WATER AUTHORTY

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Simulation of Wellington Reservoir Supply Salinities for Selected Harris Dam Project Alternatives

Appendix K

Harris Dam Project

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APPENDIX K

SIMULATION OF WELLINGTON RESERVOIR SUPPLY SALINITIES FOR SELECTED HARRIS DAM PROJECT ALTERNATIVES

1. INTRODUCTION

Construction of a storage on the Harris River, a fresh tributary of the Collie River, upstream of Wellington Reservoir will enable the salinity of supply to the Great Southern Towns Water Supply (GSTWS) Scheme to be reduced to approximately 200 to 250 mg/L TSS. However the impact of the reservoir on salinity stratification in Wellington Reservoir and hence the supply to the irrigation district is uncertain. The adopted operating procedures for the two reservoirs, combined with the effects of the complex mixing processes, are significant factors in determining the irrigation supply salinity from Wellington Reservoir.

To determine the supply qualities the joint operation of the two storages required a detailed simulation study of both short term hydrodynamic mixing and salinity layering behaviour and the long term hydrologic behaviour (ie operation through a range of high and low flow sequences).

To meet these somewhat conflicting needs a comprehensive study aimed at developing appropriate practical operating procedures while simulating the complex mixing and salinity layering processes was carried out for a critical eight year period. The aim was to investigate a number of operating procedures, dam sizes and dam sites for the Harris storage to evaluate the resulting supply salinities to the Collie Irrigation District from Wellington Reservoir.

2. APPROACH

The Centre for Water Research at the University of Western Australia has developed a complex dynamic reservoir simulation program, DYRESM, to model the mixing process in reservoirs of medium size (Imberger et al, 1978). The model uses a basic daily time step for the inflow and outflow procedures and hourly computation for meteorological forcing. Salinities and temperatures through the reservoir depth are simulated daily together with the quality of water drawn from two offtake levels.

The Centre for Water Research was contracted to adapt DYRESM for the Two Dam Simulation and to provide specialized model output specifically for the Harris-Wellington study. The Water Authority prepared the relevant input data sets, developed the routines which simulated the alternative operating procedures, and carried out the final simulation runs.

To account for the longer term effects of reservoir storage the simulation program was run over an 8 year period from June 1974 to May 1982. This sequence included the wet winter of 1974 and a very dry period in the late 1970's, thereby incorporating a wide range of hydrologic conditions.

Details of development and validation of the modified model by the Centre for Water Research are described in Report No WP 84-023 (Mears et al, 1985). Details of the simulation results carried out over the eight year sequence by the Water Authority are included in a separate Hydrology Branch report no WH1 (Hookey and Loh, 1985). This appendix summarises those results and scales up the estimates to represent the expected salinities in 2010 when most of the effects of past clearing and reforestation have developed.

3. SIMULATIONS UNDERTAKEN

The export of fresh water to the inland town supply from Wellington Reservoir catchment through a Harris River storage would, at first, appear to cause a deterioration in the supply from Wellington Reservoir. However, the additional storage on the catchment provides the opportunity for inproved operation of

Wellington Reservoir which could, if carefully planned, supply fresher water to the Irrigation District.

The construction of a Harris storage would:

(i) reduce the quantity of fresh water likely to be lost as spillage from the catchment,

(ii) enable Wellington Reservoir to be drawn down to lower levels as security of supply for town water supply is no longer required, with the specific benefit being the scour of larger volumes of early winter saline water from the reservoir base,

(iii) enable fresh water stored in the Harris Reservoir to be released only when Wellington Reservoir salinities become high, thus diluting the Wellington Reservoir during the most critical times, and

(iv) enable the current policy of supplying irrigation water from the base of the reservoir, which previously ensured the best quality for town water supply, to be relaxed thereby minimising the salinity of early irrigation season releases.

A range of simulation runs incorporating different policies able to achieve the above were undertaken to identify their relative benefits for a storage of $120 \times 10^6 m^3$ at Harris Dam Site 1.

Having identified the most appropriate operating strategy (principally in terms of winter scour from Wellington and early summer release from Harris) over the eight year sequence further simulations were undertaken using this strategy for a range of dam sizes at Dam Site 1. Finally, comparable simulations using the same operating strategy were also undertaken for Dam Site 5, located some 4.5 km upstream on the Harris River and the results compared. The following section describes the most appropriate strategy, the effect of storage size and the effect of dam sites on the irrigation supply salinity over the eight year simulation and documents fine tuning of the policy to minimise supply salinities at the end of a drought sequence.

4. RESULTS AND DISCUSSION

4.1 Operating Strategy

Table 1 summarises the eight year average daily irrigation supply salinities for four different simulation runs.

Effectively the variations in operating strategy between the different runs were related to the selection of offtake level for irrigation release from Wellington Reservoir (either base or central), the method of winter scour from Wellington Reservoir, and the method and volume of release from the Harris to Wellington Reservoir during the irrigation season.

The different simulation runs are compared with a single dam run (termed Run C) which represents the current operation of Wellington Reservoir. Individually the simulations reflect:

(i) the impact of the Harris storage with a simple operating strategy of constant annual target release to Wellington (Run E),

(ii) the change in the level of irrigation release from the base to central offtake (Run L),

(iii) the increase in volume and improvement of the timing of winter scour over that which has occurred historically (Run M), and

(iv) the adoption of a variable annual release policy from Harris Reservoir (Run H).

Details of the algorithms used for the adopted scour and variable Harris release policies are provided by Hookey and Loh (1985) and will not be repeated here.

In general terms the adopted scour policy is based on scouring all June Collie River inflows if salinity levels in the reservoir exceed given limits. Such inflows are generally saline and underflow the reservoir, lodging at the base. Constraints on the volume of scour are introduced in July, August and September based on volume considerations. The variable release policy from Harris is based on both the total volume of water in the two storages at 3 selected times just prior to and within the first months of irrigation release and also on the average salinity of Wellington Reservoir throughout the irrigation period.

The results of Table 1 clearly indicate construction of a Harris River storage of 120 x $10^6 m^3$ will on average improve the salinity of supply even with relatively simple operating rules (Run E). Refinement of those rules can more than double the improvement (Run H compared to Run E) and could be further improved with optimisation of the detailed algorithms for winter scour and summer release.

TABLE 1
EIGHT YEAR AVERAGE DAILY IRRIGATION SUPPLY SALINITIES FOR DIFFERENT OPERATING POLICIES
1974-1982

Run	No. of Dams	Source of Irrigation	Scour Policy	Harris Reservoir Release Policy	Irrigation Salinity mg/L	Benefit Over Run C mg/L	Incremental Benefit mg/L
C	1	Base	Historic	NA	733	0	-
E	2	Base	Historic	$19.7 x 10^6 m^3/a$	696	37	37(0.44)
L	2	Central	Historic	$19.7 x 10^6 m^3/a$	674	59	22(0.26)
M	2	Central	Adopted	$19.7 x 10^6 m^3/a$	656	77	18(0.21)
H	2	Central	Adopted	Variable	648	85	8(0.09)

Notes : (i) Figures in brackets are the incremental proportion of total benefits.

(ii) NA - Not Applicable

(iii) Values are based on a 120 x $10^6 m^3$ storage on Harris River at Dam Site No 1.

The factors contributing to the average improvement in irrigation salinities were studied for their incremental benefit. Comparison of the simulations suggests that the inclusion of Harris Reservoir is singularly the most important in reducing irrigation salinity levels (44%). This is attributed to the regulation of flows on the Harris River and subsequent releases during the latter portion of the low inflow sequence from 1977 to 1981.

The introduction of irrigation releases from the central offtake, a revised scour policy from Wellington Reservoir and finally a variable release rule from Harris Reservoir contribute 26%, 21% and 9% respectively of the total improvement.

However additional runs (Hookey and Loh, 1985) indicate the improvements introduced by changing the scour policy, the release policy or the offtake level are not independant. Nevertheless as a combined strategy the policies contribute some 56% of the total improvement observed over the current operating rules of Run C.

While the introduction of a variable release from Harris to Wellington Reservoir through the eight year sequence only contributes a small amount to the average improvement it provides a significant benefit at the end of a drought sequence. Table 2 indicates the average daily irrigation supply salinities at the end of the drought sequence in the year 1980/81.

TABLE 2
END OF DROUGHT SEQUENCE (1980/81) AVERAGE DAILY
IRRIGATION SUPPLY SALINITIES
FOR DIFFERENT OPERATING POLICIES

Run	No. of Dams	Source of Irrigation	Scour Policy	Harris Reservoir Release Policy	Irrigation Salinity mg/L	Benefit Over Run C mg/L
C	1	Base	Historic	NA	963	0
E	2	Base	Historic	$19.7 \times 10^6 m^3/a$	938	25
L	2	Central	Historic	$19.7 \times 10^6 m^3/a$	937	26
M	2	Central	Adopted	$19.7 \times 10^6 m^3/a$	1025	-62
H	2	Central	Adopted	Variable	911	52

Notes : (i) NA - Not Applicable

(ii) Values are based on a $120 \times 10^6 m^3$ storage on Harris River at Dam Site No 1.

Comparison of Runs M and H in Table 2 clearly illustrates the benefits of retaining fresh water in the Harris storage until Wellington Reservoir reaches higher than average salinities. Simply attempting to supply a constant release based on the "safe draw" from Harris Reservoir in fact leads to a deterioration in salinity levels at times of high salinity at the end of a dry sequence over those observed under the current operating policy (Run M compared with Run C). In contrast the release of water from Harris Reservoir in the later years of the eight year sequence has a significant positive benefit in 1980/81 (Run H compared with Run C).

Clearly the strategy of Run H was the most beneficial and was adopted for further study of the effects of storage size and comparison of dam sites.

4.2 Dam Sizes and Dam Sites

Varying the size of the Harris Reservoir clearly impacts on the levels of irrigation supply salinity from Wellington Reservoir. Increased storage allows larger volumes of fresh water to be stored on the Harris Reservoir for subsequent release to the Wellington Reservoir, thus releases could be of greater volume and also be sustained for lengthier periods than would be the case with a smaller storage.

A comparison of the improvements in average daily irrigation supply salinities with Run C is shown in Table 3 for Harris Reservoir storage sizes of 40, 80, 120 and 134 x $10^6 m^3$ using the best strategy defined in the previous section (Run H).

TABLE 3
EFFECT OF HARRIS RESERVOIR STORAGE SIZE ON AVERAGE DAILY IRRIGATION SUPPLY SALINITIES

Year	Run C Salinity (mg/L)	HARRIS D/S 1 Difference (mg/L) With Run C for Volume ($10^6 m^3$): 40	80	120	134	HARRIS D/S 5 Difference (mg/L) With Run C for Volume ($10^6 m^3$): 60	80	110
1974/75	319.5	11	9	9	7	8	7	1
1975/76	551.6	89	97	81	88	98	87	72
1976/77	645.0	45	58	42	62	29	63	53
1977/78	902.4	107	183	170	174	173	171	170
1978/79	861.3	53	134	135	141	122	144	138
1979/80	953.5	-114	22	222	224	-79	-30	199
1980/81	962.9	-159	-108	52	114	-111	-105	-42
1981/82	672.3	-17	-17	-25	-15	2	41	-16
Average	733.4	6	49	85	98	32	44	71

Note : Positive difference indicates improvement in average daily irrigation salinity.

The results show comparable improvements regardless of storage size over the initial 3 years of the sequence, reflecting a zero annual release from Harris Reservoir during this period for all cases. However there is a marked divergence in the following four years, 1977/78 to 1980/81 during a time of lower inflow. Improvements are positive and salinities significantly smaller than historically observed for the larger storages of 120 and 134 x $10^6 m^3$, but deteriorate over the period 1979 to 1981 for smaller storages of 40 and 80 x $10^6 m^3$. This is attributable to the lower volume available for release from Harris Reservoir during the irrigation season.

The adopted storage size for Harris Reservoir is therefore critical to the salinity levels which can be expected over an extended low inflow sequence.

Also included in Table 3 are the results of simulations for storages of 60, 80 and 110 x $10^6 m^3$ at Dam Site 5. The results for Dam Sites 1 and 5 are comparable for similar storage volumes and any variations result primarily from the increased inflow to Wellington Reservoir from the intervening sub-catchment between the two sites. The runoff from this area over the eight year sequence was 101 mm (6.2 X $10^6 m^3$), substantially higher than the 61 mm (19.6 X $10^6 m^3$) observed at Dam Site 5.

Had long term simulations of reservoir operation been carried out the additional water yield at the lower site, given the same storage, would have enabled a larger volume of water to be available for dilution of Wellington Reservoir. Although not shown specifically in these simulations, it is therefore considered that a dam at site no. 1 would provide a slightly lower irrigation supply salinity than one of similar storage capacity at site no. 5. The differences would, however, be small.

Irrespective of dam location substantial improvements in the level of irrigation salinity are achieved in the initial five years from 1974 to 1979 under the strategies applied in Run H for all storage sizes analysed. Releases from the Harris Reservoir commence in 1977/78 in all cases however volume constraints result in their being limited to the following 2 years for the smaller 40 and 80 x $10^6 m^3$ storages. Salinity levels in Wellington Reservoir consequently increase towards the end of the low inflow sequence and deteriorations in irrigation salinities with respect to Run C are observed.

4.3 Preliminary Optimisation of Operational Strategy

There is a trend under the adopted strategies to therefore improve salinity levels in the early stages of the low inflow sequence when historic salinities are at acceptable levels, but possibly produce disbenefits (depending on storage size) when they approach unacceptably high levels in the latter periods.

A preliminary optimisation of the release and scour strategies was therefore undertaken to minimise irrigation salinities at the end of the drought (1980/81), while not markedly affecting salinity levels in the earlier years.

The revised policy was basically aimed at improving the winter scour efficiency throughout the eight years and delaying the release of fresh water from Harris Reservoir until later in the sequence. This was achieved by increasing both the salinity level at the base of Wellington Reservoir at which winter scour was initiated and also the average Wellington salinity level at which release of Harris water was allowed.

Table 4 shows the results of simulations using the optimised strategy for the most critical storage range. In effect the results produced a redistribution of the improvements in salinities over Run C from the earlier to later years, the timing of the improvements therefore being more beneficial as they coincided with periods of historically high irrigation salinities. Although this redistribution substantially improved salinities at the end of the drought sequence in 1980/81, the average daily improvements remained comparable (see Table 3).

Table 4 clearly indicates, however, that a storage of about 90 x $10^6 m^3$ is required to avoid any deterioration relative to the current operation of Wellington Reservoir at the end of a severe dry period.

TABLE 4
EFFECT OF PRELIMINARY STRATEGY
OPTIMISATION ON AVERAGE DAILY
IRRIGATION SUPPLY SALINITIES

Year	Run C Salinity (mg/L)	HARRIS D/S 1 Difference (mg/L) With Run C for Volume (10^6m^3): 80	HARRIS D/S 1 Difference (mg/L) With Run C for Volume (10^6m^3): 100	HARRIS D/S 5 Difference (mg/L) With Run C for Volume (10^6m^3): 71 (TWS=$10x10^6m^3$)	HARRIS D/S 5 Difference (mg/L) With Run C for Volume (10^6m^3): 71 (TWS=$15x10^6m^3$)
1974/75	319.5	9	6	6	6
1975/76	551.6	89	86	57	55
1976/77	645.0	40	40	34	45
1977/78	902.4	82	71	84	71
1978/79	861.3	129	162	59	54
1979/80	953.5	154	202	123	-118
1980/81	962.9	-63	51	-89	-90
1981/82	672.3	-29	-36	-3	-5
Annual	733.4	51	73	33	4

Note : Positive difference indicates improvement in average daily irrigation salinity.

4.4 Effect of Increasing TWS

The results presented above are based on annual abstraction of $10X10^6m^3$ for TWS, the projected future demand of the GSTWS within the next 10 to 20 years. To assess the effects of a further increase to 15 x 10^6m^3 after the year 2000, an additional simulation was carried out with a storage of 71 x 10^6m^3 at Harris Damsite 5.

The results demonstrating the effect of this increased demand on average daily irrigation supply salinities are presented in Table 4. The most obvious change has been the large deterioration in supply salinities in 1979/80. Similar improvements are observed from 1974/75 to 1978/79 under both TWS demands, however with the increased annual abstraction during this period storage levels in Harris Reservoir had reduced significantly. The volume available for release from Harris Reservoir in 1979/80 (3.4 x 10^6m^3)

therefore had negligible effect on salinity levels in Wellington and resulted in a significant deterioration in supply salinities of 118 mg/L compared to Run C. Similar deteriorations were estimated for the following years under both TWS demands, as would be expected with zero release from Harris Reservoir in both cases.

For the total eight year sequence, the average daily irrigation salinities showed little overall improvement in comparison to Run C (4 mg/L).

Both the median and 5% probabilities of exceedance values were marginally higher than estimated with the lower TWS demand, reflecting the increased supply salinities in the 1978/79 and 1979/80 irrigation seasons.

This simulation clearly demonstrates the relationship between the level of TWS demand and the duration over which improvements in irrigation supply salinities can be maintained during a low inflow sequence similar to the late 1970's. Simply increasing TWS effectively reduces the storage available for release to Wellington and under the current 8 year inflow sequence reduces the period over which improvements can be maintained to the first 2 years of low inflows.

4.5 Summary

Operational strategies have been devised which ensure that average irrigation supply salinities from Wellington Reservoir will not deteriorate following the draw of $10 \times 10^6 m^3$ per annum from a storage on the Harris River exceeding $40 \times 10^6 m^3$ at either Dam Site 1 or Dam Site 5. There is little significant difference in the supply salinities from comparable storages at either site. A storage of about $90 \times 10^6 m^3$ is required to avoid increasing the salinity of supply from Wellington Reservoir at the end of a severe dry sequence when salinity levels are normally high.

Increasing TWS demand to 15 x 10^6m^3 results in deteriorations in average daily irrigation supply salinities a year earlier than was estimated under the lower 10 x 10^6m^3 demand. This reflects the effective reduction in storage available for release from Harris Reservoir during the low inflow sequence. A $70x10^6m^3$ storage is required on the Harris to ensure that average irrigation supply salinities are not increased with a TWS demand of $15x10^6m^3$.

5. FUTURE SUPPLY SALINITIES FROM THE TWO DAM SYSTEM

The salinity levels listed in the previous tables reflect the supply salinities likely to result when the inflow salinity conditions are typical of the late 1970's, that is typical of the approximate mid-point of the eight year period from 1974/75 to 1981/82.

To account for the changing inflow salinities as a result of past and planned future land use change, appropriate scaling of the supply salinities is necessary.

Evaluation of the eight year sequence indicated that an equivalent salinity of a median inflow year was 740 mg/L TSS. Simple linear scaling was employed based on the ratios of salinities of median years for the different land use conditions. Table 5 indicates the expected average irrigation supply salinities for the 3 storage sizes of Table 4 under the most likely future land use conditions.

TABLE 5
ESTIMATED AVERAGE DAILY IRRIGATION SUPPLY SALINITIES
FOR DIFFERENT TWO DAM SCHEMES AND FUTURE
LAND USE CONDITIONS

Land Use Condition	Current Condition	Completion of Current Reforestation by early 1990's 70% effective	
Date	1984	Mid 1990's	2010
	mg/L TSS	mg/L TSS	mg/L TSS
Proposed (1) Scheme			
D/S 5 71 x $10^6 m^3$	803	949	898
D/S 1 80 x $10^6 m^3$	782	928	874
D/S 1 100 x $10^6 m^3$	757	895	846
No Harris Dam (Current Operation of Wellington)	841	994	940

Notes : (1) Operating Policy based on preliminary optimisation of Run H strategy.

The table shows that construction of a 71 x $10^6 m^3$ storage at Dam Site 5 is likely to result in an average irrigation supply salinity of 900 mg/L TSS when the full effect of past clearing and future reforestation has developed. This is approximately 60 mg/L worse than estimated current average supply salinities, but is some 40 mg/L better than the ultimate average irrigation supply salinity without the construction of a Harris Dam.

Construction of a larger storage of 100 x $10^6 m^3$ at Dam Site 1 would ultimately result in an average supply of approximately 850 mg/L, some 90 mg/L better than with no storage and roughly equivalent (within 10 mg/L) to current average irrigation supply salinities.

Table 6 provides estimates of the expected irrigation supply salinities at the end of a drought sequence similar to that which occurred in the late 1970's. Construction of a 71 x $10^6 m^3$ storage at Dam Site 5 could ultimately result in irrigation supply salinities reaching 1350 mg/L TSS in these extreme conditions.

Construction of a 100 x $10^6 m^3$ storage at Dam Site 1 could reduce supply salinities to below 1200 mg/L. Ultimate development of the lower site (134 x $10^6 m^3$) could yield irrigation supply salinities of less than 1100 mg/L (not shown in Table 6), which approximates the current expected level of supply salinity in a drought sequence similar to the late 1970's with no Harris Dam.

TABLE 6
ESTIMATED AVERAGE DAILY IRRIGATION SUPPLY
SALINITY FOR A YEAR AT END OF A SEVERE DROUGHT SEQUENCE

Land Use Condition	Current Condition	Completion of Current Reforestation by early 1990's 70% effective	
Date	1984	Mid 1990's	2010
	mg/L TSS	mg/L TSS	mg/L TSS
Proposed (1) Scheme			
D/S 5 71 x $10^6 m^3$	1207	1427	1349
D/S 1 80 x $10^6 m^3$	1177	1392	1316
D/S 1 100 x $10^6 m^3$	1046	1237	1170
No Harris Dam (Current Operation of Wellington)	1105	1306	1235

Notes : (1) Operating Policy based on preliminary optimisation of Run H strategy.

Whilst not presented in Table 5, the estimated average daily irrigation salinity corresponding to an increased TWS of 15 x $10^6 m^3$ from Harris Dam Site 5 at 71 x $10^6 m^3$ is approximately 935 mg/L. The average salinities at the end of a severe drought sequence are comparable to those experienced under the lower demand of 10 x $10^6 m^3$, however it could be expected that deteriorations of this level would commence one to two years earlier depending on the severity of the inflows.

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