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TECH NOTE 66

RPT 139

WELLINGTON RESERVOIR

OPERATION WITH A WINTER SCOUR POLICY

Water Resources Section
Planning, Design and
Investigation Branch
PUBLIC WORKS DEPARTMENT

May 1977

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May 19, 1977

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1. INTRODUCTION

Investigations into the mixing processes in Wellington Reservoir by Dr Imberger's team at the University of W.A. have indicated the desirability of scouring saline water from the base of the reservoir during winter and supplying the most saline but acceptable mixture of water during the irrigation season (Ref. 1).

The quantity that can be safely scoured is a function of the storage level, the probability of future inflow and the water supply draw from the reservoir. To ensure the largest possible scour quantities but maintain an acceptable reliability of supply, even during drought periods, required the simulation of the reservoir operation over a long period of time using sequences of generated streamflow and salt load data. This report summarises results from two such simulations which define the quantities that can be scoured based on two future water supply demands. Resulting operating rules are described in Appendix 2 based on these simulations for the current irrigation demand plus a GSTWS demand of approximately twice the current water supply demand.

2. SIMULATION APPROACH

2.1 Reservoir Simulation

Reservoir operation was simulated by a computer program which maintained a record of stored water and stored salt over time by adding and subtracting input and output volumes of water and tonnes of salt each month. Water and salt stored in the reservoir was divided into two layers, each with different salinities to approximate the seasonal pattern of salinity layering in the reservoir. No attempt was made to model the processes governing the mixing processes in detail. This simplified approach resulted in an over estimate of the improvements in reservoir salinity that could be excepted from any scouring policy and is discussed further in Section 5.

2.2 Streamflow and Salt Load Generation

The main input to the model consisted of generated sequences of monthly streamflow and salt load. The streamflow sequence was generated to have similar statistical properties as the historic record, but by virtue of its longer record (1 000 years) included more critical drought sequences. Sequences of monthly salt load data typical of conditions in 1975 were developed by extrapolating results of flow - salinity relationships developed from data between 1968 and 1974 and developed from data between 1955 and 1960.

3. OPERATING PHILOSOPHY

3.1 Draw Distributions

No major supply from a reservoir can be guaranteed without the likelihood of some restrictions being imposed during a prolonged drought period. Consequently the quantities that can be supplied must be defined in terms of an acceptable frequency and severity of water restrictions. Engineer Irrigation and Drainage (WS 575/73) set acceptable limits of supplying at least 100% of water right in 95% of years and at least 60% of water right in 98% of years for irrigation draws. However a greater quantity of water can be supplied overall if water above basic irrigation allocation is supplied in years of above average storage. Water up to 1.25 times water right has been supplied in recent years. These considerations were converted into equivalent draws from the reservoir (see Appendix 1) and allowances made for town water supplies and industrial demands. Tables 1 and 2 list the two distributions of draws (one with and one without an industrial demand of 15 x $10^6 m^3$) which should be maintained with any scouring policy.

3.2 Scour Policy

During the months June to September saline water can be scoured from the base of the reservoir before the irrigation season commences. The problem is to maximise the quantity scoured but maintain the long term distribution of draws summarised in Tables 1 and 2.

3.2.1 Scour Volumes

This sub-section describes the procedures used to estimate the available scour for a particular month but still ensure that the long term distributions of draw were achieved.

At the start of the scour period (June) predictions of expected inflow to the end of September were made. Any excess over and above the current storage deficiency was defined as the first estimate of available scour for the winter period. From this estimate a volume of June scour was defined subject to various constraints and modifications depending on the actual inflow through June (see below and Appendix 2). The resulting volume of scour was included as draw from the bottom offtake in the June water and salt balance calculations. This process was repeated throughout the scour period with monthly scour volumes being redefined at the start of each month.

Functional relationships for the magnitude of future inflows of a given probability were developed from the statistics of the generated streamflow series. Scour volumes could therefore be varied by adopting a different probability for the predicted inflow. The scour volumes were maximised by changing the adopted probability so that the long term distribution of achieved draws was similar to the distributions of Tables 1 and 2.

Conversion of the predicted scour volumes to realistic operational rules was difficult since, in practise, scouring decisions will depend on the distribution of flood events within a month. Details of the suggested operational rules are given in Appendix 2. Their simulation on a monthly time scale, however, was governed by two general considerations. Firstly that scour rates and scour volumes should be restricted so that the cumulative scour at any time through the scour period should never exceed the cumulative inflow volume. Secondly scour rates should be reassessed half way through the month depending on inflow in the first two weeks. This was approximated on a monthly time scale by reducing (or increasing) the first estimate of monthly scour if the actual inflow for the month was less than (or greater than) twice the probable inflow.

3.2.2 Water Quality Constraints on Scour Volumes

The decision to scour is not only dependent on available water but also on the relative magnitudes of the inflow, reservoir and scour salinities. Because of limitations in the simplified simulation of the reservoir mixing processes and inherent limitations of using a monthly time step, no completely realistic operating rules to account for water quality considerations were possible. Instead the following three different monthly rules were simulated.

(1) Scour quantities based on reservoir storage and predicted inflow only, without additional water quality criteria (Sub-section 3.2.1). This represented the worst operational case where fresh water may be scoured to the detriment the long term reservoir salinity.

(2) Scour quantities as for (1) above except that the scour was set to zero if the inflow salinity was less than 540 mg/l TDS. The concept here was not to scour when the inflow was relatively fresh (less than 70% of the average inflow salinity).

(3) Scour quantities as for (1) above except that scour was set to zero if the combined bottom reservoir layer and the monthly inflow was less than the top layer salinity. The concept here was to assume that the inflow and consequently the final structure in the reservoir at the end of the month was known. This enabled the best decision on whether to scour or not to be made and provided the opposite extreme to the first simulation where no water quality considerations were considered.

The range of different distributions of achieved draws and reservoir salinities that resulted from these different salinity criteria are discussed in Section 5.

3.3 Irrigation Offtake Level

Previous practise has been to supply irrigation water from the central offtake through the hydro-electric plant, a consequence of which is that any saline bottom water is kept in storage and mixes with the bulk of the reservoir at the end of the irrigation season. The previous policy as well as a policy of supplying irrigation water from the base of the reservoir was investigated with the scour policy.

4. SIMULATION RESULTS

The simulation program produced distributions of achieved draws, overflow volumes average reservoir salinities etc to evaluate the effect of different operating rules and scour functions. The results discussed here are those which just achieved the design draw distributions listed in Tables 1 and 2.

4.1 Maximum Scour Capacity

Early simulation runs indicated that a maximum scour capacity of $50 \times 10^6 m^3$ per month was sufficient to pass all the necessary saline flows. Larger capacity monthly scours only increased overall scour volumes and decreased spillage volumes without improving the long term reservoir salinities. This was because salinities of inflow are low when scours of $50 \times 10^6 m^3$ or greater can be justified. All simulations discussed below used a maximum monthly scour capacity of $50 \times 10^6 m^3$. Average salinities of scour for volumes greater than and scour volumes less than $35 \times 10^6 m^3$/month were extracted separately to evaluate the benefit of increasing the scour capacity from the base of the reservoir. Bottom scour capacity could be increased to $35 \times 10^6 m^3$ by simple modification of the old country water supply .533 dia line but increased capacity to 50 x $10^6 m^3$ would require lowering of the hydro electric offtake. Simulations indicated that 31% of months with non zero scour and which improved the reservoir salinity were above 35 x $10^6 m^3$.

4.2 Scouring Qualities and Reservoir Response for a Target Draw of 78 x $10^6 m^3$

Table 3 lists details of the reservoir response for the no scouring policy and the best scour policy (No. 3 Sub-section 3.2.2) for both irrigation from the central and bottom offtakes. Figure 1 shows the associated distribution of average reservoir salinities, while operating rules for the best policy are included in Appendix 2. Table 3 indicates that the improvement obtained from scouring is of the same order as the improvement of supplying irrigation water from the bottom offtake. This confirms the results of the more detailed daily simulations for the 1975/76 irrigation season (Ref. 1) that irrigation should always be from the base except when draw salinities are unacceptable and then a mixture from both offtakes should be used to ensure that the maximum acceptable salinity is supplied.

While the suggested policies all satisfy the design draw distributions the reservoir is more efficiently used and is consequently drawn down far more than has previously occurred. For example the probabilty of the reservoir falling below 35 x $10^6 m^3$ storage and having to rely on the bottom offtake to supply the G.S.T.W.S. demand increased from 2% to 8%. Similarly the number of years of spillage (Oct to Oct) decreased from 87% to 60%.

Another feature of the operational policy was that virtually all June inflow was scoured regardless of the initial conditions of the reservoir unless water quality conditions over-ride. Similarly July inflows were also heavily scoured but in most years the major increase in reservoir storage occurred in August with the reservoir filling by the end of September in approximately 60% of years (Oct to Oct).

4.3 Scour Quantities and Reservoir Response for a Target Draw of 93 x $10^6 m^3$

Table 4 compares the reservoir response for draws of 78 x $10^6 m^3$ and 93 x $10^6 m^3$. The increased draw has reduced the quantity available for scour but has not altered the reservoir salinity. Effectively the salt which was previously scoured was discharged as increased supply and consequently the average salinity of supply increased (although not indicated in Table 4). This result emphasises that the reservoir should be operated to draw as much water as possible (subject to water quality considerations) irrespective of whether the draw is for water supply or for scour.

5. LIMITATIONS OF THE SIMULATION

The mixing processes in the reservoir are complex and highly variable. Some processes cause changes in the reservoir structure by the hour while others only cause changes by the season (Refs 2 and 3). Any long term monthly simulation must therefore be a gross over simplification.

The current monthly model places all winter inflow (May to September) into the bottom layer since it is colder and more saline than the water stored from the previous summer, while the warmer inflows (October to April) are placed in the top layer. Complete mixing occurs between layers only at the end of April each year when surface cooling and wind action usually create a uniform reservoir. No allowance has been made for entrainment and wind mixing or diffusion of salt between layers in other months.

5.1 Water Quality Criteria on Scour

The simulation of the reservoir by a simple two layer representation caused a number of problems. For example it allowed (on occasions) fresh water to be scoured from the bottom layer while more saline water was maintained in storage in the top layer. To overcome this unrealistic situation water quality criteria for scouring were introduced (Sub-section 3.2.2). Comparison of reservoir responses to different water quality criteria is shown in Table 5, while Figure 2 shows the difference in achieved draws. The marked reduction in scour and increase in spillage when water quality criteria were considered was a direct result of no longer scouring large amounts of fresh inflow in years of above average streamflow. The type of criteria used only made a minor difference to the reservoir response.

It is considered that little difficulty will occur in applying water quality criteria to the decision to scour in actual operation (see Appendix 2).

As all simulations satisfied the standards for the draw distribution, the distribution of draws actually achieved in operation will be better than the desirable standard particularly in drought years.

5.2 Withdrawal Salinity

The two layer representation of the salinity structure in the reservoir and the monthly time step precluded any valid interpretation of withdrawal layer thicknesses and consequently any realistic estimate of draw salinity. This was particularly true for draw from the central offtake because the interface between the two layers frequently occurred at or close to the level of the central offtake. To overcome this limitation improvements obtained from different operating policies were based on changes to the long term distribution of average reservoir salinities. However this meant that the increase in average salinity of draw for increases in demand rate could not be qualified (Section 4.3).

5.3 Over estimation of Improvement in Reservoir Salinities

Because no allowance was made for mixing between layers other than in April (since entrainment and wind mixing could not be simulated on a monthly time scale and diffusion was neglected) the improvements in reservoir salinities were over estimates. Neglection of entrainment would cause higher June scour salinities while neglection of wind mixing and diffusion of salt would increase the improvement gained from supplying irrigation water from the bottom rather then the central offtake.

Estimates of the error were made by studying the improvement gained during the 1975-76 season as simulated by the University's daily model. The monthly simulations indicated improvememts of approximately 1.5 times the daily simulation. Assuming that such an overestimate was typical of most years then the improvement in the median average reservoir salinity using the best scour policy plus irrigating from the bottom would be up to 10 percent, not 15 percent as suggested by Table 3.

6. ESTIMATES OF FUTURE RESERVOIR SALINITIES

Table 6 summarises the different distributions of reservoir salinities described above together with an estimated distribution of salinities for the suggested policy based on a 10% improvement. Also included are estimated distributions of reservoir salinities based on inflow salinities that could develop if no action were taken on the catchment other than the current clearing control.

The estimates were derived in the following way. It was assumed that the current legislation would restrict the total catchment clearing to 23%. The average annual inflow figure which could develop from 23% of the catchment being cleared was interpolated from previous estimates for the 1971 figure of 20% and the upper figure of 35% cleared if all alienated land were cleared(Ref 4). The previous estimates included a range of salinities with the upper limit being the most likely. For this exercise the most likely upper limits were used.

The median reservoir salinity was assumed to equal the average annual inflow salinity. The distribution of reservoir salinities about this median was estimated from the reservoir distributions characteristic of the early 1970's and 1975 (See Figure 1).

In the context of these (admittedly crude and often subjective) estimates it is strikingly apparent that the improved reservoir operation will not solve the long term problem on the catchment. Even with the best operational policy, given time for the effect of previous clearing to be fully felt, some 50% of the time reservoir salinities will be over 1 000 mg/ℓ T.D.S. Moreover 30% of the time salinities will be greater than 1 140 mg/ℓ TDS, 990 mg/ℓ NaCl or 600 mg/ℓ chloride ion, which is the World Health Organisations (W.H.O.) maximum acceptable chloride ion level for drinking purposes. It should also be noted that suggested Australian criteria for sodium ion is equivalent to about 960 mg/ℓ TDS for waters in the South West. This is for a more critical criterion than the chloride ion criterion and warrants further investigation.

Significant concentrations of salts can occur as a consequence of evaporation from distribution reservoirs in the inland towns supplied from Wellington Reservoir. For example the reticulation chloride ion at Brookton was approximately 40% higher than the chloride ion delivered from Wellington Reservoir this year. This implies that reservoir salinities as low as about 820 mg/ℓ TDS can lead to chloride ion concentrations in excess of the WHO Standards supplied through the G.S.T.W.S. schemes. If concentration from the reservoir to the distribution site only averages a low 13% then 50% of the time reticulated water will be over the WHO standards if no other action is taken and the full effect of previous clearing is allowed to develop.

7. SUMMARY AND CONCLUSIONS

This report summarises a new reservoir operation policy which draws variable quantities of water during winter and supplies the summer irrigation demand from the base of the reservoir to minimise the average reservoir salinity. The overall salinity improvement is of the order of 10% of which approximately half was obtained by supplying water from the base of the reservoir during summer. The expected 10% improvement is small in comparison with the overall deterioration expected as a consequence of previous clearing. Current rates of increase on inflow salinity are about 40 - 50 mg/ℓ per year but are expected to decrease. This compares with the overall improvement in median reservoir salinities of approximately 100 mg/ℓ using the scouring policy.

The suggested policy assumes that the reservoir can be drawn down below the central offtake. As it is not possible at this stage to supply the G.S.T.W.S. scheme from the bottom offtake modified rules for irrigation allocation have been developed and are described in Appendix 2. These are to be used temporarily until water can be pumped from the bottom offtake.

Without further action on the catchment reservoir salinities will exceed the maximum acceptable WHO standards for chloride ion (600 mg/l) even with the new operational procedure. How soon and with what frequency will they exceed this limit is a function of how soon the groundwater systems will react to the effect of previous clearing and a function of the sequencing of drought and flood years in the future. However current reservoir salinities (800 mg/l TDS or 416 mg/l Cl^-) and recent figures on the concentration between the reservoir and reticulation (40 %) suggest that chloride ion concentrations in excess of 600 mg/l could easily occur through most of next summer.

Future work must now concentrate on the feasibility of various remedial actions on the catchment and the improved prediction of the magnitude and timing of the effect of previous clearing on the salinity of total inflow to the reservoir.

TABLE 1

DESIRABLE DRAW PATTERN WITH A SCOUR POLICY

AND NO INDUSTRIAL DEMAND

% of Water Right	Irrigation Draw % of Basic Allocation	$10^6 m^3$	T.W.S. $10^6 m^3$	Total Draw $10^6 m^3$	Prob. of Exceedance %
125	110	74.8	10.0	84.8	50
113	100	68.0	10.0	78.0	90
100	88	60.0	10.0	70.0	95
60	53	36.0	10.0	46.0	98

1. Water Right - $60 \times 10^6 m^3$ (see Appendix 1)

2. Basic Allocation - $68 \times 10^6 m^3$

3. Town Water Supply - current demand is $5.5 \times 10^6 m^3$ and therefore policy allows for considerable expansion in G.S.T.W.S. demand.

TABLE 2

DESIRABLE DRAW PATTERN WITH A SCOUR POLICY AND 15x$10^6 m^3$/a INDUSTRIAL DEMAND

Irrigation Draw % of Water Right	Irrigation Draw % of basic allocation	Irrigation Draw $10^6 m^3$	T.W.S. $10^6 m^3$	Industrial[1] Demand $10^6 m^3$	Total Draw $10^6 m^3$	Prob. of Exceedance %
125	110	74.8	10.0	15.0	99.8	50
113	100	68.0	10.0	15.0	93.0	90
100	88	60.0	10.0	15.0	85.0	95
60	53	36.0	10.0	15.0	66.0	98

[1]Future demand - based on 7 x $10^6 m^3$ for Alwest
8 x $10^6 m^3$ first stage Muja (approx. only)

TABLE 3

RESERVOIR RESPONSE TO SCOURING & BOTTOM OFFTAKE IRRIGATION

ANNUAL DRAW = $78 \times 10^6 m^3$

RESERVOIR RESPONSE	No Scour Policy	Best Possible Scour+ And Irrigate From	
		Central Offtake	Bottom Offtake
MEAN ANNUAL FLOWS $10^6 m^3/a$			
Draw	83.9	81.6	81.3
Overflow	112.4	64.1	60.0
Scour	-	51.4	55.8
RES. SALINITIES mg/l , NaCl			
Mean	552	511	468
5% Exceedance	752	752	650
MIN. RESERVOIR VOLUME $10^6 m^3$	16.1	10.2	11.8
ANNUAL PROBABILITIES THAT			
Min Res Volume was $\leq 35 \times 10^6 m^3$	2%	8%	8%
Some spillage occurred	87%	65%	60%
Some scour occurred	-	94%	96%

\+ Scour decision based on condition 3, Sub section 3.2.2

TABLE 4

COMPARISON OF RESERVOIR RESPONSE +

TO TARGET DRAWS OF 78 & $93 \times 10^6 m^3$

RESERVOIR RESPONSE	TARGET DRAW	
	$78 \times 10^6 m^3$	$93 \times 10^6 m^3$
MEAN ANNUAL FLOWS - $10^6 m^3/a$		
Draw	80.7	96.3
Overflow	36.0	43.4
Scour	80.8	57.9
AVERAGE RESERVOIR SALINITY mg/l NaCl		
Mean	536	537
5% Exceedance	764	763
MIN. RESERVOIR VOLUME - $10^6 m^3$	8.9	12.6
ANNUAL PROBABILITIES THAT		
Min Res Volume was ≤ $35 \times 10^6 m^3$	10%	11%
Some spillage occurred	48%	66%
Some scour occurred	100%	90%

\+ Based on central offtake draw, with no water quality restrictions on the scour (condition 1 of Sub-section 3.2.2) and are therefore not directly comparable to data in Table 3.

TABLE 5

COMPARISON OF RESERVOIR RESPONSES +

TO DIFFERENT WATER QUALITY

OPERATIONAL CRITERIA - Annual Draw = $78 \times 10^6 m^3$

RESERVOIR RESPONSE	SCOUR BASED ON QUANTITY CRITERIA		
	ONLY	AND IF INFLOW SAL. ≥ 540	AND IF SCOUR SAL. ≥ RES. SURFACE SAL.
MEAN ANNUAL FLOWS - $10^6 m^3/a$			
Draw	81.0	81.3	81.7
Overflow	36.0	67.9	64.4
Scour	81.0	47.8	51.4
RES. SALINITIES mg/l NaCl			
Mean	536	514	508
5% Exceedance	750	746	743
MIN. RESERVOIR VOLUME $10^6 m^3$	13.2	14.9	15.4
ANNUAL PROBABILITIES THAT			
Min Res Volume was ≤ $35 \times 10^6 m^3$	10%	9%	7%
Some spillage occurred	48%	58%	64%
Some scour occurred	100%	92%	94%

+ Based on Central Offtake Draw and slightly different water restriction policy from Table 3.

TABLE 6

WELLINGTON RESERVOIR SALINITIES

MARCH 1977 SIMULATIONS

Inflow Salinities	Operation Policy	Reservoir Salinities mg/ℓ TDS (mg/ℓ NaCl) Probability of Exceedance				Comments on Simulation
		Min	50%	30%	5%	
At 1975	Previous Policy	310 (250)	710 (600)	800 (685)	980 (840)	reliable
At 1975	Best Scour Policy	280 (220)	600 (510)	680 (580)	860 (740)	improvement over estimated
At 1975	Best Scour Plus Irrigate from base	280 (220)	550 (465)	630 (530)	760 (650)	improvement over estimated
At 1975	Best Scour* Plus Irrigate from base	280	640	720	860	estimated probable improvement
Future + Salinity for 23% cleared	Previous Policy *	400 (320)	1 100 (960)	1 270 (1 110)	1 570 (1 390)	estimated
Future + Salinity for 23% cleared	Best Scour* plus Irrigate from base	380 (300)	1 010 (870)	1 140 (990)	1 420 (1 250)	estimated

* Figures estimated and extrapolated from other simulations

\+ Estimates of the salinity level that could develop if no action other than the recent legislation were taken.

8. REFERENCES

(1) Patterson, J., Loh, I., Imberger, J. and Hebbert, R. (1976) "Simulation as a Guide to Reservoir Management" Public Works File WS 899/74. To be published.

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(3) Loh, I. (1977) "Wellington Reservoir Dynamics and its Relationship to the Storage Retention Time of Withdrawal". Public Works File WS 899/74.

(4) Loh, I. (1974) "Salinity of Inflow to Wellington Reservoir - A Preliminary Report" Technical Note 50, Water Resources Section, P. D. & I. Branch, P.W.D.

DISTRIBUTION OF AVERAGE SALINITIES IN WELLINGTON RESERVOIR

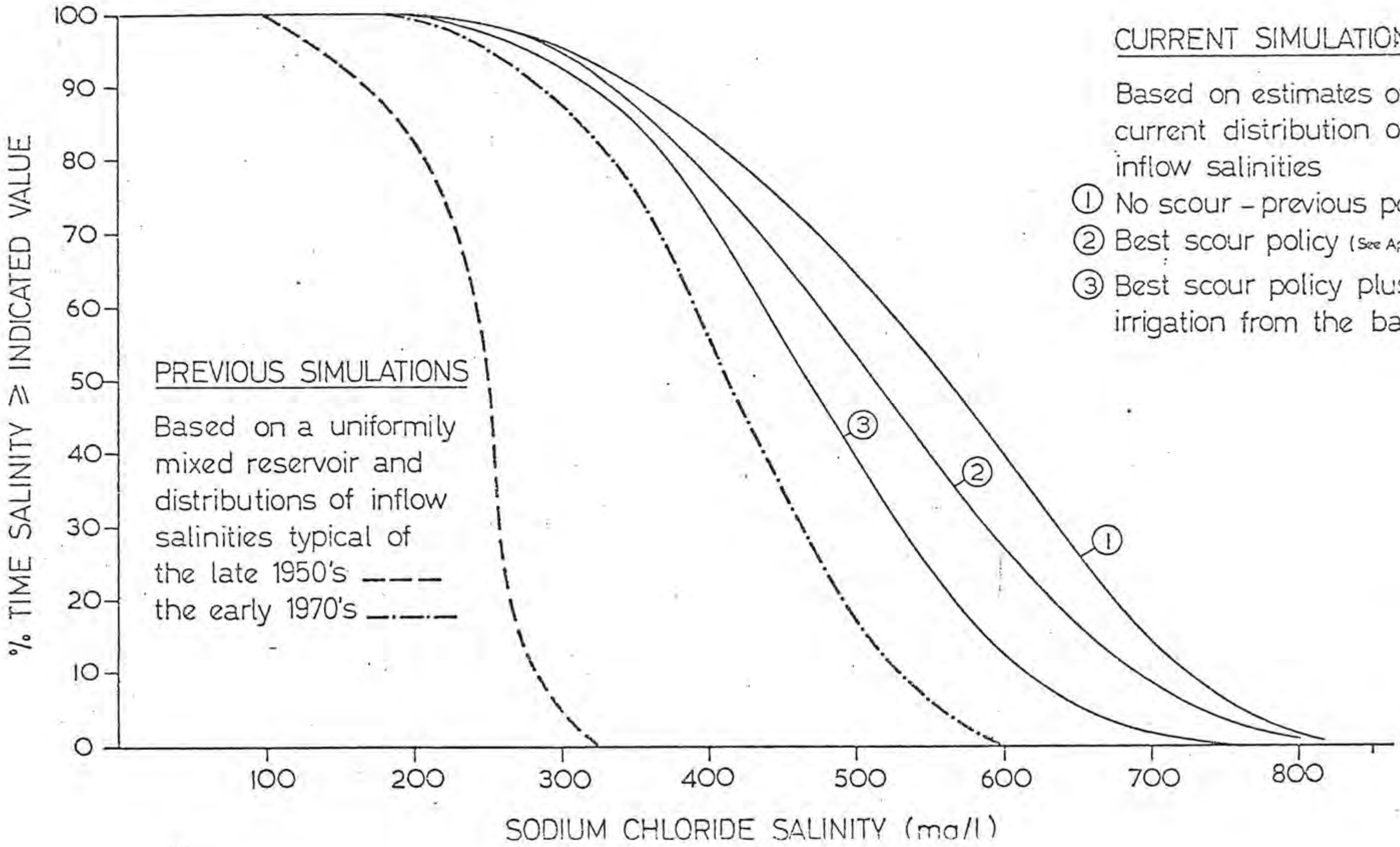

fig. 1

DISTRIBUTION OF ACHIEVED DRAWS FOR WELLINGTON RESERVOIR

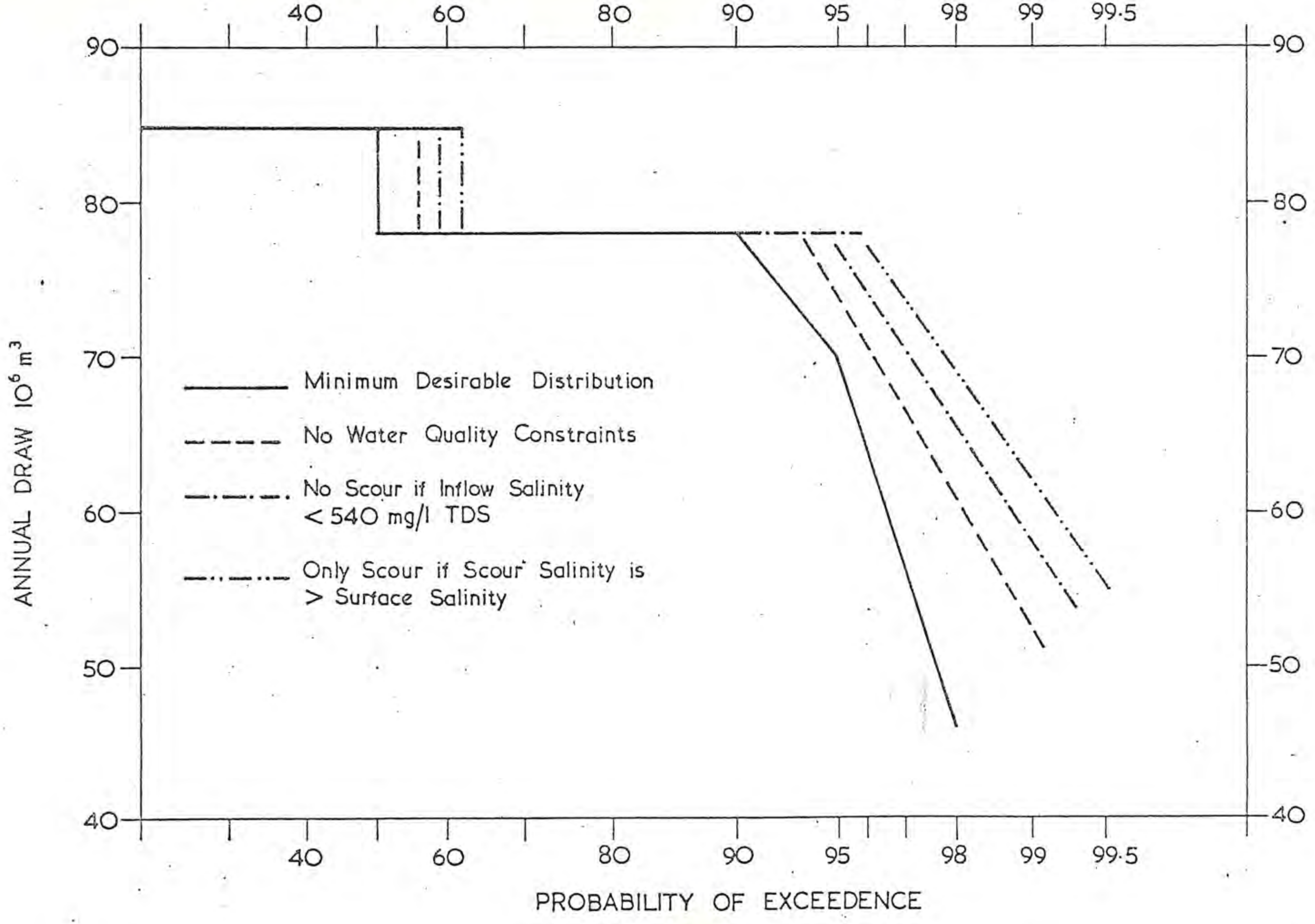

fig. 2

APPENDIX 1

RESERVOIR DRAW REQUIREMENT TO SUPPLY IRRIGATION DISTRICT WATER SUPPLY

The following estimates are based on data supplied from Operations South through the Engineer Programming & Special Projects during February 1977.

Present Rated Area of Collie Irrigation District	4 874.9 ha
Small Holding Allowance	68.3 ha
	4 943.1 ha

Water Right

$9\ 200\ m^3$/rated hectare

$= 45\ 476\ 000\ m^3$

Allow 80% channel distribution efficiency required to enter district

$= 56\ 846\ 000\ m^3$

Another $1\ 000\ 000\ m^3$ is required for sprinkler irrigators giving total entering district of

= 57 846 000

Losses between Wellington Dam and the Diversion Weir are approximately $3\ 500\ 000\ m^3$ (varying seasonally) giving a total required from the reservoir of

$= 61\ 346\ 000\ m^3$

However currently about $3\ 000\ 000\ m^3$ of water right is not used and thus a supply of $58\ 346\ 000\ m^3$ from the reservoir would allow water right of $9.2\ m^3$/rated hectare to be allocated.

For the purposes of this study the equivalent water right draw from the reservoir was rounded off to $60\ 000\ 000\ m^3$.

APPENDIX 2

OPERATING RULES FOR CURRENT WATER DEMANDS WITH A WINTER SCOUR POLICY

1. INTRODUCTION

This appendix describes the operating rules necessary to ensure the maximum volumes of saline water are scoured from the base of the reservoir during the winter months while maintaining the previous distribution of achieved draws. The operating rules provide a long term average irrigation supply of 71.3 x $10^{-6}m^3$/a (120% of water right) and a Town Water Supply of 10 x 10^6m^3/a.

Section 2 describes the operating rules during the winter scour period. Section 3 describes the operating rules used to decide the annual irrigation allocation at the start of each season.

2. OPERATING RULES FOR WINTER SCOUR

2.1 General

The rules listed below give general guide lines to the operation of Wellington Reservoir through the scour period. Decisions associated with the commencement of scour and subsequent modification of scour rates will be necessary on a short time scale (of the order of 3 to 4 days for greatest effect) and consequently must be carried out by the operating group locally.

The operating rules are based on the following philosophy. At the start of each month from June to September a maximum volume of available scour is assessed based on the current storage and the predicted additional inflow for the remainder of the scour period.

Predicted inflows are based on the statistical characteristics determined from 30 years of historic record but are also influenced by the previous months inflow. The maximum allowable monthly scour volume is re-assessed after two weeks operation based on the inflow that has occurred. The monthly scour volumes set the upper limits of available scour. Decisions of when to start and stop scour and what scour rates should be used are dependent on the current inflow rate, the occurrence of recent rains and the relative salinities and temperatures in the reservoir and of the scour water.

Essential information necessary to apply the operation rules are as follows :

1. Daily readings of temperature and conductivity at the surface, central and bottom offtakes.

2. Accurate measurement of outflows so that cumulative totals of scour throughout each month are known and so that inflows can be calculated reasonably accurately by water balance calculations.

Additional data on inflowing salinities and details of the complete reservoir profiles will also aid the decision making. Frequent profilings are planned during the scour period.

The operating rules listed below are the first attempt at converting the (somewhat) artificial monthly simulation rules to practical short term decisions. Information from the more detailed daily simulation by the university has been used to assist in this conversion but modifications will undoubtedly be made in the light of this years experience.

2.2 Operating Rules

Sub-section 2.2.1 describes a typical sequence of scouring decisions which will be necessary to take through the scour period. Sub-section 2.2.2 gives details of the necessary monthly calculations of maximum allowable scour volumes and associated two weekly re-assessments while sub section 2.2.3 provides information to assist the shorter term decisions.

2.2.1 Sequence of Decisions

(i) Calculate maximum allowable scour for June (Table A Sub-section 2.2.2)

(ii) After the first major saline inflows reach the dam wall (see Sub-section 2.2.3) commence scouring at about the current inflow rate.

(iii) Continue to scour at about or a little less than the inflow rate while the monthly cumulative scour volume is within the calculated allowable maximum quantity (see Sub-section 2.2.3).

(iv) Do not scour more than the total inflow. The storage volume should never decrease below the storage at the start of June.

(v) Do not continue to scour if the scour salinity equals or becomes less than the salinity of the well mixed surface layer.

(vi) After two weeks reassess the allowable scour volume for June (Table B - Sub section 2.2.2) and readjust scour rates if necessary.

(vii) At end of June calculate the total inflow for June from the total draw (water supply and scour) and the change in storage and determine the July maximum allowable scour volume (see Sub-section 2.2.2).

(viii) Determine an equivalent scour rate for the month based on the maximum allowable scour volume from (vii) above and adopt this as the initial July scour rate. Reduce this scour rate if there is danger that the cumulative scour volume will exceed the cumulative inflow since the start of June.

(ix) Repeat steps (v) to (viii) for subsequent months until mid September or until the reservoir spills.

(x) If the reservoir spills scour to minimise spillage when scour salinity is higher than spillage salinity (most likely). Otherwise stop scour.

(xi) If the reservoir is not spilling decisions to continue scouring through mid September and October before the irrigation season can be made in the light of whether it is considered better to provide additional irrigation water at a higher salinity or continue scouring and provide a smaller quantity of less saline water.

2.2.2 Allowable Monthly Scour Volumes

Tables A and B of this appendix list equations for the first and revised estimates of maximum allowable monthly scour volumes from June to September. The first estimate is based on the excess of the predicted inflow (with an exceedance probability of 25%) and the current storage deficit. The revised estimate after two weeks inflow is based on the first estimate plus the difference between the actual inflow in the first two weeks and the expected inflow (50% probability of exceedance) for the month. The exponential and logarithmic functions in the expressions for predicted inflow are a consequence of the Log - normal distributions of streamflow. The remaining available scour after the first two weeks for each month is simply the revised estimate of available scour minus the actual scour in the first two weeks. That is

$$MONTHR = MONTH2 - SCRA$$

where MONTHR and MONTH2 represent the remaining and revised estimates of available scour for any month and SCRA represents the actual scour in the first two weeks of the month.

TABLE A - APPENDIX 2

FIRST ESTIMATES OF MAXIMUM AVAILABLE MONTHLY SCOUR

MONTH	EQUATION FOR MONTHLY VOLUME * $10^6 m^3$		
June	JUN1 = Exp (5.401)	-	CSD
July	JUL1 = Exp (4.278 + .3042 ln (QJUN))	-	CSD
August	AUG1 = Exp (1.432 + .8259 ln (QJUL))	-	CSD
Sept	SEP1 = Exp (.786 + .6836 ln (QAUG))	-	CSD

N.B. QJUN, QJUL, AUG represent previous monthly inflows in $10^6 m^3$.

CSD represents the current storage deficit at the start of each month (185.5 - storage at start of month) in $10^6 m^3$.

* These equations can give negative values. In such situations no scouring is justified in the first two weeks. If large inflows occur during the first two weeks it is possible that scouring could commence during the second half of the month. However any negative values calculated in the first estimate must be used in calculations of the revised monthly scour volume (Table B).

TABLE B - APPENDIX 2

REVISED ESTIMATE OF MAXIMUM ALLOWABLE MONTHLY SCOUR VOLUMES

MONTH	EQUATION FOR REVISED MONTHLY SCOUR VOLUMES $10^6 m^3$
June	JUN2 = JUN1 + QJUNA - Exp (3.106)
July	JUL2 = JUL1 + QJULA - Exp (2.837+.3042 ln QJUN)
August	AUG2 = AUG1 + QAUGA - Exp (.816+.8259 ln QJUL)
Sept	SEP2 = SEP1 + QSEPA - Exp (.504+.6836 ln QAUG)

N.B. QJUNA to QSEPA are the actual inflows in the first two weeks of the months June to September.

JUN1 to SEP1 are the first estimates of allowable scour each month defined by the equations of Table A.

QJUN to QAUG are the previous monthly inflows as in Table A. All terms are in $10^6 m^3$.

2.2.3 Information to Assist Short Term Decisions

The first short term decision is at the commencement of scour when the first saline inflows reach the dam wall. This is identified by a rapid increase in conductivity (say 400 μs/cm) and an associated 1^{o} to 1.5 ^{o}C temperature drop relative to the central offtake over say a two day period. Inflow from the main Collie River is most likely to reach the dam wall some 5 to 7 days after the first heavy rainfall on the central and eastern sections of the catchment.

Some build up of salinity over the bottom say 8 metres is desirable to ensure that there is a sufficient density gradient to restrict the scour to a horizontal withdrawal layer within the most saline water. Consequently it is desirable to allow some 5 to 6 x $10^{6}m^{3}$ of saline water to develop at the base of the reservoir before scour is commenced. The time for this to develop after the first saline water has reached the wall would depend on the inflow rate and could be as little as one day for a large flood or over a week for a small flood. Knowledge of the actual reservoir profile is desirable at this stage.

Ideally once scour has commenced it should continue at a rate equivalent to the build up of saline water at the base of the reservoir during the time the available scour volume is governed by the inflow rate. This is usually the case through June in all non-flood years but can extend into July and even August in drought years. The actual rate of increase in volume of saline water entering the base of the reservoir is a complex function of the inflow volume from the main Collie River and the degree of entrainment mixing that occurs as the water flows down the reservoir bed. Consequently it is only indirectly related to the total inflow rate. However daily comparison of salinities and temperatures from the surface, central and bottom offtakes should provide sufficient information to decide whether to stop or reduce the scour rate. For example when the well mixed surface layer extends below the central offtake and the salinity of the scour water is only say 50 mg/l (or 100 μs/cm) greater than the well mixed layer then the scour rate should be reduced or stopped so that a greater density gradient can form at the base of the reservoir.

Again, complete profiling data and detail about current inflow would result in better scouring decisions. However it is considered that the additional improvement would be marginal and daily sampling will be sufficient in most situations. Frequent reservoir surveys during this period are planned but some automated system of obtaining profiling information daily will ultimately develop.

If scouring in June and July has been large then the allowable scour volumes for August and September will be small so that the reservoir can fill (or partially fill) before the irrigation season commences. In this period scour rates will be limited by the reservoir storage deficit rather than the inflow rate and consequently there should be little danger of scouring too rapidly, weakening the density structure and thereby scouring fresher water than desirable. Water quality considerations are important, however, as fresh water can still be scoured unnecessarily if the inflow is sufficiently cold to dominate the density and underflow all previously stored water despite its relatively low salinity. Such a situation should be observable from the surface, central and bottom offtake samples and the scour stopped accordingly.

Table C - Appendix 2 gives an example of winter operation for a hypothetical above average winter (25% probability of exceedance) with a late major inflow in early September (12% probability of exceedance). Note the large allowable scour volumes and the restricted volumes actually scoured during June and July. Significant increases in storage only occurred after mid August.

To fully utilise the computer simulation model developed by the University of W.A. would necessitate an on-line computer with telemetric data input producing real time forecasts of the consequences of different short term scouring decisions. However such a system will take time to develop. In the short term a thermistor and conductivity chain centred in the reservoir and providing on-line information to aid operation would be an intermediate step and would reduce the need for costly reservoir profiling.

3. OPERATING RULE FOR IRRIGATION ALLOCATION EACH SEASON

Included in the long term simulation was a decision on the quantity of irrigation water to be allocated at the start of the season based on the reservoir storage at the start of October. It was necessary to assess the storage volume at which water restrictions (below basic irrigation allocation) were required during drought years and the storage level at which additional water above basic irrigation allocation could be supplied in above average years. After a number of trial and error simulation runs the following operation rule was found to provide the desired distribution of draws.

TABLE C - Appendix 2

EXAMPLE OF WINTER SCOUR OPERATION

Information Required		How Determined	Jun	Jul	Aug	Sep
			Month *			
INITIAL STORAGE		Measured	81	87	94	139
STORAGE DEFICIT		Reticulated	105	99	92	47
PREVIOUS MONTH'S INFLOW		Previously Calculated	-	25	77	75
FIRST EST. OF MAX. ALLOWABLE SCOUR (MONTH 1)		From Table A	116.6	92.9	59.3	-5.0
FIRST TWO WEEKS	ADOPTED SCOUR	Based on Inflow & Salinity Conditions	7[1]	40[2]	29[2]	0[3]
	STORAGE CHANGE	Measured	6	5	1	40
	CALCULATED INFLOW	Water Balance Calculations	13	45	30	40
SECOND EST. OF MAX. ALLOWABLE SCOUR (MONTH 2)		From Table B	107.3	83.6	7.6	3.3
REMAINING ALLOWABLE SCOUR (MONTH R)		By difference	100.3	43.6	-21.4 (0)	3.3
SECOND TWO WEEKS	ADOPTED SCOUR	Based on Inflow & Salinity Conditions	12[2]	30[2]	0[3]	2[4]
	STORAGE CHANGE	Measured	0	2	45	7
	CALCULATED INFLOW	Water Balance Calculations	12	32	45	?[5]
TOTAL MONTHLY INFLOW		Summation	25	77	75	49+
TOTAL MONTHLY SCOUR		Summation	19	70	29	2
FINAL STORAGE		Measured	87	94	139	186

* All figures are in $10^6 m^3$.

1. The decision to scour only 7 x $10^6 m^3$ of the first 13 x $10^6 m^3$ inflow was to allow some build up of saline water at the base of the reservoir to ensure withdrawal of the most saline water (See Sub-section 2.2.3).
2. Scour volumes were controlled by the volume of inflow and/or salinity of scour.
3. Scour restricted by water quantity considerations.
4. Unseasonal inflow in the first two weeks of September enabled some scour to be considered in the second half of the month.
5. Spillage occurred in late September making estimates of inflow inaccurate.

Storage at Start of Irrigation Season $= x \times 10^6 m^3$	Allocation	
	% of Basic Allocation	Volume $\times 10^6 m^3$
$x > 150$	120	74.8
$90 \leq x \leq 150$	100	68
$20 \leq x \leq 90$	$\frac{(x-20)}{70}$ 100	$\frac{(x-20)}{70} \times 68$

That is additional water can be supplied when the October storage is greater than $150 \times 10^6 m^3$ and restrictions below water allocation (not necessarily water right) introduced when storage is less than $90 \times 10^6 m^3$. Water allocations below $90 \times 10^6 m^3$ are a linear function of storage and reduce to zero at $20 \times 10^6 m^3$ to allow for Town Water Supply draw and evaporation. The minimum volume of water allocated for irrigation in the 1 000 year simulation was $18.5 \times 10^6 m^3$ or 31% of water right while the once in 100 year allocation was $40.2 \times 10^6 m^3$ or 67% of water right (See Figure 2 of main report).

The above operating rule for irrigation allocation is based on using the full reservoir storage and drawing water from the bottom offtake for Town Water Supply. As this cannot currently be done the following rule has been developed to ensure that water can always be supplied from the mid level offtake (that is it will maintain $35 \times 10^6 m^3$ in storage).

Storage at Start of Irrigation Season $= x \times 10^6 m^3$	Allocation	
	% of Basic Allocation	Volume $\times 10^6 m^3$
$x > 160$	120	74.8
$120 \leq x \leq 160$	100	68
$105 \leq x < 120$	88	60
$45 \leq x < 105$	$\frac{(x-45)}{68}$ 100	x-45