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The History of Catchment and Reservoir Management on Wellington Reservoir Catchment, Western Australia

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THE HISTORY OF CATCHMENT AND RESERVOIR MANAGEMENT ON WELLINGTON RESERVOIR CATCHMENT W.A.

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CATCHMENT MANAGEMENT IN AUSTRALIA IN THE 1980'S
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1. INTRODUCTION

The impact of agricultural development on the surface water resources of the south west of Western Australia has been dramatic. Prior to agricultural development virtually all the divertible surface water resources were believed to be fresh. Recent updating of the water resources inventory (WAWRC, 1986) indicates that only 48% remain fresh (less than 500mg/L TSS) and 35% have become so saline they are no longer potable (greater than 1000mg/L TSS). The remaining 17% are of marginal quality and require active catchment management to minimise their further deterioration.

The most important of these marginal resources is the Collie River, a resource dammed some 35 kilometres to the east of the Coastal Town of Bunbury. The reservoir formed by Wellington Dam has a capacity of 186 x $10^6 m^3$ and an annual yield of about 100 x $10^6 m^3$. As such it is the largest single developed water resource in the region. Current draw from the reservoir is about 80 x $10^6 m^3$ per year of which over 90% is supplied to the Collie River Irrigation District on the coastal plain. The remaining draw (about 6 to 7 x $10^6 m^3$ per annum) is supplied to inland towns throughout the southern wheat belt region of the Western Australia.

Towns connected to the scheme include Collie, Williams, Narrogin, Brookton, Wagin, Katanning, Kojonup, Gnowangorup and Lake Grace.

Wellington Dam was originally constructed in 1933 as a small storage (35 x $10^6 m^3$) to satisfy the then small irrigation demand. A small raising took place in 1946 to satisfy increased irrigation demand. However, by the mid 1950's a major increase in storage was required to satisfy plans for a much enlarged irrigation district and to supply the proposed Great Southern Towns Water Supply Scheme. Under a construction programme governed by severe limitations of funds the current dam was commenced in 1955 and completed in 1960.

Concern about agricultural development in the catchment of Wellington Reservoir and its likely impact of salinity has a long history. A Government Advisory Committee on the Purity of Water first expressed concern about continued release of crown land for agricultural development as early as 1951. Administrative action halted further alienation of crown land in 1960, and legislation to control large scale agricultural develop on private land, was past by State Parliament in 1976. New reservoir operational procedures were introduced in the same year to minimise the supply salinity to the inland towns while a partial reforestation scheme was commenced in 1979/80 to reduce the inflow salinity to the reservoir in the long term. Engineering investigations commenced of a proposal to dam the Harris River, a fresh forested tributary within the Wellington Reservoir Catchment to substantially reduce the salinity of supply to the inland towns. In late 1987 State Government and the Environmental Protection Authority gave final approval for the construction of the Harris River Dam Project. However, as a condition of the environmental approval, the Water Authority was committed to review its current reforestation programme with the view of continuing a catchment management approach, with the long term aim of returning supplies from Wellington Reservoir to potable levels.

Wellington Reservoir Catchment represents a classic example of the deterioration of a surface water resource as a result of agricultural development. The history of the related catchment and reservoir management also represents one of the first large scale attempts at control of a major non point source pollution problem. This paper aims to review of the history of catchment management decision making in relation to the hydrologic record and the changing social and political climate about salinity issues which have occurred over the last 40 years. The lessons that can be learnt from this history hopefully will be of value to others involved in similar seemingly intractable non point source pollution problems.

2. BACKGROUND

The relationship between clearing native forest vegetation for agriculture and the subsequent increase in stream salinity has been clearly demonstrated in recent years (Collins and Fowlie, 1981; Loh and Stokes, 1981) although the first observation of the effects were reported early in the century (Wood, 1924). The permanent removal of deep rooted forest vegetation and its replacement with shallow rooted crops and pastures has led to an increase in the soil water passing the base of the root zone each winter. Consequently, groundwater levels rise (Sharma et al, 1987, Peck, 1983) and contribute additional groundwater discharge to the surface stream system (Williamson and Bettenay, 1979). Increases also occur in the quantity of shallow subsurface seepage and surface runoff contributing to streamflow (Stokes and Loh, 1982). The overall effect on stream salinity is a complex function of the quantity and particularly the salinity of the additional groundwater discharge, as well as the quantity and quality of the additional shallow seepage and surface runoff water.

Large quantities of salts have accumulated in the deep lateritic soil profiles of the Darling Range in regions with annual rainfalls of less than 900mm per year (Dimmick et al, 1974; Stokes et al, 1980). Clearing for agricultural development in this region leads to very high salinities of discharging groundwater and results in typical average stream salinities in excess of 3 000 mg/L Total Soluble Salts. In higher rainfall regions where smaller amounts of salts have accumulated in the landscape, and where significant additional shallow seepage and surface runoff contribute to streamflow following clearing, much smaller and often undetectable changes in stream salinity occur following clearing (Loh et al, 1983).

The catchment area of Wellington Reservoir is a 2830 sq. km. and spans a rainfall range over 1100 mm per annum in the west to 600 mm per annum in the east (See Figure 1). A complex pattern of agricultural development is superimposed on this rainfall distribution and results in a highly complex spatial and temporal pattern of stream salinity (Loh and Stokes, 1981; Barrett and Loh, 1982).

3. TRENDS IN INFLOW SALINITIES

Despite the wealth of recent data and research papers that document the impact of agricultural development on stream salinity virtually no reliable quantitative information was available until the mid 1970's.

The lack of quantitive information through the 1960's significantly affected catchment management decisions at the time. It is therefore instructive to re-examine the early hydrologic record as background to the catchment management history.

Although periodic sampling programmes of tributaries within the catchment have been carried out the only long term data set available on the catchment as a whole has been the monthly supply salinities from the Reservoir (PWD, 1984).

Variations in the storage capacity, offtake level of supply, density stratification and seasonal carry over effects all complicate the use of the supply quality as an indicator of the water quality deterioration caused by the catchment clearing. In particular, it has not been possible to identify the variations in salinity caused by variations in inflow volume from the reservoir supply salinity record, thereby making it much more difficult to identify trends in the water quality record.

By reassessing the available salinity data and reservoir operational records and by using a simple annual salt and water balance for the storage it has been possible to reconstruct a consistent set of annual water year flow volumes and annual inflow salinity for 1945/46 to 1984/85 (Loh, 1986).

Figure 2 plots the salinity against the inflow volume, expressed as a ratio of the median annual inflow volume. Salinity deviations from a simple power law regression of inflow salinity versus streamflow shown in Figure 2 are plotted against time in Figure 3. Two points are apparent from Figure 3. Firstly the time trend is clearly non-linear and secondly there is evidence that the variability of salinity caused by streamflow variations increases with time and salinity level. As there is no a priori reason to adopt any particular functional form of the time trend, an unbiassed method was developed for estimating the salinity of a medium inflow year over time taking both these points into consideration. The resultant "average" inflow salinity to Wellington Reservoir over time is plotted as figure 4.

The salinity of an average inflow year has increased from 280 mg/L in 1945/46 to 790 mg/L in 1982/83. Extrapolation to 1985/86 indicates a current average inflow salinity of 880 mg/L. This represents a 600 mg/L rise, or an increase in excess of 300% over the 41 years. Also plotted on figure 4 is, the historic level of agricultural clearing within the catchment. The strong correlation and lag between clearing and salinity is clearly apparent.

An important feature of the inflow salinity data is that the first 20 years showed an increase of 120 mg/L compared with a 480 mg/L increase in the following twenty years. Prior to 1955/56 the rate of increase was low at less than 5 mg/L per year. However, the rate of increase increased through the subsequent decade reaching 15 mg/L per year by 1965/66. The rate of increase continued to grow over the following 15 years to its current value of 30 mg/L per year. This characteristic of an acceleration in the rate of deterioration of salinity is an important feature of the record which played a significant role in the evolution of catchment management decisions.

4. PREVENTATIVE CATCHMENT MANAGEMENT

4.1 Historical Perspective

The early 1950's was the start of the major post war expansion of land release and agricultural development in the south-west. It was also the time of the design, investigation, and construction of the Great Southern Town Water Supply Scheme and the expansion of the Collie Irrigation District. Recognising the potential conflict between agricultural expansion and the additional demands of water from the Collie River a committee of senior public servants was established in 1950 to advise Government on Water Purity issues relating to the Wellington Dam Catchment. The committee later amalgamated with a similar committee studying water purity problems of catchments which served the Perth metropolitan area.

Representatives came from the Departments of Agriculture, Forestry and Public Health, the Government Chemical Laboritories as well as the two water authorities (Metropolitan Water Board and the Public Works Department).

The committee received its first submission from the Public Works Department to halt further free hold clearing on Wellington Dam Catchment in 1951. No known legislation was available to control clearing at the time and the matter was referred to the Crown Law Department for comment. The concern, however, stimulated stream sampling by the Department of Agriculture in the following years. By the mid 1950's results from the programmes had indicated that highly saline water was issuing from cleared land in the east of the catchment and the major tributaries of the Collie River, which were only 10% cleared, had average salinities of 2.5 to 3.5 times those of the major forested tributaries (Smith and Storeman, 1956). As can be seen from figure 4, average inflow salinities were still below 300 mg/L TSS.

It wasn't until 1960 that the Advisory Committee on the Purity of Water was sufficiently concerned to recommend to the Department of Lands and Surveys in the strongest possible terms, "that the application for alienation of any further areas of the Wellington Dam catchment be opposed". This was supported by the Minister and effectively became policy in August 1960. The decision was taken the year after a very dry winter in 1959 in which the inflow salinity reached 428 mg/L TSS.

The current estimate of the then "average" inflow salinity was only 325 mg/L TSS.

Of great concern to a small number of agricultural scientists and water resource engineers in the early 1960's was the very high salinity of small tributaries in the east of the catchment.

While the majority of the land had been released for settlement prior to 1930 the proportion of farms cleared by 1950 was low. Considerable growth in the Agricultural Sector through the 1950's highlighted that control over release of further land may not be sufficient to ensure that the quality of inflow to Wellington Reservoir would remain acceptable.

Debate within the Purity of Water Committee about the causal relationship between agricultural development and stream salinity and the need for further action reached a head in the mid 1960's. Legal opinion was sought as to whether a by-law associated with the existing Country Areas Water Supply Act (1947) was sufficient to control clearing on private land. The Crown Law Department advised that it was "ultra vires" the Act and by implication special or modified legislation would be required.

During 1965 the Purity of Water Committee reviewed data on reservoir supply salinities to 1964/65 and discussed preliminary results from Public Works Department sampling programmes within the catchment. Although documentation of the actual discussions is unavailable it is generally believed that the data was not considered convincing as it did not show statistically significant time trends in the supply salinities from the reservoir. Poor correlations also existed between clearing on major sub catchments and the then available measures of the salinity of major tributories of the Collie River.

Two reasons would have contributed to not being able to identify a time trend from the reservoir supply data. Firstly the rate of increase was still small relative to the yearly variation, and secondly the flood years of 1963 and 1964 had reduced reservoir salinities dramatically at the end of the period studied. As the estimates of streamflow volumes and inflow salinities were not available in the mid sixties it was not possible to remove the effect of streamflow variability and identify the underlying salinity trends at the time.

Interestingly enough, simple analysis of the current set of annual inflow salinities also do not show a significant time trend to 1964/65. Only after formulation of multiple regression equations involving both annual inflow volume and time were small but significant trends of increasing salinity identified using data to 1964/65 (Loh, 1986).

The accuracy and reliability of streamflow and water quality data from the major tributaries of the Collie River was very poor. Streamflow estimates were particularly unreliable and sampling frequency was not high. Considerable bias in salinity statistics were possible. At the time it was not appreciated how variable the salinity of a river which drains a large (500 sq km) partly cleared catchment could be. Members of the Water Purity Committee were probably unappreciative of the possible bias in such data, a fact which undoubtedly contributed to a lack of clear correlation between the salinity of major tributaries of the Collie and their sub catchment clearing.

However, considerable knowledge of the impact of salinity in the wheatbelt and on both domestic and railway water supply catchments was available at the time (Power 1963). Sampling of the smaller tributaries in the east of the catchment in the mid 1950's (Smith and Stoneman, 1956) and again in 1965 clearly demonstrated the correlation.

While it is uncertain how much of the small catchment data was available the evidence from the reservoir supply figures and the major tributory sampling was unconvincing to the Committee and they dropped the issue, effectively delaying the chance to introduce control on agricultural development by at least 10 years.

Again it must be remembered that supply salinity in 1964 and 1965 were the lowest for seventeen years. The actual inflow salinity in the wet year of 1964/5 was 185 mg/L while the best current estimate of the "average" inflow salinity for the same year was 390 mg/L.

While poor quality hydrometric data and limitation in statistical time trend analysis procedures were undoubtedly important factors in delaying management action, they were by no means the only factors.

Most importantly there was no adequate data to, or means of, predicting the full effect of past clearing or the likely effect of further development on stream salinity. Quantitative knowledge about the processes causing the salinity problem did not exist, nor were their individuals fully committed to studying the problem. It was the era prior to inter disciplinary studies and a time when communication between engineers, agriculturalists and foresters was minimal. The specialities of hydrology, soil physics and plant water relations barely existed and were disciplines which were unfamiliar to the senior water supply engineers of the day.

Although the Purity of Water Committee was aquainted with wide spread nature of salinity problem in the South-west no regional perspective of how much of the water resources had been seriously degraded was available.

The social and political context at the time was also critical (Sadler and Cox (1986) emphasise these aspects of the history of catchment management decision making. The Government was strongly committed to development through agricultural expansion. Many farmers held land under a conditional purchase scheme whereby they had to clear and develop a certain percentage of their farm before they could be granted freehold title. The political difficulties involved in effectively reversing these procedures were presumably appreciated by the Water Purity Committee members. Strong objections had already been raised against the earlier restrictions on alienation of further crown land.

The political difficulties were compounded by a lack of public awareness of the seriousness of the salinity problem. Little positive support for control of clearing on private land would have been likely. The community was not attuned to environmental issues, nor did local conservation lobby groups exist at that time.

With this perspective it is not surprising that the committee was reluctant to act.

Following the decision to drop the issue in the Purity of Water Committee, work on salinity within the Public Works Department was reduced as other more pressing engineering hydrologic design tasks were given priority. Reservoir salinities rose after the wet years of 1963 and 1964 but were again reduced in the wet year of 1967.

By the late 1960's a small group of concerned engineers, agriculturalists and soil scientists commenced planning of a long term research study to clearly document the relationship between clearing and stream salinity increases in a scientifically valid, unquestionable way. Impetus for this work was assisted by the high salinities which resulted from the dry year of 1969. By this stage the salinity of an "average" inflow year had reached 480 mg/L although the actual inflow salinity for 1969 was 652 mg/L TSS. A rigous paired catchment approach was proposed. Pairs of small research catchments were to be selected across different rainfall zones and instrumented to measure the input and output of salts and to monitor the response of the groundwater system. Following a period of pre treatment one catchment in each pair was to be developed for agriculture and the relative changes in salt and water balances and groundwater responses identified. In this way natural variations in the hydrologic response of small catchments were to be seperated from the treatment effect.

Planning for this detailed research programme proceeded through the early 1970's but it wasn't until 1974 that 5 research catchments were fully established.

During this time major changes had occurred in the broader perception of the salinity problem. A regional outlook had replaced the previously localised view point in water planning, and the first region wide review of resources, demands, and potential water strategies was made (Sadler and Field, 1972). This review included resource inventories which for the first time allowed simple illustration of the region wide effect of salinity on the available water resources.

A broader group than water supply engineers and agriculturalists were now studying the problem. Soil physicists using the old relatively poor quality salinity and streamflow information, but with additional years of record, were able to clearly establish the disturbances to the salt balance of catchments that occurred following agricultural development (Peck and Hurle, 1973). Soil geomorphologists documented the quantities of salinities stored in the Darling Range soils (Dimmock et al, 1974). Methods for roughly estimating the effect of clearing on different catchments were being developed (Peck, 1976).

Professional and academic institutions contributed greatly to the public articulation of this additional information through a variety of public seminars and conferences which attracted media interest. Furthermore, a native forest conservation lobby vigorously picked up the salinity issue as an argument against bauxite mining within State Forests and made salinity a more prominent public issue than water authorities might have achieved unilaterally.

Most importantly the salinity of supply was deteriorating at an alarming rate. Between 1970 and 1973 the rate of increase of the salinity of an "average" inflow year increased from 20 to 25 mg/L per year.

Again the issue was emphasised in the dry year of 1972 when inflow salinities reached 685mg/L TSS.

By 1974 there was a general acceptance within the Public Works Department that action had to be taken. The need was emphasised by predictions of the impact that both current and further clearing might have on the eventual inflow salinity to Wellington Reservoir (Loh, 1974).

The estimates indicated that without control of further clearing average inflow salinities could ultimately reach 1700 mg/L. No rigorous scientific validation of the simple model used was made, nor was it possible at the time. However, the estimates were never seriously questioned and were used as a major point in the argument for the introduction of clearing controls. After considerable debate, within the bureaucracy and within government, about the appropriate legislation to be used and whether compensation should be paid to farmers financially affected, a bill amending the Country Areas Water Supply Act was passed in November 1976.

While small scale essential clearing is licenced, large scale agricultural development is not permitted. Farmers affected can claim compensation for their inability to further develop their farm enterprise.

Application of the legislation has effectively held the level of clearing to 64 000 ha or 23% of the total catchment and has avoided the expansion of agriculture to a possible 100 000 ha or 35% of the total catchment.

Prediction at the time indicated that if clearing was maintained at the 1976 level the salinity of inflow in a median year would ultimately reach about 1100 mg/L TSS. Subsequent detailed groundwater simulation studies (Hookey, 1987) have been carried out on subcatchments in the extreme eastern portion of the catchment which suggest that the original estimates are of the correct order. If the catchment as a whole is similar to the areas studied in detail then salinities observed to date reflect about two-thirds of the full effect of past clearing. The ultimate salinity of a median inflow year could range from 1050 to 1250 mg/L but the best estimate is considered to be approximately 1150 mg/L TSS. The groundwater simulations indicate the salinity of inflow discharge will approach 1100 mg/L in about the year 2010 when 95% of the full effect of previous clearing should have developed. Ultimate equilibrium is approached slowly and should be achieved about 2040.

The estimated future "average" inflow salinities resulting from past clearing are shown in Figure 5.

Figure 5 also shows the trend in salinities of median inflow years if the clearing control legislation had not been imposed and clearing had continued to its potential of 100 000 ha by 1990. Ultimate salinity in a year of median flow would have reached 1700 mg/L TSS, while in a dry year (90% probability of exceedance) salinity would have approached 3000 mg/L TSS.

4.2 What Can We Learn From This History?

Drawing lessons from history is clearly a subjective activity. Moreso when the interpretation can cover the diverse fields of statistical analysis, scientific research, engineering planning and investigation and the socio-political mileau in which these technical disciplines operate.

There can be little argument that much improved accuracy in the streamflow and water quality record of the 1960's would have made it very difficult to dispute the correlation between clearing and increases in stream salinity. A sound accurate long term data collection and analysis programme is clearly necessary to identify and adequately quantify the effect of non-point source pollution problems at the water resource scale. They may not be sufficient, however, to ensure either preventitive or corrective actions are initiated early or at all.

Long delays between the cause and the full deleterious effect and the characteristic acceleration of the water quality deterioration with time, features common to many environment problems and certainly present in the Wellington Reservoir inflow salinity case, significantly limit the value of monitoring programmes alone. The first identification of deterioration in quality can be so delayed that preventative measures alone will often be insufficient protection and expensive corrective measures are likely to become essential.

The ability to reliably predict future inflow salinities is clearly also necessary if land use planning and catchment management is to be improved and made more timely.

In our case study it wasn't until the early 1970's that the first statistical analysis could show any significant time trend of deterioration in reservoir supply salinities (Gwynne, 1972). The reworking of the original data (Loh, 1986) showed that, with considerable effort to remove seasonal variations caused by wet and dry years, a small but significant deterioration by the mid 1960's could be identified. Neither of these analyses could show the ultimate deterioration that is likely to occur.

Prediction of the impact of catchment management and land change on water quality is very difficult. Scientific understanding of factors causing the problem and quantification of these effects over a wide range of space and time scales is required for sound verifiable predictions. Establishing a scientifically rigorous prediction method is costly, time consuming and open to ongoing scientific debate.

Our history suggests that events can overtake the establishment of long term scientifically rigorous experiments. One of the initial aims of the experimental catchments in the Wellington Catchment region was to establish clear evidence for the link between clearing and increases in salinity. However, within a year of the study being fully established this relationship was generally accepted within the bureacracy and within government and action to introduce clearing controls had been commenced. This is not to say that the research has not been extremely valuable. The objectives were redirected to emphasise the quantification of the impact of agricultural development and have therefore proved useful in improving stream salinity predictions and evaluating remedial strategies.

Our case history also indicates that scientific rigor and validation of prediction estimates was <u>not</u> a necessary condition before prediction results were accepted and difficult catchment management decisions made.

It is a fact of life that prediction of the effects of land use change will always be uncertain. Whether the prediction results create controversy has as much or more to do with the social and political environment of the day, as the adequacy of the prediction itself. There is little doubt that any suggestion in the mid 1960's that inflow salinities to Wellington Reservoir could reach 1700 mg/L if all privately owned land had been cleared, would have been strongly questioned by those involved in the agricultural industry. "Average" inflow salinities at the time were only about 400 mg/L. Independent scientific validation would have been demanded but would not have been possible at the time. In a strict scientific sense it is still probably not possible today.

The regional water resource planning perspective and public awareness of the severity of the problem which had emerged by the mid 1970's, was clearly most important in changing the socio-political climate from one of general reluctance to act to one of recognising an urgent need to act.

By the mid 1970's prediction techniques were required to support the already accepted need for action rather than convince reluctant decision makes of the need for action. In this context relatively simple prediction techniques applicable to large river basins, using the then current regional data and limited quantitative knowledge was all that was required. Sophisticated groundwater simulation studies validated from detailed long term research at specific sites would not have contributed much to the argument for legislative control. In other words detailed scientific study of the hydrologic processes involved may be desirable but not essential to improved catchment management policy.

In summary, the following influences all contributed to the establishment of clearing controls in 1976.

- high supply salinities in dry years,
- regional water resource monitoring and related hydrologic analysis,
- scientific study of the problem,
- regional water resource planning and related public awareness of the seriousness of the problem.

The relative importance one places on these specific areas is a subjective judgement influenced strongly by whether ones background is in water supply engineering, hydrologic monitoring and analysis, the earth sciences or water resource planning.

Nevertheless, all contributed and it is necessary to recognise this fact.

Perhaps the most important lessons to be learnt from this history is that catchment management is not the preserve of any one discipline, that factors far removed from stream sampling strategies or soil salt storage determinations can be most important and that relevant work to improve catchment management decisions needs to proceed on a broad front, incorporating numerous disciplines, working at a variety of time and space scales.

5. STRATEGIES TO REDUCE RESERVOIR SUPPLY SALINITIES

The predicted increases in salinity of inflow even with the clearing control clearly indicated that additional remedial action was required. During the mid to late 1970's a range of engineering and catchment management options were investigated and implemented.

5.1 Improved Reservoir Operations

While the quality of supply from Wellington Reservoir is dominated by the quality of inflow there is scope to operate the reservoir in such a way as to minimise the salinity of supply to the Great Southern Towns Water Supply Scheme.

Results from a research project on the water mixing processes in Wellington Reservoir (Imberger and Hebbert, 1980) first identified strong seasonal layering of salinity in the reservoir in 1975. Initial flows from the eastern portion of the catchment at the start of each winter are cold and highly saline, often over 3000 mg/L TSS. As this inflow is more dense than the stored water, it underflows the waterbody and lodges at the base of the reservoir. By selectively releasing this saline water during early winter and also by supplying summer irrigation water from the base of the reservoir, improvements in the town water supply quality are possible. A new operating policy based on these concepts was introduced in 1976 and has been working effectively since.

The benefits obtained have been studied in detail using the most recent version of a complex reservoir simulation programme which takes into account all the main mixing processes in Wellington Reservoir (Meares, Jokela and Patterson, 1985). Daily simulations of the salinity and temperature structure and daily predictions of the salinity of both town water supply and irrigation releases have been made for an eight year study period from 1974 to 1982 (Hookey and Loh, 1985).

Average improvements in salinity of approximately 10% and 5% have been estimated for town water and irrigation supplies respectively. Smaller percentage improvements occur in times of high salinity. While the percentage improvements are relatively small they have been achieved at little or no cost and have been important in limiting the salinity of supply through a very dry period in the late 1970's when salinities reached their highest levels yet recorded.

5.2 Saline Diversion Options

While improved management of the reservoir provided an important if small, benefit at little cost, it was recognised that major improvements in supply salinities had to come from reducing inflow salinity to the reservoir.

Active evaluations of remedial actions commenced in 1977. Initial saline diversion feasibility studies were carried out in conjunction with costing of a partial reforestation strategy (PWD, 1979). The diversion schemes involved constructing up to 3 dams on saline tributories in the east and south of the catchment and pumping the discharge over the divide to the already saline Blackwood River System. For similar reductions in stream salinity, the diversion costs were at least 3 times more expensive than the then estimated costs of partial reforestation. More detailed engineering evaluations in 1981 indicated that the most effective schemes would produce improvements of order 400 mg/L in the salinity of an average inflow year for a net present value of $24 million (in 1982 dollar values).

They remained much more expensive than the reforestation strategies that were assessed as costing between $7 and $14 million. The saline diversion storages impacted significant agricultural land and posed environmental problems associated with the disposal of the saline effluent.

However, the reassessment of saline diversions highlighted some of the positive aspects of engineering solutions. They have clear quantifiable benefits in reducing inflow salinities to the reservoir and these reductions are larger in the drought years when inflow salinities are naturally higher. Moreover their benefits are realised immediately construction is completed.

5.3 Partial Reforestation

Although very little was known about the magnitude and time scales of the effects of reforestation strategies in the late 1970's, the biological or catchment management approach appeared much more attractive than engineering options.

The reforestation programme was initially proposed to run for six to ten years with an annual replanting target of 2000 ha. This was adopted as an ambitious target with the hope that it would be sufficient to avoid the need for other engineering solutions to the inland towns water supply scheme. The actual planting rate achieved has varied between 700 and 800 ha per year, with a total of 4 300 ha having been reforested to 1085. The reforestation strategy involved planting along the valley bottoms and lower side-slopes, the remaining mid and upper slopes providing viable strips of cleared farmland which could then be exchanged for lower slope land areas on adjacent farmland to further extend the area of reforestation.

By September 1984 sufficient land had been purchased to enable approximately 8000 ha to be planted. When planting of this area is complete, the total costs of reforestation are expected to be $13 million. This reforestation, which will take several years to complete, will in the longer term exert some control of salt discharges from 18 500 ha of the 51 000 ha of cleared farmland in the highly salt susceptible zones of the catchment. There is however, considerable uncertainty in assessing the magnitude of the salinity reductions which will be achieved by the present reforestation programme.

Despite the difficulties in reliably estimating the effects of reforestation, calculations can be made using knowledge of the distribution of water and salt discharge across the catchment and by assuming various levels of effectiveness of the reforestation in controlling saline groundwater discharge. Estimates of the time scale for reforestation to reduce groundwater levels has been based on the groundwater simulation studies noted above. Assuming the current replanting programme is moderately effective (reducing groundwater discharges by 70%) then long-term salinities of inflow will ultimately reach about 950 mg/L TSS in a median year. The current reforestation programme should therefore reduce the expected level in 2010 (1100 mg/L TSS) by about 150 mg/L, equivalent to a long-term deterioration of about 70 mg/L TSS over 1985/86 levels (see Figure 6).

However, an important limitation on the usefulness of reforestation is the slow rate at which trees become effective in reducing the discharge of saline groundwaters to the surface stream system. The problem is further compounded by the present rate of planting, which is significantly below the rate initially envisaged. Reforestation is not achieving the required salinity reductions quickly enough to meet the needs of the Great Southern Towns Water Supply.

While the reforestation programme will limit the rate of rise of inflow salinity during the 1980's present knowledge suggests that trees will not significantly reduce inflow salinities until the mid to late 1990's. Peak inflow salinities can therefore be expected in the early to mid 1990's.

The inflow salinity in a median year in the mid 1990's is expected to be about 1005 mg/L and reach approximately 1610 mg/L in a dry year.

With the reforestation scheme and implementation of the improved reservoir operating strategies inland town supply salinities are expected to the limited to an average of 940 in the early to mid 1990s. If that period turns out to be a run of dry years similar to the late 1970's supply salinities could exceed 1310 mg/L TSS.

5.4 Engineering Options to Improve the Inland town Water Supply.

The need to more rapidly improve the inland town water supply was recognised in the early 1980's only a few years into the partial reforestation scheme. A large number of engineering alternatives were considered to determine the most cost effective means of improving the inland town supply. Comprehensive cost benefits analysis was performed on some 9 options and a full Environmental Review and Management Programme prepared (WAWA, 1985).

The proposed Harris River storage, on a fresh tributory of the Wellington Reservoir was selected as the most cost effective solution. Town Water Supply salinities would be reduced to below 250 mg/L TSS. Detailed hydrologic and hydrodynamic studies were performed (Hookey and Loh, 1985) to develop a feasible operating strategy to ensure that the new storage would not adversely affect the average quality of irrigation supply. Considerable public debate occurred over the location and sizing of the storage during the environmental review process. The capital cost of the final scheme approved is about $35 million.

This expenditure only provides 11 x $10^6 m^3$ of good quality town water supply. The remaining 80 x $10^6 m^3$ of current irrigation demand remains of marginal quality. The storage was sized to ensure that the irrigation quality was on average, not made worse by the scheme.

5.5 Discussion

As the development of remedial strategies have only occurred over the last 10 years and are ongoing, it is difficult to provide a clear historical perspective. Nevertheless the experience has emphasised some important contrasts between engineering and land management options.

For an engineering organisation such as the Public Works Department to opt for a catchment management strategy rather than engineering solutions was unusual even in the late 1970's. The difficulties and expense of saline diversions, particularly their ongoing pumpage costs and significant environmental problems with the effluent disposal from the catchment were very apparent (Sadler and Williams, 1981). From a broad planning perspective the partial reforestation scheme appeared highly attractive, despite its considerable uncertainties. A relatively conservative approach to the partial reforestation design could be adopted and still provide a cheaper and more environmentally sound approach than saline diversion.

While the uncertainties of reforestation were appreciated in a planning sense, the difficulties of land aquisition, subdivision and exchange and of the practical forestry issues of tree establishment and management were under estimated.

Implementation of the scheme required specific information about groundwater recharge rates and hydraulic properties of the aquifers involved and knowledge on tree survival, growth rates and water use characteristics. Much of this information was not available at the early years of the programame although considerable applied research and investigation is now providing much useful data to improve reforestation design.

Early uncertainties in the design and difficulties in land aquisition, exchange and ongoing management emphasised the inability to quantify the benefits and costs of reforestation. They contributed to decisions to proceed with investigating engineering options to solve the inland town water supply problem and to the decision in 1985 to limit the scale of the reforestation programme.

Catchment management strategies are relatively easy to substantially modify or scale down as they proceed unlike many engineering schemes. Other (related) factors also contributed. The restructuring of the water industry in Western Australia took place in 1985 with the merging of the Metropolitan Water Authority and the Engineering Division of the Public Works Department. The resultant organisation, the Water Authority of Western Australia, is a semi government body with a stronger commercial orientation than the previous Public Works Department.

Consequently the pressure for comprehensive economic evaluation and more detailed cost benefit analysis of proposed projects had increased by the mid 1980's.

Cost benefit analysis strongly favours engineering solutions over long term catchment management strategies such as reforestation. Engineering solutions accrue benefits quickly in contrast to catchment management strategies which often take many years to implement and may take decades before their benefits are fully realised.

The economic rationalist approach effectively addresses the efficient use of financial resources in the short term and lets the future look after itself.

When it became clear that reforestation would not provide a benefit sufficiently quickly for the inland towns and an alternative would have to be found, a continued reforestation programme would only benefit the irrigation area or some other future water user if the resource became unfit for irrigation. As no concrete evidence was available that there had been an economic loss to the irrigation district there was little economic justification for continued reforestation.

Nevertheless as a consequence of the 'environmental review process' and as a condition of approval of the Harris Dam Project, the EPA made it a statutory requirement of the Water Authority to review its reforestation programme and commit itself to an ongoing catchment management strategy of restoration of the full water resource.

A long term objective was set of "returning the Collie River to a salinity level such that the quality of water supplied from Wellington Reservoir is suitable for domestic water supplies".

CONCLUDING REMARKS

Our historical review of catchment and reservoir management on Wellington Reservoir Catchment has highlighted a wide range of issues spanning the technical, scientific, social and political arenas.

A common thread between them, however, is the long time frame between cause and effect and between recognition of the problem and the development of a satisfactory solution. The delay between clearing and its ultimate effect on stream salinity made it very difficult to obtain political action in the 1960's when action was required.

A rigorous prediction capacity would have been necessary to highlight the need for action. Such information was not available as the problem was not widely recognised and resources were not available for such research. The situation had to deteriorate before a commitment to research developed.

Research always lags behind need. The problem is accentuated when the time frames to both quantify the problem and identify effective solutions are so long. While the current emphasis on economic efficiency within the water industry does not fit easily with long term reforestation strategies ultimately necessary to resolve the salinity problem, the pressure to protect and restore scarce resources for environmental and long term strategic planning reasons is also strong.

Our history has also emphasised the social and political context in which water resource planning decisions are made. Unfortunately social and political processes operate on a much shorter time frame than our stream salinity problem. The Wellington Reservoir catchment salinity issue is but one example of a whole range of catchment management and environmental problems that are inherently difficult to avoid and/or resolve because of their long term nature. An important lesson from our history is that a wider public awareness of the seriousness of the problem and its long term nature was a most important difference between the 1960's and 1970's, a fact that contributed to the successful introduction of clearing central legislation in 1976.

Rational and informed debate within the community on such planning and management issues are critical if we are to improve out catchment management decision making.

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LIST OF TITLE OF FIGURES

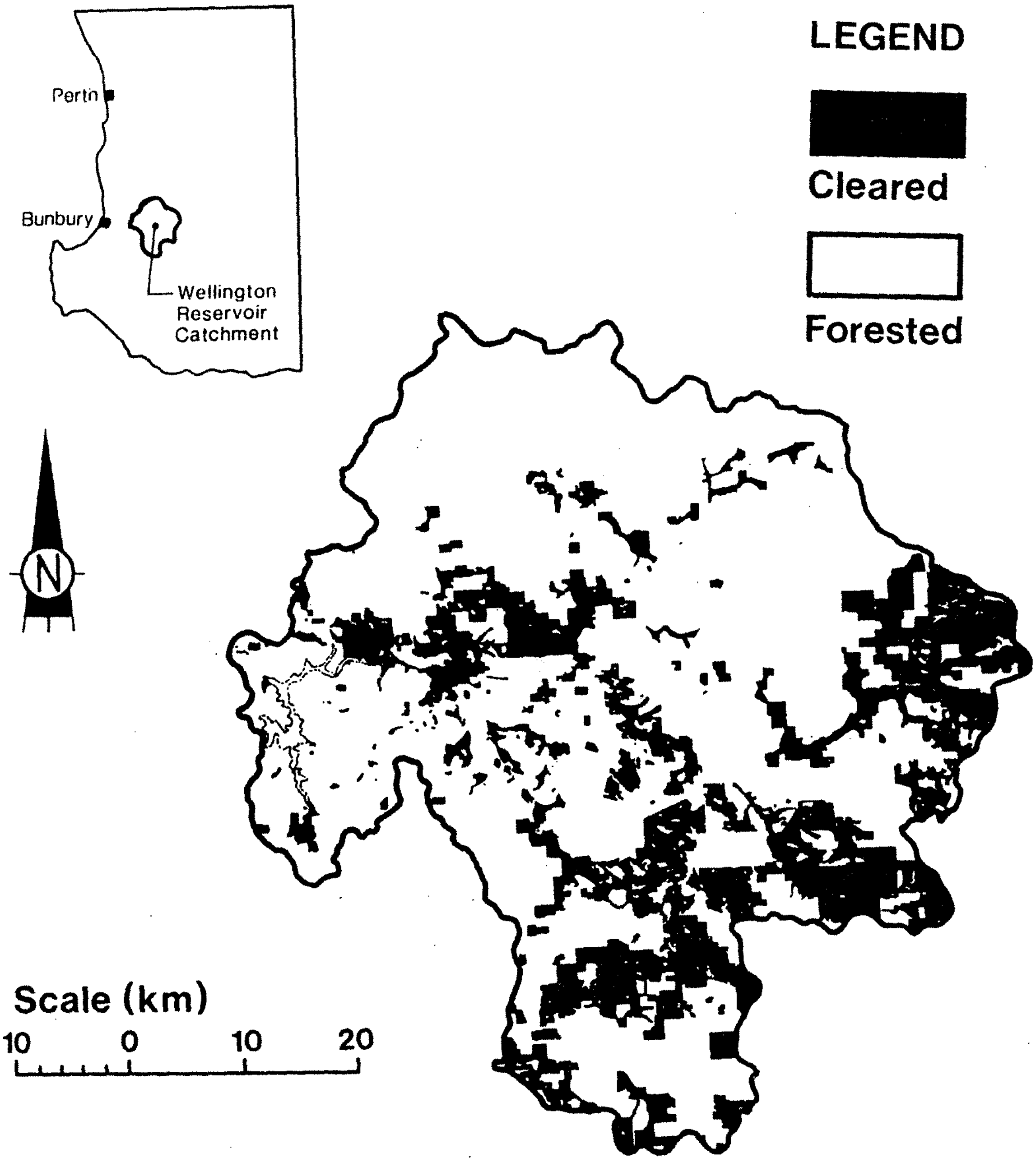

Figure 1 Location and Distribution of Agricultural Development on Wellington Reservoir Catchment (as at 1977)

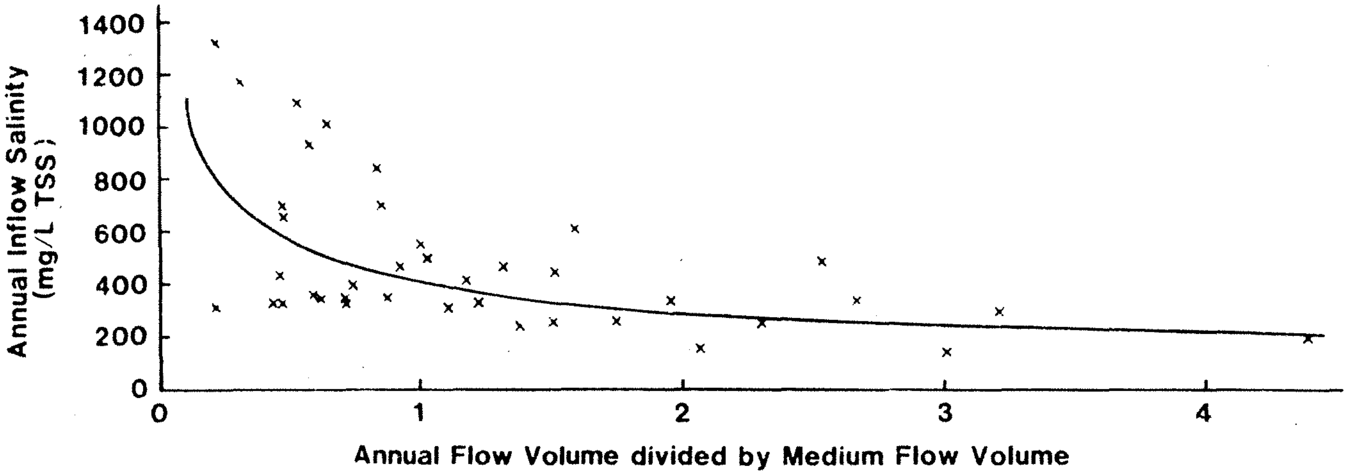

Figure 2 Relationship between Annual Inflow Salinity and Inflow Volume

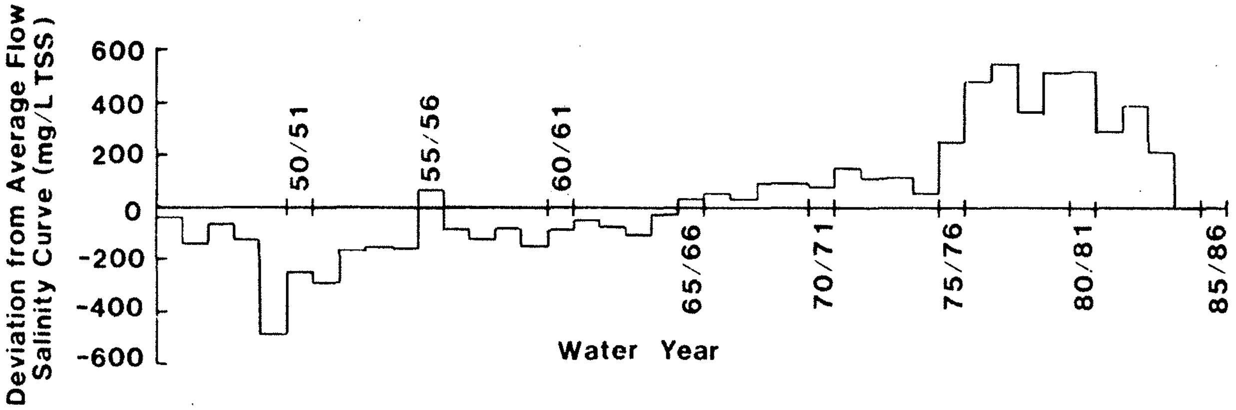

Figure 3 Time trend in deviations from average flow - salinity relationship

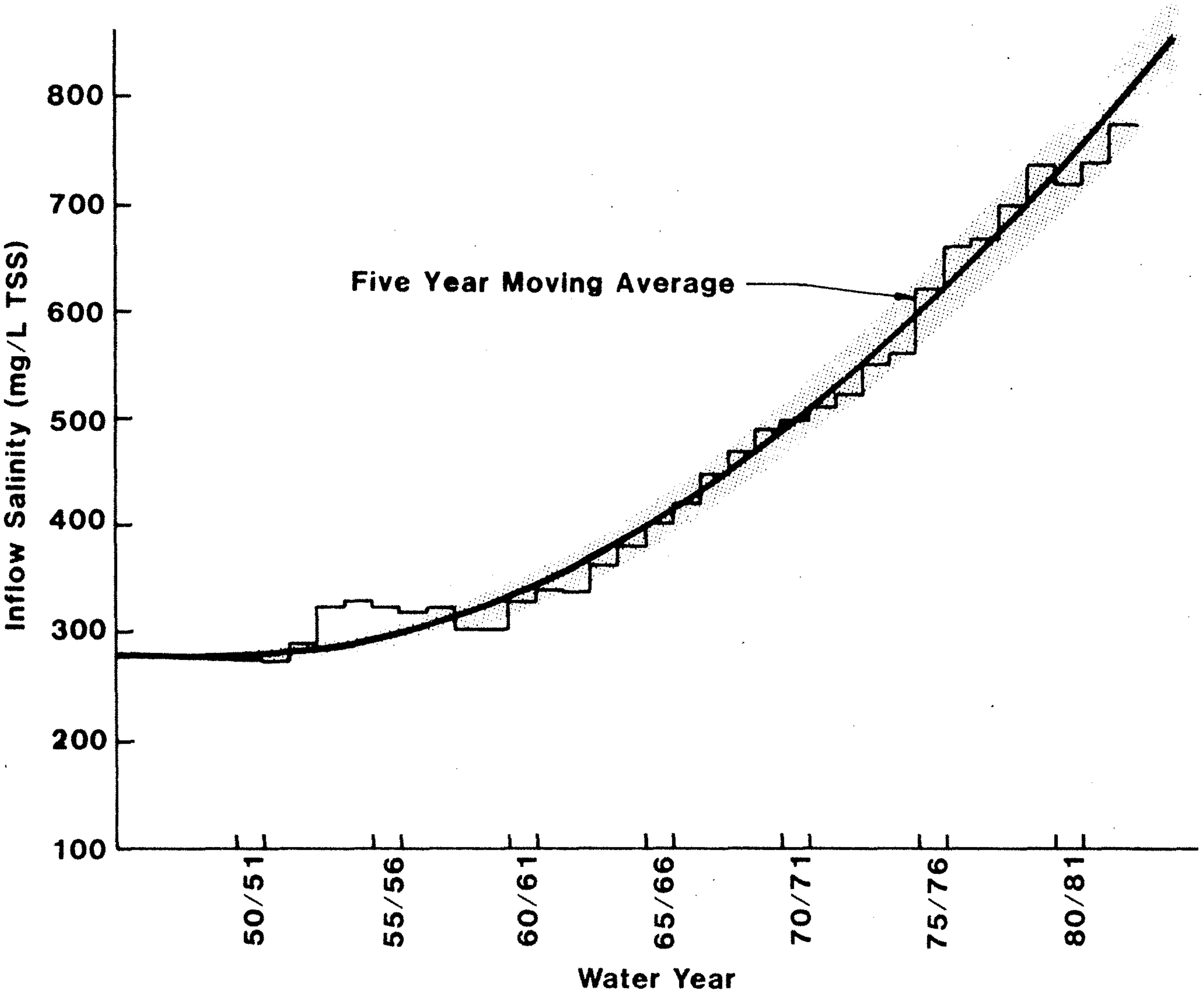

Figure 4 Time trend in the salinity of a median in flow year

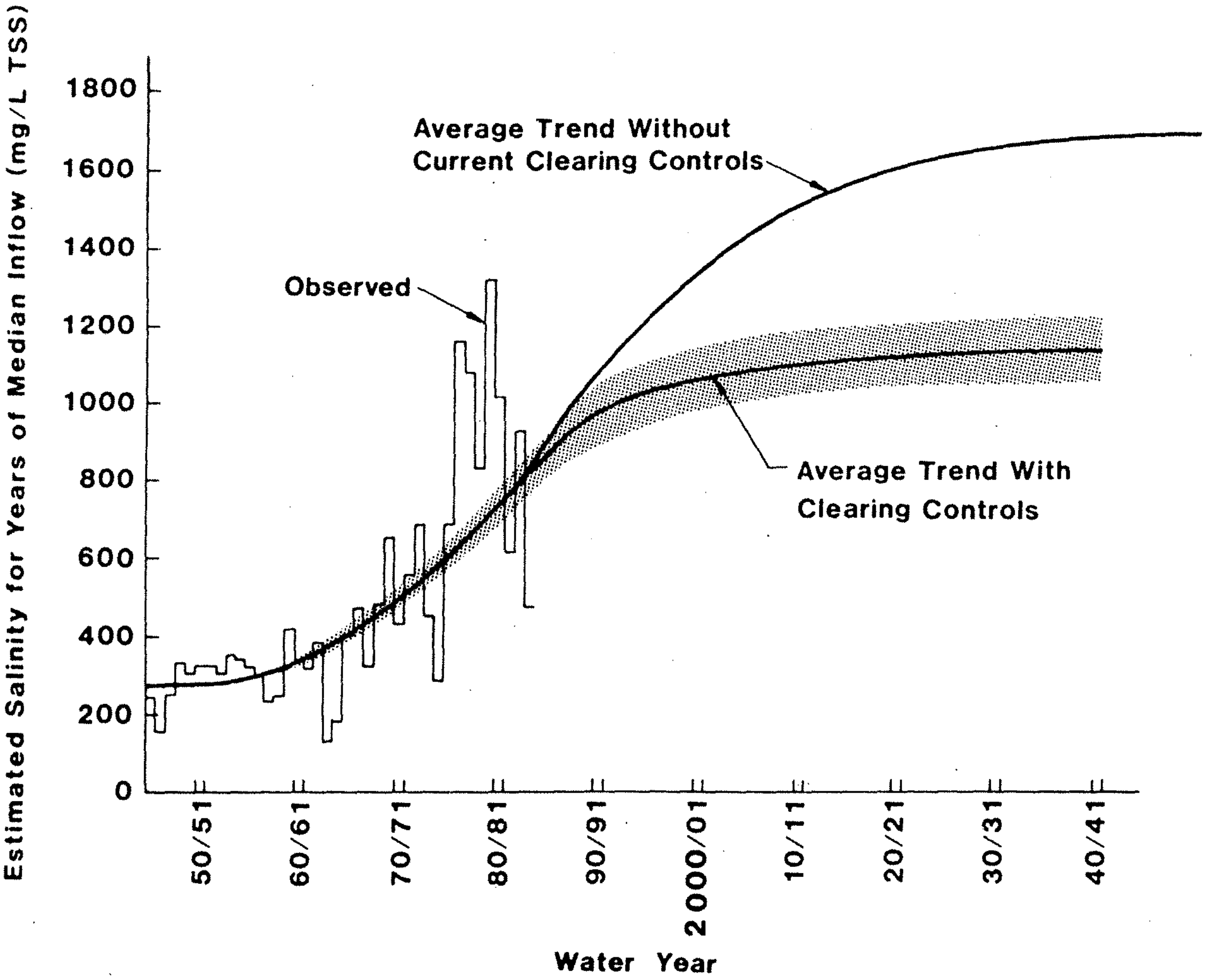

Figure 5 Observed and projected salinities for a median inflow year, with and without clearing controls

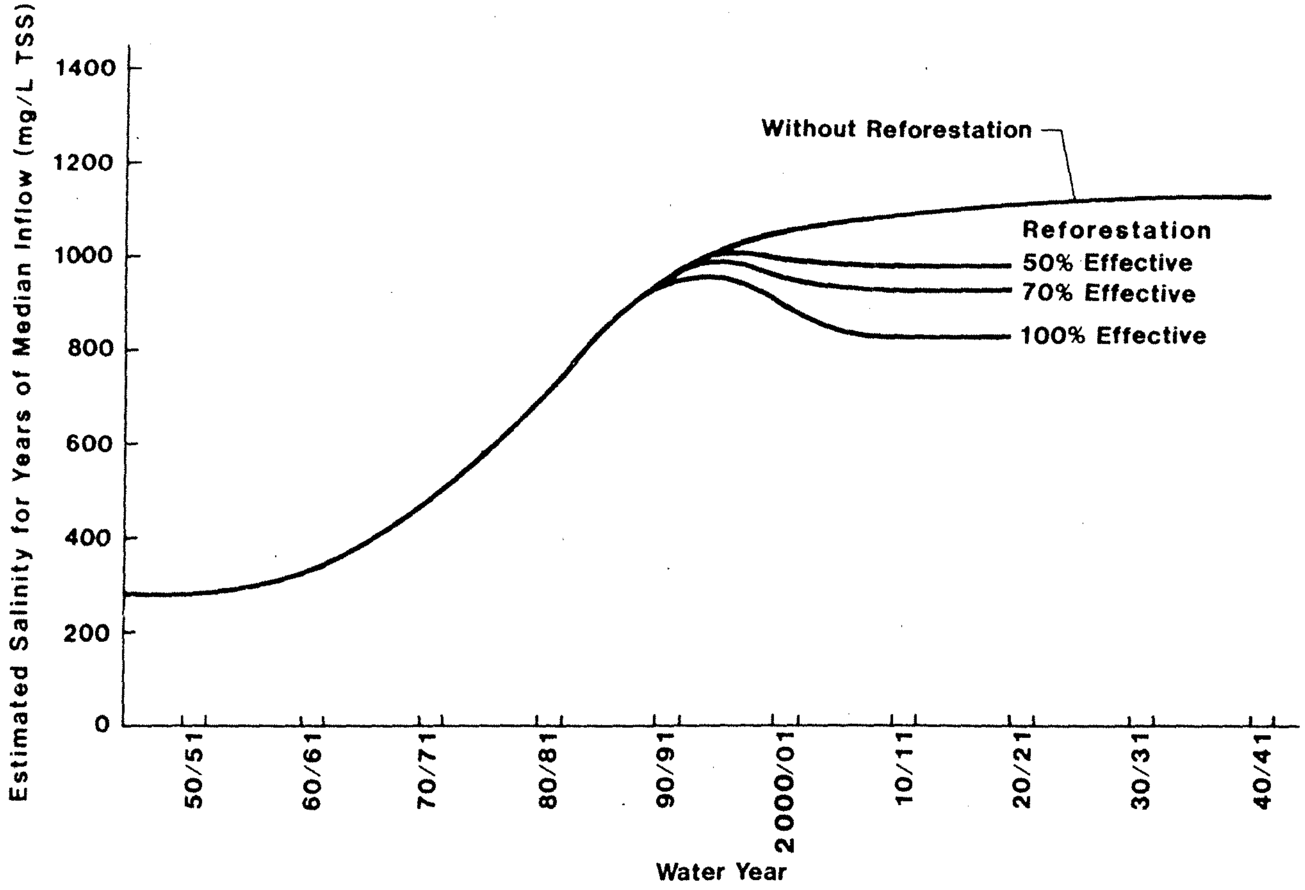

Figure 6 The effect of the current 8000 ha reforestation programme on salinities of a median inflow year.