flows	Damage control	Zero Flows (1)
	N1	D1	N2	D2	
Oct	$5m^3/s$ for 6 days and $1m^3/s$ for 25 days		$5m^3/s$ for 6 days and $1m^3/s$ for 25 days		
Nov	$1m^3/s$ for a month	$0.2m^3/s$ for a month	$1m^3/s$ for a month	$0.2m^3/s$ for a month	
Dec	$0.7m^3/s$ for a month	$0.2m^3/s$ for a month	$0.7m^3/s$ for a month	$0.2m^3/s$ for a month	
Jan	$0.6m^3/s$ for a month	$0.2m^3/s$ for a month	$0.6m^3/s$ for a month	$0.2m^3/s$ for a month	
Feb	$0.2m^3/s$ for a month	$0.2m^3/s$ for a month	$0.2m^3/s$ for a month	$0.2m^3/s$ for a month	
Mar	$0.2m^3/s$ for a month		$0.2m^3/s$ for a month		
Apr	$0.2m^3/s$ for a month				
May	$0.2m^3/s$ for a month				
Jun	$0.2m^3/s$ for a month				
Jul	$0.2m^3/s$ for a month				
Aug	$0.2m^3/s$ for a month				
Sep	$0.2m^3/s$ for a month				

(1) As an additional concession the damage control flows in scenario 7b were reduced to zero for 1 out of 10 years to increase the yield.

4.3.1 Detailed procedures

The releases specified for these two scenario sets are described in Table 4-2. Typical monthly flows for each year were calculated from the cases in Table 4-2 and are shown in Table 4.3 below.

Table 4-3 Typical monthly flows (Mm^3)

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Total
N1 - Normal IFR for scenario 6 (Mm^3)	4.75	2.59	1.87	1.61	0.49	0.54	0.52	0.54	0.52	0.54	0.54	1.04	15.53
N2 - Normal IFR for scenario 7 (Mm^3)	4.75	2.59	1.87	1.61	0.49	0.54	0.00	0.00	0.00	0.00	0.00	0.00	11.85
D - Drought IFR for scenarios 6 and 7 (Mm^3)	0.00	0.52	0.54	0.54	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08
0 -No EWR (Mm^3)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 4-2 shows the storage trajectory of the Impofu and Churchill dams supplying the Historical Firm Yield of about 32 Mm^3/a for the period from 1927 to 2000. Note how the storage is drawn down only over the extreme drought from 1983 to 1992. To increase the yield it was necessary to reduce the estuary releases by as much as possible over this period. If the curtailed drought EWR was introduced at the same time as curtailing the supply to the urban consumers (say at about 60% of the storage), then nine consecutive years of drought estuary releases would be necessary to maximise the yield. Other scenarios, which were less harsh on the environment, introduced gaps of normal EWR from 1 to 3 years between the damage control EWR. Table 4-4 shows the annual timing of the different releases from the dam for the different scenarios. Other timings of the gap years are possible, for instance it may be possible to have two sequential damage control years before introducing an increased release to the estuary.

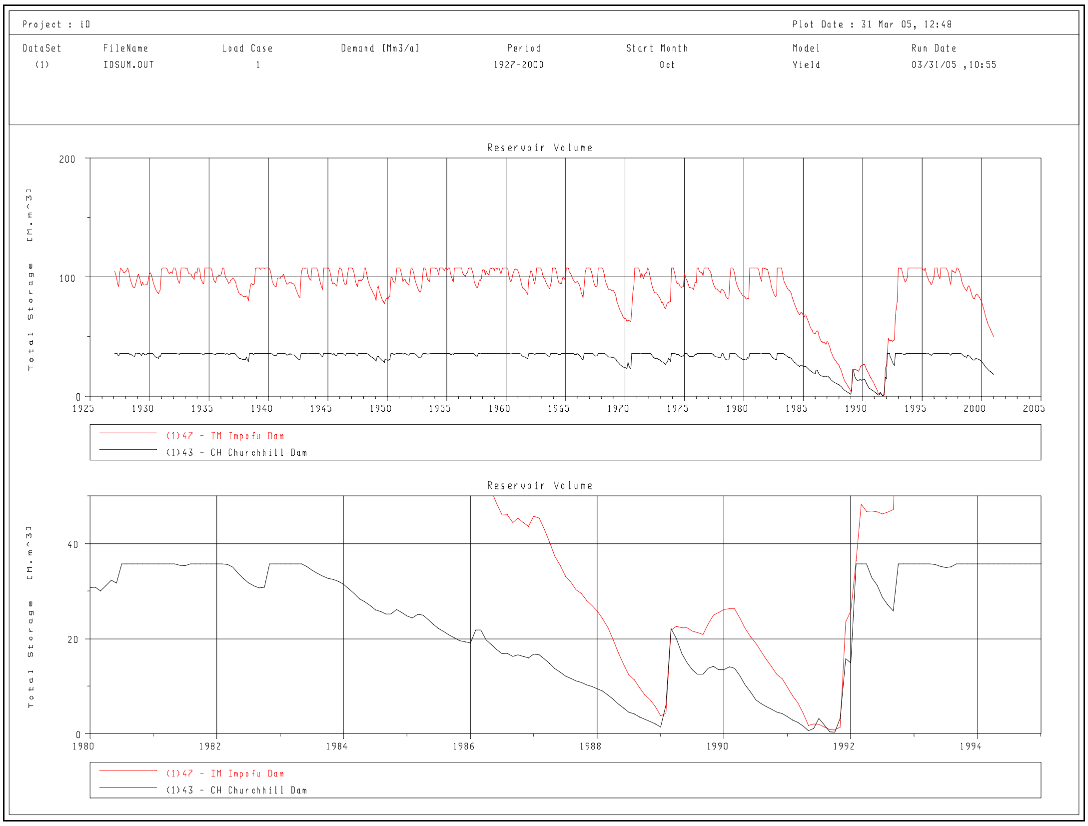

Figure 4-2 No EWR Releases: Supplying 32.5Mm^3/a from Churchill and Impofu dams to urban and agricultural consumers

Table 4-4 Distribution of drought years for the different scenarios

Year	Existing Scenario 6 Zero gap	Existing Scenario 6 One year drought gap	Existing Scenario 6 Two year drought gap	Existing Scenario 6 Three year drought gap	Existing Scenario 7 Zero gap	Existing Scenario 7 One year drought gap	Existing Scenario 7, Two year drought gap	Existing Scenario 7 Three year drought gap	Existing Scenario 7 (No gap with 0 flow for one year in critical drawdown period)	Existing Scenario 7 One year drought gap with 0 flow for one year in critical drawdown period	Existing Scenario 7 Two year drought gap with 0 flow for one year in critical drawdown period	Existing Scenario 7 Three year drought gap with 0 flow for one year in critical drawdown period
A	B	C	D	E	F	G	H	I	J	K	L	M
1927	N1(1)	N1	N1	N1	N2(2)	N2	N2	N2	N2	N2	N2	N2
1928	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1929	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1930	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1931	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1932	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1933	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1934	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1935	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1936	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1937	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1938	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1939	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1940	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1941	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1942	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1943	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1944	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1945	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1946	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1947	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1948	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1949	D(3)	D	D	D	D	D	D	D	D	D	D	D
1950	D	N1	N1	N1	D	N2	N2	N2	D	N2	N2	N2
1951	D	D	N1	N1	D	D	N2	N2	D	D	N2	N2
1952	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1953	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1954	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1955	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1956	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1957	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1958	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1959	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1960	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1961	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1962	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1963	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2

Year	Existing Scenario 6 Zero gap	Existing Scenario 6 One year drought gap	Existing Scenario 6 Two year drought gap	Existing Scenario 6 Three year drought gap	Existing Scenario 7 Zero gap	Existing Scenario 7 One year drought gap	Existing Scenario 7, Two year drought gap	Existing Scenario 7 Three year drought gap	Existing Scenario 7 (No gap with 0 flow for one year in critical drawdown period)	Existing Scenario 7 One year drought gap with 0 flow for one year in critical drawdown period	Existing Scenario 7 Two year drought gap with 0 flow for one year in critical drawdown period	Existing Scenario 7 Three year drought gap with 0 flow for one year in critical drawdown period
1964	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1965	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1966	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1967	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1968	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1969	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1970	D	D	D	D	D	D	D	D	D	D	D	D
1971	D	N1	N1	N1	D	N2	N2	N2	D	N2	N2	N2
1972	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1973	D	D	D	N1	D	D	D	N2	D	D	D	N2
1974	D	N1	N1	D	D	N2	N2	D	D	N2	N2	D
1975	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1976	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1977	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1978	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1979	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1980	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1981	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1982	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1983	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1984	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1985	D	D	D	D	D	D	D	D	D	D	D	0
1986	D	N1	N1	N1	D	N2	N2	N2	D	N2	N2	N2
1987	D	D	N1	N1	D	D	N2	N2	D	D	N2	N2
1988	D	N1	D	N1	D	N2	D	N2	0	N2	0	N2
1989	D	D	N1	D	D	D	N2	D	D	0	N2	D
1990	D	N1	N1	N1	D	N2	N2	N2	D	N2	N2	N2
1991	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1992	D	N1	N1	N1	D	N2	N2	N2	D	N2	N2	N2
1993	D	D	N1	D	D	D	N2	D	D	D	N2	D
1994	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1995	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1996	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1997	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1998	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
1999	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
2000	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
2001	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
2002	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2
2003	N1	N1	N1	N1	N2	N2	N2	N2	N2	N2	N2	N2

(1) N1 – Normal IFR for Scenario 6 (Mm^3).
(2) N2 – Normal IFR for Scenario 7 (Mm^3).
(3) D – Drought IFR for Scenarios 6 and 7 (Mm^3).

4.3.2 Results

The yields obtained for the different scenarios sets are provided in Table 4-5.

For Scenario 6, the EWR release during normal years is about 16 Mm^3/a, which reduces to a "damage control" volume of 2 Mm^3/a in drought periods. If the drought EWR is maintained without gaps for the approximately nine years when the system is drawn down below 60% storage, then the reduction in yield is limited to 4.7 Mm^3/a (Column B of Table 4-5). If gaps in the "damage control" releases are introduced by making normal annual releases the yield decreases. For gaps of 1, 2 and 3 years the reduction in the yield increases by 9.4, 10.4 and 12.2 Mm^3/a respectively.

For Scenario 7, the EWR release during normal years is about 12 Mm^3/a, which reduces to "damage control" volume of 2 Mm^3/a in drought periods. If the "damage control" releases are maintained without gaps for the approximately nine years when the system is drawn down below 60% storage, then the reduction in yield is limited to 3.9 Mm^3/a. If gaps in the drought releases are introduced by making normal annual releases, the yield decreases. For gaps in the damage control releases of 1, 2 and 3 years durations alternating with drought years the reduction in the yield increases by 7.2, 7.8 and 9.5 Mm^3/a respectively.

If an additional year of 0 releases is introduced into Scenario 7, the yields increase by approximately 0.3 Mm^3/a, though the increase will be more for a shorter draw-down period.

The reduced Historical Firm Yields obtained for the period from 1927 to 2000 are presented in column C of Table 4-5. If the last drought period from 1983 is ignored then the yields will increase and these yields have been estimated in Column D of Table 4-5 – simply by applying the reductions determined for the 1983 to 1992 period (Column B) to the Historical Firm Yield for the shorter period of 56.9 Mm^3/a. If the 1 in 50 yield of 44.1 is used instead of the Historical Firm Yield then the yield estimates in Column E are obtained. A stochastic analysis was not used to determine these 1 in 50 year yields.

The upper window of Figure 4-3 shows the dam trajectories for Scenario 6 assuming that the releases are reduced to 2 Mm^3/a for the full period from 1985 to 1993 while supplying the Historical Firm Yield of 27.8 Mm^3/a to urban and agricultural consumers. The lower window in Figure 4-3 shows the dam trajectories for Scenario 7 also reduced to 2 Mm^3/a for the full period from 1985 to 1993 while supplying the Historical Firm Yield of 28.6 Mm^3/a to urban and agricultural users. (The applied Historical Firm Yields have been shaded in column C of Table 4-5.) The inflows to the estuary for Scenarios 6 and 7 are provided in Table 4-6 and Table 4-7 respectively. The trajectories in the upper and lower window of Figure 4-3 are very similar and the dams remain relatively full for most of the period and spill frequently.

To simulate the spills from the Churchill and Impofu dams more realistically, larger target drafts based on the 1 in 50 year yield, were applied to the system. The applied drafts of 41.7 and 42.5 Mm^3/a for Scenarios 6 and 7 have been highlighted in column E of Table 4-5. The associated dam trajectories are illustrated in Figure 4-4 and the inflows to the estuary are provided in Table 4-8 and Table 4-9. Additional variants based on these inflows can be obtained by increasing the "damage control" releases to those corresponding with normal years in for some years in the period between 1985 and 1993, which will reduce the yield as indicated in Table 4-5.

Figure 4-5 and Figure 4-6 compare the flow sequence obtained at the estuary for the 4 cases analysed:

- Scenario 6 (reducing to $2Mm^3/a$ when the storage falls below about 60%) and supplying the Historical Firm Yield ($27.8Mm^3/a$).
- Scenario 7 (reducing to $2Mm^3/a$ when the storage falls below about 60%) and supplying the Historical Firm Yield ($28.6Mm^3/a$).
- Scenario 6 (reducing to $2Mm^3/a$ when the storage falls below about 60%) and supplying the approximate 1 in 50 year yield ($41.7Mm^3/a$).
- Scenario 7 (reducing to $2Mm^3/a$ when the storage falls below about 60%) and supplying the approximate 1 in 50 year yield ($42.5Mm^3/a$).
  The upper portion of the graph in these figures, provide the actual monthly flow sequence while the lower blocks represent the annual average.

Table 4-5 Yield results

Scenario/s	**Reduction Yield (Mm^3)**	**Approximate HFY Nov 83 - June 92 (Mm^3)**	**HFY for period before Nov 83 (Mm^3)**	**Approximate 1 in 50 year Yield (Mm^3)**
(A)	**(B)**	**(C)**	**(D)**	**(E)**
No EWR Releases [(1)]		30.2	54.6	44.1
Agricultural releases from Impofu		2.3	2.3	2.3
Sum of no EWR releases and agricultural releases from Impofu		32.5	56.9	46.4
Existing Scenario 6 (No gap)	-4.7	27.8	52.2	41.7
Existing Scenario 6 One year drought gap	-9.4	23.1	47.5	37.0
Existing Scenario 6 Two year drought gap	-10.4	22.1	46.5	36.0
Existing Scenario 6 Three year drought gap	-12.2	20.3	44.7	34.2
Existing Scenario 7 (No gap)	-3.9	28.6	53.0	42.5
Existing Scenario 7 One year drought gap	-7.2	25.3	49.7	39.2
Existing Scenario 7 Two year drought gap	-7.8	24.7	49.1	38.6
Existing Scenario 7 Three year drought gap	-9.5	23.0	47.4	36.9
Existing Scenario 7 (No gap with 0 flow for one year in critical drawdown period)	-3.6	28.9	53.3	42.8
Existing Scenario 7b One year drought gap with 0 flow for one year in critical drawdown period	-7	25.5	49.9	39.4
Existing Scenario 7b Two year drought gap with 0 flow for one year in critical drawdown period	-7.6	24.9	49.3	38.8
Existing Scenario 7b Three year drought gap with 0 flow for one year in critical drawdown period	-9.3	23.2	47.6	37.1

(1) From "I:\HYDRO\400118\WRYM\v9\flow requirements.xls". Yield from Scenario pp00 and pp83 plus $2Mm^3/a$ from Environmental Releases from Impofu.

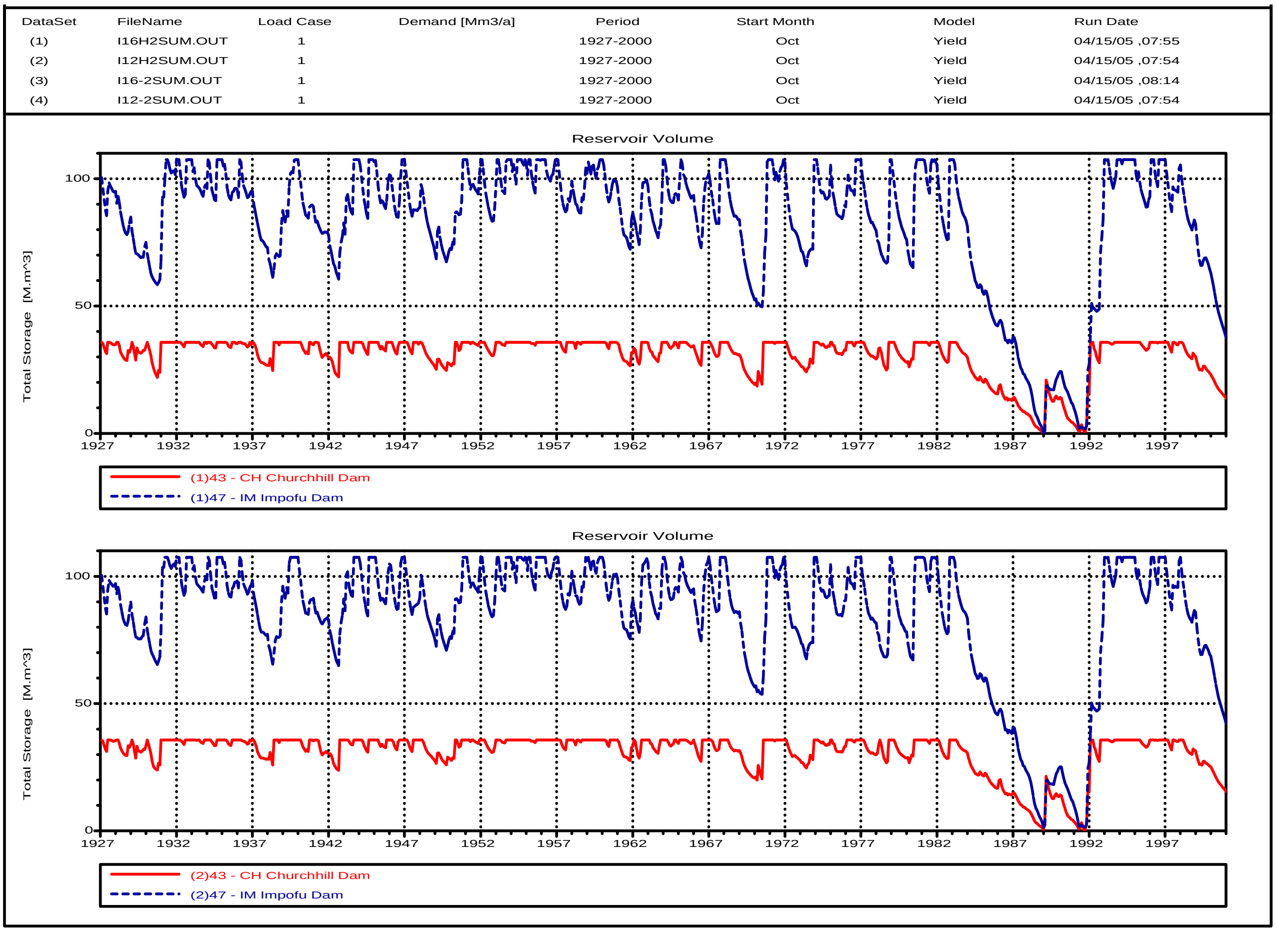

Figure 4-3 Storage in the Churchill and Impofu dams supplying the Historical Firm Yield under Scenario 6 (top) and Scenario 7 (bottom). The releases to the estuary drop to 2 Mm^3/a when the storage drops below about 60%

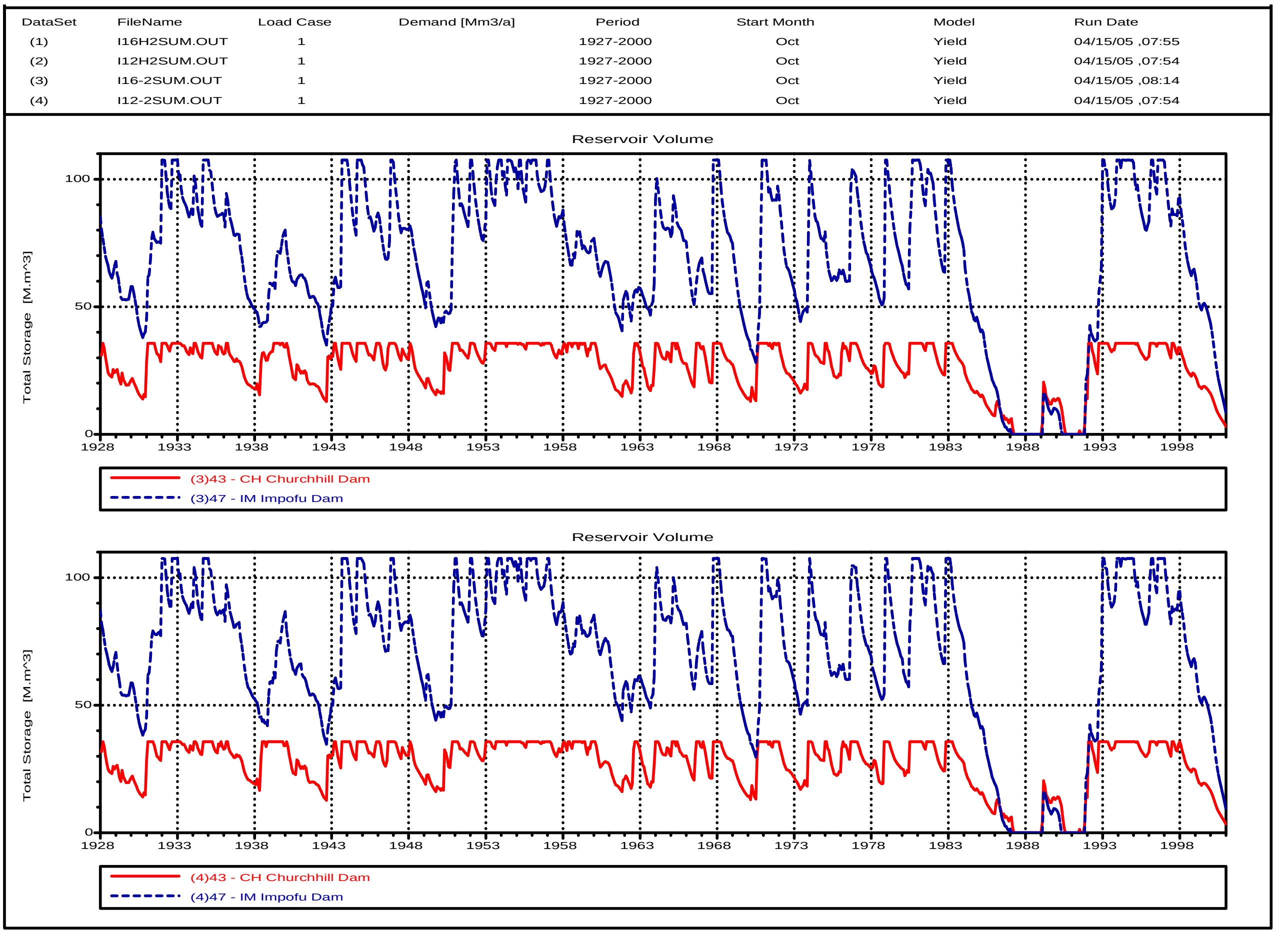

Figure 4-4 Storage in the Churchill and Impofu dams supplying the approximate 1 in 50 year yield under Scenario 6 (top) and Scenario 7 (bottom). The releases to the estuary drop to 2 Mm^3/a when the storage drops below about 60%

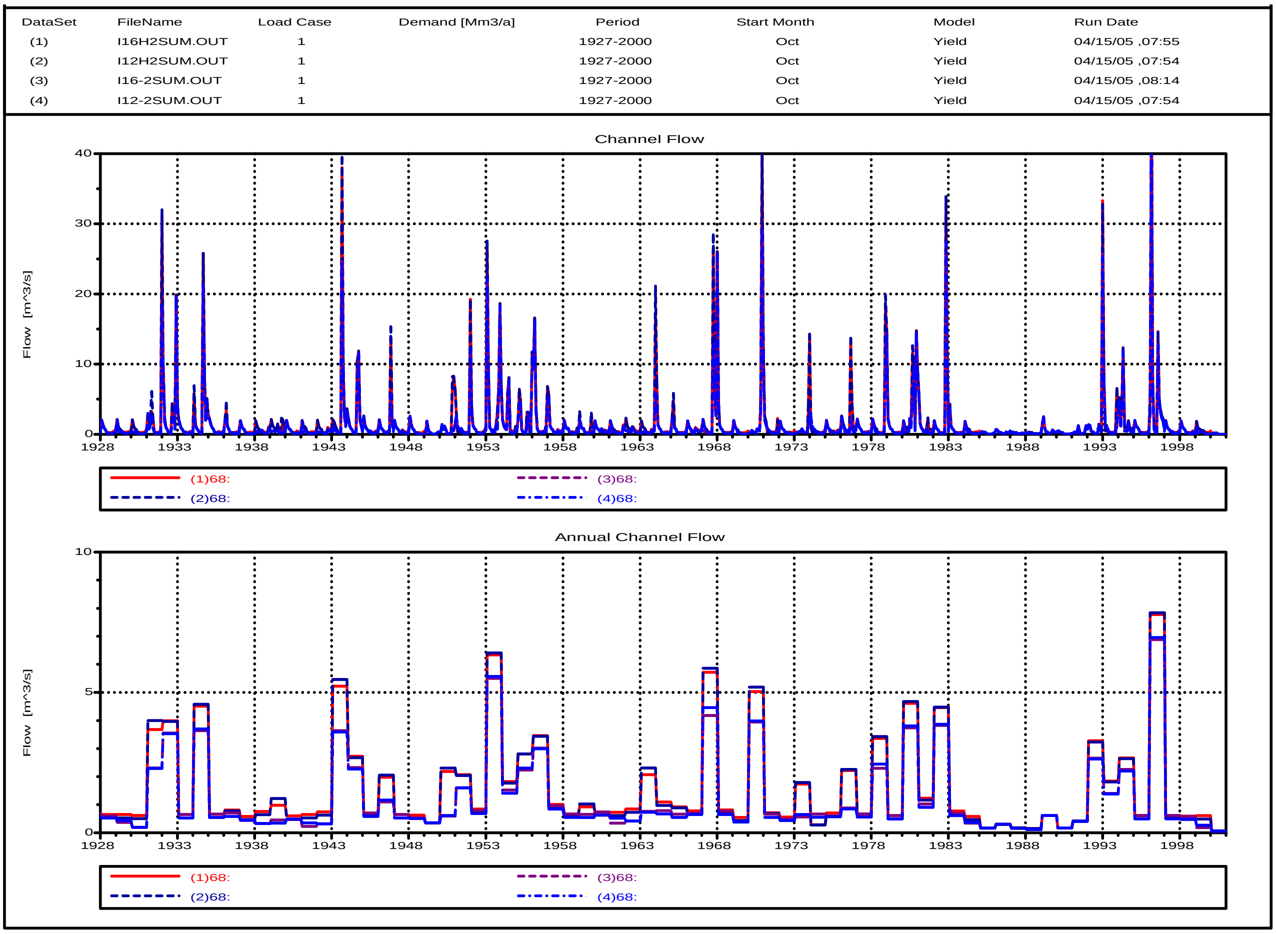

Figure 4-5 Flows at the estuary for different scenarios and target drafts

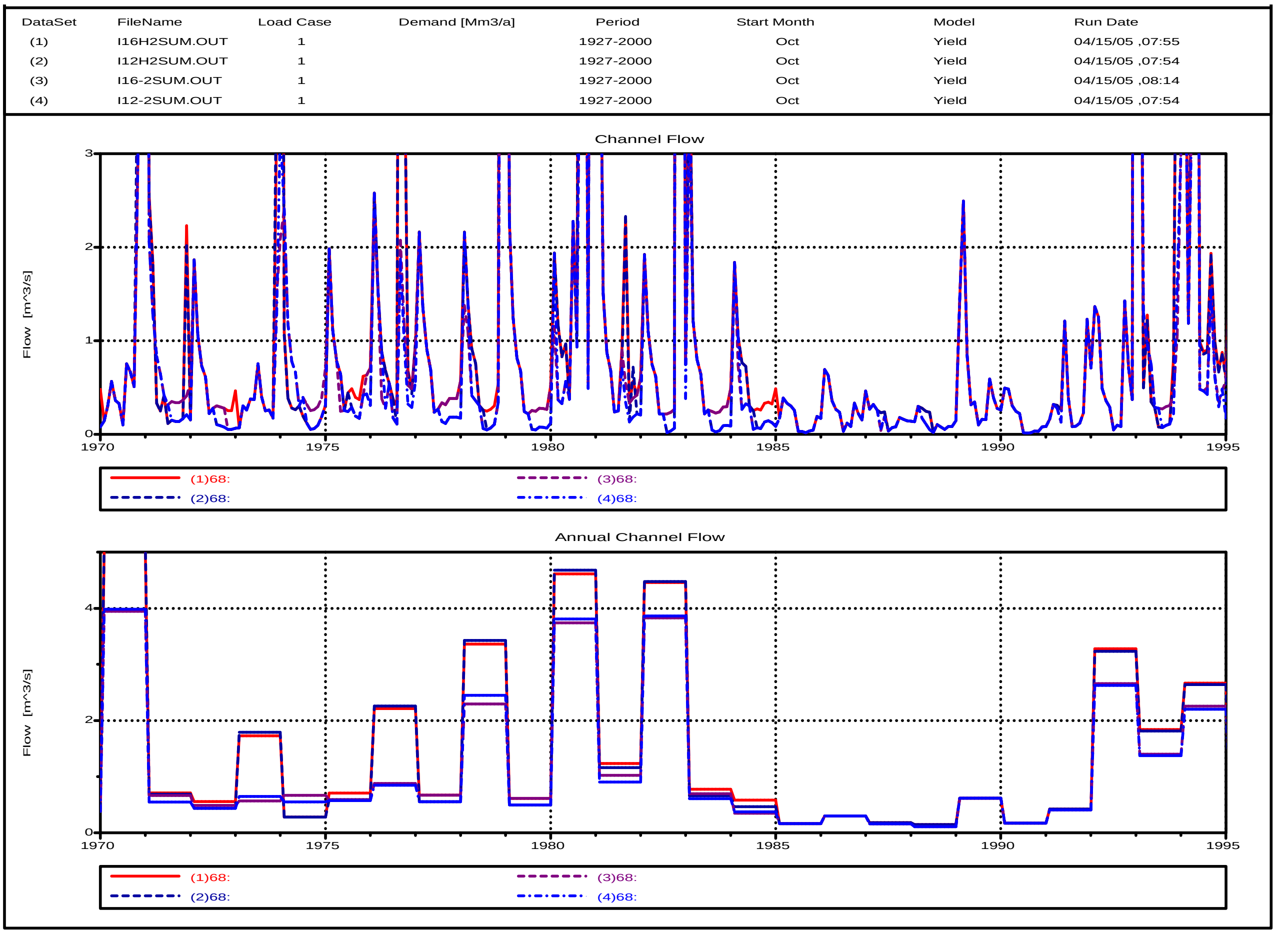

Figure 4-6 Flows at the estuary for different scenarios and target drafts for 1970 to 1990

Table 4-6 Scenario 6 – System supplying the Historical Firm Yield of 27.8 Mm^3/a and releasing 15.5 Mm^3/a to the estuary during normal years and 2 Mm^3/a during droughts

Scenario 6 Reducing to 2Mm3/a supplying HFY

File : 68-I16H2.NSI
Units : [Mm3]
Descrip. : Estuary Inflow for 1927 to 2000

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1927	5.01	2.81	2.01	1.68	0.58	3.22	1.79	0.81	0.75	0.72	0.79	1.57	21.7
1928	5.42	3.56	2.31	1.77	0.57	0.60	0.57	0.66	0.68	1.05	1.05	2.09	20.3
1929	5.56	3.01	2.09	1.70	0.90	0.91	0.78	0.76	0.86	0.89	1.18	1.70	20.3
1930	5.53	3.02	2.06	1.82	0.60	0.65	0.64	0.64	0.61	0.85	0.84	2.23	19.5
1931	7.92	3.97	3.73	8.69	6.16	0.94	0.77	0.71	0.74	0.90	0.84	80.73	116.1
1932	27.70	5.73	2.61	1.82	0.60	0.68	0.72	11.58	7.50	2.99	53.26	10.77	125.9
1933	5.48	3.65	2.31	1.83	0.70	0.84	0.73	0.70	0.68	1.13	1.07	1.42	20.5
1934	15.72	3.69	2.17	1.71	0.57	0.62	0.73	69.06	20.99	6.33	13.68	7.10	142.4
1935	5.95	3.68	2.48	1.86	0.59	0.67	0.65	1.00	0.87	0.93	0.89	1.34	20.9
1936	5.47	8.79	3.01	1.86	0.60	0.70	0.65	0.62	0.73	0.85	0.83	1.48	25.6
1937	5.18	2.98	2.18	1.81	0.58	0.59	0.66	0.76	0.74	0.75	0.74	1.34	18.3
1938	5.14	3.14	2.17	1.72	1.38	1.44	1.01	0.85	0.75	0.85	2.85	2.53	23.8
1939	5.63	3.34	2.59	2.11	1.30	1.52	1.06	0.90	1.13	5.47	2.11	3.80	30.9
1940	5.28	2.97	2.06	1.73	0.57	0.64	0.69	0.68	1.20	1.00	0.84	1.33	19.0
1941	5.25	2.97	2.88	2.25	0.70	0.66	0.65	0.95	0.95	0.94	0.93	1.35	20.5
1942	5.35	3.02	2.17	1.92	0.66	0.67	0.66	0.67	2.49	1.85	1.54	2.47	23.5
1943	5.63	4.52	2.99	1.94	0.68	0.96	0.91	101.82	23.88	8.13	3.92	9.43	164.8
1944	6.05	3.17	2.14	1.73	0.57	0.59	0.57	27.67	30.79	6.51	4.24	1.95	86.0
1945	6.62	3.42	2.15	1.73	0.56	1.36	0.95	0.70	0.65	1.08	1.22	1.63	22.1
1946	5.50	3.01	2.06	1.70	0.53	0.88	0.84	1.27	1.52	37.05	5.79	2.21	62.4
1947	5.38	3.06	2.14	1.74	0.59	0.70	1.63	1.17	0.85	0.85	0.84	1.46	20.4
1948	6.85	3.60	2.18	1.75	0.58	0.61	0.60	0.61	0.57	0.58	0.59	1.13	19.7
1949	0.09	4.84	2.26	0.68	0.56	0.05	0.09	0.12	0.09	0.46	0.93	0.81	11.0
1950	1.01	3.55	1.87	3.12	1.48	0.25	0.14	0.21	0.31	18.08	22.17	16.59	68.8
1951	8.37	1.05	0.79	0.71	1.99	0.65	0.18	0.22	0.26	0.28	0.94	49.85	65.3
1952	10.75	3.42	2.30	1.78	0.61	0.63	0.60	0.61	0.69	1.00	1.38	2.74	26.5
1953	70.91	24.32	2.52	1.85	0.57	1.62	1.15	3.89	7.93	17.44	49.93	17.89	200.0
1954	5.56	3.08	2.15	1.77	14.33	21.66	1.76	1.40	0.80	0.86	2.19	1.98	57.5
1955	5.35	15.85	13.41	1.83	0.72	0.88	0.74	8.27	8.17	1.98	1.19	30.28	88.7
1956	26.09	43.01	10.64	2.16	0.95	0.97	0.89	1.06	1.24	1.24	3.24	17.63	109.1
1957	15.29	3.21	2.12	1.69	0.52	0.76	0.68	1.80	1.33	0.97	1.44	1.82	31.6
1958	5.32	2.92	2.08	2.31	0.86	0.74	0.93	0.93	0.83	0.91	1.35	1.75	20.9
1959	5.54	3.02	2.17	2.23	0.80	0.66	0.65	0.81	0.86	6.22	2.59	3.48	29.0
1960	5.18	2.88	2.05	1.75	0.67	2.07	1.45	1.72	1.41	1.33	1.27	1.56	23.3
1961	5.20	2.88	2.01	1.70	0.56	1.00	0.99	0.84	0.73	0.74	3.54	2.68	22.9
1962	6.18	3.38	2.17	2.12	0.73	2.92	2.51	1.63	1.22	1.17	1.11	1.49	26.6
1963	5.09	2.93	2.44	2.08	0.71	0.75	0.69	0.68	1.88	1.50	1.77	44.69	65.2
1964	19.91	3.58	2.30	1.77	0.54	0.70	0.73	0.92	0.91	0.90	0.85	1.30	34.4
1965	6.15	12.35	2.44	1.91	0.73	0.68	0.61	0.66	0.63	0.64	0.84	1.39	29.0
1966	5.10	2.99	2.14	1.73	0.54	0.61	2.53	2.26	1.56	1.48	1.45	2.30	24.7
1967	5.64	3.07	2.13	1.72	0.56	0.63	0.98	0.96	67.94	21.09	8.14	67.52	180.4
1968	12.34	3.36	2.22	1.78	0.58	0.65	0.61	0.63	0.69	0.74	0.75	1.34	25.7
1969	5.24	2.92	2.01	1.70	0.58	0.61	0.56	0.57	0.56	0.57	0.70	1.24	17.3
1970	0.38	0.78	1.51	0.97	0.80	0.27	1.96	1.79	1.32	7.94	109.69	31.34	158.7
1971	6.81	4.77	0.89	0.67	1.04	0.31	0.39	0.37	0.36	0.45	5.98	0.40	22.4
1972	5.00	2.75	1.96	1.65	0.54	0.74	0.79	0.78	0.72	0.68	0.68	1.20	17.5
1973	0.18	0.79	0.70	1.01	0.90	2.02	1.03	0.67	0.67	0.46	9.07	37.04	54.5
1974	2.92	1.00	0.75	0.70	0.73	0.52	0.31	0.14	0.16	0.25	0.50	0.81	8.8
1975	5.31	2.88	2.08	1.73	0.64	1.18	1.26	1.06	0.96	1.66	1.69	1.84	22.3
1976	6.92	3.98	2.36	1.82	1.32	1.01	0.80	34.59	11.41	1.84	1.30	2.51	69.8
1977	5.79	3.53	2.43	1.85	0.57	0.72	0.87	0.84	0.99	1.03	1.03	1.48	21.1
1978	5.79	3.64	2.44	2.03	0.74	0.70	0.64	0.71	0.79	1.44	48.98	38.14	106.0
1979	6.08	3.24	2.18	1.82	0.60	0.58	0.66	0.66	0.72	0.74	0.71	1.34	19.3
1980	5.19	3.03	2.22	2.59	0.90	6.09	2.94	30.99	26.08	2.36	39.61	23.55	145.5
1981	15.95	3.91	2.34	1.82	0.58	0.67	2.34	6.21	0.86	1.52	1.12	1.57	38.9
1982	5.15	2.85	2.01	1.66	0.53	0.57	0.56	0.63	0.69	88.41	35.54	2.03	140.6
1983	11.53	3.14	2.15	1.72	0.55	0.70	0.63	0.60	0.62	0.78	0.79	1.27	24.5
1984	4.93	2.72	2.05	1.94	0.73	0.68	0.70	0.70	0.86	0.92	0.87	1.26	18.4
1985	0.46	1.00	0.89	0.81	0.62	0.09	0.08	0.05	0.09	0.12	0.51	0.44	5.1
1986	1.85	1.63	0.96	0.71	0.57	0.09	0.31	0.22	0.86	0.58	0.41	1.20	9.4
1987	0.72	0.83	0.70	0.61	0.60	0.09	0.18	0.21	0.46	0.43	0.39	0.36	5.6
1988	0.36	0.77	0.74	0.66	0.57	0.05	0.27	0.21	0.14	0.22	0.22	0.38	4.6
1989	3.87	6.46	2.27	0.84	0.84	0.27	0.41	0.42	1.53	1.05	0.74	0.67	19.4
1990	1.32	1.25	0.82	0.66	0.54	0.05	0.04	0.05	0.09	0.09	0.21	0.21	5.3
1991	0.43	0.83	0.83	0.70	3.03	1.02	0.21	0.23	0.31	0.61	3.29	1.84	13.3
1992	3.66	3.25	1.31	0.96	0.70	0.12	0.25	0.22	3.70	1.91	0.99	86.32	103.4
1993	21.79	1.29	3.41	0.93	0.70	0.21	0.18	0.25	0.28	2.19	17.54	9.20	58.0
1994	14.04	3.08	13.29	33.06	2.39	2.36	2.33	5.18	2.59	1.83	2.34	1.57	84.1
1995	5.29	3.10	2.67	2.00	0.68	0.70	0.64	0.62	0.57	0.70	0.93	1.48	19.4
1996	13.76	134.43	18.38	1.95	0.62	0.68	37.93	12.85	9.30	7.19	5.96	2.28	245.3
1997	5.24	2.93	2.04	1.77	0.57	1.14	0.85	0.72	0.69	0.72	1.13	1.56	19.4
1998	5.11	2.93	2.17	1.78	0.58	0.63	0.64	0.66	0.62	1.21	1.01	1.31	18.6
1999	4.92	2.66	2.05	1.88	0.98	1.50	1.10	0.84	0.73	0.68	0.66	1.20	19.2
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
AVE :	7.55	5.94	2.67	2.14	1.02	1.16	1.34	4.84	3.64	3.94	6.78	9.02	50.0
SD :	9.23	16.16	2.86	3.77	1.74	2.56	4.35	15.18	9.62	11.43	16.79	18.01	52.5

Table 4-7 Scenario 7 – System supplying the Historical Firm Yield of 28.6 Mm^3/a and releasing 11.8 Mm^3/a to the estuary during normal years and 2 Mm^3/a during droughts

Scenario 7 Reducing to 2Mm3/a supplying HFY

File : 68-I12H2.NSI
Units : [Mm3]
Descrip. : Estuary Inflow for 1927 to 2000

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1927	5.01	2.81	2.01	1.68	0.58	3.22	1.27	0.27	0.23	0.19	0.25	0.53	18.1
1928	5.42	3.56	2.31	1.77	0.57	0.60	0.05	0.12	0.16	0.52	0.52	1.05	16.7
1929	5.56	3.01	2.09	1.70	0.90	0.91	0.26	0.22	0.34	0.35	0.64	0.66	16.6
1930	5.53	3.02	2.06	1.82	0.60	0.65	0.12	0.10	0.09	0.32	0.30	1.19	15.8
1931	7.92	3.97	6.67	16.32	6.08	0.94	0.25	0.17	0.22	0.37	0.30	82.97	126.2
1932	27.62	5.65	2.61	1.82	0.60	0.68	0.20	11.69	7.45	2.94	53.20	10.71	125.2
1933	5.48	3.65	2.31	1.83	0.70	0.84	0.21	0.16	0.16	0.59	0.54	0.38	16.9
1934	18.52	3.69	2.17	1.71	0.57	0.62	0.21	69.09	20.93	6.28	13.63	7.04	144.4
1935	5.95	3.68	2.48	1.86	0.59	0.67	0.13	0.47	0.36	0.40	0.35	0.30	17.2
1936	5.47	11.51	3.01	1.86	0.60	0.70	0.13	0.09	0.21	0.32	0.29	0.44	24.6
1937	5.18	2.98	2.18	1.81	0.58	0.59	0.14	0.22	0.22	0.21	0.21	0.30	14.6
1938	5.14	3.14	2.17	1.72	1.38	1.44	0.49	0.32	0.24	0.32	2.31	1.49	20.2
1939	5.63	3.34	2.59	2.11	1.30	4.03	1.67	0.49	5.98	5.58	2.05	3.73	38.5
1940	5.28	2.97	2.06	1.73	0.57	0.64	0.17	0.14	0.68	0.47	0.30	0.30	15.3
1941	5.25	2.97	2.88	2.25	0.70	0.66	0.13	0.41	0.43	0.41	0.39	0.31	16.8
1942	5.35	3.02	2.17	1.92	0.66	0.67	0.14	0.13	1.97	1.32	1.00	1.43	19.8
1943	5.63	4.52	2.99	1.94	0.68	0.96	0.39	110.07	23.83	8.07	3.86	9.36	172.3
1944	6.05	3.17	2.14	1.73	0.57	0.59	0.05	27.62	30.74	6.45	4.18	1.16	84.4
1945	6.99	3.42	2.15	1.73	0.56	1.36	0.43	0.16	0.13	0.55	0.68	0.59	18.8
1946	5.50	3.01	2.06	1.70	0.53	0.88	0.32	0.73	1.01	41.10	5.73	2.15	64.7
1947	5.38	3.06	2.14	1.74	0.59	0.70	1.11	0.63	0.33	0.32	0.30	0.42	16.7
1948	6.85	3.60	2.18	1.75	0.58	0.61	0.08	0.08	0.05	0.05	0.05	0.09	16.0
1949	0.09	4.84	2.26	0.68	0.56	0.05	0.09	0.12	0.09	0.46	0.93	0.81	11.0
1950	1.01	3.55	1.87	3.12	1.48	0.25	0.14	0.21	0.31	22.01	22.11	16.53	72.6
1951	8.29	1.05	0.79	0.71	1.99	0.65	0.18	0.22	0.26	0.28	0.94	49.13	64.5
1952	10.67	3.42	2.30	1.78	0.61	0.63	0.09	0.08	0.17	0.47	0.84	1.71	22.8
1953	73.81	24.25	2.52	1.85	0.57	1.62	0.64	3.35	8.52	17.38	49.88	17.83	202.2
1954	5.56	3.08	2.15	1.77	13.94	21.60	1.71	1.34	0.28	0.33	3.08	0.94	55.8
1955	5.35	16.66	13.33	1.83	0.72	0.88	0.22	8.46	8.12	1.92	0.90	30.44	88.8
1956	26.02	42.93	10.56	2.16	0.95	0.97	0.37	0.53	0.73	0.70	4.85	17.56	108.3
1957	15.21	3.21	2.12	1.69	0.52	0.76	0.16	1.26	0.82	0.44	0.90	0.78	27.9
1958	5.32	2.92	2.08	2.31	0.86	0.74	0.41	0.39	0.31	0.37	2.41	0.72	18.8
1959	8.67	3.02	2.17	2.23	0.80	0.66	0.13	0.27	0.34	8.12	2.53	3.41	32.4
1960	5.18	2.88	2.05	1.75	0.67	2.07	0.93	1.19	0.89	0.79	0.73	0.52	19.6
1961	5.20	2.88	2.01	1.70	0.56	1.00	0.47	0.30	0.21	0.21	3.01	1.64	19.2
1962	6.18	3.38	2.17	2.12	0.73	2.92	1.99	1.09	0.71	0.64	0.57	0.45	23.0
1963	5.09	2.93	2.44	2.08	0.71	0.75	0.18	0.14	1.36	0.96	1.24	54.82	72.7
1964	19.83	3.58	2.30	1.77	0.54	0.70	0.21	0.39	0.39	0.36	0.31	0.27	30.6
1965	6.15	15.15	2.44	1.91	0.73	0.68	0.09	0.12	0.12	0.10	0.31	0.36	28.2
1966	5.10	2.99	2.14	1.73	0.54	0.61	2.01	1.73	1.05	0.94	0.91	1.68	21.4
1967	5.64	3.07	2.13	1.72	0.56	0.63	0.46	0.42	73.70	21.03	8.08	67.45	184.9
1968	12.26	3.36	2.22	1.78	0.58	0.65	0.09	0.09	0.18	0.21	0.21	0.30	21.9
1969	5.24	2.92	2.01	1.70	0.58	0.61	0.05	0.04	0.04	0.04	0.16	0.21	13.6
1970	0.38	0.78	1.51	0.97	0.80	0.27	1.96	1.79	1.32	12.03	110.50	31.27	163.6
1971	6.73	4.69	0.89	0.67	1.04	0.31	0.39	0.37	0.36	0.45	5.40	0.40	21.7
1972	5.00	2.75	1.96	1.65	0.54	0.74	0.27	0.25	0.20	0.14	0.14	0.17	13.8
1973	0.18	0.79	0.70	1.01	0.90	2.02	1.03	0.67	0.67	0.46	11.09	36.97	56.5
1974	2.84	1.00	0.75	0.70	0.73	0.52	0.31	0.14	0.16	0.25	0.50	0.81	8.7
1975	5.31	2.88	2.08	1.73	0.64	1.18	0.74	0.52	0.44	1.12	1.15	0.80	18.6
1976	6.92	3.98	2.36	1.82	1.32	1.01	0.28	36.69	11.35	1.78	1.16	2.53	71.2
1977	5.79	3.53	2.43	1.85	0.57	0.72	0.36	0.31	0.47	0.49	0.49	0.45	17.5
1978	5.79	3.64	2.44	2.03	0.74	0.70	0.12	0.18	0.27	0.90	53.21	38.07	108.1
1979	6.08	3.24	2.18	1.82	0.60	0.58	0.14	0.12	0.20	0.20	0.18	0.31	15.7
1980	5.19	3.03	2.22	2.59	0.90	6.09	2.42	33.78	26.03	2.31	39.55	23.49	147.6
1981	15.87	3.91	2.34	1.82	0.58	0.67	1.82	6.24	0.34	1.92	0.59	0.53	36.6
1982	5.15	2.85	2.01	1.66	0.53	0.57	0.05	0.09	0.17	90.74	35.48	1.93	141.2
1983	11.48	3.14	2.15	1.72	0.55	0.70	0.12	0.07	0.10	0.25	0.25	0.23	20.8
1984	4.93	2.72	2.05	1.94	0.73	0.68	0.18	0.16	0.34	0.39	0.33	0.22	14.7
1985	0.46	1.00	0.89	0.81	0.62	0.09	0.08	0.05	0.09	0.12	0.51	0.44	5.1
1986	1.85	1.63	0.96	0.71	0.57	0.09	0.31	0.22	0.86	0.58	0.41	1.20	9.4
1987	0.72	0.83	0.70	0.61	0.60	0.09	0.18	0.21	0.46	0.43	0.39	0.36	5.6
1988	0.36	0.77	0.74	0.66	0.57	0.05	0.27	0.21	0.14	0.22	0.22	0.38	4.6
1989	3.87	6.46	2.27	0.84	0.84	0.27	0.41	0.42	1.53	1.05	0.74	0.67	19.4
1990	1.32	1.25	0.82	0.66	0.54	0.05	0.04	0.05	0.09	0.09	0.21	0.21	5.3
1991	0.43	0.83	0.83	0.70	3.03	1.02	0.21	0.23	0.31	0.61	3.29	1.84	13.3
1992	3.66	3.25	1.31	0.96	0.70	0.12	0.25	0.22	3.70	1.91	0.99	84.90	102.0
1993	21.72	1.29	3.26	0.93	0.70	0.21	0.18	0.25	0.28	1.75	17.48	9.14	57.2
1994	13.96	3.08	13.13	32.98	2.32	2.29	2.28	5.13	2.54	1.78	2.28	1.50	83.3
1995	5.29	3.10	2.67	2.00	0.68	0.70	0.12	0.09	0.05	0.17	0.39	0.45	15.7
1996	16.57	134.35	18.30	1.95	0.62	0.68	37.65	12.79	9.25	7.13	5.90	2.21	247.4
1997	5.24	2.93	2.04	1.77	0.57	1.14	0.33	0.18	0.18	0.18	0.60	1.34	16.5
1998	5.11	2.93	2.17	1.78	0.58	0.63	0.12	0.12	0.10	0.68	0.48	0.27	15.0
1999	4.92	2.66	2.05	1.88	0.98	1.50	0.59	0.30	0.21	0.14	0.12	0.17	15.5
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
AVE :	7.70	6.02	2.70	2.24	1.01	1.19	0.97	4.69	3.47	3.85	6.62	8.61	49.1
SD :	9.56	16.18	2.88	4.04	1.70	2.58	4.36	16.12	10.24	12.02	17.09	18.56	54.5

Table 4-8 Scenario 6 – System supplying the 1 in 50 year yield of 41.7 Mm^3/a and releasing 15.5 Mm^3/a to the estuary during normal years and 2 Mm^3/a during droughts

Scenario 6 Reducing to 2Mm3/a supplying 1 in 50 Dem

File : 68-I16-2.NSI
Units : [Mm3]
Descrip. : Estuary Inflow for 1927 to 2000

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1927	5.00	2.81	2.01	1.68	0.58	3.22	1.79	0.81	0.75	0.72	0.79	1.57	21.7
1928	5.41	3.56	2.31	1.77	0.57	0.60	0.57	0.12	0.16	0.52	1.05	2.09	18.7
1929	5.55	0.93	0.75	0.63	0.90	0.38	0.26	0.22	0.34	0.35	0.64	0.66	11.6
1930	0.77	0.95	0.72	0.75	0.60	0.12	0.12	0.10	0.09	0.32	0.30	1.19	6.0
1931	7.91	1.90	3.73	6.68	2.30	0.94	0.77	0.71	0.74	0.90	0.84	45.32	72.7
1932	26.32	4.46	2.61	1.82	0.60	0.68	0.72	4.39	6.54	2.00	52.27	9.63	112.0
1933	5.47	3.65	2.31	1.83	0.70	0.84	0.73	0.70	0.68	1.13	1.07	1.42	20.5
1934	6.85	3.69	2.17	1.71	0.57	0.62	0.73	54.39	20.03	5.35	12.69	5.96	114.7
1935	5.94	3.68	2.48	1.86	0.59	0.67	0.65	1.00	0.87	0.93	0.89	1.34	20.9
1936	5.46	5.36	3.01	1.86	0.60	0.70	0.65	0.62	0.73	0.85	0.83	1.48	22.2
1937	5.18	2.98	2.18	1.81	0.58	0.05	0.14	0.22	0.22	0.21	0.21	0.30	14.1
1938	0.39	1.07	0.83	0.65	1.38	0.90	0.49	0.32	0.24	0.32	2.31	1.49	10.4
1939	0.87	1.27	1.25	1.04	1.30	1.52	1.06	0.90	1.13	1.26	1.05	1.82	14.5
1940	5.27	2.97	2.06	1.73	0.57	0.10	0.17	0.14	0.68	0.47	0.30	0.30	14.8
1941	0.50	0.90	1.54	1.18	0.70	0.12	0.13	0.41	0.43	0.41	0.39	0.31	7.0
1942	0.60	0.95	0.83	0.85	0.66	0.13	0.14	0.13	1.97	1.32	1.00	1.43	10.0
1943	0.88	2.45	1.65	0.87	0.68	0.42	0.39	66.12	22.92	7.14	2.92	8.29	114.7
1944	6.04	3.17	2.14	1.73	0.57	0.59	0.57	17.89	29.83	5.51	3.24	1.95	73.2
1945	6.61	3.42	2.15	1.73	0.56	1.36	0.95	0.70	0.65	1.08	1.22	1.63	22.1
1946	5.49	3.01	2.06	1.70	0.53	0.88	0.84	1.27	1.52	10.72	4.80	1.91	34.7
1947	5.37	3.06	2.14	1.74	0.59	0.70	1.63	1.17	0.85	0.85	0.84	1.46	20.4
1948	6.84	3.60	2.18	1.75	0.58	0.61	0.60	0.08	0.05	0.05	0.05	0.09	16.5
1949	0.09	4.84	2.26	0.68	0.56	0.05	0.09	0.12	0.09	0.46	0.93	0.81	11.0
1950	1.01	3.55	1.87	3.12	1.48	0.25	0.14	0.21	0.31	1.78	1.90	3.05	18.7
1951	6.17	3.12	2.13	1.78	1.99	1.19	0.70	0.76	0.78	0.82	1.48	29.66	50.6
1952	9.37	3.42	2.30	1.78	0.61	0.63	0.60	0.61	0.69	1.00	1.38	2.74	25.1
1953	56.96	22.99	2.52	1.85	0.57	1.62	1.15	3.89	2.46	13.82	48.94	16.75	173.5
1954	5.54	3.08	2.15	1.77	7.69	20.48	0.88	0.82	0.80	0.86	1.83	1.98	47.9
1955	5.33	8.94	12.03	1.83	0.72	0.87	0.74	3.34	6.39	1.17	1.19	27.96	70.5
1956	24.71	41.67	9.26	2.16	0.95	0.97	0.89	1.06	1.24	1.24	1.35	9.67	95.2
1957	13.91	3.21	2.12	1.69	0.52	0.76	0.68	1.79	1.33	0.97	1.44	1.82	30.3
1958	5.31	2.92	2.08	2.31	0.86	0.74	0.93	0.93	0.83	0.91	1.35	1.75	20.9
1959	5.53	3.02	2.17	2.23	0.80	0.66	0.65	0.81	0.86	1.18	1.15	1.69	20.8
1960	5.17	2.88	2.05	1.75	0.67	2.07	1.45	1.72	1.41	1.33	1.27	1.56	23.3
1961	1.77	0.81	0.68	0.63	0.56	0.47	0.47	0.30	0.21	0.21	3.01	1.64	10.7
1962	1.43	1.30	0.84	1.05	0.73	2.38	1.99	1.09	0.71	0.64	0.57	0.45	13.2
1963	0.34	0.85	1.10	1.01	0.71	0.21	0.18	0.14	1.36	0.96	1.24	15.89	24.0
1964	10.32	3.58	2.30	1.77	0.54	0.70	0.73	0.92	0.91	0.90	0.85	1.30	24.8
1965	6.14	4.17	2.44	1.91	0.73	0.68	0.61	0.66	0.64	0.64	0.84	1.39	20.8
1966	5.09	2.99	2.12	0.66	0.54	0.08	2.01	1.73	1.56	1.48	1.45	2.30	22.0
1967	5.63	0.99	0.79	0.65	0.56	0.09	0.46	0.42	28.72	20.10	7.15	66.38	131.9
1968	10.96	3.36	2.21	1.78	0.58	0.65	0.61	0.63	0.69	0.74	0.75	1.34	24.3
1969	5.23	2.92	2.00	0.63	0.58	0.08	0.05	0.04	0.04	0.04	0.16	0.21	12.0
1970	0.38	0.78	1.51	0.97	0.80	0.27	1.96	1.79	1.32	8.47	76.06	30.20	124.5
1971	5.53	3.34	2.23	1.74	1.04	0.84	0.91	0.90	0.87	0.98	1.10	1.43	20.9
1972	4.99	2.75	1.96	1.65	0.54	0.74	0.79	0.78	0.72	0.14	0.14	0.17	15.4
1973	0.18	0.79	0.70	1.01	0.90	2.02	1.03	0.67	0.67	0.46	3.98	5.40	17.8
1974	6.44	3.07	2.09	1.78	0.73	1.06	0.83	0.68	0.68	0.79	1.04	1.85	21.0
1975	5.30	2.88	2.08	0.66	0.64	0.65	0.74	0.52	0.44	1.12	1.69	1.84	18.6
1976	6.14	3.98	1.02	0.74	1.32	0.47	0.28	5.56	3.01	1.40	1.30	2.50	27.7
1977	5.78	3.53	2.43	1.85	0.57	0.72	0.87	0.84	0.99	1.03	1.03	1.48	21.1
1978	3.69	2.85	1.11	0.96	0.74	0.16	0.12	0.18	0.27	0.90	24.41	36.99	72.4
1979	6.07	3.24	2.18	1.82	0.60	0.58	0.66	0.66	0.72	0.74	0.71	1.34	19.3
1980	3.09	0.96	0.88	1.52	0.90	6.09	2.94	14.15	25.12	1.48	38.51	22.41	118.1
1981	14.57	3.91	2.34	1.82	0.58	0.67	2.34	1.46	0.86	1.03	1.12	1.57	32.3
1982	5.14	2.85	2.01	1.66	0.53	0.57	0.56	0.63	0.69	69.56	34.55	2.03	120.8
1983	9.01	3.14	2.15	1.72	0.55	0.70	0.64	0.60	0.62	0.78	0.79	1.27	22.0
1984	4.92	1.93	0.71	0.87	0.73	0.14	0.18	0.16	0.34	0.39	0.33	0.22	10.9
1985	0.46	1.00	0.89	0.81	0.62	0.09	0.08	0.05	0.09	0.12	0.51	0.44	5.1
1986	1.85	1.63	0.96	0.71	0.57	0.09	0.31	0.22	0.86	0.58	0.41	1.20	9.4
1987	0.72	0.83	0.70	0.11	0.47	0.09	0.18	0.21	0.46	0.43	0.39	0.36	5.0
1988	0.36	0.77	0.45	0.30	0.12	0.05	0.27	0.21	0.14	0.22	0.22	0.38	3.5
1989	3.87	6.46	2.27	0.84	0.84	0.27	0.41	0.42	1.53	1.05	0.74	0.67	19.4
1990	1.32	1.25	0.82	0.66	0.54	0.05	0.04	0.05	0.09	0.09	0.21	0.21	5.3
1991	0.43	0.83	0.74	0.35	3.03	1.02	0.21	0.23	0.31	0.61	3.29	1.84	12.9
1992	3.66	3.25	1.31	0.96	0.70	0.12	0.25	0.22	3.70	1.91	0.99	66.70	83.8
1993	20.42	3.36	2.58	2.00	0.70	0.74	0.70	0.79	0.80	1.12	2.84	8.06	44.1
1994	12.65	3.08	10.57	31.67	1.16	1.24	1.30	4.19	1.63	0.94	1.26	1.49	71.2
1995	5.28	3.10	2.67	2.00	0.68	0.70	0.64	0.62	0.57	0.70	0.93	1.48	19.4
1996	8.07	122.49	17.00	1.95	0.62	0.68	33.15	11.85	8.34	6.20	4.97	1.82	217.1
1997	5.23	2.93	2.04	1.77	0.57	1.14	0.85	0.72	0.69	0.72	1.13	1.56	19.4
1998	5.10	2.93	2.17	1.78	0.58	0.63	0.64	0.66	0.10	1.21	1.01	1.31	18.1
1999	0.16	0.59	0.71	0.81	0.98	0.96	0.59	0.30	0.21	0.14	0.12	0.17	5.7
2000	0.00	0.52	0.54	0.54	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.1
AVE :	6.16	5.13	2.33	1.87	0.86	1.02	1.14	3.04	2.71	2.69	5.08	6.49	38.5
SD :	7.81	14.80	2.57	3.61	0.91	2.45	3.81	10.09	6.36	8.51	13.17	13.49	43.1

Table 4-9 Scenario 7 – System supplying the 1 in 50 year yield of 42.5 Mm^3/a and releasing 11.8 Mm^3/a to the estuary during normal years and 2 Mm^3/a during droughts

Scenario 7 Reducing to 2Mm3/a supplying 1 in 50 Dem

File : 68-I12-2.NSI
Units : [Mm3]
Descrip. : Estuary Inflow for 1927 to 2000

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1927	5.00	2.81	2.01	1.68	0.58	3.22	1.27	0.27	0.23	0.19	0.25	0.53	18.1
1928	5.41	3.56	2.31	1.77	0.57	0.60	0.05	0.12	0.16	0.52	0.52	1.05	16.6
1929	5.55	3.01	0.75	0.63	0.90	0.38	0.26	0.22	0.34	0.35	0.64	0.66	13.7
1930	0.77	0.95	0.72	0.75	0.60	0.12	0.12	0.10	0.09	0.32	0.30	1.19	6.0
1931	7.91	1.90	3.73	6.68	2.30	0.94	0.25	0.17	0.22	0.37	0.30	47.47	72.3
1932	26.24	4.46	2.61	1.82	0.60	0.68	0.20	4.42	6.49	1.94	52.21	9.56	111.2
1933	5.47	3.65	2.31	1.83	0.70	0.84	0.21	0.16	0.16	0.59	0.54	0.38	16.8
1934	6.85	3.69	2.17	1.71	0.57	0.62	0.21	57.17	19.97	5.29	12.64	5.89	116.8
1935	5.94	3.68	2.48	1.86	0.59	0.67	0.13	0.47	0.36	0.40	0.35	0.30	17.2
1936	5.46	5.36	3.01	1.86	0.60	0.70	0.13	0.09	0.21	0.32	0.29	0.44	18.5
1937	5.18	2.98	2.18	1.81	0.58	0.05	0.14	0.22	0.22	0.21	0.21	0.30	14.1
1938	0.39	1.07	0.83	0.65	1.38	0.90	0.49	0.32	0.24	0.32	2.31	1.49	10.4
1939	0.87	1.27	1.25	1.04	1.30	1.52	0.54	0.36	0.61	0.72	0.52	0.78	10.8
1940	5.27	2.97	2.06	1.73	0.57	0.64	0.17	0.14	0.68	0.47	0.30	0.30	15.3
1941	4.48	0.90	1.54	1.18	0.70	0.12	0.13	0.41	0.43	0.41	0.39	0.31	11.0
1942	0.60	0.95	0.83	0.85	0.66	0.13	0.14	0.13	1.97	1.32	1.00	1.43	10.0
1943	0.88	2.45	1.65	0.87	0.68	0.42	0.39	64.95	22.87	7.08	2.87	8.22	113.3
1944	6.04	3.17	2.14	1.73	0.57	0.59	0.05	17.85	29.78	5.46	3.19	0.91	71.5
1945	6.61	3.42	2.15	1.73	0.56	1.36	0.43	0.16	0.13	0.55	0.68	0.59	18.4
1946	5.49	3.01	2.06	1.70	0.53	0.88	0.32	0.73	1.01	15.36	4.74	1.01	36.8
1947	5.37	3.06	2.14	1.74	0.59	0.70	1.11	0.63	0.33	0.32	0.30	0.42	16.7
1948	6.84	3.60	2.18	1.75	0.58	0.61	0.08	0.08	0.05	0.05	0.05	0.09	16.0
1949	0.09	4.84	2.26	0.68	0.56	0.05	0.09	0.12	0.09	0.46	0.93	0.81	11.0
1950	1.01	3.55	1.87	3.12	1.48	0.25	0.14	0.21	0.31	1.78	1.37	4.29	19.4
1951	6.91	3.12	2.13	1.78	1.99	1.19	0.18	0.22	0.26	0.28	0.94	31.60	50.6
1952	9.29	3.42	2.30	1.78	0.61	0.63	0.09	0.08	0.17	0.47	0.84	1.71	21.4
1953	59.86	22.91	2.52	1.85	0.57	1.62	0.64	3.35	1.94	14.88	48.89	16.68	175.7
1954	5.54	3.08	2.15	1.77	7.31	20.42	0.75	0.35	0.28	0.33	1.29	0.94	44.2
1955	5.33	11.67	11.95	1.83	0.72	0.87	0.22	2.80	7.06	0.93	0.65	28.56	72.6
1956	24.63	41.60	9.18	2.16	0.95	0.97	0.37	0.53	0.73	0.70	0.82	11.75	94.4
1957	13.83	3.21	2.12	1.69	0.52	0.76	0.16	1.26	0.82	0.44	0.90	0.78	26.5
1958	5.31	2.92	2.08	2.31	0.86	0.74	0.41	0.39	0.31	0.37	0.81	0.72	17.2
1959	5.53	3.02	2.17	2.23	0.80	0.66	0.13	0.27	0.34	0.65	0.62	0.66	17.1
1960	5.17	2.88	2.05	1.75	0.67	2.07	0.93	1.19	0.89	0.79	0.73	0.52	19.6
1961	5.19	2.88	0.68	0.63	0.56	0.47	0.47	0.30	0.21	0.21	3.01	1.64	16.2
1962	1.43	1.30	0.84	1.05	0.73	2.38	1.99	1.09	0.71	0.64	0.57	0.45	13.2
1963	0.34	0.85	1.10	1.01	0.71	0.21	0.18	0.14	1.36	0.96	1.24	14.86	23.0
1964	10.32	3.58	2.30	1.77	0.54	0.70	0.21	0.39	0.39	0.36	0.31	0.27	21.1
1965	6.14	4.17	2.44	1.91	0.73	0.68	0.09	0.12	0.12	0.10	0.31	0.36	17.2
1966	5.09	2.99	2.14	1.73	0.54	0.08	2.01	1.73	1.05	0.94	0.91	1.27	20.5
1967	5.63	3.07	2.13	1.72	0.56	0.09	0.46	0.42	33.18	20.04	7.09	66.31	140.7
1968	10.88	3.36	2.21	1.78	0.58	0.65	0.09	0.09	0.18	0.21	0.21	0.30	20.5
1969	5.23	2.92	2.01	0.63	0.58	0.08	0.05	0.04	0.04	0.04	0.16	0.21	12.0
1970	0.38	0.78	1.51	0.97	0.80	0.27	1.96	1.79	1.32	7.94	77.87	30.13	125.7
1971	5.53	3.33	2.23	1.74	1.04	0.84	0.39	0.37	0.36	0.45	0.56	0.40	17.2
1972	4.99	2.75	1.96	1.65	0.54	0.74	0.27	0.25	0.20	0.14	0.14	0.17	13.8
1973	0.18	0.79	0.70	1.01	0.90	2.02	1.03	0.67	0.67	0.46	3.45	8.46	20.3
1974	6.44	3.07	2.09	1.78	0.73	1.06	0.31	0.14	0.16	0.25	0.50	0.81	17.3
1975	5.30	2.88	2.08	1.73	0.64	0.65	0.74	0.52	0.44	1.12	1.15	0.80	18.1
1976	6.90	3.98	2.36	0.74	1.32	0.47	0.28	5.02	2.49	0.86	0.77	1.46	26.7
1977	5.78	3.53	2.43	1.85	0.57	0.72	0.36	0.31	0.47	0.49	0.49	0.45	17.4
1978	5.78	3.64	1.11	0.96	0.74	0.16	0.12	0.18	0.27	0.90	26.40	36.93	77.2
1979	6.07	3.24	2.18	1.82	0.60	0.58	0.14	0.12	0.20	0.20	0.18	0.31	15.6
1980	5.18	0.96	0.88	1.52	0.90	6.09	2.42	14.88	25.07	1.32	38.56	22.34	120.1
1981	14.49	3.91	2.34	1.82	0.58	0.67	1.82	0.92	0.34	0.50	0.59	0.53	28.5
1982	5.14	2.85	2.01	1.66	0.53	0.57	0.05	0.09	0.17	73.36	34.49	0.99	121.9
1983	9.90	3.14	2.15	1.72	0.55	0.70	0.12	0.07	0.10	0.25	0.25	0.23	19.2
1984	4.92	2.72	0.71	0.87	0.73	0.14	0.18	0.16	0.34	0.39	0.33	0.22	11.7
1985	0.46	1.00	0.89	0.81	0.62	0.09	0.08	0.05	0.09	0.12	0.51	0.44	5.1
1986	1.85	1.63	0.96	0.71	0.57	0.09	0.31	0.22	0.86	0.58	0.41	1.20	9.4
1987	0.72	0.83	0.70	0.16	0.47	0.09	0.18	0.21	0.46	0.43	0.39	0.36	5.0
1988	0.36	0.77	0.45	0.30	0.12	0.05	0.27	0.21	0.14	0.22	0.22	0.38	3.5
1989	3.87	6.46	2.27	0.84	0.84	0.27	0.41	0.42	1.53	1.05	0.74	0.67	19.4
1990	1.32	1.25	0.82	0.66	0.54	0.05	0.04	0.05	0.09	0.09	0.21	0.21	5.3
1991	0.43	0.83	0.74	0.35	3.03	1.02	0.21	0.23	0.31	0.61	3.29	1.84	12.9
1992	3.66	3.25	1.31	0.96	0.70	0.12	0.25	0.22	3.70	1.91	0.99	65.72	82.8
1993	20.33	3.36	2.58	2.00	0.70	0.74	0.18	0.25	0.28	0.58	4.30	8.00	43.3
1994	12.58	3.08	10.42	31.60	1.16	1.24	1.10	4.14	1.58	0.79	1.29	0.45	69.4
1995	5.28	3.10	2.67	2.00	0.68	0.70	0.12	0.09	0.05	0.17	0.39	0.45	15.7
1996	8.07	126.20	16.92	1.95	0.62	0.68	32.88	11.80	8.29	6.14	4.91	1.07	219.5
1997	5.23	2.93	2.04	1.77	0.57	1.14	0.33	0.18	0.18	0.18	0.60	0.53	15.7
1998	5.10	2.93	2.17	1.78	0.58	0.63	0.12	0.12	0.10	0.68	0.48	0.27	15.0
1999	2.81	0.59	0.71	0.81	0.98	0.96	0.59	0.30	0.21	0.14	0.12	0.17	8.4
2000	0.00	0.52	0.54	0.54	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.1
AVE :	6.41	5.32	2.36	1.91	0.85	1.02	0.86	2.81	2.53	2.57	4.89	6.14	37.7
SD :	7.99	15.19	2.54	3.60	0.87	2.44	3.81	10.26	6.69	9.06	13.42	13.74	44.1

4.4 Considerations when selecting sequences for the estuary

The flow sequence at the estuary is affected by both the release from the Impofu Dam during droughts and the magnitude of the normal abstraction from the Churchill / Impofu system:

a) Releases from Impofu Dam. In the 1980's, the Kromme River was subjected to a protracted drought. In this period, reducing the releases from the Impofu Dam to the estuary from the "normal" requirement to a "damage control" requirement would have increased the yield from the system, but could also have impacted negatively on the ecology of the estuary. The yield of the system would be maximised if the estuarine releases and urban demands were curtailed at the same time when, for example, the system storage dropped to about 60%. In the 1980's these reduced releases could have been applied for about 8 years. Increasing the releases to the estuary during this period would provide respite to the estuary but would impact on the yield. How many consecutive years of "damage" control or drought releases can be tolerated by the estuary, will have a significant impact on the yield.

b) Magnitude of normal abstraction from the system. The greater the abstraction from the Churchill/Impofu system the less the inflows to the estuary because the dams will be more severely drawn down and spill less often. The demands on the system were increased to approximate demands that would require some restrictions during 1 in 50 year droughts and more severe curtailments during more severe droughts such as the drought in the 1980s. If the urban and agricultural demands on the system increase from the Historical Firm Yield to the 1 in 50 year demand then the spills reduce from about 50 (Table 4-6) to 38 Mm^3/a (Table 4-8).

5 SEEKOEI / SWART RIVER HYDROLOGY

The Seekoei River catchment (K90F) is characterised by two rivers, the Seekoei River and the Swart River (also known as the Rondebosch River in its upper reaches). Both rivers originate in the mountains to the north of Humansdorp. The Seekoei River has a length of approximately 30km and a catchment area of about 145km^2, while the Swart River is about 28km long and has a catchment of about 105km^2. The confluence of these rivers is at the estuary. Both catchments, especially to the south of the N2, are heavily impacted by farm dams in the middle and lower reaches, which are mainly used for irrigation purposes.

Relevant data for quaternary catchment K90F are summarised in
Table 5-1.

Table 5-1 Hydrological data: Quaternary K90F

Description	Quaternary K90F
Sub-catchment Area (km^2)	250
Sub-catchment MAP (mm)	699
Afforested Area (1991) (km^2)	0.0
Irrigation Area (1991) (km^2)	10.8 (1)
Irrigation water use (Mm^3/a)	8.3
Farm dam capacities (1991) (Mm3)	7.24 (1)
Alien vegetation water use (Mm3/a)	0.2
Naturalised MAR (Mm^3/a)	18.8
Present day MAR (Mm^3/a)	Not available

(1) Letter from PR de Wet 24 Oct 2003 with enclosure from Kleynhans and Associates.

The town of Humansdorp, which is located in the Seekoei River sub-catchment, draws water from boreholes and the Churchill supply pipeline and has little effect on the surface runoff in the catchment. However, a small scale irrigation scheme at Kruisfontein to the north of Humansdorp is planned for developing farmers, which will have some impact on the availability of water for downstream users. The feasibility study for this possible future scheme would however only commence following the Reserve determination.

5.1 Seekoei / Swart ecological scenarios

The Seekoei / Swart rivers are characterised by a large number of farm dams intercepting the river flows just upstream of the estuary. These farm dams and the associated demands in the entire Seekoei / Swart system were lumped as a single dam and demand upstream of the estuary. Under present day condition no releases are made from the dams to the estuary and the estuary only receives spills (present day scenario). Additional hypothetical EWR scenarios were generated (using the Desktop Reserve Model) by introducing hypothetical releases from the lumped farm dam to restore the river downstream to various river categories, namely B, C and D (The “category B river”, “category C river” and “category D river” scenarios). To increase the volume of water entering the estuary still further beyond that achieved from the category B river releases, the magnitude of the lumped farm dam and irrigation demand lumped farm dam and the irrigation demand were reduced to about 60% and 30% of the current development levels (The “13 Mm^3/a to estuary” and “15 Mm^3/a to estuary” scenarios). An additional scenario with the lumped farm dam and irrigation demands reduced to 30% of the current levels and generating category “A” river releases, was also prepared.

Methodology

This section describes the simulation of inflows into the Seekoei/Swart River estuary to enable modelling the behaviour of the estuary. Figure 5-1 illustrates how these inflows were determined:

A. Firstly the natural inflow from quaternary catchment K90F.nat was simulated from rainfall records using the Pitman model.
B. Then the releases to maintain the river in various categories were deducted from this natural flow to determine the stream flow retained in the dummy reservoir.
C. The dummy reservoir represents the total storage in the Seekoei/ Swart catchments and the demands acting on the reservoir are the total demands supplied from surface water (excluding groundwater) in the catchment. The Resssim programme was used to determine the volume actually supplied to irrigation and the spills to the actuary.
D. Thereafter the spill from the dummy reservoir (step C) was added to the ecological releases (Step B) to determine the inflow to the estuary.

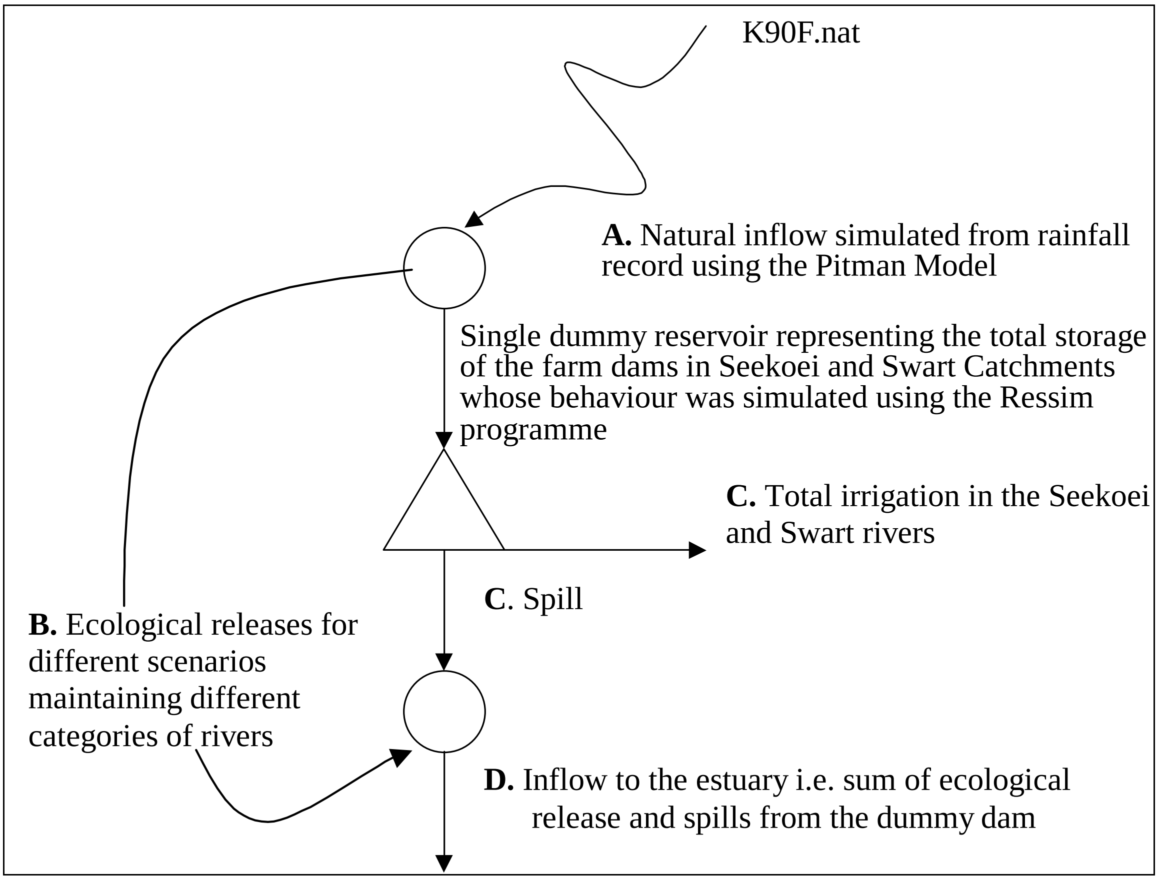

Figure 5-1 Modelling the inflow to the estuary for the Seekoei / Swart system

5.1.1 Results

Table 5-2 summarizes the supply to the estuary and to the irrigators for different scenarios. As the estuary inflow increases from the present day estimate of 9.5 Mm^3/a to 15 Mm^3/a (column H of Table 5-2), the supply to the irrigators decreases to 33% of the present value (column K of Table 5-2).

Table 5-2 Supply to the estuary and to the irrigators for the estuarine scenarios

Scenario	River release maintains category	Dummy farm dam size	Irrigation target	Natural inflow	Riverine Release	Spill	Estuary inflows = Release + Spill	Supply to irrigation	% Supply to irrigation	Evaporation losses
A	B	C	D	E	F	G	H	I	J	K
Present day	0- Pday	7.2	8.3	18.4	0.0	9.5	9.5	7.5	100%	1.4
Category D River	D	7.2	8.3	18.4	2.5	7.6	10.1	7.1	95%	1.2
Category C River	C	7.2	8.3	18.4	3.4	7.1	10.4	6.9	91%	1.1
Category B River	B	7.2	8.3	18.4	4.6	6.3	10.9	6.5	86%	1.0
Category B River with 13 Mm^3/a to estuary	B	4.3	5.0	18.4	4.6	8.3	12.9	4.5	60%	1.0
Category B River with 15 Mm^3/a to estuary	B	2.2	2.5	18.4	4.6	10.5	15.2	2.5	33%	0.8
Category A River with 15 Mm^3/a to estuary	A	2.2	2.5	18.4	6.2	9	15.2	2.5	33%	0.8

5.1.2 Discussion

Figure 5-2 shows the contribution of different scenarios to the inflow at the estuary. For instance in 1999 about 55 million m^3 would have entered the estuary under present day conditions (top of red block corresponding with 1999 in Figure 5-2).

By reducing the irrigation demands and the dummy farm dam to about 60% of their present values the estuary inflow would have increased by a further 8 Mm^3/a (cyan block corresponding with the "13 Mm^3/a estuary inflow" scenario in Figure 5-2). A further reduction of irrigation demands and the dummy farm dams to 30% of their present values would have increased the estuary flows by a further 5 Mm^3 (dark blue block corresponding with 1999 in Figure 5-2 giving the total estuary inflow for this scenario ("15 Mm^3/a estuary inflow") in 1999 to 68 million m^3.

Figure 5-2 also shows that the inflow to the estuary would have been zero from 1991 to 1995 if no riverine EWR releases were made. Maintaining the river in a category B state by making releases from the dummy dam increased the inflows into the estuary by about 3 to 5 Mm^3. Reducing the farm dam capacities and irrigation demands to 60% ("13Mcm/a estuary inflow") increased the estuary inflows from 2 to 5 Mm^3. The scenario making releases of about 15 Mm^3/a to the estuary added about 3 to 5 Mm^3 though inflows in the dry period from 1997 to 1995 but did not increase significantly.

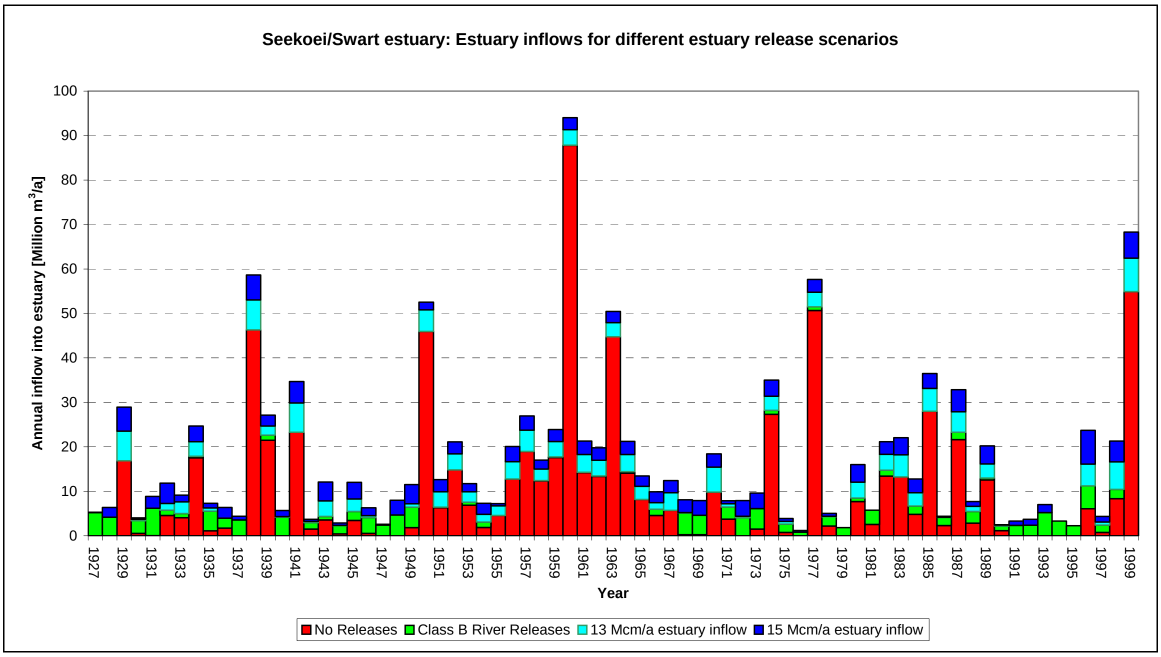

Figure 5-2 Seekoei/ Swart estuary inflows for different estuary release scenarios

Figure 5-3 and Figure 5-4 show the monthly inflow into the Seekoei / Swart estuary for various scenarios.

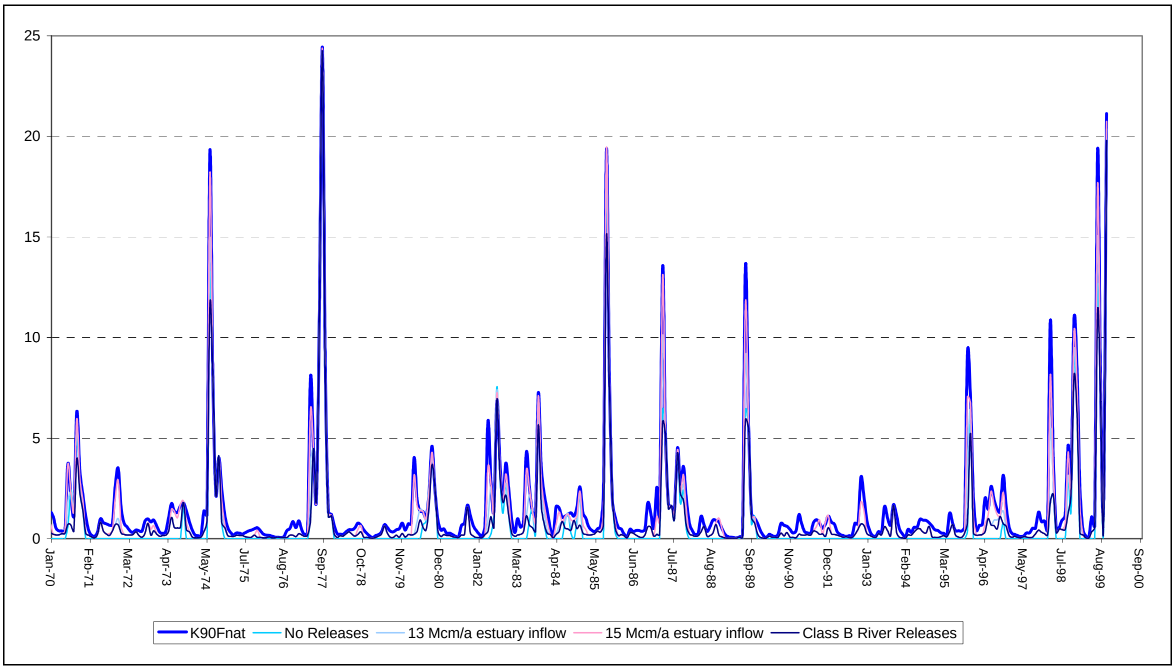

Figure 5-3 Monthly inflow into the Swart / Seekoei Estuary for various scenarios

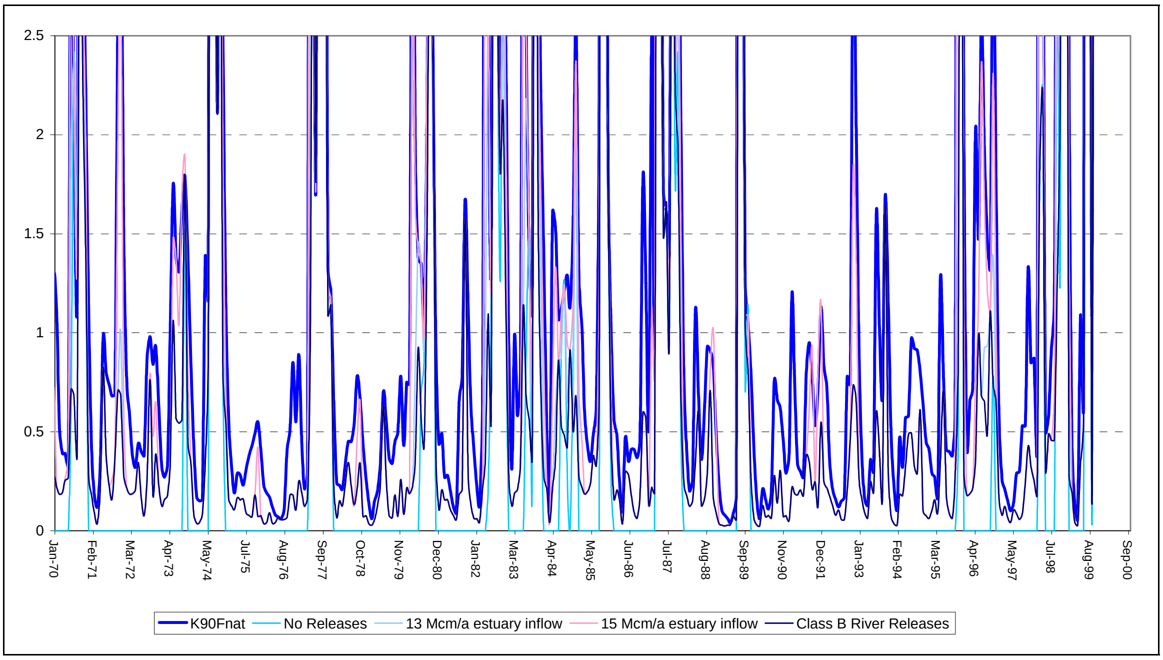

Figure 5-4 Monthly inflow into the Swart / Seekoei Estuary for various scenarios

The annual water supply to irrigators under different scenarios is illustrated in Figure 5-4. In the scenario providing 15 Mm^3/a to the estuary on average, the irrigators only receive about 2 to 3 Mm^3/a (blue blocks in Figure 5-5. If the estuary requirements are relaxed then the supply to the irrigators increases. In the 13 Mm^3/a estuary supply scenario, an additional 2 to 3 Mm^3/a is added to the supply to the irrigators (cyan blocks in Figure 5-4. In the category B river release scenario and the "no releases/ present day" scenario, the supply to irrigation increases by the green and red blocks respectively.

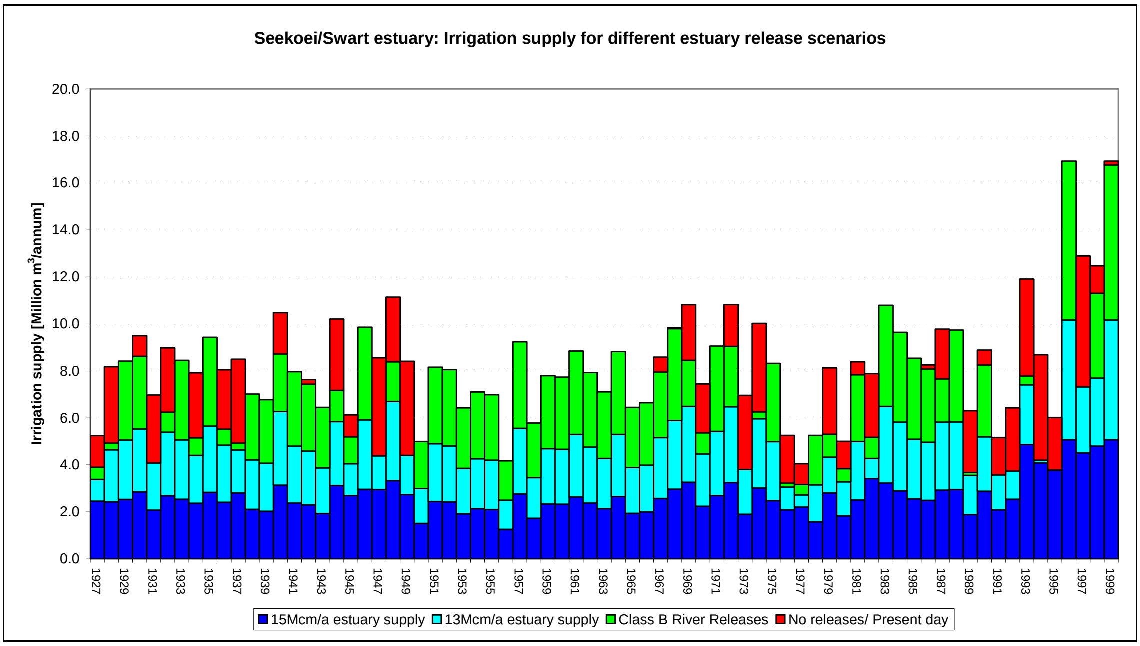

Figure 5-5 Seekoei /Swart Irrigation supply for different estuary release scenarios

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Appendix A

Spills and releases from Churchill and Impofu dams

CHURCHILL DAM: MONTHLY RIVER DISCHARGES (Mm3) - Spills and releases

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1967	1.947 S	0.29	0.26	0.289	0.283	0.297	0.34	0.324	41.29 S	2.759 S	5.449 S	53.853 S	**107.38**
1968	7.809 S	0.272 S	0.246	0.313	0.223	0.238	0.213	0.246	0.213	0.273	0.246	0.181	**10.47**
1969	0.182	0.168	0.139	0.166	0.135	0.131	0.13	0.129	0.122	0.161	0.155	0.163	**1.78**
1970	0.171	0.117	0.161	0.15	0.157	0.153	1.09	11.554 S	6.682 S	22.505 S	70.523 S	14.39 S	**127.65**
1971	7.092 S	4.875 S	0.096	0.094	0.534 S	0.107	0.098	0.115	0.145	0.159	7.292 S	0.386 S	**20.99**
1972	0.129 S	0.14 S	0.137	0.139	0.104	0.115	0.127	0.134	0.124	0.11	0.169	0.251	**1.68**
1973	0.121	0.124	0.129	0.099	0.09	0.08	0.106	0.104	0.106	0.129	25.667 S	25.958 S	**52.71**
1974	1.77 S	0.171	0.161	0.139	0.121	0.129	0.124	0.134	0.109	0.099	0.083	1.387 S	**4.43**
1975	0.453 S	0.192	0.131	0.112	0.128	0.27	0.106	0.134	0.075	0.179	0.204	0.192	**2.18**
1976	3.927 S	8.685 S	0.244 S	1.299 S	0.119	0.137	0.232	27.646 S	3.851 S	2.167 S	0.79 S	0.298	**49.40**
1977	0.346	0.298	0.217	0.228	0.186	0.204	0.179	0.147	0.14	0.096	0.091	0.145	**2.28**
1978	0.121	0.21	0.158	0.166	0.157	0.233	0.202	0.233	0.203	3.184 S	56.642 S	27.486 S	**89.00**
1979	0.927 S	0.334	0.281	0.221	0.262	0.244	0.237	0.153	0.101	0.152	0.094	0.075	**3.08**
1980	0.054	0.041	0.048	0.048	0.089	13.367 S	3.691 S	27.269 S	23.659 S	1.888 S	22.694 S	16.683 S	**109.53**
1981	9.539 S	1.822 S	0.805 S	0.243	0.233	0.312	0.734	4.813 S	0.286	1.785 S	0.269 S	1.171 S	**22.01**
1982	0.537	0.26	0.249	0.256	0.2	0.175	0.143	0.197	0.345	72.366 S	14.072 S	0.539 S	**89.34**
1983	11.185 S	1.103 S	0.475	0.432	0.476	0.515	0.509	0.431	0.377	0.515	0.4	0.386	**16.80**
1984	0.378	0.501	0.043	0.037	0.042	0.04	0.052	0.054	0.377	0.515	0.4	0.052	**2.49**
1985	0.054	0.052	0.054	0.054	0.048	0.054	0.052	0.054	0.052	0.054	0.054	0.052	**0.63**
1986	0.054	0.052	0.054	0.201	0.101	0.028	0.054	0.029	0.023	0.005	0.032	0.021	**0.65**
1987	0.013	0.031	0.029	0.043	0.045	0.005	0.008	0	0	0	0	0.003	**0.18**
1988	0.011	0.013	0.016	0.056	0.015	0.008	0.005	0.008	0.005	0.005	0.005	0.003	**0.15**
1989	0.003	4.25 S	0.179 *	0.000 *	0.031 *	0.029	0.031	0.024	0.01	0.019	0.022	0.594 S	**5.19***
1990	1.61 S	0.192 S	0.104	0.182	0.08	0.233	0.039 *	0.000 *	0.000 *	0.000 *	0.000 *	0.000 *	**2.44***
1991	0.000 *	0.035 *	0.077	0.034	0.061	0.056	0.02	0.029	0.057	0.047	16.056 S	0.63 S	**17.10***
1992	20.995 S	7.331 S	0.601 S	0.108	0.081	0.111	0.05	3.211	9.916 S	0.576 S	0.554 S	30.572 S	**74.11**
1993	6.235 S	0.454 S	0.093	0.071	0.071	0.1	0.081	0.094	0.088	0.12	7.86 S	1.521 S	**16.79**
1994	3.837 S	0.099 S	2.329 S	6.661S	0.17 S	0.498 S	3.82 S	3.692 S	1.529 S	0.195	0.112	0.113	**23.06**
1995	0.086	0.047	1.613 S	0.268 S	0.119	0.107	0.112	0.091	0.082	0.102	2.944	2.15	**7.72**
1996	3.194	58.289 S	4.443 S	1.6 S	0.163	0.16	28.818 S	7.636 S	8.168 S	7.826 S	3.428 S	1.666 S	**125.39**
1997	0.286 S	0.199	0.246	0.212	0.163	0.155	0.133	0.13	0.09	0.079	0.097	0.062	**1.85**
1998	0.069	0.078	0.069	0.066	0.052	0.048	0.052	0.048	0.031	0.064	0.034	0.063	**0.67**
1999	7.256	2.123	0.031	0.032	0.036	0.043	0.028	0.017	0.013	0.027	0.047	0.042	**9.70**
2000	0.035	0.064	0.033	0.061	0.037	0.048	0.051	0.039	0.032	0.029	0.014	0.054	**0.50**
2001	0.052	0.038	0.012 *										
Avg.	2.661	2.733	0.417	0.427	0.145	0.542	1.261	2.695	2.979	3.582	7.167	5.489	

S: Spill

*: Periods of no record

IMPOFU DAM: MONTHLY RIVER DISCHARGES (Mm3) - Spills and releases													
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Total**
1984	0.059	0.123	0.195	0.092	0.021	0.065	0.057	0.007	0.068	0.090	0.014	0.120	**0.91**
1985	0.122	0.069	0.058	0.108	0.112	0.115	0.117	0.087	0.112	0.120	0.079	0.050	**1.15**
1986	0.094	0.061	0.113	0.114	0.104	0.140	0.129	0.110	0.079	0.143	0.083	0.116	**1.29**
1987	0.081	0.097	0.183	0.146	0.158	0.183	0.162	0.160	0.109	0.096	0.274	0.176	**1.83**
1988	0.241	0.425	0.199	0.171	0.045	0.002	0.000	0.002	0.005	0.003	0.000	0.000	**1.09**
1989	0.012	0.221	0.168	0.165	0.187	0.144	0.148	0.124	0.143	0.013	0.307	0.006	**1.64**
1990	0.186	0.412	0.233	0.181	0.002	0.210	0.336	0.126	0.005	0.004	0.004	0.000	**1.70**
1991	0.002	0.002	0.002	0.000	0.028	0.012	0.008	0.004	0.013	0.010	0.072	0.019	**0.17**
1992	0.210	8.09 S	1.273 S	0.168	0.105	0.184	0.012	0.011	15.037 S	2.039 S	1.625 S	67.557 S	**96.31**
1993	14.344 S	0.444 S	0.086	0.006	0.042	0.009	0.137	0.006	0.005	0.011	11.860	3.638	**30.59**
1994	5.157 S	0.287 S	0.322 S	7.423 S	0.262 S	1.514 S	6.144 S	5.065 S	1.643 S	0.331 S	0.608 S	0.242 S	**29.00**
1995	0.074	0.007	0.013	0.004	0.317	0.101	0.088	0.089	0.050	0.155	0.017	0.014	**0.93**
1996	12.377 S	34.085 S	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	**46.46***
1997	0.000*	0.000*	0.000*	0.000*	0.041	0.0430	0.0730	0.0480	0.0790	0.0390	0.0060	0.0090	**0.34***
1998	0.003	1.620	0.043	0.105	0.116	0.111	0.080	0.003	0.003	0.010	0.003	0.008	**2.11**
1999	0.006	0.001	0.004	0.001	0.003	0.031	0.004	0.003	0.134	0.102	0.051	0.045	**0.39**
2000	0.042	0.095	0.089	0.054	0.085	0.035	0.097	0.087	0.041	0.072	0.044	0.008	**0.75**
2001	0.038	0.066	0.128	0.001	0.103	0.043	0.061	0.059	0.002	0.016	0.086	0.006*	**0.61***
Avg.	1.944	2.712	0.194	0.546	0.102	0.173	0.450	0.352	1.031	0.191	0.890	4.501	

S: Spill

*: No record