DRAFT

WATER AUTHORITY
of Western Australia

Harris Dam Project
Environmental Review and Management Programme

ISBN 0 7244 6798 X

Dames & Moore
October 1985

DRAFT

WATER AUTHORITY
of Western Australia

WATER RESOURCES DIRECTORATE
Water Resources Planning Branch

Harris Dam Project
Environmental Review and Management Programme

Published by the
Water Authority of Western Australia
John Tonkin Water Centre
629 Newcastle Street
Leederville WA 6007
Telephone: (09) 420 2420

ISBN 0 7244 6798 X
Report No. WP 2
October 1985

TABLE OF CONTENTS

Page No.

Page No.

Page No.

VOLUME OF APPENDICES (SEPARATE DOCUMENT)

LIST OF FIGURES

LIST OF TABLES

SUMMARY

SUMMARY

THE PROBLEM

Drinking water supplied from Wellington Reservoir to consumers on the Great Southern Towns Water Supply (GSTWS) scheme is expected to increase in salinity content to levels which exceed the National Health and Medical Research Council's long term objective for water quality most of the time. Annual variations have the potential to exceed acceptable levels for two or three years in ten. The salinity of the water supplied for irrigation purposes from Wellington Reservoir is expected to be only marginally acceptable for irrigation. These salinity increases have resulted from the clearing of native vegetation from farmland within the catchment. Revegetation of the catchment would only slowly reverse the rising salinity trend and the degree of correction possible is still uncertain.

An improved, secure source of low salinity water is therefore required for the GSTWS. Solutions with the potential to better manage salinity levels in the irrigation water would also be desirable. This source must be feasible, cost-effective and have an acceptable level of environmental impact in view of the benefits it produces. This Environmental Review and Management Programme (ERMP) reviews the options available, considers their costs, benefits and environmental impacts and proposes management strategies to minimise adverse impacts and optimise positive impacts.

OPTIONS CONSIDERED

The quality of water supplied to the GSTWS could be improved by:

- Revegetation to slow the release of salt
- Removing salt from the existing reservoir
- Diverting saline water away from the existing reservoir
- Developing a new supply source

Combinations within and between these strategies have also been considered. In all, over 200 options and combinations were considered. Those which were most likely to be feasible, cost-effective and have acceptable environmental impacts are considered in detail in this ERMP. These options are:

- Partial reforestation of Wellington catchment and reservoir management
- Full reforestation
- Desalination of Wellington Reservoir water
- Diversion of saline flows away from Wellington Reservoir
- Development of Collie Coal Basin groundwater
- Raising the existing Stirling Dam
- Building a new dam on the Brunswick River
- Building a new dam on the Harris River

The Harris and Brunswick Dam options are the only ones able to cost effectively meet all objectives for the supply of adequate, high quality water to the GSTWS in the short term. As the Harris Dam has the highest benefit - cost ratio and rates slightly better than the Brunswick Dam on environmental issues, it is the selected alternative. A dam on the Harris River will supply water with average salinities better than 250mg/l because the catchment is forested. Better management of freshwater inflows from Harris Dam to Wellington Reservoir will also permit irrigation salinity levels to be better controlled.

THE HARRIS DAM

Two sites were examined in detail on the Harris River. The Harris 5 site has better foundation conditions and avoids resumption of farms located between it and the lower Harris 1 site. However it is not capable of developing the same yield.

The dam would be homogenous faced earth fill, 430 m long at the crest and 30 m from riverbed to crest. Full supply level would be 223.5 m above Australian Height Datum which will avoid flooding the environmentally sensitive Twenty-Two Mile Pool and the Lane-Poole Reserve upstream. The reservoir will store 71×10^6 m^3 of water and have a reservoir surface area of about 990 ha. The expected cost is $30M at December 1985 values. Construction would be scheduled to start in August 1987 and be complete by May 1989.

ENVIRONMENTAL ISSUES AND THEIR MANAGEMENT

The key environmental issues in the Harris River catchment are the wetlands and pools of Trees Plain, the status of the upper part of the catchment as a conservation reserve (Lane-Poole Reserve), the clearing of slightly less than 850 ha of forest and the need to maintain forest hygiene standards.

The full supply level of the proposed dam has been designed to stay below the lowest of the permanent pools; Twenty-Two Mile Pool. As such it also avoids Trees Plain, Lane-Poole Reserve and a site of significance to Aborigines at Wuridjong Pool.

A small population of the gazetted rare plant species Grevillea drummondii would be flooded by the reservoir. This species also occurs at a number of locations below the damsite. The plant is commercially available and attempts will be made to have it included in landscaping the site. Two sensitive animals, the Quokka (Setonix brachyurus) and the Red-Eared Firetail Finch (Emblema oculata) occur in the catchment. Both favour the thickets typical of the Trees Plain swamp; hence protection of the swamp will afford protection of these species.

Arrangements will be made with the Department of Conservation and Land Management (CALM) to have all merchantable timber removed prior to clearing. Full liaison will be maintained with CALM in accordance with forest hygiene requirements. Equipment will be confined to the reservoir basin and the immediate area of the dam wall and associated works.

Creation of a new GSTWS supply on the Harris River will free Wellington Reservoir for recreation. The Water Authority proposes to prepare a management plan for recreation on the Wellington Reservoir, in conjunction with surrounding landowners, state and local government agencies and other interested parties.

The Water Authority ackowledges its obligations under the Aboriginal Heritage Act and will comply with the directions of the relevent Minister in regard to the archaelogical sites present.

CONCLUSIONS

A study of over 200 options to supply high quality drinking water to the GSTWS has identified the Harris River Dam as the most cost-effective and least environmentally sensitive source of supply. Properly managed, in accordance with the commitments made in this ERMP, the construction and operation of the dam should not result in environmental impacts which are likely to outweigh the potential benefits.

DRAFT ENVIRONMENTAL REVIEW AND MANAGEMENT PROGRAMME HARRIS DAM PROJECT

1.0 INTRODUCTION

1.1 GENERAL

At present, Wellington Reservoir, 19km southwest of Collie, Western Australia, supplies domestic water to the Great Southern Towns Water Supply (GSTWS) and to the Collie Irrigation District on the Swan Coastal Plain (Figure 1).

The Reservoir has a capacity of $185 \times 10^6 m^3$ and an annual yield of $100 \times 10^6 m^3$. Domestic supplies to Collie and the GSTWS Scheme from Wellington Dam amounted to almost $7 \times 10^6 m^3$ in 1984/85, and a further $70 \times 10^6 m^3$ are supplied for irrigation purposes. Demand for the Great Southern Scheme is expected to rise to $11 \times 10^6 m^3$ per year within the next 20 years.

The trend of increasing salinity in the water supplied from Wellington Reservoir over the last decade is cause for considerable concern (Figure 2). Current projections indicate that the quality of water supplied from Wellington Reservoir will not comply with National Health and Medical Research Council (NH&MRC) limits for considerable periods of time.

A wide ranging investigation of the options available for correcting the salinity problem has been undertaken. This report considers the case for supplying water to the GSTWS from a location known as Damsite 5 on the Harris River (Figure 1).

This document presents the Environmental Review and Management Programme (ERMP) for the proposal prepared in accordance with requirements of the States' Environmental Protection Act, 1971-80.

Wherever 'environmental report' is referred to in this report, it refers to this ERMP.

1.2 OBJECTIVES

Alternatives for the supply of water to the GSTWS and Collie Irrigation District have been examined in the light of the following objectives:

- To determine the optimum quality of the water which should be supplied to domestic services
- To supply water of this quality, in a cost effective manner, as soon as possible
- To ensure adequate water is available to meet the projected demand for domestic supplies serviced by the GSTWS beyond the year 2000
- To facilitate the management of freshwater inflows into Wellington Reservoir so that the average quality of irrigation water can be maintained.

2.0 DESIRABLE WATER QUALITY CRITERIA

Water quality standards are set primarily to achieve satisfactory health, taste and aesthetic levels. The NH&MRC, within the Australian Department of Health, sets out two criteria for water quality. "Desirable current criteria" are maximum levels which may be used, as appropriate to present Australian conditions, to give water of satisfactory quality. "Long term objectives" are more stringent levels which could be aspired to, and which, if achieved, result in drinking water of excellent quality (Australian Department of Health, 1980). Thus new sources should attempt to meet the long term objectives wherever possible.

Comparisons of World Health Organisation (WHO) and NH&MRC recommendations on some commonly adopted quality criteria for total salts, chlorides and sodium are set out in Table 1.

TABLE 1

WATER QUALITY CRITERIA

SOURCE	PARAMETER TSS (mg/l)	CHLORIDE (mg/l)	SODIUM (mg/l)
NH&MRC 1980			
desirable current criteria	1500	600	
longterm objective	500	200	
WHO 1984			
guideline values	1000	250	200

The NH&MRC criterion for drinking water sets 1,500mg/l total salts as an acceptable upper limit for drinking water quality, with chlorides limited to 600mg/l. Palatability becomes quite adversely affected at this level of chlorides. In the waters typical of southwest Australian rivers, the chloride criterion is exceeded before salinities reach the total salts criterion. The 600mg/l upper limit for chlorides corresponds to 1,100 mg/l of total salts in these waters.

The NH&MRC sets a long term objective of 500mg/l for total salts and 200mg/l for chlorides. The 200mg/l chloride limit corresponds to just under 400mg/l total salts in southwest Australian rivers. Thus, the relatively high level of chlorides in these waters sets the quality criteria for total salts effectively at 1,100mg/l as an acceptable upper limit, and 400mg/l as a long term objective.

Sodium has been implicated as a contributing factor to elevated blood pressure and hypertension. Although there are no set standards for sodium content of water for human consumption, an Australian National Health and Medical Research Council working party has suggested a maximum level of 115mg/l with a long-term objective of 57.5mg/l (NH&MRC, 1984). These levels are well below the 200mg/l guideline value for sodium set by the World Health Organisation (WHO, 1984) and could not be met for many water supplies in this country. While the working party recommendation has not been adopted by the Australian Water Resources Council, it is an indication that some health benefits can accrue through having water supply quality at levels lower than the long term objective.

3.0 WATER QUALITY DETERIORATION

The causes of, projections for, and present control of water supply salinities are outlined below. A more detailed discussion of these important topics is contained in Appendix M.

3.1 CAUSES OF THE INCREASE IN SALINITY

Removal of perennial forest vegetation and its replacement with annual crops and pastures has resulted in additional water recharging the groundwater system. As groundwaters rise, some of the salts stored in the soil profile are mobilised, and eventually additional salt and groundwater discharge to the surface streams. Major increases in stream salinities result in the accumulation of large stores of salts at low points in the landscape. This generally occurs where annual rainfall is less than 900mm per annum. Streams draining agricultural land in these regions commonly have average salinities in excess of 3,000mg/l.

Where rainfall is over 1,000mm per annum, salt storage is much lower, and clearing may result in additional flows of fresh, rather than salty, surface and shallow subsurface waters. Under these conditions, increases in streamflow salinity are much smaller or even undetectable (Appendix M). In addition, much of this area is State forest and will continue to support perennial vegetation.

3.2 EFFECT OF CATCHMENT CLEARING ON SALINITY

The impact of agricultural development on the inflow salinity to Wellington Reservoir is clearly depicted in Figure 2. While large variations in inflow salinity occur from year to year, as a result of variations in the volume of streamflow to the reservoir, a clear trend of deteriorating water quality is apparent. The salinity of median inflow for 1945 has been estimated to have been about 280mg/l Total Soluble Salts (TSS). By 1984 the salinity of a year of median inflow had deteriorated to 850mg/l TSS and is continuing to deteriorate at a rate of 30mg/l per year. Salinities in dry years can be 50% to 100%

higher than values in average years. The current estimate of the salinity in a dry year (defined here as a year with rainfall which is exceeded in 90% of years) is 1,370mg/l.

If clearing of the alienated land in the Wellington Dam catchment had been allowed to continue (see Section 3.3), water quality could have deteriorated to a predicted average of 1,700mg/l total salts. In extremely dry years the salinity could have approached 3,000mg/l. This problem is further exacerbated by increases in salinity, due to evaporative concentration, as the water flows through the storages in the distribution system serving the Great Southern Towns. Salinity increases of the order of up to 15% are not uncommon.

As well as concern for the effect of rising salinity on the water being supplied to Collie and the Great Southern towns, there is concern for the effect on irrigation supplies and the, as yet undeveloped, part of the resource which will be needed by future generations.

3.3 CLEARING CONTROLS AND REFORESTATION

In 1976 the Country Areas Water Supply Act was amended to prohibit unlicensed clearing of native vegetation within Wellington Dam catchment. At that time 100,000 hectares of catchment had been alienated and 64,000 hectares had been cleared. With clearing restrictions as the only control measure, the salinity of inflow to Wellington Reservoir was expected to rise to an average of 1,100mg/l TSS by about 2010. This average could then be exceeded one year in two and in extremely dry years the salinity could reach a peak of approximately 1,800mg/l TSS by about 2010. As this quality is unacceptable for both drinking and irrigation purposes and would limit the future utility of presently uncommitted yield, partial reforestation of cleared farmland to reverse the salinity trend in drier parts of the catchment commenced in 1979.

The partial reforestation programme was initially proposed to run for six to ten years with a target of 2,000 hectares being planted each year. However, due to the limited availability of land, the replanting rate actually achieved has been between 700 and 800 hectares per year and a total of 3,370 hectares have now been planted. The reforestation strategy involves 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 salt-affected areas and adjacent lower slope farmland, to further extend the area of reforestation.

By September 1984 sufficient land had been purchased to enable approximately 8,000 hectares to be planted. When this planting is complete, the total costs of partial 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 hectares of the 51,000 hectares 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 reforestation programme.

3.4 WATER QUALITY PROJECTIONS

Year to year there are significant fluctuations in the salinity of water in Wellington Reservoir. With the good winter flows into Wellington Reservoir in 1983, the mean salinity in the reservoir fell to 450mg/l TSS. The 1985 winter inflows were somewhat more saline and the water quality currently being supplied to the GSTWS is about 740-800mg/l TSS.

Presently the average annual inflow salinity to Wellington Reservoir is estimated to be 850mg/l TSS. The benefits of the reforestation programme are not expected to begin to counteract the rising salinity trend until the mid 1990's and the total effect may not be experienced for some time after that.

If the reforestation programme were moderately effective it would be expected to result in inflow salinity levels around 1,000mg/l TSS in an average year, with levels around 1,600mg/l in a run of dry years (Figure 2) by the early 1990's.

As the effect of the reforestation programme becomes more pronounced, inflow salinities to Wellington reservoir could be expected to stabilise at about 950mg/l in an average year and around 1500mg/l in a dry year.

While the quality of the water supplied 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 the supply to the GSTWS. The expected ranges of salinity which would occur in both the GSTWS and irrigation supplies are shown in Table 2, assuming moderately effective reforestation and the current best operational policy for the reservoir. The salinities shown for water supply will exceed the NH&MRC's longer term objective most of the time and annual variations will then have the potential to raise the level of chlorides over the NH&MRC's acceptable level for two or three years in ten. The irrigation water salinities shown in Table 2 are expected to be only marginally acceptable for irrigation purposes.

TABLE 2

EXPECTED SALINITIES OF WELLINGTON RESERVOIR SUPPLY (mg/l)

USER	SEASONAL* CONDITION	YEAR MID 1990's	2010
GSTWS	1	940	890
	2	1329	1256
	3	1311	1240
IRRIGATION	1	994	940
	2	1410	1333
	3	1306	1235

* 1. Mean daily salinities in an average year
2. Daily salinities which would be exceeded for 5% of the time
3. Mean daily salinities which would occur in the last year of a drought sequence similar to the late 1970's.

4.0 BENEFITS FROM IMPROVED QUALITY

4.1 PUBLIC HEALTH

Improvements in water quality have a positive value in terms of cost savings attributable to improved health standards and reductions in the need for medical care, time off work and other disbenefits. Although data, relating dollar values to increments in water quality are not available for Western Australia, the concept of benefits accruing from improved water quality is clear. This concept is embodied in the two tiered quality criteria set for drinking water by the Australian Department of Health, whereby they suggest suppliers aim for improvement in water quality above the acceptable "desirable current criteria" to the "long term objective" level and this level is considered to be appropriate for a major scheme such as the GSTWS.

4.2 CONSUMER SAVINGS

4.2.1 Domestic Services

Domestic services are here defined as those supplied to households, commercial premises and rural users. The most recent study available on the economic effect of salinity on domestic water services summarises the results of investigations in Adelaide, Melbourne and Geelong and concludes that increasing salinity by 1mg/l costs a household $0.408/year (1980 prices) (AMDEL, 1982). The major costs are incurred in soaps, detergents and water softening agents (47%) and damage to pipework, water fittings and hot water systems (40%).

There are no local data available to enable a salinity benefit function to be developed for the GSTWS. The water quality parameters for the South West and those reported in the AMDEL study are fairly similar, although the alkalinity of the Adelaide water was higher. The use of the AMDEL data, corrected for differences in the hardness of GSTWS water, is considered appropriate.

When projected to December 1985 values, this cost amounts to $0.57 per mg/l per service per year. A 1mg/l reduction in salinity is therefore assumed to save the same amount annually. Commercial and rural consumers are assumed to suffer similar types of damage as domestic users but at a reduced level, due to their lower levels of consumption.

4.2.2 Industrial Services

Information available from studies in the United States on an industrial salinity damage function (Macdonald et al., 1978) suggests that the value of salinity improvement to industry is approximately half of the value of domestic salinity improvement. In their report on the "Effect of Salinity on Industrial Users", AMDEL (1983) note that the largest costs are incurred in the use of water for boiler feed. Water salinity also has an impact on process water use and on cooling water. If lower salinity water is available, it can be recycled longer between blowdowns, thereby reducing losses of heat, water and chemicals. However, industrial water use on the GSTWS amounts to only about 8% of the total supply, and the salinity damage costs have been ignored.

4.3 IRRIGATION SUPPLIES

Increasing the salinity of irrigation water can affect overall irrigation productivity in a number of ways;

- o reduced plant growth and productivity

- o increasing the rate of rise of saline groundwater tables

- o reducing the diversity of crops which can be grown.

Of these three factors only the first has been the subject of any investigation. To date the research has not been able to show a reliable decrease in yield due to increases in salinity. The effects are expected to be small and have been marked by the variability caused by other sources of error. For instance the 1% drop in productivity per 100 mg/l salinity increase reported in the Department of Agriculture trials at Benger is not regarded as significant, as it was possible that other sources of error could have masked the true yield differences (George, 1980). However, work in the Goulburn Valley, Victoria (Mehanni and Repsys, ANCID, September 1980) indicated a 2.5% drop in pasture production as salinity levels were increased from 500mg/l to 1500mg/l.

In the past it has been assumed that changes in crop species could compensate for decreases in water quality. The change from lucerne to paspalum and kikuyu grasses in the Collie irrigation district had been noted as such a change. More recent work by the Department of Agriculture has shown that although pasture growth can be largely maintained, metabolism of these pastures is lower, reducing overall productivity. Studies on the Waterloo soils has suggested that the mix of pasture species could be responsive to salinity changes and this could lead to overall productivity changes directly related to water quality.

Although this work suggests that the salinity of the supplied irrigation water could have an impact on the overall productivity of the irrigation district, the evidence is not conclusive. Given this indeterminacy it is not possible to assign benefits for improvements in irrigation water quality.

5.0 PLANNING BASIS AND METHODOLOGY

5.1 BACKGROUND STUDIES

Early work on the solutions to the water quality problems on the Collie catchment covered a comprehensive range of over 200 alternative schemes (Collie River Salinity Control Working Papers; PWD, 1981), many of which considered combined schemes to produce water blends. A variety of strategies for reforestation were also evaluated. With the present programme of partial reforestation now established, it has been possible to use this as a base case and re-examine the various options. These include schemes which only improve supplies to the GSTWS and schemes which improve the total resource, although not to the same standards.

A broad assessment was made of the nett benefits and costs of these alternatives relative to their impact on domestic and industrial water services. Seven alternatives most likely to meet the objectives of Section 1.2 were selected for further study and are discussed in this report. These alternatives are:

- o Full Reforestation
- o Desalination
- o Saline Diversion
- o Coal Basin Groundwater
- o Raising Stirling Dam
- o Brunswick River Dam
- o Harris Dam

Figure 3 shows locations of the alternative water supply schemes for the region.

5.2 STUDY PERIOD AND DEMAND PROJECTIONS

The prime study period used for this discussion is the next 15 years, to the year 2000. Prices and costs are based on estimated December 1985 values. During the study period, demand is expected to grow at a modest rate to approximately 8 x $10^6 m^3$/annum in 1990 and about 10.8 x $10^6 m^3$/annum in the year 2000. The major proportion of this demand is domestic. No allowance has been made for the use of water for power stations in the coal basin. Similarly, increases in demand created by further expansion of Collie townsite due to the freeing up of current town planning restrictions or increased recreation have not been allowed for, although these developments might be expected to occur if a new source of supply (e.g. Harris Dam) was established.

5.3 DISCOUNT RATES

The analysis of discounted costs and benefits has been made at interest rates of 10% and 7% with prices held at 1985 values. The higher rate, whilst being under the current long term bond rates, is intended to reflect the opportunity cost of the development. The lower rate examines the alternative schemes at what could be regarded as a high real rate of return. If inflation runs at 8%, these rates would effectively be 18.8% and 15.6%.

5.4 BENEFIT-COST ANALYSIS

Both capital and operating costs are considered for each option. Operating costs have been calculated using energy and water treatment costs based on historic records appropriate to each option. However, costs which are common to all options, such as distribution system maintenance, have not been included.

The dominant influence on the benefit function is salinity improvement to the GSTWS. Benefits are based on reductions in salinity damage to domestic and industrial hardware as well as reduced usage of soaps or other water additives. Some alternatives derive additional benefits from increased hydro-electric power generation at Wellington Dam. No benefit values have been allocated for health improvements. No allowance has been included for any benefits generated for irrigation. Thus the benefits indicated may be regarded as conservative. The benefit function assumes that future salinity trends will follow the mean values estimated in Section 3.

The major proportion of water on the GSTWS is consumed through domestic, commercial and rural services, with approximately 8% being used for industrial purposes. The benefits generated from improving industrial water quality have been ignored.

New sources of supply, which completely replace Wellington Dam as the source of water for the GSTWS, create opportunities for recreation and for future development of Collie town. These aspects are discussed further in Section 7.6.

One result which emerged early in the benefit cost analysis was that for schemes which can supply water with a range of salinities through blending, the highest benefit-cost ratios were obtained with the better quality waters. This was largely due to the fact that although schemes for blending supplies could make some reductions in headworks capital costs, the increase in salinity of the water supply significantly reduced the benefits generated. On average, schemes producing water at 200mg/l had benefit-cost ratios 60% higher than similar schemes producing water at 500mg/l. The evaluation of each alternative has therefore focussed on the configurations which produced the better quality water.

5.5 ENVIRONMENTAL ASSESSMENTS

Major environmental issues, for which information was readily available for all potential alternative sources of GSTWS water, have been listed in Table 5. Where quantitative data exist they have been broadly categorised, to reflect the degree of likely impact. For example, the lengths of roads and railways inundated have been allocated to categories on a scale from 0 to 2.

Where quantitative data are not available or are not applicable to all options, are not directly comparable (eg. various types of wastes) or where subjective judgements are involved, the impact is noted as present or absent. Methodologies used to assess each item are outlined below:

- o Road/Rail inundated - quantitative rating based on transport routes which would be inundated at full supply level (FSL), assessed from maps; makes no allowance for increases in length required to bypass the installation.

- o Forest cleared - quantitative rating of State forest and uncleared alienated land which would be inundated, or cleared to accommodate structures; assessed from maps.

- o Residences affected - quantitative rating of dwellings to be permanently vacated; assessed from aerial photographs, maps and ground survey.

- o Farmland affected - quantitative rating of area of crop or pasture land which would be permanently removed from full production; assessed from aerial photographs and maps.

- o Pipelines - quantitative rating of length of all new pipelines required regardless of land use type traversed; plotted from maps.

- o Dieback distribution - rating based on assessment of dieback distribution at locations of structures and along pipeline routes. Based on Department of Conservation and Land Management (CALM) 1976 mapping of disease distribution.

- o Forest/Streamzone recreation - qualitative assessment of the present potential for walking or canoeing which would be lost.

- o Reserves - presence of areas gazetted or recommended as reserves according to the report of the System Six Committee (Environmental Protection Authority, 1983).

- o Pine plantations - presence of plantations which would be removed; assessed from maps.

- o Treatment wastes - presence of effluents generated by options where water requires treatment; based on chemical and engineering studies carried out by the Water Authority.

6.0 DESCRIPTION OF ALTERNATIVE SOLUTIONS

The seven major alternatives for the supply of water to the GSTWS are outlined below. They are contrasted with the current situation of partial reforestation and reservoir management.

6.1 PARTIAL REFORESTATION AND RESERVOIR MANAGEMENT

This approach, described in Sections 3.2 and 3.3, represents the status quo condition. The partial reforestation programme aims to reverse the salinity trend throughout the catchment by increasing water use by trees.

Some 8,000ha will be replanted. Reservoir management involves release, or scouring, of denser, more saline water from the base of the reservoir in early winter and the selective release of the best available water for domestic supplies or irrigation.

Partial reforestation has two major limitations:

- o The slow planting and growth rates of trees means that significant improvements in catchment salinity are not expected to occur for 10-15 years.
- o Projections suggest that partial reforestation is likely to produce salinity levels in the GSTWS of about 940mg/l, on average, in the mid 1990's and that levels as high as 1,330mg/l may be reached in dry years.

Partial reforestation can help to improve the quality of the entire Wellington catchment water resource, will be of benefit to the users of irrigation water and can preserve and enhance the opportunities for salinity control in the long term. However, it cannot produce sufficient improvement to meet the long term quality objectives for domestic water supplies.

6.2 FULL REFORESTATION

Full reforestation of the catchment would involve replanting perennial trees on more than 50,000ha of highly salt susceptible farmland. Throughout the catchment, a degree of salinity reversal, greater than the partial reforestation case, could be anticipated eventually. However, it is still quite uncertain whether the long term salinity objectives would be met.

An important limitation on the usefulness of any reforestation strategy is the slow rate at which trees become effective in reducing the salinity in streams. Even full reforestation cannot achieve the required salinity reductions quickly enough to meet the quality needs of the GSTWS. For this reason reforestation options are not pursued here and no benefit - cost ratios are presented.

In general, however, a major reduction in agricultural output and significant expenditures on land acquisition and replanting would be involved for uncertain, although positive, improvements in water quality over 10-15 years.

6.3 DESALINATION

The three main processes which can be economically applied to the desalination of water from Wellington Reservoir are:

- o Reverse Osmosis
- o Electrodialysis
- o Ion Exchange.

These methods are mainly distinguished by the method in which energy is used to achieve the separation of dissolved salts from the solution. For example, electrodialysis uses electrical energy to achieve this separation. By far the most widely accepted technology for brackish water desalination is reverse osmosis which uses pressure energy to achieve the salt separation.

A review of currently available literature on reverse osmosis plants covering both Australian and overseas experience, together with advice from consultants and information from the Water Authority's own reverse osmosis plant operations have been used to analyse the cost effectiveness of such plants. Although Australian experience is limited to relatively small plants (less that 1,000m^3/day, compared to a requirement of up to 70,000m^3/day) overseas plants with capacities of 46,000m^3/day have been constructed. Contracts for plants to 84,000m^3/day have recently been let in the United States.

The periodic replacement of reverse osmosis membranes can be a significant component of the operating cost of these plants. A three year life can generally be guaranteed, provided strict feedwater specifications are met, although more recent developments are producing membranes which may not be as susceptible to fouling. The pretreatment stage is fairly critical if scaling and fouling of the membrane are to be prevented. This generally consists of coagulation and filtration, although softening may be required to reduce calcium and silica concentrations. Care is also required to prevent biological fouling of membranes.

The ion exchange process uses chemical energy in the regeneration of the membranes to provide the energy source for separation of the salts from solution. Ion exchange technology is well advanced with plants of up to 10,000m^3/day capacity overseas.

In Australia, ion exchange is used for high quality boiler feed supplies. It has been suggested that this process may be appropriate to desalination of water for the GSTWS, with its large variation in feed salinities and summer/winter flow rates as the operating costs are directly proportional to the volume of water treated and the quality of salts removed from the water.

The conventional chemical regeneration process is relatively expensive when compared with reverse osmosis. However, thermal regeneration of the membranes (Sirotherm) offers some prospects of being competitive in the range of flows above 10,000 to 20,000m^3/day. The process is still in the development stage and it will be some time before such plants become available commercially.

The present estimates have therefore been based on reverse osmosis plants using currently available information on membrane performance. Desalination of the whole Collie River resource is undoubtedly far too expensive and the estimates have been prepared for plants to progressively be upgraded to meet the demands on the GSTWS at product qualities of 200mg/l and 500mg/l. The different product qualities are achieved by blending with raw water. Brine disposal from the desalination process has been based on discharging into the ocean through a pipeline from the plant site.

6.4 SALINE DIVERSION

Reductions in the salinity of Wellington Reservoir can be achieved by defining the more saline sub-catchments and intercepting some or all of the saline discharge and diverting it from the Wellington catchment (Figure 3). On the basis of available topographic information, preliminary estimates have been prepared for constructing storage dams and pumping saline water to the Blackwood River catchment. The Blackwood River was selected as it has a large mean annual flow and has an average salinity of approximately 1,000mg/l and thus would be least affected by further saline inputs. However, the flows diverted from the Collie catchment would have salinities up to 14,000mg/l so that, in the summer months, they could still significantly increase salinity levels in the Blackwood. Diversion of saline flows to the ocean would markedly increase capital costs for piping.

Of three alternative schemes considered, salinities could at best be reduced by 12%. Combinations of schemes are the most cost effective and benefit-cost data on a typical combination are shown in Table 4. Environmental data in Table 5 are also based on a typical combination scheme.

Under the present reforestation programme, more than half of the salinity which could be diverted will be controlled eventually anyway. This reduces the ultimate benefits which would be generated on the catchment by constructing saline diversion schemes. Saline diversion does have the advantage over reforestation that the effects are immediate.

Given their marginal benefit, and major potential impact on the Blackwood River, saline diversion schemes are not favoured.

6.5 COAL BASIN GROUNDWATER

Investigations in the Collie Coal Basin have shown that limited supplies of low salinity groundwater occur east and south of Collie township (Figure 3). The area is close to the Muja water supply pipeline extension and the Collie pumping station on the GSTWS main. The annual yield of the area is estimated to be of the order of $4 \times 10^6 m^3$ per annum. The water has a salinity of about 400mg/l but would require treatment for its acidity, and high iron and manganese content. Up to about 1990, the bores could be blended with water from Wellington Dam in a 50/50 mix, but limited supplies would gradually reduce this to a 37/63 mix by the year 2000. The proposed borefield would include bores drilled into old mine workings as well as conventional bores, pumping to a treatment plant located near Collie pumping station. Correction of the acidity would be carried out at each bore. From a clear water reservoir at the treatment plant, water would be pumped via Collie pumping station into the GSTWS system.

One of the major issues in the use of the coal basin water resource is the interaction with coal mining and power generation. The State Energy Commission (SECWA) now draws all its water for the power station from dewatering operations in the mines and a borefield at Shotts. The limiting water quality parameter for this water is the concentration of silica, which causes deposition of scale on the heat exchange equipment of the cooling circuit. In practice the feedwater quality has to be better than about 400 or 500 mg/l to be acceptable.

The current SECWA demand for water is 12 x $10^6 m^3$/annum. By 1990 it is expected to rise to 20 x $10^6 m^3$/annum. The ultimate development of power stations on the coal basis could require 26 x $10^6 m^3$/annum.

Present SECWA water use is considered to be approaching the limit of the yield from the groundwater source and further development of the coal basin as a power generation source will require the mining of water from the groundwater basin. While this overuse is considered to be compatible with the mining and power generation activities, it does cause a conflict of interest with use of the resource for water supply purposes.

6.6 RAISING STIRLING DAM

Currently the Stirling and Harvey Dams (Figure 3) are too small to fully utilise the annual flow of the Harvey River. Stirling, with a storage of 91% of the mean annual flow (MAF) develops a yield of approximately 66% of the MAF (40 x $10^6 m^3$ per annum). By doubling the storage it would be possible to increase the yield to meet the needs of the GSTWS to the year 2000. The enlargement would require raising the existing embankment and spillway by about 10m, and construction of a pump station and rising main connection to Worsley tank.

The Stirling Dam option could supply high quality water to the GSTWS scheme but only up to the year 2000.

6.7 BRUNSWICK DAM

The Brunswick River is one of the largest undeveloped freshwater resources on the Darling Scarp between Bunbury and Perth (Figure 3). With a MAF of 70 x $10^6 m^3$, at its lowest point of development, it has the potential to play a major role in future water supply developments in the South West. Two prime sites for development ofurface resource exist; the lower site (Brunswick 26)* has potential for developing water to improve Collie irrigation supplies as well as the GSTWS. An upper site (Brunswick 37) would only supply water to the GSTWS. Total salinity levels in the Brunswick Dam would be expected to be of the order of 250mg/l for the lower site, although slightly lower levels could be expected for the upper site.

*Site numbers refer to the distance upstream from the point where the river discharges into the ocean or another large river.

The connections to the GSTWS for either dam would be through a pipeline connected to the Worsley tank and then through the existing pipelines to Collie and Bingham pump stations.

The operating costs for the upper Brunswick site would be approximately the same as for the Stirling alternative and marginally more than for the existing operation from Wellington Dam. At the lower site they would be slightly higher. As the benefits generated by schemes which improve irrigation water supplies have been ignored, the Brunswick 37 site has the highest benefit-cost ratio and this alternative has been used for subsequent analyses.

6.8 HARRIS DAM

The two sites (Damsite 1 and Damsite 5) considered in detail on the Harris River are shown on Figure 3. The following paragraphs compare the relative merits of each site.

6.8.1 Storage Size and Yield

Damsite 1 has a catchment area of 383 km^2 and a mean annual flow of 46 x 10^6m^3, while Damsite 5 has a catchment area of 321 km^2 and a mean annual flow of 36 x 10^6m^3. At Damsite 1 it would be possible to construct a dam with a storage volume of 130 x 10^6m^3, yielding approximately 33 x 10^6m^3 per year. At Damsite 5 the maximum storage size which could be developed is approximately 71 x 10^6m^3, yielding 20 x 10^6m^3 of water per year. While larger storages could be built at Damsite 5, the higher full supply levels would flood Twenty-Two Mile Pool and possibly some sites of significance to aboriginal people. The environmental significance of Twenty-Two Mile Pool is discussed in more detail in later sections. In any event the total yield which could be developed with the larger storages at Damsite 5 (140 x 10^6m^3) would be 24 x 10^6m^3/year. To meet the needs of the GSTWS to the year 2000, without unduly affecting irrigation water salinity, the construction of a dam at Damsite 5 to store 71 x 10^6m^3 would be required. At Damsite 1, a dam to produce the same yield would require a storage volume of 46 x 10^6m^3.

The yield of Damsite 5 can be increased by pumping back streamflow from the catchment between Damsites 1 and 5. This would require the construction of a small pipehead dam and pumping station at Damsite 1 together with a delivery main from Damsite 1 to the storage at Damsite 5. However, the yield of 2 x 10^6m^3/year which could be developed by this method is relatively expensive.

6.8.2 Irrigation Water Quality

One issue which has been examined in some detail (see Appendix K) is the impact of construction of the Harris Dam on the quality of irrigation water released from Wellington Dam. With the retention of fresh water in the Harris storage, there is scope for improving the efficiency of the reservoir management policy at Wellington Dam. In addition, there is sufficient storage in the Harris reservoir, releases from the Harris storage can further dilute the salinities in Wellington.

Analysis of this aspect of the scheme has been carried out using a two dam hydrodynamic simulation model. The results from this modelling indicate that the improvement in irrigation water quality is dependent on;

(a) the GSTWS draw.
(b) the size of the Harris storage.

The actual salinities which would occur with a dam at Damsite 5, under various conditions of catchment reforestation and demands on the GSTWS are shown in Table 3. The tabulation indicates that on average, irrigation salinities would be improved by approximately 40mg/l. However, as the demand on the GSTWS expands beyond the figures projected for the year 2000, the average improvement in irrigation water quality is gradually reduced. At the end of a drought sequence irrigation salinities can be 120 to 140 mg/l worse than would have occurred if the Harris Dam was not built. The average improvement in irrigation water quality for a dam of 45 x $10^6 m^3$ storage at Damsite 1 is approximately 25mg/l in the late 1990's and there is a chance that irrigation salinities at the end of the drought sequence could be 120 to 140 mg/l worse for one or two years. However, for a 90 x $10^6 m^3$ storage at this site, salinities at the end of the drought would not be any worse.

For either site and the storage sizes under consideration, additional works could be required to meet increases in demand on the GSTWS beyond the year 2000, if further deterioration of irrigation water quality is to be avoided. In the case of Damsite 5 this would have to take the form of additional source developments or further reforestation. At Damsite 1 the storage size could be increased by raising the embankment and spillway crest levels.

TABLE 3

IRRIGATION SALINITIES RESULTING FROM JOINT OPERATION OF HARRIS DAMSITE 5 AND WELLINGTON DAMS (mg/l)

PERIOD		CURRENT SALINITIES	LATE 1990's	BEYOND 2010
ANNUAL SUPPLY TO GSTWS			$10 \times 10^6 m^3$	$15 \times 10^6 m^3$
Harris ($71 \times 10^6 m^3$ Storage)	1	803	949	935
	2	1227	1451	1404(4)
	3	1207	1427	1373(4)
No Harris	1	841	994	940
	2	1193	1410	1333
	3	1105	1306	1235
DIFFERENCES	1	-38	-45	-5
	2	+34	+41	+71
	3	+102	+121	+138

NOTES:
1. Mean daily salinities in an average year
2. Daily salinities which would be exceeded for 5% of the time
3. Mean daily salinities which occur in the worst year of a drought sequence similar to the late 1970's
4. For this condition these salinities could occur over the last two years of a drought sequence.

6.8.3 Comparison of Sites

Geotechnical investigations to date have indicated that both sites have deep weathering profiles, the depth being somewhat greater at the lower site. Similar types of homogeneous embankments would be required for either site, with special measures required to control foundation seepage. The pumping station would be located at the toe of the dam and the pipelines would follow existing roads and power line routes.

Damsite 1 would require the relocation of a portion of the SECWA transmission line and four private land holdings, including one domestic dwelling would have to be resumed. Land holdings affected by Damsite 5 have already been purchased by the Water Authority. Both sites flood a portion of State Forest, 800ha at Damsite 5 and 300ha at Damsite 1. Current estimates indicate that after all these factors are taken into account, there is little difference in the capital costs of development of the two sites for the sizes of storages being compared. For larger yielding schemes the capital costs of Damsite 5 increase at a faster rate than for Damsite 1.

The investigations have shown that the environmental impacts of both Harris sites can be considered acceptable, provided the full storage levels do not flood Twenty-Two Mile Pool. The direct environmental impact of Damsite 1 would be lower due to lower surface area of the reservoir, although the impact on existing landholders would be greater.

The Water Authority has selected Damsite 5 with a storage volume of $71 \times 10^6 m^3$ as the appropriate Harris site for further consideration.

6.9 OTHER OPTIONS

A number of other options have been considered but detailed evaluation of their costs and benefits is not justified as they are obviously not practical or economical. These include:

- Bitumen Catchments: To supply GSTWS requirements, a total of 50-70km^2 of bitumen catchment and 30 x 10^6m^3 of excavated storage would be required. The estimated cost of these is of the order of $300 million.

- Collie River Dam below Wellington: Storage on the Collie River could be increased by building a dam at Burekup, downstream of Wellington Dam. Although such a dam would exploit high quality water from the relatively high yielding lower catchment, the overall improvement in salinity to either the GSTWS or to irrigation would be too small to be useful. The cost of constructing works for diverting saline scour flows from Wellington around a lower reservoir would be prohibitive.

- Perimeter Diversions: Consideration has been given to diverting saline flows around the perimeter of Wellington Reservoir but the control of such a facility would be complex. The improvement in water quality would be of the order of 60mg/l for irrigation water and 90mg/l for the GSTWS. Early indications of high cost ruled out further evaluation of the proposal.

- Reservoir management: As a result of early investigations of the salinity problem, an active process of scouring and selective withdrawal of water is presently being used to marginally improve water quality. Exhaustive studies by the Water Authority indicated that there is no scope for significant improvements in reservoir management practices.

7.0 ANALYSIS OF ALTERNATIVES

7.1 THE SELECTED ALTERNATIVE

The ability of each option to meet the objectives outlined in Section 1.2 for improved GSTWS water quality are summarised in Table 4. As discussed below, the Harris and Brunswick Dams are the only options able to cost effectively meet all the objectives for the supply of adequate, high quality water to the GSTWS in the short term. As the Harris Dam has the highest benefit - cost ratio and rates slightly better than Brunswick Dam on environmental issues (Table 5) it is the selected alternative.

7.2 HEALTH BENEFITS

Under average conditions all options meet the current desirable criteria for TSS and chloride. Continuing the present programme of operation at Wellington Dam, with partial reforestation of the catchment, is expected to exceed the limit for chlorides two or three years in ten, as discussed in Section 3.3. This comment could also apply to the saline diversions and groundwater schemes, although somewhat less frequently. Harris, Brunswick and Stirling Dams, and Desalination are the only options capable of meeting the most stringent long term chemical quality objectives including the WHO sodium criteria. Colour analyses for Harris River water are within the NH&MRC desirable current criteria but, like the existing Wellington supply, do not come within the NH&MRC long term objectives for considerable periods of time. Colour is an aesthetic criterion and does not affect health or taste at these levels. Thus, to supply the best quality water, with the maximum health benefit, the Harris Dam, Stirling Dam or Desalination system should be selected.

7.3 BENEFIT - COST ANALYSIS

The results of the benefit-cost analysis for the GSTWS are summarised in Table 4. At a discount rate of 10%, the Harris Dam option has the highest benefit-cost ratio, followed by the Stirling and Brunswick options. All seven options are relatively insensitive to changes in the discount rate.

No detailed assessment has been made of the benefits to irrigation. However, even larger schemes than those detailed here would be required to significantly improve water quality supplied for irrigation and these are not likley to be cost effective. A dam on the Harris River will however provide the opportunity for better management of freshwater flows into Wellington reservoir through the year and hence will lead to a small improvement in irrigation water quality on average during the early years of operation of the scheme.

TABLE 4

OBJECTIVES MET BY OPTIONS FOR SUPPLY OF GSTWS WATER

OBJECTIVE	HARRIS	STIRLING	BRUNSWICK	DESALINATION	SALINE DIVERSION	BOREFIELD	FULL REFORESTn.
Water Quality							
Desirable Current Criteria	+	+	+	+	+	+	Uncertain
Long Term Objectives	+	+	+	+	-	-	-
Timing	+	+	+	+	+	+	-
Benefit-Cost Ratio	4.5	3.1	3.0	0.8	0.5	1.5	
Adequate Resource	+	-	+	+	+	-	+
Improve Irrigation	+	-	+	-	+	-	+

\+ - objective met
– - objective not met
\- not assessed

TABLE 5

ENVIRONMENTAL ASSESSMENT RATINGS FOR GSTWS OPTIONS

PARAMETER	HARRIS 5	STIRLING	BRUNSWICK 37	DESALINATION	SALINE DIVERSION	BOREFIELD	FULL REFORESTn.	RATINGS
Pipelength	2	3	2	3	3	2	0	0 = 0 km 1 = 1-10
Road/Rail	2	1	1	0	2	0	0	2 = 11-20 3 = 21-30
Dieback	1	0	1	0	0	2	?	0 = 0% 1 10% 2 10%
Stream	1		3					1 = Minor 2 = Intermediate 3 = Major
Forest Cleared	2	1	2	1	2	1	0	0 = 0ha 1 = 1-100 2 = 101-1000
Farmland	0*	0	0	0	3	0	4	3 = 1001-10000 4 = 10000+
Residences	0*	0	0	0	3	0	3	0 = 0 1 = 1-5 2 = 5-10 3 = 10+
Pine Plantation		*	*					* = present
Reserves		*						= not applicable or absent
Waste				*	*	*		

* NOTE: One residence and several hundred hectares of farmland have already been resumed by the Water Authority in this area. These impacts are not included here.

7.4 TIMING

All options involving new construction will take the same order of time to build, about 3-4 years. This then is the shortest time in which improved supplies can be made available to the GSTWS.

As discussed earlier, reforestation options would take 10-15 years to materially affect salinity levels. This time lag is not considered acceptable for the GSTWS. However slow improvements to the total Collie catchment resource are worth pursuing and the existing reforestation programme is expected to continue in concert with a new source for the GSTWS.

7.5 ENVIRONMENTAL ISSUES

Broad environmental issues for which information was readily available across all options are summarised in Table 5. Given the necessary caution required when summing environmental impact ratings across widely varying parameters, there is little difference between the two options which meet the water supply objectives, namely Harris Dam and Brunswick Dam. Further detailed studies, undertaken in the region influenced by the Harris Dam option, are discussed in subsequent sections.

7.6 SECONDARY BENEFITS

New sources of supply, which completely replace Wellington reservoir as the source of drinking water for the GSTWS, create opportunities for additional secondary benefits. These are outlined below. No benefit-cost analyses have been performed on these secondary benefits.

- Additional recreational values would be generated. As Wellington Reservoir would primarily become an irrigation source, there would be scope for recreation on the reservoir (Appendix F) and developments along the reservoir foreshore (Figure 12). As there are limited opportunities for freshwater recreation in the Darling Range this could be particularly highly valued.

  Landscaping of the area below a new dam could also provide a new focus for recreation. However, recreation would not be permitted on the water body formed by a new dam.

- At present, further land development in and around Collie townsite is constrained by the risk of polluting the Collie River and hence Wellington reservoir. If Wellington Reservoir is replaced as the source for domestic water supplies, it would then be used solely for supplying irrigation water. The water pollution hazard from Collie townsite would then be of far less concern from the Public Health viewpoint, making additional land development in the vicinity of Collie possible.

- With the new storage becoming the primary domestic water source, the cost of pumping sewerage effluent from the Wellington catchment could be reduced. Nevertheless such changes must conform with environmental and public health standards and must be compatible with any decisions made regarding recreation.

Realisation of these benefits and their degree, is dependent on the size of storage constructed

8.0 PROPOSED PROJECT

8.1 COMPONENTS

The proposed Harris River Dam Project includes the following components:

- Main dam embankment
- Spillway
- Intake tower
- Outlet culvert
- Pump station and rising main
- Public viewing areas, recreation facilities and amenities.

The locations of these items are shown on Figure 4. The overall capital cost of the project is expected to be \$30m in December 1985 values.

As design of the various facilities proceeds, it is expected that the final details of the locations and types of structures may vary from those described in this report.

The main physical statistics for the proposed project are:

EMBANKMENT

Embankment Crest Level	228.5 m AHD
Volume of Fill in the Embankment	667,000 m^3
Length of the Embankment Crest	430 m
Width of the Embankment Crest	8 m
Upstream Embankment Slope	1:4
Downstream Embankment Slope	1:3
Width of the Embankment Base	220 m

RESERVOIR

Full Supply Level (FSL)	223.5 m AHD
Storage Volume at FSL	71.67 million m^3
Reservoir Surface Area at FSL	990 ha
Minimum Operating Level	200m AHD

SPILLWAY

Type	concrete lined chute
Crest Width	40m
Maximum Discharge	720 m^3/s

8.2 MAIN DAM EMBANKMENT

The main embankment for the Harris Dam would be of the homogeneous earthfill type, constructed at the site shown on Figure 5. Constructed from local clay soils, it will incorporate filters and the upstream slope will be protected with a rip rap layer of rockfill material. Foundation stripping will be required over the entire embankment area to remove organic and other unsuitable materials. Deeper excavation in the area of the river bed to remove pervious alluvium will be necessary.

Provision of effective seepage control measures is being investigated in some detail. The large depths of weathered material at the site pose a number of problems which can be solved in a variety of ways. Designs incorporating an upstream impervious blanket, foundation cutoffs, downstream drainage to reduce uplift pressures and added weighting of the toe of the embankment are being considered.

8.3 SPILLWAY

Current studies indicate that the spillway would have an ungated ogee crest with an open, lined concrete chute. Site investigations indicate that the crest structure and chute can be founded on rock excavation, a proportion of which can be used as a source of rockfill for the works. A terminal structure and stilling basin would be located where the spillway flows re-enter the river. The spillway will have the capacity to pass all floods up to the probable maximum flood, after allowing for flood attenuation in the reservoir.

8.4 INTAKE TOWER

The intake tower would consist of a reinforced concrete stem and a sheet steel clad hoist house. Access to the hoist house would be provided from the embankment by bridge. Site investigations of the tower foundations have shown low bearing capacity and therefore piled foundations are under consideration. The tower will have multiple intake ports to enable water to be drawn over a range of water levels.

8.5 OUTLET CULVERT

A concrete outlet culvert will extend from the intake tower to the pump station located immediately downstream of the embankment. The culvert will house two 900 nominal diameter pipelines with access walkways on either side of the pipelines. The culvert will be articulated to accommodate embankment settlement. Construction will be carried out early in the programme so that the culvert can divert river flows that occur during construction.

8.6 PUMP STATION AND RISING MAIN

A rising main will be constructed from the pump station to link with the GSTWS pipeline from Wellington Dam approximately 3km east of Collie Pumping Station. The possible location of the pipeline is shown on Figure 6.

8.7 OTHER FACILITIES

The power supply to the pump station is expected to be via a power line from the SECWA southwest grid. Final location for the line has not been determined but it is expected to be adjacent to the main site access road from Tallanalla Road. Other permanent facilities will include sealed access roads linking all the major facilities (Figures 5), public vantage points (with associated parking facilities) and a public recreation area located downstream from the embankment. Site access will be via the Tallanalla-Collie Road. This road will facilitate heavy vehicle access to the site. As the Tallanalla-Collie Road passes through the damsite, and will be within the reservoir storage area, relocation of the road will be necessary. The environmental impact of the road relocation is addressed in this environmental report.

8.8 SOURCES OF CONSTRUCTION MATERIALS

Potential sources of suitable materials have been identified and these locations are shown on Figure 7. Earthfill material will be produced from a borrow area located in the area immediately upstream of the damsite. Additional areas may be necessary. however, all earthfill borrow pits are expected to be within the resevoir area. Fine filter materials will be produced from sand deposits located near Griffin (see Figure 7) this area is outside the reservoir area. Course filter material, aggregate for concrete structures and rip rap material will be obtained from established local quarries. Rock obtained from the spillway excavation will also be used for rip rap material.

8.9 CONSTRUCTION PROGRAMME

The following programme of works is based on the assumption that an environmental clearance is received and that satisfactory arrangements can be made with the Australian Government for financial assistance.

- October 1985 — Detailed investigation and design of the project commences
- December 1986 — Complete design and tender documentation
- March 1987 — Call tenders for major civil works
- July 1987 — Award contract for major civil works

- o August 1987 Commence construction
- o May 1989 Complete construction ready to store water
- o September 1989 Deliver water to GSTWS

8.10 OPERATION OF THE RESERVOIR

Due to low salinity levels of the Harris River water and the close proximity of the dam to the GSTWS pipeline, the water will be used to supply the total requirements of the GSTWS. This requirement is expected to be 10.8 x 10^6 m^3 per annum by the year 2000. By pumping to West Bingham tank, the Collie pump station will not be required and Collie, Allanson and Worsley will be backfed along the GSTWS main conduit. The available yield from the Harris Dam is in excess of the expected supply to the GSTWS. This excess yield will be used to improve the quality of water in Wellington Reservoir. The fresher Harris River excess water will be released into the Wellington Reservoir at the completion of saline scouring. This will also improve the yield from the Collie River catchment as it is presently under-regulated.

9.0 DESCRIPTION OF THE PHYSICAL ENVIRONMENT

9.1 CLIMATE

A detailed report on the climate of the project area is contained in Appendix A.

The Harris River area experiences a Mediterranean climate with mild wet winters and hot dry summers.

The annual average rainfall for Collie 10km to the south is 971mm and mean annual rainfall decreases rapidly towards the east. A late autumn, winter and early spring predominance of rainfall occurs with the peak in June - July. Less than ten percent of the annual rainfall falls between November and March. The seasonal rainfall distribution results in a distinct pattern of winter inflow to the dam and summer drawdown.

Temperatures recorded at Collie are moderate, with the highest mean monthly maximum recorded in January (30.5^{o}C) and the lowest mean monthly minimum being recorded in July (4.2°C). Evaporation rates at Collie range from 50mm during July to 275mm in January. Evaporation rates at Collie exceed the annual average rainfall by approximately 70%.

The low summer rainfall and associated low humidity levels indicate that humidity would rarely be oppressive or have an adverse impact on construction activities. Frosts occur throughout the winter from May to September with rare occurrences recorded in April, October and November.

The computed wind rose (Appendix A) indicates that the prevailing winds occur from the northwest and west. The majority of the winds (37%) are in the speed range 1-5 km/hr, and 24.6% are in the 6-10km/hr speed range. Only 1.2% of winds exceed a constant speed of 41km/hr.

9.2 GEOLOGY

9.2.1 Regional Geology

The Harris River occupies a semi-mature valley incised in the Darling Plateau. The plateau comprises an undulating lateritized surface, underlain by rocks of mainly Precambrian age. These rocks are generally granitic or gneissic in composition and are variably foliated and intruded by dykes and sheets of dolerite.

The plateau surface comprises massive and pisolitic laterite and some lateritized sand, usually overlying a weathering profile, which may exceed 20m depth. Valley slopes are mantled by colluvial deposits, and the valley floors comprise alluvial sands, silts and clays.

Despite the extensive cover of superficial deposits, there is evidence that structural trends in the underlying geology exercise some control over present day topography. The orientation of the Harris River Valley in the vicinity of the damsite appears to be related to structural lineaments in the bedrock.

9.2.2 Seismic Risk

The Harris River damsite is shown on the Earthquake Risk Map of Australia (1979) to lie to the south of the southwest Seismic Zone. The Risk Map defines four risk zones, namely O, A, 1 and 2; in increasing order of seismic risk. The damsite lies approximately on the boundary between Zones O and A. The zone boundaries are defined by means of a chart relating Earthquake Return Period to Earthquake Intensity, in terms of both ground particle velocity and the empirical Modified Mercalli Scale. The zone boundary chart is reproduced as Figure 8. The zoning of the damsite shows that for a return period of 300 years or less, a maximum intensity of VI on the Modified Mercalli Scale could be anticipated, increasing to intensity VIII at a return period of 6000 years.

For comparative purposes, it may be noted that the City of Perth, and the water catchment areas in the Darling Range are all assessed at a higher seismic risk, falling either within Zone A or on the boundary between Zones A and 1.

9.3 LANDFORM AND SOILS

9.3.1 Landform

A comprehensive description of catchment landforms is contained in Appendix A.

Landform mapping units identified from published data include:

- Dwellingup Unit - undulating hills and shallow depressions
- Goonaping Unit - shallow upland valleys
- Yarragil Unit - floors and streams of minor valleys
- Pindalup Unit - valley floors and slopes
- Murray Unit - deeply incised valleys with floodplains.
  (Department of Conservation and Environment, 1980)

Materials eroded from the surface have been sorted and deposited and have resulted in exposure of variously weathered and unweathered substrata (McArthur et al., 1977).

9.3.2 Soils

A detailed description of the soils identified in the catchment area is contained in Appendix A. Six individual soil types were identified using the Northcote (1979) system of soil classification. These six soil types have been mapped under four soil mapping units and include:

- o Gravelly earthy sands
- o Earthy sands
- o Lithosols
- o Swamp soils.

The major feature of the gravelly earthy sands and lithosols is the high percentage (greater than 70%) of lateritic gravel present.

The soil erodibility of the soil mapping units varies from very high to low. Soil erosion hazard for the landform mapping units varies from high to low.

9.3.3 Erosion Status

An assessment of erosion status for the catchment showed no evidence of massive erosion on the forested lands although spatially discrete areas of soil erosion occur along roads within the forest. These discrete areas of erosion were contributing minor amounts of sediment to the drainage system. The cleared agricultural lands are contributing sediment from sheet erosion and this is the major form of accelerated erosion in the catchment.

The small area used for agriculture, and the large area managed as State forest within the catchment, serves to damp the hydrologic response. The presence of the forests ensures good retention of rainfall and ensures low energy input into stable drainage lines. The low incidence of erosion within a low energy environment results in minimal transport of sediment.

9.4 HYDROLOGY

9.4.1 Catchment Description and Available Data

The catchment, which has a mean annual rainfall of 969mm, lies in the high to medium winter rainfall climatic zone.The catchment is characterised by its low to moderate relief with undulating plateau and bauxite laterite soils over Archean granitic rocks. The river is moderately incised in its lower reaches but is broad and swampy in its upper reaches. There are two long term gauging stations on the Harris River and three temporary stations installed in its tributaries as tabulated in Table 6.

TABLE 6
AVAILABLE STREAMFLOW DATA

STATION		PERIOD OF RECORD	
Name	Area (km^2)	From	To
Harris River Stubbs Farm	383.00	Jan 1952	Mar 1976
Harris River Tallanalla Road	382.00	Apr 1976	Date
Hanson Bk River Bend	8.19	Jun 1983	Date
Harris River Trib. Scar Road	15.25	Jun 1983	Date
Harris River Trib. Norm Road	20.84	Jun 1983	Date

The proposed Harris damsite (Damsite 5) is about 4 kilometres upstream from the main stream gauging station sites and has a catchment area of 321 square kilometres. Flows from the intervening 62 square kilometre catchment between the damsite and the main stream gauging station have been estimated using data from the three temporary stations installed in June 1983.

Rainfall data for the period 1972 to 1983 was obtained from four pluviograph stations distributed fairly uniformly over the catchment. Longer term records were available from the Collie Post Office (1907 to 1983).

9.4.2 Methodology

The Sacramento rainfall runoff model was calibrated to the catchment using the observed streamflows and the catchment rainfalls obtained from the pluviograph record for the period 1972 to 1983. The period of the catchment rainfalls was extended by correlating them with Collie Post Office rainfalls during the common period. The extended historical catchment rainfall estimates were then used as inputs to the calibrated Sacramento model to produce stream flows covering the 77 years from 1907 to 1983. These estimates are presented in detail in Appendix L.

9.4.3 Yield Estimation

For the purposes of yield estimation the 77 years of historical data was considered inadequate and longer synthetic records of 500 years were generated from the 77 year record. Storage and surface area data (Table 7) for the site have been developed from topographical information collected for this purpose. A reservoir simulation programme was used to simulate the system yields for a variety of draw conditions. The model simulated the behaviour of the reservoir on a monthly basis for the period of the synthetic records, the results being shown in Table 8. The nominal yield for the 71 x $10^6 m^3$ storage is 20 x $10^6 m^3$/annum. The average salinity for the inflow for the relatively dry period of record 1974 to 1982 was 195mg/l and the expected average salinity of water supplied to the GSTWS is 220mg/l. In dry years salinity in the Harris storage could reach 260-280 mg/l. Table 9 shows the elements of the water balance for the storage.

9.4.4 Flood Estimation

A flood frequency investigation was carried out in order to give an appreciation of the magnitude of recorded floods on the catchment. Observed data were available from two gauging stations giving total of 32 years of data from 1952 to 1983. The top five floods from the annual flood series are shown in Table 10.

TABLE 7

CAPACITY TABLES FOR HARRIS DAMSITE 5

SUPPLY LEVEL (AHD)		INCREMENT 0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00
190.00	V	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.5
	A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.0
200.00	V	49.3	135.7	276.0	485.5	782.3	1217.0	1839.8	2659.6	3684.4	4950.0
	A	63.6	110.9	173.0	247.7	354.8	523.9	722.3	918.4	1138.1	1398.8
210.00	V	6493.7	8352.9	10562.7	13129.5	16060.1	19390.7	23162.3	27446.0	32313.1	37800.8
	A	1694.5	2030.8	2389.4	2744.6	3124.2	3542.2	4013.5	4566.3	5173.6	5807.4
220.00	V	43946.8	50827.0	58517.5	67059.5	76494.3	86898.1	98347.4	110885.1	124557.9	139478.1
	A	6497.9	7275.6	8111.7	8978.6	9904.4	10916.2	11989.9	13090.9	14278.1	15578.3
230.00	V	155773.0	173672.4	193416.4	215255.1	239430.9	266072.9	295303.7	327301.4	361868.6	
	A	17053.9	18782.7	20745.5	2976.1	25393.4	27911.9	30577.7	33451.0	36375.6	

SL 223.5 : V 71661.3

A 9431.5

V = volume in thousands of cubic metres

A = surface area in thousands of square metres

TABLE 8

SUMMARY OF THE YIELD FOR DAMSITE 5

Catchment Area: 321 Square Kilometres
Mean Annual Streamflow: 36.2 million cubic metres

STORAGE		ANNUAL DRAW			
	% Mean Annual Flow	2% Prob. of Failure (1:50 years)		5% Prob. of Failure (1:20 years)	
($10^6 m^3$)		($10^6 m^3$)	% Mean Annual Flow	($10^6 m^3$)	% Mean Annual Flow
18	50	10.40	29	12.20	34
36	100	16.00	44	18.20	50
54	150	18.40	51	21.00	58
80	221	20.65	57	23.65	65
100	276	22.85	63	24.85	69
120	331	23.45	65	25.70	71

TABLE 9

WATER BALANCE HARRIS DAMSITE 5

$71 \times 10^6 m^3$ STORAGE

ANNUAL INPUTS	$m^3 \times 10^6$	(%)	ANNUAL OUTPUTS	$m^3 \times 10^6$	(%)
Harris Inflow	35.47	(85)	Draw	19.44	(46)
Direct Rainfall	6.41	(15)	Evaporation	10.06	(24)
			Spillway	12.38	(30)
TOTAL	41.88				41.88

TABLE 10
ANNUAL FLOOD SERIES,
1952 to 1983

STORM	RANK	PEAK DISCHARGE (m^3/s)
Aug 1964	1	95.40
Aug 1963	2	46.70
Aug 1974	3	37.70
Jun 1982	4	33.70
Jul 1958	5	31.80

A probability distribution was fitted to this annual flood series and an estimate of $140m^3$/sec was calculated for the flood with an annual exceedance probability of 1 in 1000.

Flood design of the spillway will be based on floods derived from estimates of probable maximum precipitation provided by the Bureau of Meteorology. Preliminary estimates of these rainfalls and inflow floods are shown in Table 11. These estimates will be reviewed and updated as part of the design process.

TABLE 11
PROBABLE MAXIMUM PRECIPITATION AND FLOODS

DURATION (hr)	PROBABLE MAXIMUM PRECIPITATION (mm)	PEAK FLOW (m^3/s)
6	222	659
12	305	857
24	395	991
48	445	830

9.4.5 Water Quality Parameters

While the actual salinity levels of the water to be supplied from the Harris River have been dealt with in Section 9.4.3, Table 12 shows results of the analysis of the major ions in Harris River water for the expected average salinity to be supplied from the reservoir.

TABLE 12

DISTRIBUTION OF MAJOR IONS

MAJOR ION	CONCENTRATION (mg/l)
Total Soluble Salts	220
Chloride	130
Sodium	55
Sulphate	11
Hardness	40-50
Bicarbonate	11
Magnesium	8
Calcium	4
Potassium	1

The pH of the Harris River is reasonably neutral and this is expected to be reflected in the water quality of the proposed Harris Reservoir. There will be additional environmental factors such as stratification that may affect the pH in the reservoir.

In addition the following four parameters have been given more detailed examination:

- o Turbidity
- o Colour
- o Microorganisms
- o Trihalomethanes.

Turbidity in the Harris River is generally very low, with only 10% of samples exceeding the NH&MRC long term criteria of 5 turbidity units. Retention in the storage will reduce these values even further. Turbidity levels in Wellington Reservoir are normally less than five turbidity units and levels in the Harris Reservoir could be expected to be lower. The low turbidity levels also indicate that the suspended sediments loads in the river are relatively low. This factor together with the absence of any significant bed load material in the stream bed indicates that long term sedimentation of the storage is not expected to be a problem.

The relative ranges of the values of the colour and turbidity parameters are shown in Tables 13 and 14.

TABLE 13

SELECTED QUALITY PARAMETERS:

WELLINGTON RESERVOIR, COLLIE RIVER AND HARRIS RIVER

PARAMETER	UNIT	WELLINGTON	COLLIE	HARRIS (1)	COMMENT
Colour (Range)	HU	5-50	5-175	5-90	1980-1984
Colour (Average)	HU	19(2)	39(3)	41(3)	1980-1984
Turbidity (Max)	TU	8.3	4.5(4)	4.9(4)	

(1) - Tallanalla Road
(2) - Offtake
(3) - Flow-weighted
(4) - 90 percentile

TABLE 14

FLOW-WEIGHTED COLOUR:

COLLIE RIVER AND HARRIS RIVER,

1980-1983

STREAM	PERIOD	NO. SAMPLES	AVERAGE COLOUR	(HU *)
Harris River	1980/81	7	39	
(STN. 612017)	1981/82	177	48	
(Tallanalla Road)	1982/83	76	33	
	1983/84	42	46	
	Mean	-	41.5	
Collie River	1980	24	28	
(STN. 612002)	1981	59	38	
(Mungalup Tower)	1982	197	45	
	1983	269	45	
	Mean	-	39.0	

* Flow-weighted

The results in these tables indicate that there is no significant difference in the colour of the Harris and Collie Rivers. While colour levels in Wellington Reservoir have been relatively high on occasions, they have been observed to naturally decline during certain months of the year. The processes which are believed to be operating are blending, bleaching due to ultra violet light, microbiological degradation, oxidation and settling. The rate of reduction appears to be a function of the temperature regimes and hydrodynamic conditions in the reservoir.

Using the results of the observations on Wellington Reservoir it has been possible to predict the likely ranges of colour levels in the Harris storage (Table 15). The predictions show that colour in the storage would meet the NH&MRC current colour criteria and that with appropriate reservoir management, colour can be kept to levels which are not expected to cause any adverse consumer reactions.

TABLE 15

EXPECTED COLOUR LEVELS IN THE HARRIS STORAGE

PERCENTILE	GSTWS SUPPLY RATE	
	$10 \times 10^6 m^3$/year	$20 \times 10^6 m^3$/year
10	8.3	9.5
20	10.5	11.8
50	15.7	17.0
90	28.5	31.5
95	33.2	35.2
97	35.5	38.1
99	39.9	41.3

The level of pathogenic organisms in the Harris Reservoir impoundment will be low and it would be possible to meet coliform standards in disinfected water without the need for filtration. There is, however, a risk of Nagleria fowleri (amoebic meningitis).

Filtration would ensure that the cysts of Nagleria would not be introduced into the system from raw water sources. However, because there are open reservoirs on the system and because there would be an accumulation of debris in certain parts of the distribution system, filtration would provide little additional insurance against the potential risk of Nagleria existing, or being reintroduced into the system. Under current conditions, the safest way of ensuring satisfactory microbiological standards in the distribution system would be to provide adequate disinfection by either chloramination or chlorination.

Trihalomethanes (THM) are chlorinated organic compounds which are created by the addition of free chlorine to water containing certain natural organic materials. The term THM covers four or five compounds including chloroform and bromoforms. In the US, there is a maximum containment level of 0.10mg/l for total THM's. The WHO recommended maximum level is 0.03mg/l, for chloroform only, as this is the only compound from this group which poses a potential health risk.

Under certain conditions, total THM in chlorinated Wellington Reservoir water exceeds the US level of 0.10mg/l for THM but the WHO standard for chloroform is not exceeded. The high THM in Wellington Reservoir water is due to the presence of bromide in the water during periods of high salinity. These react with oxidising agents to form bromoforms. It is doubtful, therefore, that such conditions could occur with chlorinated water from the Harris River. Within the past two years, most control practices have centered on alternative disinfectants such as monochloramine. Such control involves minimal additional capital and operational costs. If alternative disinfectants are adopted there would be no problem due to THM or chloroform. This aspect is currently being given detailed consideration.

10.0 DESCRIPTION OF THE BIOLOGICAL ENVIRONMENT

Details of vegetation, flora and fauna surveys, the techniques used, and the results obtained are presented in Appendices B, C and D. This section summarises the results and describes significant features that may be affected by the project.

10.1 VEGETATION

The Harris Dam is located within the Northern Jarrah Forest most of which is designated State forest (Figure 9). Considered on a broad scale, the native vegetation is of two basic types:

- o Jarrah (Eucalyptus marginata) forest on the plateaux and slopes, usually with marri (E. calophylla) as a co-dominant or sub-dominant
- o Flooded gum (Eucalyptus rudis) - paperbark (Melaleuca spp.) shrub complexes in depressions and valleys, sometimes with yarri (E. patens) and often variable, diverse and dense understorey shrubs.

Although most of the catchment is still covered by native vegetation, a few areas of private property have been cleared for agricultural purposes and are shown in Figure 9.

10.1.1 Catchment Area

The forest of the catchment area is, for the most part, jarrah open forest and jarrah-marri open forest of types that are widespread on and typical of forested lateritic slopes and uplands between Dwellingup and Collie.

Although this forest appears essentially uniform from the air, there is a shift in understorey species between the western, higher rainfall zone and the eastern, lower rainfall zone. For instance, the Bossiaea aquifolium, Pteridium esculentum and Lasiopetalum floribundum that characterise the high rainfall forest are replaced by Bossiaea ornata, Styphelia tenuiflora and Isopogon dubius in the lower rainfall forest. Furthermore, wandoo (Eucalyptus wandoo) becomes an important dominant in some of the eastern forests, while yarri is important is some western ones. Bullich (E. megacarpa) occurs in a few small stands in valleys in the western part of the catchment.

The apparent uniformity of the forest is reflected in the vegetation maps of Smith (1974) and Beard (1981), but Heddle et al., (1980) recognise the west-east variation in their mapping of complexes.

There are also differences in the eastern forests and western forests not related to species composition. More logging has been carried out in the western forests than in some of the eastern areas, where there is still virgin jarrah forest, and dieback disease (Phytophthora cinnamomi) has affected more of the western forest than the eastern. Prime virgin jarrah forest with parts unaffected by dieback were set aside in Surface Management Priority Area (now part of the Lane-Poole Reserve) east of Asquith Road. This is the largest area of uncut jarrah forest north of the Blackwood River.

Heddle et al. (1980) map four vegetation complexes in the catchment area that are characterised by swamp, stream and heath associations. One of these, the Swamp Complex, contains the most extensive, most diverse and best-developed stand of swamp-scrub-heath vegetation between Dwellingup and Collie, as well as Lake Nalyerin, a major seasonal lake. The vegetation of Lake Nalyerin includes restionaceous and cyperaceous sedgelands, shrubs dominated by species of Melaleuca, open low-woodlands dominated by paperbark (Melaleuca preissiana) and swamp banksia (Banksia littoralis). The lake and surrounding areas are in the former Nalyerin Management Priority Area (now part of Lane-Poole Reserve).

The most important stand of Swamp Complex vegetation begins in the Harris River valley south of Lake Nalyerin, is broadest north of Lake Yourdamung and extends west to Tallanalla Road and MacDougal Road. This vegetation contains swamp cypress (Actinostrobus pyramidalis), woody pear (Xylomelum occidentale) and some other species that are poorly represented in the Darling Range. The most diverse parts of the stand are above the FSL. Some of this Swamp Complex vegetation lies within the old Surface Management Priority Area.

10.1.2 Reservoir Area

The vegetation of the reservoir area is primarily jarrah-marri open forest on the slopes and a complex of open forests and shrublands along the river and on the riverine flats (Figure 10). Fringing forest of flooded gum with dense understoreys of wattles and other legumes, proteaceous and myrtaceous shrubs, and sedges are characteristic along the watercourses in the relatively narrow valleys in the lower part of the reservoir. Upstream, where the valley is broader and shallower and where there are flats, the vegetation is dense, 1m-2.5m tall Melaleuca spp. and mixed shrublands and low paperbark woodlands. Yarri trees are common, sometimes as emergents, in the valley vegetation of the reservoir area.

10.1.3 Downstream Riverine Vegetation

The native vegetation along the river below the damsite is essentially the same as that in the lower part of the reservoir. In places both sides of the river have been cleared and are pastured.

10.2 FLORA

The richness of the vascular plant flora of the catchment and reservoir area, undoubtedly reflects the diversity of the Harris River vegetation. No fewer than seven species of eucalypts (jarrah, marri, wandoo, flooded gum, bullich and limestone mallet) and a total flora probably in excess of 500 species occurs in the catchment.

10.2.1 Rare and Geographically Restricted Species

Two species of rare or geographically restricted plants have been found in the catchment, but as its flora is still incompletely known, more may be discovered. Senecio leucoglossus, a species that is most common after burning, is restricted to the Darling Range. Grevillea drummondii is a gazetted rare species that ranges from Bolgart to the Shannon River area. The grevillea is usually found on sandy soil, often near large rocks (Rye and Hopper, 1981). The Senecio is reasonably common in jarrah-marri forest along Trees Road above the FSL. The grevillea was found near the intersection of the Old Collie Road with the Collie-Tallanalla Road below full supply level and has been reported in a number of locations below the dam embankment.

10.3 FAUNA

Details of fauna surveys and of animals expected to be found in the project area are contained in Appendix C. Summaries for each group of animals appear below.

10.3.1 Mammals

The survey recorded nine species of mammals, of which six are native and three introduced. The six native species are the Echidna (a monotreme), one carnivorous marsupial, two kangaroos, a bat and a rat. The three introduced species recorded consisted of the fox, rabbit and feral pig.

Distributional data in Strahan (1983) shows that the native mammals that were recorded were already known to occur in the southwest. Section 4.1.3 of Appendix C also shows that an additional 22 species possibly occur in the survey area.

With the exception of the Quokka (Setonix brachyurus) all of the native mammal species recorded during the survey are widely distributed in Western Australia. The dense swamp vegetation upstream of Twenty-Two Mile Pool comprises an important habitat for the Quokka.

10.3.2 Birds

A total of 46 species were recorded during the survey. This figure comprised 19 species of non-passerines and 27 species of passerines. All but seven of the species found by this survey have wide distributions across Australia. Of the seven exceptions three are restricted to southwest forest and coast, the remainder having more substantial ranges over southern Western Australia. All recorded species have previously been recorded in the southwest (Pizzey, 1980). Most of the expected residents and the commoner nomads and migrants were recorded in the survey.

10.3.3 Reptiles

The survey recorded 15 species of lizards and 3 snakes. Distributional data in Cogger (1979) shows that all recorded species are widely distributed in the southwest division and that only two are restricted to that division. Another five lizard species are expected to occur in the survey area.

Snakes are far more difficult to trap or observe than lizards. This was reflected in the results of the survey, during which only three species were recorded from a total of nine that could be expected in the area based on their known habitat preferences and distributions. All snake species found were within their previously recorded geographic ranges.

10.3.4 Frogs

A total of eight species of frogs was recorded during the survey, including six ground frogs and two tree frogs. Some frog species are difficult to collect and it is likely that several additional species occur in the survey area. All species recorded were from within their known geographic ranges, and all range widely in the southwest of Western Australia.

10.3.5 Animals of Special Significance

One species of bird recorded during the survey, the Red-eared Firetail (*Emblema oculata*), is listed under the Western Australian Wildlife and Conservation Act as likely to become extinct, rare or otherwise in need of special protection.

The recording of the Red-eared Firetail is of particular interest. The distribution and abundance of this species is described by Pizzey (1980) as "confined to suitable pockets of habitat in coastal and near coastal south-west Western Australia from about Mundaring Reservoir in the Darling Ranges near Perth, south to Manjimup and coastally east to Hamersley River near Hopetown. Also Lucky Bay, Mississippi and Duke of Orleans Bays east of Esperance. Common to uncommon, sedentary and often very local". Recent locality records were reviewed by Nichols *et al.*, (1982). As this bird species is widespread in its range it is not expected that the construction of the dam will endanger the abundance of the species.

10.4 AQUATIC BIOLOGY

10.4.1 Description of Lakes and Streams

The Harris River catchment streams have a dendritic pattern contained within broad shallow valleys.

The Harris River is an ephemeral stream usually flowing from April to October (during the wet season). As the dry season progresses, the river usually dries to disjointed pools, with only Twenty-Two Mile Pool having any permanency.

Within the upper reaches of the Harris River there is an area locally known as "Trees Plain". This plain is a low gradient swamp which extends from Twenty-Two Mile Pool upstream to Treesville, a distance of 15km. This swamp is vegetated with a complex of sedge, shrub and heathland communities and includes peat deposits. It is a major water retention area within the catchment and releases shallow trickle (groundwater) flows to the Harris River.

Twenty-two Mile Pool and Trees Plain are important for the conservation of wetland-dependant species of plants and animals and as centres of interest in the landscape.

The wetlands also are important as summer drought refuges for waterbirds and as breeding grounds for frogs, turtles and other aquatic animals (Department of Conservation and Environment, 1981).

10.4.2 Invertebrates and Vertebrates

An aquatic fauna survey was undertaken to survey the resident native and introduced fish fauna and to obtain an inventory of the macroinvertebrates present in the Harris River pools. The work effort was concentrated from Damsite 5, upstream to Twenty-Two Mile Pool. A detailed report on the survey is contained in Appendix D.
A total of 75 taxa of macroinvertebrates was identified of which there were 52 insects, 8 crustaceans, 4 molluscs, 3 arachnids and 8 members of other minor phyla. No rare or endangered invertebrates were recorded.

Five species of fish were recorded, of which two species were introduced (Mosquito Fish and Redfin). The native species included the Western Minnow, Nightfish and the Western Pigmy Perch. There was no recording of the native Migratory Minnow (Galaxias maculatus) which had been reported locally. The study area is outside the known range of the species which is similar in appearance to the Western Minnow.

Marron (Cherax tenuimans) have been reported locally from the Harris River, however, none were caught by the sampling techniques outlined in Appendix D.

10.4.3 Water Plants

The term 'water plants' (or aquatic plants) refers both to algae and to vascular plants. Algae occur along the Harris River in a variety of forms and sizes, from macroscopic to microscopic. Like the river itself, the algae and the submerged and floating aquatic vascular plants it supports, are ephemeral or seasonal. They disappear, except as spores, seeds or dormant, buried structures, during the summer and autumn.

Algae in the Harris River occur as films, thin mats and loosely attached masses of cells on surfaces of mud, rocks and other solids in the river and next to it and, more rarely, as structured plants in still and slowly moving water. In the water they are most common amongst dense growths of Baumea vaginalis and other vascular aquatics, especially during late spring and summer.

Although the algae flora of the Harris River was not determined, it appears likely that the species occurring there are the same as in other small, Darling Plateau rivers.

Only one species of submerged or floating aquatic vascular plant was found during the survey, water ribbon (Triglochin procera). It was common in the river bed throughout most of the reservoir area.

Several species of other vascular plants occur as emergents when the river is flowing. Common species include Gonocarpus hexandrus, Lobelia alata, Centella asiatica, Myriophyllum aquaticum and Baumea vaginalis.

11.0 DESCRIPTION OF SOCIAL ENVIRONMENT

11.1 SOCIO-ECONOMIC STATUS

11.1.1 Population and Employment

The Shires in proximity to the Harris River damsite are Collie and Harvey, both being part of the Preston Statistical Sub-Division. Collie Shire, the focus of the present study, has a population of 8947 and Harvey has a population of 8027 (1981 census). All private land holdings within the storage area have been purchased by the Water Authority and are now leased back to their original owners.

The employment structure of the regional economy varies markedly between Collie Shire and Harvey Shire. The Shire of Collie employment base is largely based on coal mining electricity generation, and alumina refining whereas Harvey Shire is dependent upon agricultural and primary processing industries.

Employment multipliers were calculated for the Shires and the Preston Statistical Sub-Division. The "total employment multiplier" measures the changes in service industry jobs that result from changes in the region's basic industries. The multiplier analysis shows "total employment multipliers" for the Preston Statistical Sub-Division of 2.86 and 1.5 for Collie Shire. The addition of one job to the construction industry would lead to 0.5 service jobs within Collie, whereas at the regional level an increase of one basic job would lead to 1.86 service jobs.

11.1.2 Housing

Permanent housing within Collie Shire is at a premium due to recent resource developments within the Shire, mainly at the Worsley Alumina Refinery and Muja D Power Station. Local Shire personnel have indicated that there are also shortages of land around the township suitable for residential development.

In the past few years there has been an extreme shortage of short term and rental accommodation due to the above developments. This pressure has now eased somewhat, however private accommodation is still at a premium.
Within the Collie township, renovation of older hotels has increased the availability of hotel units. In 1985 the Royal Automobile Club of Western Australia (RAC) figures indicated there were 120 caravan park sites, and 94 motel, hotel and guesthouse units. Temporary accommodation in the broader Bunbury region is more plentiful because of the tourist areas along the adjacent coastline.

11.1.3 Forest Management

Prior to 1976, timber felling was a major land use in the Harris River catchment's jarrah forest, but since then all the State forest east of the Collie-Tallanalla Road has been declared a disease risk area and no logging has occured in it. Since 1977, the only logging in the catchment west of the Collie-Tallanalla Road has been in small areas, mostly on the catchment margin. These logged areas have either been affected by dieback or are associated with the Worsley Alumina Refinery. Fire control operations and patrols of the Lane-Poole Reserve will continue to be necesary.

11.1.4 Beekeeping

The Collie - Harvey forest produces honey from mid-October to March and during this period beekeepers are actively engaged in honey production.

The principal honey producing species in the Collie - Harvey area are jarrah, marri, yarri, bull banksia, bullich, and wandoo. Currently 23 sites have been allocated within the Harris River catchment area (Figure 11).

The number of sites available in State forest is limited by the Department of Conservation and Land Management (CALM) based on constraints such as a minimum spacing between sites, dieback disease management, and forest regeneration (Forests Department, 1982). Also, the Water Authority restricts sites to a minimum distance of 1.5km from the FSL of any domestic water supply dam and to a minimum distance of 200m from any stream (Water Authority, undated).

11.1.5 Mining

Damsite 5 is located within the Bauxite Mining Lease 1SA held by Alcoa of Australia. Generally only the flanks and ridges of the Plateau are prospective for bauxite.
It is understood , however, that proposed mining is a long term prospect and that ore density tends to be low. The easement resumed for the conveyor belt, which carries bauxite from Boddington to the Worsley Alumina Refinery, passes across the northern and northwestern section of the Harris River catchment.

There is an occurrence of vanadium in the vicinity of Twenty-Two Mile Pool and the Trees Plain is believed to be prospective for coal.

11.1.6 Agriculture

There are small private parcels of land located adjacent to Damsite 5 totalling 165ha in area. They are now owned by the Water Authority. Below Damsite 5 there are 536ha which have been cleared for fodder cultivation and stock grazing. These properties have limited rights to water in the Harris River under the Rights in Water and Irrigation Act.

11.1.7 Reserves

The entire eastern portion of the Harris River catchment is contained within the Lane-Poole Reserve, which is managed by the the Department of Conservation and Land Management.

The main purpose of the portion of the 49,200ha reserve within the Harris River catchment is to protect and conserve the flora, fauna and landscape of the area, particularly the largest area of virgin jarrah forest north of the Blackwood River. The swamps in the catchment part of the reserve are unique and provide an excellent wildlife refuge (Darling Range Study Group, 1982). The reserve also has regional park potential (Environmental Protection Authority, 1983).

The register of the National Estate in Australia does not contain any registered listings from the project area.

11.1.8 Transportation

The main road connecting the project area to Collie is Tallanalla Road, an unsealed, shire road.

The majority of the project area is criss-crossed with forestry roads/tracks which traverse forest disease risk areas and are not available for public use. They are important for forest management and fire control purposes however.

11.2 RECREATION

A recreation survey was undertaken and a detailed report is contained in Appendix F. A brief summary of the survey is contained in this Section.

The survey investigated the current recreation usage of the Collie area and concentrated on the Harris River/Collie region, the Wellington Reservoir, Wellington Dam and the downstream gorge.

It is anticipated that recreational pressures on the area are likely to increase in the future, as the population of the Bunbury Region increases by 50,000 people by the decade 1990-2000. This increase will have a substantial impact on the limited recreation sites available in the area.

The recreational and tourist resources of the area are currently substantial and comprise natural assets (forests, rivers and scenery) and man-made features (coal mines, power stations, alumina refineries and dams), but the potential usage of these resources has not yet been fully developed. Developed tourist and recreation facilities in the study area are minimal and concentrated at Wellington Dam and the Wellington Mills Holiday Camp.

Wellington Dam is extensively used and good facilities are provided (car parks, kiosk, picnic facilities). No camping is permitted and the principal users are day visitors. Substantial overcrowding occurs at peak times.

The Collie River gorge below Wellington Dam is intensively used for a variety of recreational purposes including:

- Sightseeing at the dam spillway
- Road touring the narrow tracks
- Hiking and bushwalking
- Camping in designated "picnic" grounds
- Marroning
- Swimming and canoeing.

These activities are concentrated between the dam and River Road Bridge but recreational vehicle driving, canoeing and shooting occurs further downstream and may conflict with the ecological value of the area.

There was no observed recreational usage of the Harris River valley. However, it has been pointed out by Local Authorities and individuals that pig hunting, marroning and car rallying occur in the region of the Harris River. The river is not well suited to canoeing as it is narrow, overgrown, dries up in summer and does not have navigable rapids.

11.3 ARCHAEOLOGY

A preliminary archeological survey for Aboringinal sites was undertaken throughout that part of the Harris River valley which might have been affected by a Dam at site 5 with a water level up to the 227m contour. The results reported here therefore cover a larger area than would be affected by a full supply level of 223.5m. Prior to final site selection, the survey was extended downstream to include Damsite 1. All results are reported fully in Appendix G. The survey located 53 low to high density stone artefact sites within the study area and 2 isolated finds within Damsite 5. Extension into Damsite 1 located a further 11 sites and 8 isolated quartz artefacts.

Five stratified sites were located during the survey. These sites were visible due to ground disturbance (such as recent road/culvert construction and recently upturned trees with root systems intact).

Significant results include:

- Most sites contained 10 or less pieces (75.5%, N=40)
- The density of (small) sites is high, in comparison to the results of other study areas closer to the scarp. A site is defined as two or more pieces in close association. A considerable number of isolated finds were located.
- Most of the sites (and isolated finds) are located adjacent to well defined drainage channels of the valley system on relatively flat ground (67.9%, N=36)
- A large number of sites are located on, or adjacent to, forestry tracks and paths (60.4%, N=32). This is considered to be largely a product of increased surface visibility.

Most of the sites and isolated finds are congregated around the major drainage channels of the valley system on relatively flat ground. The largest sites are located on lateritic surfaces adjacent to swampy areas. Most of the sites are associated with a valley - bottom vegetation of open forest/low open woodland. Only a few sites were located within swamp and valley-slope vegetation complexes.

The stone tool assemblages would suggest that most of these sites are no older than mid-Holocene. The presence of a specific chert in one stratified site and early Holocene dates from similar forest environments indicates that earlier material is likely to be found here.

The high density of small artefact scatters (and isolated finds) is postulated as representing a pattern of human movement marked by small, highly mobile family groups exploiting this inland forest on a seasonal basis.

11.4 ETHNOHISTORY

The ethnohistorical data, compiled as a component of the archaeology report (Appendix G), suggests a model of seasonal exploitation of the jarrah forest in the vicinity of Collie.

Information was taken from a limited number of exploration journals of people who, at an early stage, travelled into the jarrah forest. Sightings of larger aggregations of Aborigines on the coastal plain and their fires, were made by Collie and Preston and the early French explorers Baudin, Peron and Freycinet. The summer season provided a period of abundance of estuarine resources, such as fish and water fowl, with freshwater being plentiful. Large aggregations of people (possibly over 100 individuals) attest to the relative bounty of these resource bases. In the winter season, however, a combination of flooding on the coastal plain, dispersal of fish and water fowl from the estuaries, and restricted movement over the plain, added impetus to the migration of people into the uplands.

In addition, the inland rivers yielded freshwater during winter, and as staple foods such as yam and zamia were available, these resources would have encouraged the movement of the Aboriginal groups to the uplands. On this basis, it appears that the large summer coastal groups would have dispersed in smaller groups during winter across the coastal plain and into the coastal uplands and it is possible that some of these groups would have gone as far as the Harris River.

11.5 ETHNOGRAPHY

An ethnographic survey was undertaken to interview Aboriginal people with knowledge of the area surrounding Collie, and to locate sites and obtain information on the significance of these sites to living Aborigines. The survey report is contained in Appendix I and a summary is presented below.

The swamp in the upper reaches of the Harris River from the junction of Mistley and Trees Roads was known to local Aborigines as Piling. Although the swamp did not have mythological significance, it was believed that Waugal (a mythical serpent) lived among the rocks in the hills on the northern side.

A claypan which forms a deep pool is located 100m east from the wooden bridge over the swamp on Mistley Road (Figure 6). This pool was known to local Aborigines as Wuridjong Pool where Waugal was believed to reside.

No other mythical associations were reported for the Harris River upstream of Damsite 5.

Two additional sites were identified outside the catchment area. An area from the boundary of the Coates Hire Service yard to the GSTWS pipeline has been identified as an old Aboriginal Reserve. The other site is located on the Collie River East Branch at Eight Mile Pool. Neither site is likely to be affected by the project.

12.0 PROJECT IMPACTS AND MANAGEMENT PROCEDURES

In this Section assessments are made of the potential environmental impacts resulting from construction of the dam and development of a reservoir on the Harris River. Emphasis is placed on the water quality effects.

Management procedures for the mitigation of potentially adverse impacts are presented in bold type.

12.1 CONSTRUCTION

12.1.1 Clearing of Forest and Rehabilitation

The reservoir developed at the Harris River will involve the flooding of some 990ha of farmland, forest and swampy plains vegetation. Approximately 850ha are presently uncleared native vegetation designated as State Forest.

Trees and large scrub up to the full supply level will be removed before flooding the reservoir. This is necessary as rotting organic matter could produce an oxygen demand that could lower water quality as well as creating a toxic environment for aquatic biota attempting to colonise the reservoir.

CALM will be contacted as early as possible to arrange for logging of suitable timber in the reservoir basin. Timber to the east of the dam could be logged at the same time. The remaining vegetation will be heaped up within the cleared reservoir basin and burnt on site. Clearing equipment will be confined to the reservoir basin and the immediate area of the dam wall and associated works. Full liaison will be maintained with CALM, in accordance with forest hygiene requirements.

Topsoil from the reservoir area will be stockpiled for use in rehabilitation of disturbed areas. Disturbed areas above full supply level which do not support improvements will

be rehabilitated. Such areas will include cut and fill faces and construction pads which are not required for further construction activities. Topsoil that has been stockpiled during construction will be used to cover the disturbed areas. They will then be deep ripped to promote water infiltration, control erosion and encourage root penetration. Revegetation in the vicinity of the dam wall will conform to a landscaping plan prepared in consultation with CALM officers. Elsewhere, CALM prescriptions for rehabilitation in the jarrah forest will be adhered to.

Regular inspections of rehabilitated areas will be undertaken to identify areas requiring further treatment and maintenance. These inspections will be undertaken annually, prior to each winter season. The prescribed treatments will include:

- o Control of noxious weeds
- o Repairs where signs of soil erosion are evident.
- o Replanting as required

Such treatments will be regarded as routine maintenance. It is anticipated that once satisfactory rehabilitation is achieved, it will be self-sustaining.

12.1.2 Surface Disturbance and Erosion Control

The major impacts of construction will be concentrated around the damsite. Disturbance will also be associated with the relocation of the Collie - Tallanalla Road. These activities will have a direct effect on habitats and forest as well as pre disposing the ground surface to accelerated surface erosion, which is a potential source of sediment in the river. Generation of sediment and turbidity immediately downstream will be unavoidable and will impact water quality and the freshwater ecosystem in the near vicinity. The extent of these effects will be minimised by:

- o Most of the earthworks will be carried out during the summer period when runoff is normally low. This will minimise the opportunities for erosion and limit the extent of sediment transport downstream.
- o Early construction of the dam outlet culvert will bypass river flows around the construction site.

Elsewhere environmental impacts from surface disturbance will be minimised by:

- Restricting clearing operations to the minimum required for construction and safe access
- Utilising the area upstream from the dam wall and below full supply level for borrow material and construction facilities
- In consultation with the relevant authorities, upgrading and using existing roads for access during logging, clearing and construction
- Revegetating disturbed areas outside the storage area as soon as possible after construction is completed.

12.1.3 Dust and Noise

Adverse dust and noise impacts on local residents are expected to be low at Damsite 5. Worsley Alumina Refinery is 11km to the west of the site and Collie township 10km south. There are two households located close to the main access road and these will experience a degree of dust and noise impact due to heavy vehicle traffic. The other two households are off the road and are unlikely to experience significant impact.

Noisy, heavy equipment will only operate during daylight hours to minimise any inconvenience to residents. Residents will be fully informed of any blasting operations and all people will be excluded from the danger area during shot firing. The sealing of the Tallanalla Road from Collie will minimise noise and dust due to heavy vehicle traffic.

As construction will be undertaken during the drier summer months, some of the access roads, cleared reservoir areas and haulage roads from borrow pits will require dust suppression.

Working areas will be sheeted with gravel or when necessary, watering will be carried out using a water tanker fitted with sprays. Watering will be minimised consistent with dieback control requirements where relevant. Adverse effects from dust and noise are likely to be largely confined to the construction workforce. Employees exposed to unacceptable noise or dust levels will be issued with suitable protective equipment.

12.1.4 Construction Operations

Except for temporary site offices, canteen and ablution facilities, it is not anticipated that there will be a requirement for accommodation at the construction site. Satisfactory accommodation will be provided at Collie which is 14km by road from Damsite 5. It is important that adverse impacts upon the forest be kept to a minimum during construction.

Adverse impact upon the site environment will be minimised by:

- o Using cleared areas below FSL, wherever feasible, for construction facilities and parking areas for worker's cars
- o Removal of temporary buildings, construction refuse and hardstand material at the completion of the construction programme
- o Supplying appropriate facilities for workers, with regular removal of refuse to approved disposal facilities.

It will be necessary to upgrade Tallanalla Road from Collie to the damsite to improve large vehicle access. Upgrading will include:

- o Sealing the road and contructing table drains
- o Drainage off the road will be controlled wherever practicable.

Care will be exercised in storage and handling of petroleum based products, as there is the potential for contamination of surface soils and water from oil or fuel spills. These petroleum products adhere to rocks and vegetation and may cause pollution downstream.

All oils and fuel will be stored according to the requirements of the appropriate regulations. All wastes will be collected in a sump and trucked to an approved waste disposal site.

12.1.5 Management of Forest Disease Risk Area

All of the State forest east of Tallanalla Road is designated as a disease risk area (Section 10.1.1). This designation means that this forest is relatively free of the dieback disease and that access to it is restricted.

As Damsite 5 and the majority of the reservoir are located within the disease risk area (DRA), stringent conditions will be enforced by the Water Authority on its staff and contractors to minimise the spread of dieback in the disease risk area. The Water Authority will establish guidelines for dieback control in consultation with CALM.

12.2 IMPACT OF DAM ON EXISTING ENVIRONMENT

12.2.1 Aquatic Ecosystems

Aquatic ecosystems along the length of the Harris River which are inundated will be radically altered. An ecosystem characterised by the change from flowing water in winter to shallow disconnected pools in summer will be altered to a permanent deep lake. This new system is discussed in section 12.5.2.

Twenty-Two Mile Pool is an important summer refuge in an otherwise dry environment. **To protect Twenty-Two Mile Pool, the full supply level of Harris Dam has been fixed at 223.5m. The low gradients in this area this means that the reservoir surface will remain at least half a kilometre from the pool. To further ensure the integrity of the pool ecosystem, it is proposed to retain a buffer area of swamp vegetation below it. This will be achieved by limiting clearing in the shallow upper part of the reservoir to the 223m contour. As this part of the reservoir will dry out annually the existing vegetation is expected to survive, since it is adapted to seasonal inundation.**

12.2.2 Vegetation and Flora

The immediate impact of the dam and reservoir will be to destroy approximately 850ha of jarrah-marri open forest and riverine vegetation. The long term impact may be the creation of habitats for water plant communities and for plants that colonise and vegetate shores along fluctuating lake margins.

The eucalypt tree communities to be removed are better represented in other parts of the catchment and the Northern Jarrah Forest. The swamp vegetation in the Harris River valley, especially above Twenty-Two Mile Pool, is remarkable and unusual. **Vegetation upstream of Twenty-Two Mile Pool will be protected by selection of the 223.5m contour as full supply level.**

A small stand of one gazetted rare species, Grevillea drummondii, will be inundated by the reservoir. It is not possible to avoid this stand of plants. The wide range of this species suggests that removal of this one stand will not result in loss of the species as a whole. The plant is commercially available and attempts will be made to include it in the landscaping associated with the dam.

12.2.3 Fauna

The flooding of the Harris River will destroy habitats which are currently available for terrestrial fauna and it will also create new aquatic habitats. Although there are no species unique to the existing forest or stream ecosystems, some are dependent upon the physical components of the stream for all or part of their life cycles. **The full supply level has been set at 223.5m to avoid the swamps above Twenty-Two Mile Pool, on which sensitive species such as the Quokka (Setonix bracyurus) depend.**

The development of the reservoir storage will probably result in an overall decrease in the diversity and abundance of animals. However, it will favour colonisation by open-water species of birds such as ducks (Anatidae), cormorants (Phalacrocoracidae), Black Swan (Cygnus atratus) and the Coot (Fulica atra). Open country insectivorous birds will also become much more common around the dam edges due to the greater availability of food resources. Other possible animals to colonise the dam will be some species of frogs and the Water Rat (Hydromys chrysogaster). The upper reaches of the reservoir are likely to become a useful summer refuge for many species, especially as clearing in this area is restricted to the 223m contour.

Inundation of dense streamzone vegetation will reduce the habitat available to the Red Eared Firetail finch. As this species has now been shown to be more widespread than previously thought (Nichols, 1982), and there is a large area of similar habitat upstream, this loss is unlikely to significantly affect the overall status of the species.

The presence of feral pigs in the catchment area in large numbers could possibly cause water purity problems and it is essential that methods be continued to reduce them (McKinnell, 1983).

12.2.4 Employment and Population Distribution

The peak construction workforce at the construction site is not expected to exceed 200 persons. This figure is based on the manpower requirements for the construction of the Harding Dam, 23km south of Roebourne. At the Harding Dam the peak construction workforce totalled 110-120 contract staff and 25 Water Authority staff (R. Wark, Water Authority, pers. comm).

When this number is compared to the peak construction workforce of over 3,200 for the Worsley Alumina Refinery, the local population of Collie is not expected to be significantly changed. It is considered that the majority of the workforce would be available locally. The population of Collie is not anticipated to increase unduly during the construction of the dam and the workforce should be catered for by existing services and infrastructure.

Using a "total employment multiplier" of 1.5, the additional employment generated in the Collie Shire is estimated to be 100. Caution should be used in the interpretation of this figure as there is likely to be considerable excess capacity in the local economy due to the finalisation of the Worsley Alumina project. The figure of 100 service jobs should therefore be considered to be the upper limit. No full time employment will be generated in the operations phase, as the site will be jointly maintained with other Water Authority projects in the southwest region.

The timing of the peak construction period for a project of this size will be limited in duration to approximately two years. As it is considered that the majority of the workforce will be available locally, the requirement for non-permanent accommodation during the construction phase is not expected to be great. Consequently, short term and rental accommodation stocks in Collie are likely to be adequate.

12.2.5 Forest Management Use

Up to 850ha of forest will be removed from future production by inundation. Much of the mature jarrah in the reservoir area has been logged.

CALM will be consulted regarding utilisation of timber remaining in the reservoir area, before the reservoir fills. Access to the east of the dam will be retained via Norm Road. The Water Authority will liaise with CALM to ascertain if direct access to the Collie - Tallanalla road is required in the long term for fire control and reserve management.

12.2.6 Beekeeping

Approximately eight sites will be affected by a reservoir behind a dam constructed at Damsite 5. As each apiary site produces approximately nine tonnes of honey each year, this represents a potential annual loss of up to 2.9% of the total honey produced in Western Australia annually. (L. Allan, Department of Agriculture, pers. comm.).

The Water Authority will liaise with CALM and affected apiarists on the need to rationalise and re-locate apiary sites, in keeping with the need to minimise conflict with other land uses while maintaining honey production.

12.2.7 Mining

Little direct impact on mining is anticipated given that the reservoir does not coincide with known mineral deposits. **In the longer term as Bauxite Mining approaches the reservoir, the Water Authority will liaise with the relevant parties as it now does regarding sites elsewhere in the Darling Range. It is possible that constraints will be placed on future mining operations in order to maintain water quality.**

12.2.8 Agriculture

No adverse impacts on agriculture are expected as a result of dam construction. Existing, limited, water rights will be retained by property owners downstream. Sufficient flow to service these rights is expected to be available from subcatchments downstream of the damsite.

12.2.9 Reserves

The proposed project will not impact the Lane-Poole Reserve. Creation of a reservoir may be consistent with achieving better control of access to the reserve by limiting direct access from the Collie-Tallanalla Road more effectively.

12.2.10 Transportation

The present alignment for Tallanalla Road will be flooded by the reservoir. Existing forestry tracks would be severed requiring the use of alternative routes via Asquith and Trees Roads. There will be short term adverse impacts from heavy construction traffic utilising unsealed roads in the area.

The following guidelines for relocation of Tallanalla Road will be used in the final design:

- **All affected authorities including CALM, Collie and Harvey Shires, SECWA, Worsley Alumina Company and property owners will be consulted regarding relocation**
- **Relocation west of the current alignment will take into account the need to minimise the potential for the spread of dieback as well as maintain water quality**
- **No detailed environmental studies have been carried out as the desired alignment has not been delineated. The wider studies which have been carried out in the catchment suggest however, that it is unlikely that significantly increased environmental impacts are likely to accrue from road re-location.**

Access for forestry management activities east of the dam will be provided in consultation with officers from CALM. The opportunity for further control of access may well be consistent with the conservation and disease management needs of this area. Liaison will be maintained with the Shires regarding the need for increased road maintenance due to construction traffic. It is anticipated that the unsealed portion of the Collie - Tallanalla Road will be sealed.

12.2.11 Downstream Ecosystems

Although the Harris River usually carries flows only from late autumn to early spring, it is anticipated that the construction of a dam may have an impact on downstream aquatic flora and fauna. Factors which will be altered and which are critical to the ecology of aquatic fauna include:

- o Water temperature, which controls invertebrate egg laying, moulting of insect instars and emergence of adult insects
- o Flow, which affects seasonal distribution and abundance of species as well as oxygenation
- o Water quality, where offtake of stratified layers will supply photic zone, nutrient-rich waters, or anoxic bottom layers to downstream ecosystems
- o Food supply, where a reservoir will prevent flow-transported plant and animal components of downstream aquatic faunal diet
- o Migration, whereby construction of a dam wall prevents fish, crustaceans and insects from moving up and down the stream for feeding or breeding.

Significant alteration to any of the above factors will result in a change in the population dynamics of the aquatic ecosystem. These changes are less likely to be mitigated due to the usually seasonal nature of river flows in the Harris River.

Surveys will be undertaken to assess changes in species distribution and abundance.

12.2.12 Proposed Spillway

The construction of the dam will reduce flood flows downstream, as on average, approximately 65% by volume of Harris River flows will be stored in the reservoir. The reduction in spill volume will decrease the flow rates, and hence the potential for long term scour of the river bed will be significantly reduced. However, some scour during major flood flows may still occur where flow down the spillway enters the river channel.

The spillway will be designed to incorporate a stilling basin structure which will minimise scour where spillway flow enters the river.

12.3 IMPACT OF THE PIPELINE ON EXISTING ENVIRONMENT

An alignment for the pipeline route from Harris Dam to link up with the GSTWS pipeline (from Wellington Dam) is shown in Figure 6.

The proposed pipeline will follow the transmission line corridor and the Collie-Tallanalla Road throughout its length. Current indications are that the pipeline will be buried and the backfilled trench allowed to revegetate by separate return of stockpiled topsoil over backfilled spoil.

12.4 IMPACT OF RESERVOIR ON WATER SUPPLY

Section 3.0 describes the need for the project to lower the salinity level in waters supplied from Wellington Dam to the GSTWS and Collie Irrigation District and in Section 6.0, alternatives to development of the Harris Dam are described.

The construction and operation of the Harris Dam will have beneficial impacts which will improve water quality to the GSTWS. In the short term and, in conjunction with the benefits obtained from catchment management, there will be a small reduction in the expected average irrigation salinities.

The beneficial impacts achieved by the Harris Dam will be:

- **Immediate improvement in the quality of water supplied to the GSTWS by the supply of low salinity Harris River water**
- **A small improvement on average in quality of Wellington Dam water, reducing the salinity of irrigation water supplied to users in the Collie Irrigation District.**

12.5 IMPACT OF DEVELOPMENT ON SHORELINE AND RESERVOIR HABITATS AND ECOSYSTEMS

12.5.1 Nature of Proposed Reservoir

An understanding of the nature and behaviour of the proposed reservoir under normal and extreme conditions is basic to assessment of environmental impacts. The factors to be considered include frequency of filling, rate and duration of drawdown and water quality.

The reservoir would be expected to fill in three to four years. Thereafter, filling will occur during the main inflow months of June to October. The decline of water levels due to withdrawal and evaporative loss would be slow. With a storage of 71×10^6 m^3 and annual draw of 10×10^6 m^3, reservoir level will normally fluctuate by about 2-3m each year.

As the water level in the reservoir declines due to outflow or rises due to inflow, the reservoir bed exposed will increase or decrease. The reservoir will for most of the time have a small bed area exposed. The rate of recession of the reservoir shoreline during periods of declining water level will vary from one part of the reservoir to another and is dependant on the shoreline slope and the season of the year. The areas where shoreline recession will proceed at the greatest rates are the gently sloping reservoir margins which occur in the upstream part, and in the eastern section which will flood Tulloch Road.

To minimise the exposure of bare reservoir bed in the gently sloping upper reaches, it is proposed that the bed remain uncleared beyond the 223m contour in the area of swamp immediately downstream of Twenty-Two Mile Pool. Vegetation in this area would be expected to tolerate seasonal inundation, as it does now.

12.5.2 Reservoir Habitats and Ecosystems

The development of new ecosystems following the flooding of a previously forested area will depend upon a large number of factors including:

- o Adaptive ability of surviving species to take advantage of a new range of available habitats
- o Ecological stability in the new habitats and whether they are reliable sources of habitat requirements for surviving and colonising species
- o Dynamics of interrelationships between the biological, physical and chemical components of the new ecosystems, for example the seasonal fluctuations in water level.

Planktonic and other algal communities will form the trophic basis of the aquatic ecosystem and the reservoir will probably develop a population of macroinvertebrates and fish. The aquatic survey did not locate any marron, however their known distributional range includes many freshwater streams of the Darling Plateau. Local people from Collie have indicated that marron do occur in the Harris River. Water birds are likely to colonise the new waterbody in the region and take advantage of new food sources.

It is anticipated that the construction of a dam will result in a reduction in the abundance of the native fishes (Perch and Minnow) and an increase in the number of Mosquito Fish and Redfin.

The reservoir may provide a habitat suitable for the establishment of several species of aquatic plants that are pests in man-made lakes elsewhere in Australia. However no aquatic weeds have been recorded in other Darling Range reservoirs.

The reservoir and its shores will be inspected to detect the introduction of any aquatic weeds and appropriate remedial measures will be implemented.

12.5.3 Shoreline Habitats and Ecosystems

The types of shoreline habitat and ecosystem that will develop are heavily dependant upon the frequency, rapidity and degree of fluctuation of the reservoir water level. If the vertical fluctuation is 2m or more, as will often be the case with the proposed reservoir, the probability of fringing vegetation establishing successfully is very low.

The relatively flat gradients in the upper reservoir area will result in large expanses of dry reservoir bed being exposed for part of the year. **Retention of existing vegetation down to the 223m contour will limit the extent of bare reservoir bed exposed and limit opportunities for the establishment of exotic species. Controls on public access to the reservoir margin will further limit the disturbance to the exposed bed.**

The fluctuations in water level and the consequent extension and recession of the shoreline may also alternately flood and expose food resources for sedge-feeding birds and enrich the food stock available for waders. Various species of dotterels and other shore birds can be expected to utilise the mudflats formed by the receding storage water level. The reservoir, especially the shoreline, will also be attractive to amphibians, some reptiles and mammals.

12.6 IMPACT ON AESTHETICS

A reservoir on the Harris River will result in the following changes in aesthetic character:

- Visual impact of man-made features in a natural environment

- Creation of a scenically attractive large open water body.

Like other reservoirs in the South West, the Harris Reservoir will be subject to fluctuations in water level with parts of the bare reservoir bed being exposed from time to time.

It is proposed to capitalise on the aesthetic opportunites provided by a new dam by:

- **Landscaping the area adjacent to the dam wall**
- **Providing vistas across the reservoir at selected sites.**

12.7 IMPACT ON RECREATION

12.7.1 Harris Reservoir

The Harris Dam and reservoir will create an additional tourist attraction in the region. This attraction is expected to be similar to that which occurs for Canning, Serpentine, Stirling, Wellington and other dams.

The Harris Reservoir will inundate the Tallanalla - Collie Road. This road has some current use and has significant potential as a tourist/recreation route from Dwellingup to Collie.

Opportunites for marroning and (illegal) pig shooting will be reduced. Car rallying paterns may be altered due to changes in road access and improved conditions.

The Water Authority also proposes to:

- **Examine the suitability of the area downstream of the dam for recreation, particularly picnicking and bushwalking**
- **In conjunction with other relevant authorities, give due consideration during the design stage to the tourism potential of the rerouted section of Collie-Tallanalla Road.**

12.7.2 Wellington Reservoir

The construction of the Harris Reservoir and its usage for GSTWS has the potential to enable the Wellington Reservoir to be released for recreational activity (Figure 12). This would be of significant value for both local recreation and the regional tourism industry. Wellington Reservoir, a resource which is suitable for a wide range of recreational/tourist activity would become available for activities such as:

- Unpowered boating (yachting, canoeing, rowing)
- Powered boating and perhaps houseboating under controlled circumstances
- Boat and shoreline fishing (marron and redfin perch)
- Shoreline hiking and recreation driving
- Shoreline picnicking with casual swimming and other passive sporting activities.

The forest and lake scenery and the indented shoreline of Wellington Reservoir would enable the introduction of a variety of tourist and recreation accommodation such as:

- Camping areas and caravan parks
- Holiday cabins
- Motels
- Club camps.

However, as much of the of land surrounding Wellington Reservoir is in private ownership, development of recreation and tourist facilities will depend upon:

- A positive approach by the landowner, or
- Acquisition by the Crown, and
- Amendment to the regulation preventing camping activities in declared water catchments.

In conjunction with affected landholders, state and local government agencies and other interested parties, the Water Authority will prepare a management plan defining opportunities for recreation, on the waterbody and on the shorelines around Wellington Reservoir. This plan would indicate the locations and densities of recreational facilities and activities taking into account:

(a) Engineering services and access
(b) Environmental issues - water quality
- erosion
- flora and fauna
(c) Landscape quality
(d) Conflicts in recreation use
(e) Finance, management and maintenance
(f) Public attitudes to development of the area.

12.8 EFFECT ON ETHNOGRAPHIC VALUES AND ARCHAEOLOGICAL SITES

12.8.1 Ethnographic Values

Wuridjong Pool, a site of significance to living Aborigines is located above the proposed FSL of 223.5m and will not be adversely affected by the project. It is not anticipated that any recreational development will occur at the site as it is located within the CALM dieback risk area and therefore not accessible to the public.

12.8.2 Archaeological Sites

The 53 sites and 61 isolated finds reported in Section 11.3 will be inundated, destroyed, and/or lose their integrity in the event of the construction of the dam. Approximately three sites and four isolated finds will be destroyed by a dam constructed at Damsite 5.

- **The Water Authority acknowledges its obligations to site protection as outlined in the Western Australia Aboriginal Heritage Act, 1972-80, and will comply with any directions given by the Minister.**

- **Sites S1848, S1869, and S1878 will be test pitted**

- **Sites S1865 and S1871 will be recorded in detail and the archaeological material collected**

- **Any new sites discovered during the course of the work will be reported to the Registrar.**

13.0 BIBLIOGRAPHY

AMDEL (1982). Summary of Effects of Salinity on Municipal and Industrial Water Consumers in Respect to the River Murray, South Australia - Stage II. Engineering and Water Supply Department. Report No. 1. March 1982.

------ (1983). Summary of effects of Salinity on Municipal and Industrial Consumers in Respect of the River Murray, South Australia - Stage II. Engineering and Water Supply Department. Report No. 2. May 1983.

Beard, J.S. (1981) Swan: Vegetation Survey of Western Australia. 222pp and accompany sheet (1:1,000,000 scale)

Cogger, H.G. (1979) Reptiles and Amphibians of Australia. Sydney: Reed. 2nd Ed.

Darling Range Study Group (1982). Land Use in the Darling Range Western Australia. Perth: Darling Range Study Group. 259pp.

Department of Conservation and Environment (1980). Atlas of Natural Resources Darling System Western Australia. Perth: Dept of Cons. and Environ. Explanatory Text 86pp and accompanying maps.

------------------------(1981). The Darling System, Western Australia - Proposals for Parks and Reserves. The System 6 Study Report. Perth: Dept. Cons. & Environ. 347pp.

Department of Health (1980). Desirable Quality for Drinking Water in Australia. Canberra: Aust. Govt. Publ. Serv. 8pp.

Environmental Protection Authority (1983). The Darling System - System 6 Part I - General Principles and Recommendations. Perth: Dept Cons. & Environ. 36pp.

Forests Department (1982). General Working Plan for State Forests in Western Australia. Perth: Conservator of Forests. Working Plan No. 87 Part I. 99pp.

George, R.R. (1980). Soil and Water Salinity Problems in the Collie Irrigation Area. Inland and Stream Salinity Seminar, Western Australia, November 1980.

Heddle, E.M., Loneragan, O.W. and Havel, J.J. (1980). Vegetation complexes of the Darling System, Western Australia. In Department of Conservation and Environment (1980).

MacDonald, D.V., Kline, P.B. (Jr) and Smith, R.A. (1978). Quality Considerations for Water Supply Evaluations. J. Env. Eng. Div. EE2. April 1978. pp 245-258.

Mehanni, A.H. and Repsys, A.P. (1980). Use of saline groundwater for pasture irrigation Goulburn Valley Victoria. ANCID. Issue No. 9. September 1980.

McKinnell, F.H. (1983). Impact of forestry activities on the sustainability of water resources in south western Western Australia. Proc. ANZAAS Conf., Perth.

McArthur, W.M., Churchward, H.M. and Hick, P.T. (1977). Landforms and soils of the Murray River catchment area of Western Australia. C.S.I.R.O. Land Resource Management Series No. 3.

National Health and Medical Research Council. Australian Water Resouces Council (1980). Desirable Quality for Drinking Water in Australia. Aust. Govt. Publ. Serv. 1980.

National Health and Medical Research Council (1984). Report of the Working Party on Sodium in the Australian Diet. Aust. Govt. Publ. Serv. 1984.

Nichols, O.G., Watkins, D. and Kabay, E.D. (1982). The Distribution of the Red-eared Firetail (*Emblema oculata*) in relation to bauxite mining in the northern jarrah forest. Emu 82: 169-172.

Northcote, K.H. (1979). A Factual Key for the Recognition of Australian Soils. Adelaide: Rellim. 124pp.

Pizzey, G. (1980). A Field Guide to the Birds of Australia. Sydney: Collins.

Public Works Department (1981). Collie River Salinity Control. Perth: PWD.

Royal Automobile Club of Western Australia (Inc.) (1985). 1985 Touring and Accommodation Guide. RAC Perth.

Rye, B.L. and Hopper, S.D. (1981). A Guide to the Gazetted Rare Flora of Western Australia Perth: Dept of Fisheries & Wildlife. Report No. 42.

Smith. F.G. (1974). Vegetation Map of Collie. Perth: W.A. Dept. Agric. 40pp. and 1:250,000 scale accompanying map.

Standards Association of Australia (1979). SAA Earthquake Code. AS. 2121-1979 North Sydney: SAA. 96pp.

Strahan, R. (Ed.) (1983). Complete Book of Australian Mammals. Sydney: Angus & Robertson. 530pp.

W.A. Water Authority (Undated). Water authority requirements for holders of apiary sites. PWD. Unpubl.

World Health Organisation. (1984). Guidelines for Drinking Water Quality. Vol I. Recommendations. World Health Organisation. Geneva.

14.0 STUDY TEAM

PROPONENT - Water Authority of Western Australia

R.J. Wark	Project Liaison - Coordinator
R. Harvey	Hydrology

DAMES & MOORE - Principal Consultant

J.P. Trudinger	Partner
D.C. Blandford	Principal in Charge
K.E. Lindbeck	Project Manager
W.H. Tacey	Principal - Environmental Studies

Technical

Dr A.S. Weston	Vegetation and Flora
K.E. Lindbeck	Landform, Soils, Environmental Report Compilation
R.D. Martin	Social and Economic Analysis
R.L. Sinclair	Climatology, Social and Economic Analysis
N.A. Daetwyler	Geology
C. Paxton	Environmental Report Compilation
W.H. Tacey	Environmental Report Compilation
S.L. Willmott	Environmental Report Compilation

Graphics

D.J. Buchan	Draftsman
M.W. Rikli	Drafting Assistant
O. Castle	Computer Graphics

Report Production

J.K. Sharry	Word Processing Operator
D.J.L. Smith	Word Processing Operator
J. Machlin	Typist
L.A. Davies	Word Processing Operator
C.A. Jamieson	Word Proccesing Operator
D.A. Lorkin	Word Processing Operator
S.A. O'Connor	Word Processing Operator

Laboratory (Soils) Testing

R. Gay	Laboratory Manager
P. Eldon	Technician

SUB-CONSULTANTS TO DAMES & MOORE

G. Harold	Terrestrial Fauna
P. Davies	Aquatic Fauna
P. Veth	Archaeology
K. Ward	Ethnohistory
R. O'Connor	Ethnography
Feilman Planning Consultants	Recreation
J. Griffiths	

CONSULTANT TO PUBLIC WORKS DEPARTMENT OF W.A.

B. Stone	Water Colour Issues

15.0 AUTHORITIES CONSULTED

The following authorities were consulted during the preparation of this document.

Commonwealth Bureau of Meteorology
Department of Conservation and Environment, W.A.
Western Australian Museum
Western Australian Herbarium
Department of Conservation and Land Management, W.A.
Department of Agriculture, W.A.
Geological Survey of W.A.
Australian Bureau of Statistics
Department of Lands and Surveys, W.A.
Department of Tourism, W.A.
Department of Youth, Sport and Recreation, W.A.
Collie Shire Council
Commonwealth Scientific and Industrial Research Organisation
Battye Library of W.A.
University of W.A.
Main Roads Department, W.A.
National Trust of Australia
Town Planning Department, W.A.
Commonwealth Department of Aviation
Heritage Committee, W.A.
Harvey Shire Council
South West Development Authority
Commonwealth Employment Service

In addition, the following individuals were consulted on specific aspects of the project.

Mr N. Allen	Worsley Alumina Pty Ltd
Mr J. Quilty	Alcoa of Australia
Mr E. Riley	Collie

We wish to record our appreciation of the many people in both official and private capacities, who gave freely of their time and expertise. They are too numerous to mention here, but included officers of government departments, people from private organisations and individuals.

16.0 GLOSSARY OF TERMS

Abutment - The lateral natural walls on which the dam walls reside.

Aggregate - A structural unit in a soil in which individual particles are held together.

Alien - An exotic plant or animal that has been introduced into an area where it does not naturally occur, by humans, either directly or indirectly, and has in most cases become established.

Alluvium - Stream or river deposited material of comparatively recent origin.

Aquatic Habitat - The place where a freshwater organism lives.

Aquifer - A geological formation capable of receiving, storing and transmitting significant quantities of water.

Arachnid - A member of the class Arachnida, contains scorpions, spiders, ticks, mites, harvest-men and king crabs.

Association, Plant - A group of plants with a characteristic form, structure and dominant species.

Basic Industry - In this study, an industry where the relative share of employment in the local economy exceeds the share of that industry at a regional level.

Batter - Slope caused by cutting or filling.

Bedding - Stratification or layering in sedimentary deposits.

Bedrock - A term applied to substantial rock mass underlying soils or superficial deposits.

Benthic - Those animals and plants living on the bottom of the sea or lake (crawling or burrowing there; or may be attached), from high water mark to the deepest levels.

Biomass - The total living matter in an ecosystem.

Biota - The totality of plants and animals of a specified area.

Blowdown - Cooling water (in this instance, from a power station) in which the salt content has risen above an acceptable level.

Chemical Weathering - Chemical decomposition of rock substances which occurs due to surface and near-surface agencies, such as air and groundwater.

Chert - Cryptocrystalline silica which may be of organic or inorganic origin

Chiroptera - The order of mammals to which bats belong.

Colluvial - The downslope movement of soil, rock fragments, mud or scree under the influence of gravity.

Colour - Measured in Hazen Units; "apparent colour" for unfiltered water samples "true colour" for filtered samples.

Conductivity - Specific conductance (reciprocal of specific resistance) is the ability of a solution to pass an electrical current and is proportional to the concentration of ions in solution i.e. the concentration and extent of dissociation of dissolved salts; measured in millisiemens per metre (ms/M).

Crustacean - Invertebrate, generally aquatic or marine, with a hard carapace or exoskeleton e.g. marron, crabs, amphipods.

Cryptocrystalline - A term used to describe a very finely crystalline aggregate in which the crystals are so small as to be indistinguishable except under powerful magnification.

Dasyurid - A member of the family Dasyuridae, to which small to medium-sized carnivorous marsupials belong.

Dendritic - A term used to describe any form which is branching, ramifying or dichotomising, thus giving the appearance of a tree in silhouette.

Dieback - An exotic plant disease caused by the fungus Phytophthora cinnamomi.

Direct Employees - Employees working within the industry.

Dispersion - Breakdown of soil structure into fine particles, such as clays, when soil comes in contact with water.

Dolerite - A medium-grained basic hypabyssal igneous rock.

Dominant species - The most abundant species in the tallest or most important stratum of a plant association.

Drainage Pattern - The pattern formed by drainage lines, gullies, streams and rivers.

Duplex Soil or Profile - A soil with a marked increase in clay in the B horizon compared with the A horizon.

Ecology - The study of the interrelationships of plants and animals and their environments. Also, the totality or pattern of these interrelationships within a specified area, community or ecosystem.

Economic Base - Regional economic activity which involves sales to individuals or firms located outside the region thus giving rise to inflow of money.

Ecosystem - An interacting set of plants, animals and non-biotic components of their habitat, and their interactions. An ecosystem is usually defined by its dominant vegetation (e.g. forest) and plant species or by the habitat in which it occurs (e.g. riverine).

Environment - All aspects of the surroundings of man including the physical, economic, cultural and social aspects. This includes the complex of habitat factors, both biotic and abiotic, that do or will impinge or have impinged upon a plant or animal or groups of plants or animals.

Ephemeral - Short-lived, lasting only a few days.

Epilimnion - The layer of freely circulating surface water of well stratified lakes, above the metalimnion.

Erosion Hazard Rating - A subjective assessment derived from the interaction between soil erodibility, rainfall erosivity, the steepness and length of slope, vegetative cover, and management of the site.

Erosion Status - The degree and intensity of contemporary soil erosion processes existing at a stated period of time.

Erosivity - The eroding power of raindrops, running water and sliding or flowing soil masses.

Feral - Escape from domestication and now living and breeding in the wild.

Floodplain - A plain, bordering a river, which has been formed from deposits of sediment carried down by the river.

Flora - The totality of plant species of a specified area.

Floristically Diverse - A plant community which contains a comparatively higher number of plant species is floristically diverse.

Foliation - A lamination in igneous or metamorphic rock types resulting from segregation of different minerals into layers.

Formation, Plant - Characteristic structure and form of a plant community e.g. open woodland.

Full Supply Level - Water level when the reservoir is at maximum capacity.

Geomorphology - The scientific interpretation of the origin and development of the landforms of the earth.

Gneissic - Banded rocks formed during high-grade regional metamorphism.

Gorge - A valley which is more than usually deep and narrow with steep walls.

Great Soil Group - The level in soil classification based on total profile features.

Groundwater Surface or Water Table - That surface within the saturated zone at which the pressure is atmospheric. Level at which water stands in uncased or screened shallow well in unconfined aquifer. A perched water table is one which occurs above an impermeable zone, which is underlain by unsaturated materials.

Habitat (and habitat components and requirements) - The place where species or populations of plants or animals live. A habitat contains a system of components that satisfies the requirements of an animal, essential to the continued survival of the species, such as food, shelter and adequate territory. The habitat components of an animal include both living (e.g. vegetation) and non-living features.

Hazen Units - Units of colour; water samples are compared with platinum-cobalt standards whereby one hazen unit is equivalent to 1 mg/l chloroplatinate ion with cobaltous iron added to modify the hue of the water.

Herpetofauna - A collective term for reptiles and amphibians

Holocene - (or Recent) The younger of the two geological epochs in the Quarternary Period. The Quarternary being one of two periods in the Cenozoic era.

Hypabyssal - A term applied to intrusire igneous rocks which have crystallised under conditions between plutonic and volcanic.

Hypolimnion - The deep layer of a stratified lake lying below the metalimnion and separate from surface influences.

Igneous Rocks - Crystalline or glassy rocks which have solidified from molten rock.

Indirect Employees - Employees servicing an industry but not employed by that industry.

Induced Employees - Employees whose work is created by the consumption activity of direct and indirect employees.

Indurated Rock - A rock which has been hardened by heat, pressure or secondary sedimentation.

Infrastructure - Systems of services and utilities within a community; e.g. physical (water, sewerage, electrical, transport) and social (health, education, safety, communications).

Input-Output Table - Used to assess how each dollar of construction expenditure and each unit of operational output directly and indirectly affects the output, income and employment of other sectors in the regional, state and national economy.

Intrusion - Body of igneous rock which has forced itself into pre-existing rocks.

Ions - The dissociated, or electrically charged, form of elements of molecules in solution.

Joints - Planar or near-planar discontinuities in the rock mass along which little or no displacement has occurred.. Formed in response to stresses associated with compaction, folding, shrinking, etc. Sheet Joints are those which develop near-parallel to the ground surface, due to stress relief.

Landform - The shape, form and nature of a specific feature of the earth's land surface.

Laterite - Iron-rich material which hardens on exposure to the atmosphere and is associated with deeply weathered profiles.

Limnology - The study of the biological, chemical and physical aspects of the inland waters.

Limnology - The study of the biological, chemical and physical aspects of the inland waters.

Lithology - Science of the nature and composition of rocks.

Lithosol - Shallow, undifferentiated soil formed on rock.

Kilolitre - A metric unit of volume; 1000 litres.

Mean Annual Flow - The sum of annual flows for a given set of years divided by the number of years.

Median - The point in a population below which 50% of the population fall.

Metalimnion - The zone in a lake between the surface and deep layers wherein the temperature gradient is steep; virtually synonymous with thermocline.

Migratory Animals - Animals that move from one region to another, instinctively and usually seasonally.

Milligram - A metric unit of mass; 0.001 grams.

Mollusc - A member of the phylum Mollusca; mostly aquatic; soft bodied, often with a hard shell; unsegmented with a head and muscular foot. Includes mussels, snails and octopuses.

Monoclinal - Streams and valleys which have a direction parallel to the strike of the rocks.

Multiplier, Employment - A number used to calculate the amount of direct and indirect employment generated as a consequence of project construction and operation.

Niche - A particular role (or set relationships) of organisms in an ecosystem, which may be filled by different species in different geographical areas.

Nomadic Animals - Animals that wander intermittently in response to the needs for food, shelter and/or nesting facilities.

Osmosis - The movement of water and dissolved particles across a semi-permeable membrane in response to a concentration gradient.

Passerine - General term for perching birds of similar size to a sparrow.

Pedal - Soil containing aggregates of soil within a profile.

Pedology - Study of the genesis and morphology of soils, particularly using field soil profiles.

pH - Log H^+; the negative logarithm of the concentration of hydrogen ion in solution; less than 7 is increasingly acidic and greater than 7 is increasingly basic (alkaline) with pH 7 being neutral.

Photic Zone - Surface zone of sea or lake sufficiently illuminated for photosynthesis

Pisolitic - Structure consisting of pea-like cemented nodules or concretions.

Planation - The denudation of rocks to produce a fundamentally flat surface.

Plateau - An extensive, level or mainly level area of elevated land.

Precambrian - The earliest geological era. Life formed in the late Precambrian, over 3,000 million years ago.

Quartzite - A sandstone or essentially pure sandy formation that has been metamorphised to form indurated rock.

Rehabilitation - Processes necessary to return disturbed land to a predetermined surface, land use or productivity.

Salinity - Total content of salts dissolved in water, expressed as milligrams of salts per litre of water.

Scour - Erosion due to water moving at an increased velocity.

Scouring - Release of unwanted, usually more saline, water from the base of the dam.

Sedimentary Rocks - Rock formed from an accumulation of sediment.

Soil Erodibility - The resistance of a soil to water erosion as a function of soil texture, soil structure, aggregate stability, infiltration and permeability rate, and water holding capacity.

Soil Erosion (Wind) - Removal of soil material by abrasion or saltation and affected by factors such as wind patterns, vegetative growth and surface roughness.

Species Diversity - A number which relates the density of organisms of each species present in a habitat.

Status (rarity) - The abundance of a species throughout its known distribution i.e. rare, common etc.

Strike - The direction or bearing of a horizontal line on an inclined planar feature, perpendicular to the direction of dip.

Structurally Complex - Vegetation that is structurally complex has greater diversity of physical structure types than other types of vegetation.

Superficial Deposits - Unconsolidated, residual, alluvial or glacial deposits lying on the bedrock.

Taxonomy (taxonomic classification) - The systematic classification of plants and animals. The basic unit of classification is 'species', which consists of a pair of italicized or underlined latinised words, the first of which is a noun, the genus name, and the second of which is a modifier of the first.

Terrain - The physical character of an area, its configuration.

Topography - Detailed description of surface features, both natural and artificial, of an area.

Trophic Level - The level of an organism in the food chain. Each level derives its energy from the level preceding it and provides energy for the one following it.

TSS - Total Soluble Salts; Obtained from the equation Conductivity (25^{o}C) of 1:5 Aqueous Extract x 0.6. A measure of soluble chemical constituents of groundwater or surface water.

Turbidity - Cloudiness of the water.

Value/chroma Rating - System of soil classification based on colour characteristics and standard colour charts.

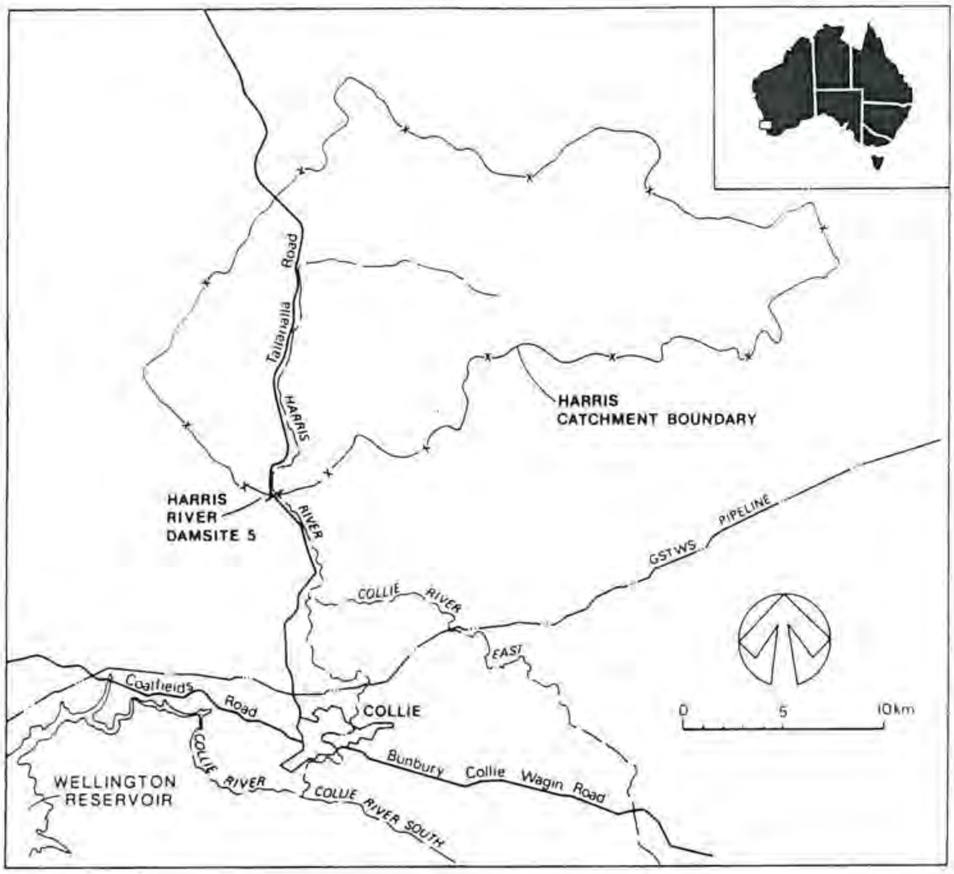
Vegetation - The plant cover of a specified area. It is described primarily in terms of form and structure.

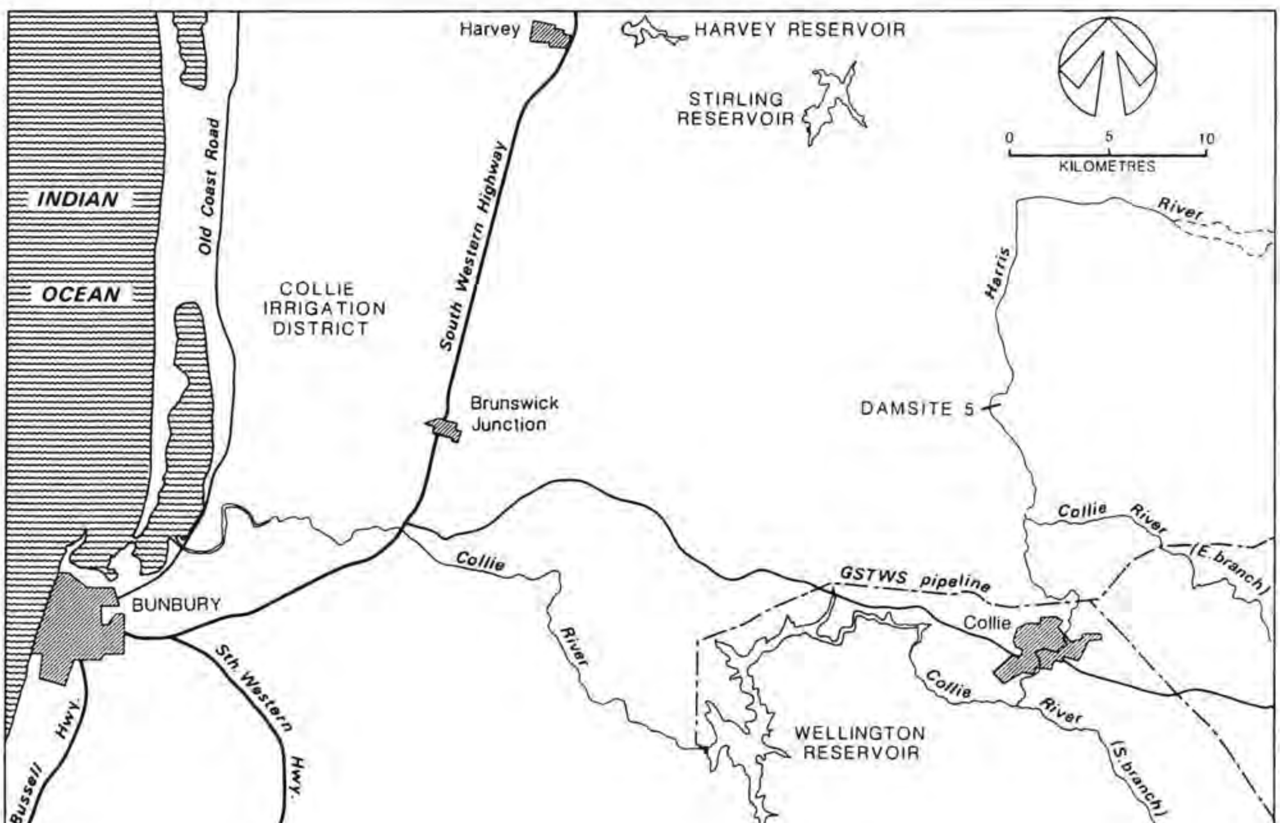
Water Yield - The volume of water generated by surface runoff from a catchment area.

Weathering Profile - The results of chemical and mechanical weathering of a rock medium. It is generally characterised by clayey or impervious material.

Yilgarn Block - Name given to a large Proterozoic and Archaean rock mass underlying most of south Western Australia. It represents the remnants of a stable continental craton.

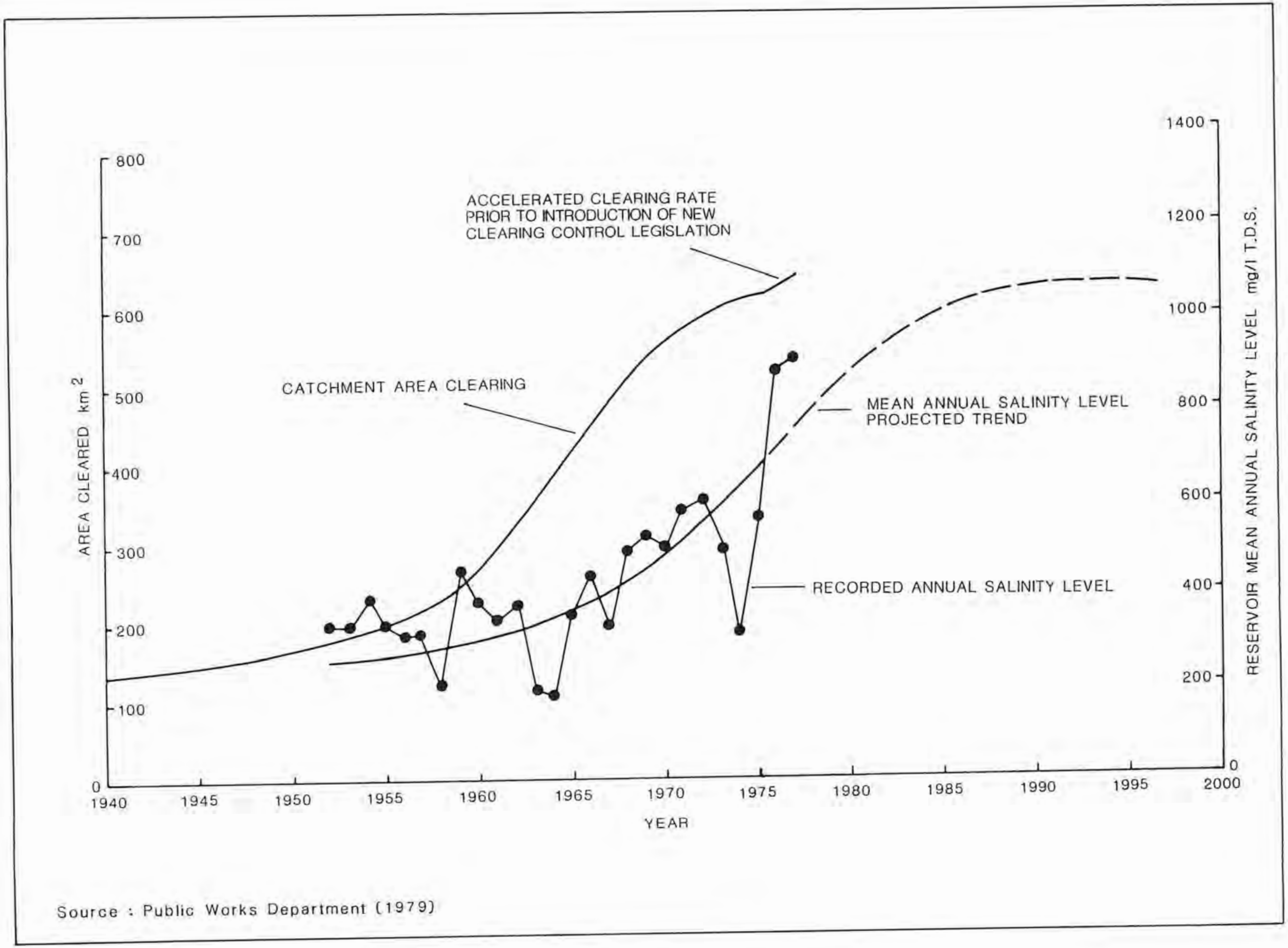
FIGURES





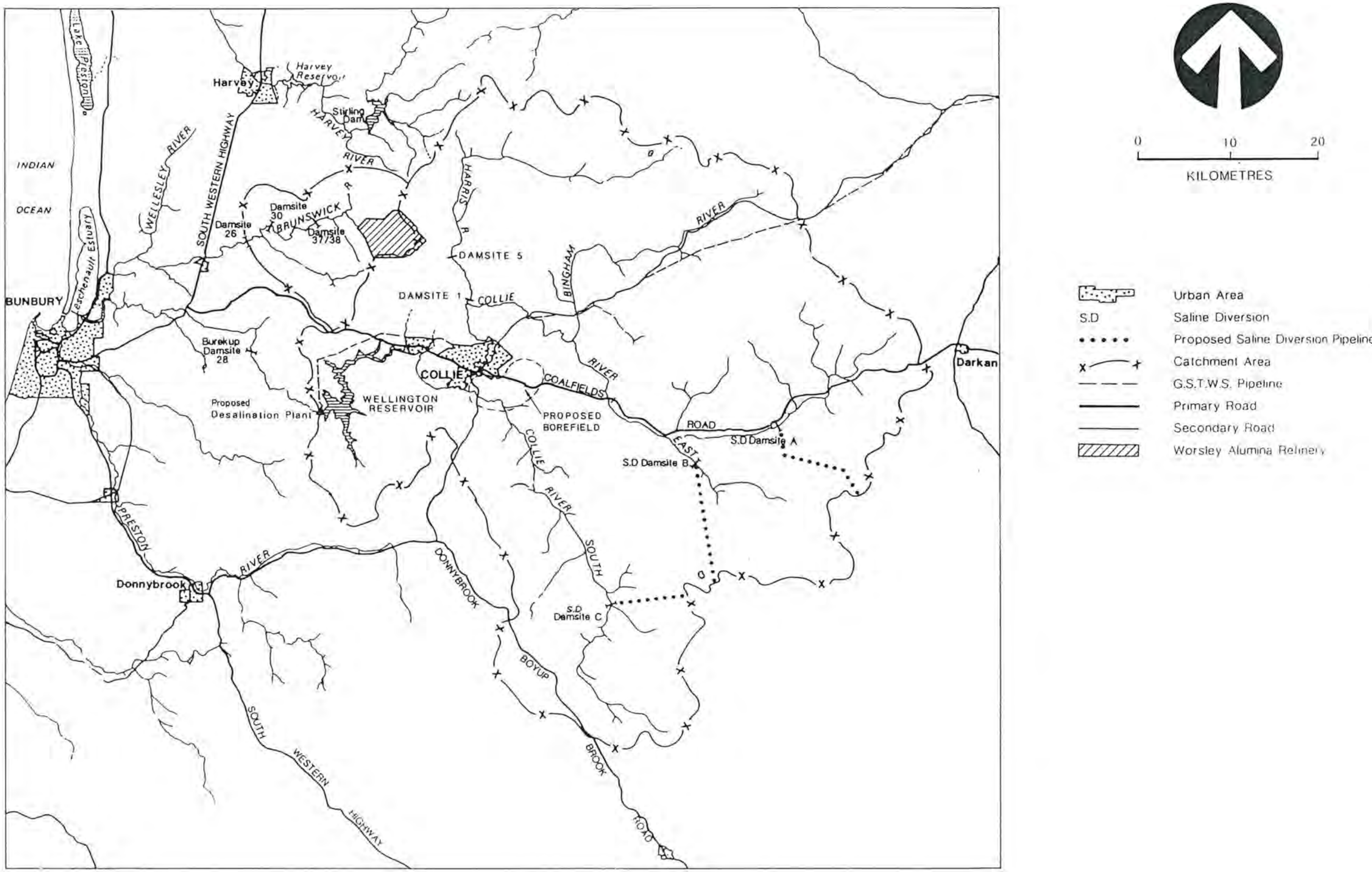
PROJECT LOCATION

Figure 1
Dames & Moore



WELLINGTON DAM CATCHMENT AREA
CLEARING AND MEAN ANNUAL SALINITY LEVEL PROJECTION

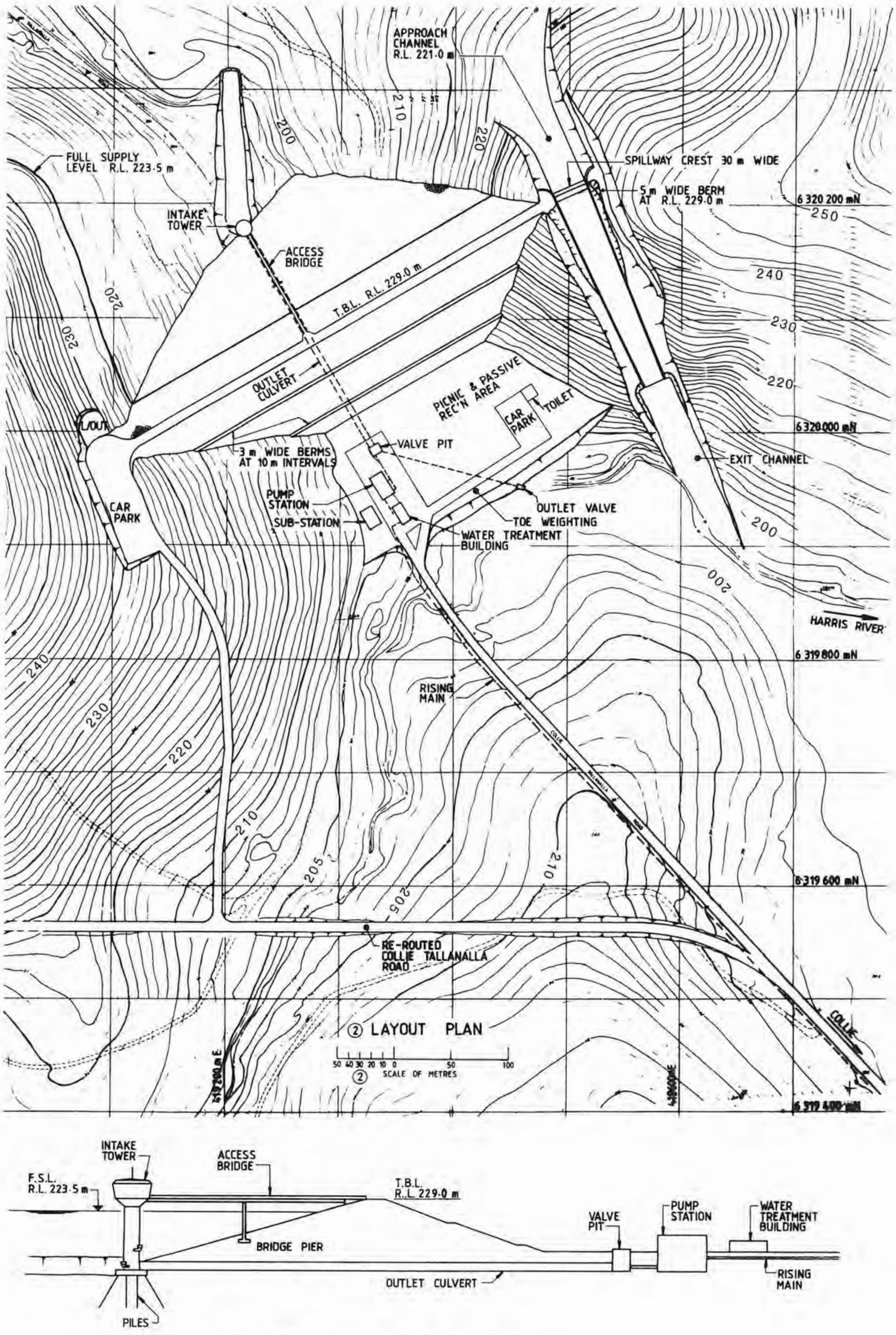
Figure 2
Dames & Moore



REGIONAL ALTERNATIVES

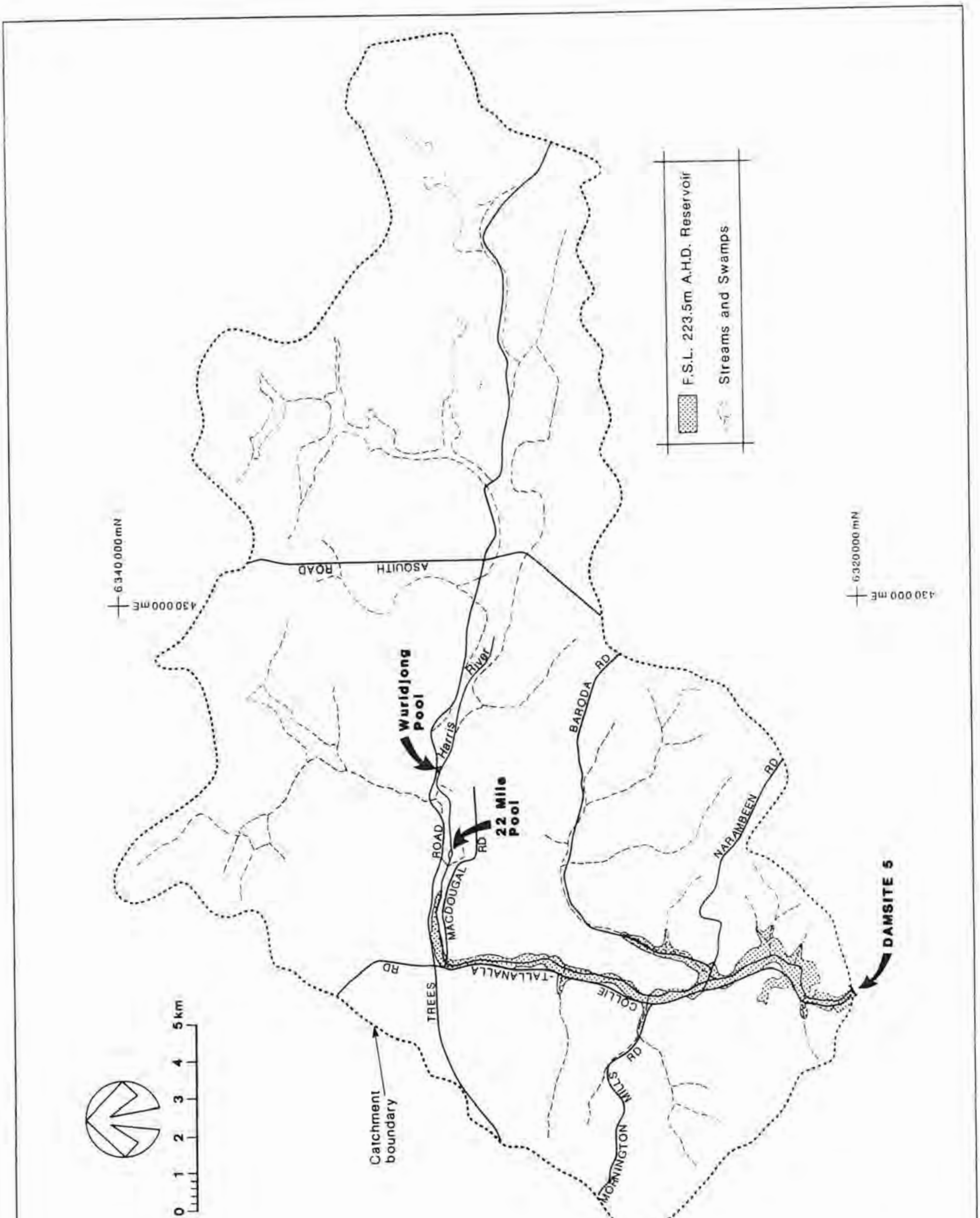
Figure 3

Dames & Moore



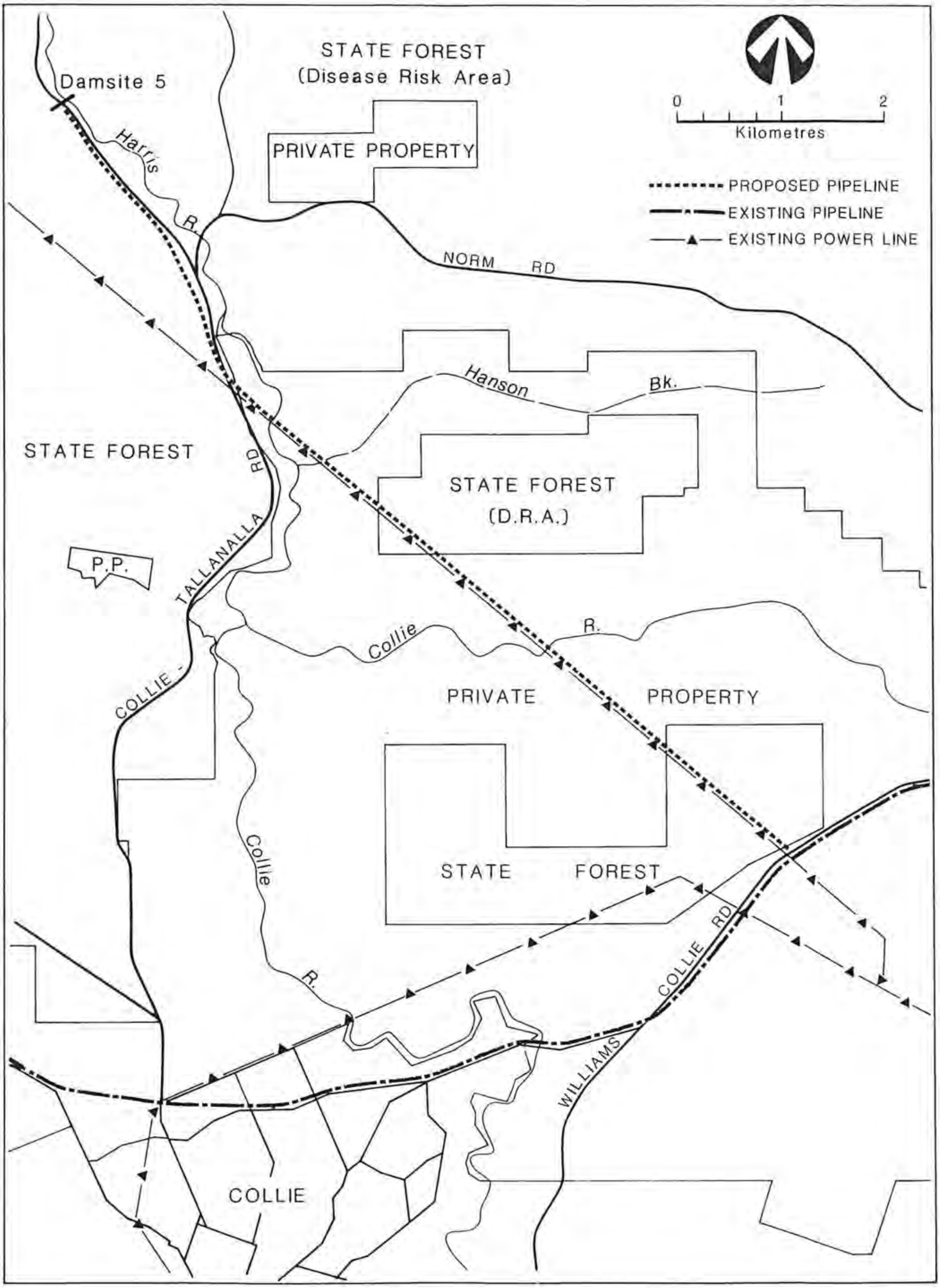
DAM INFRASTRUCTURE

Figure 4
Dames & Moore



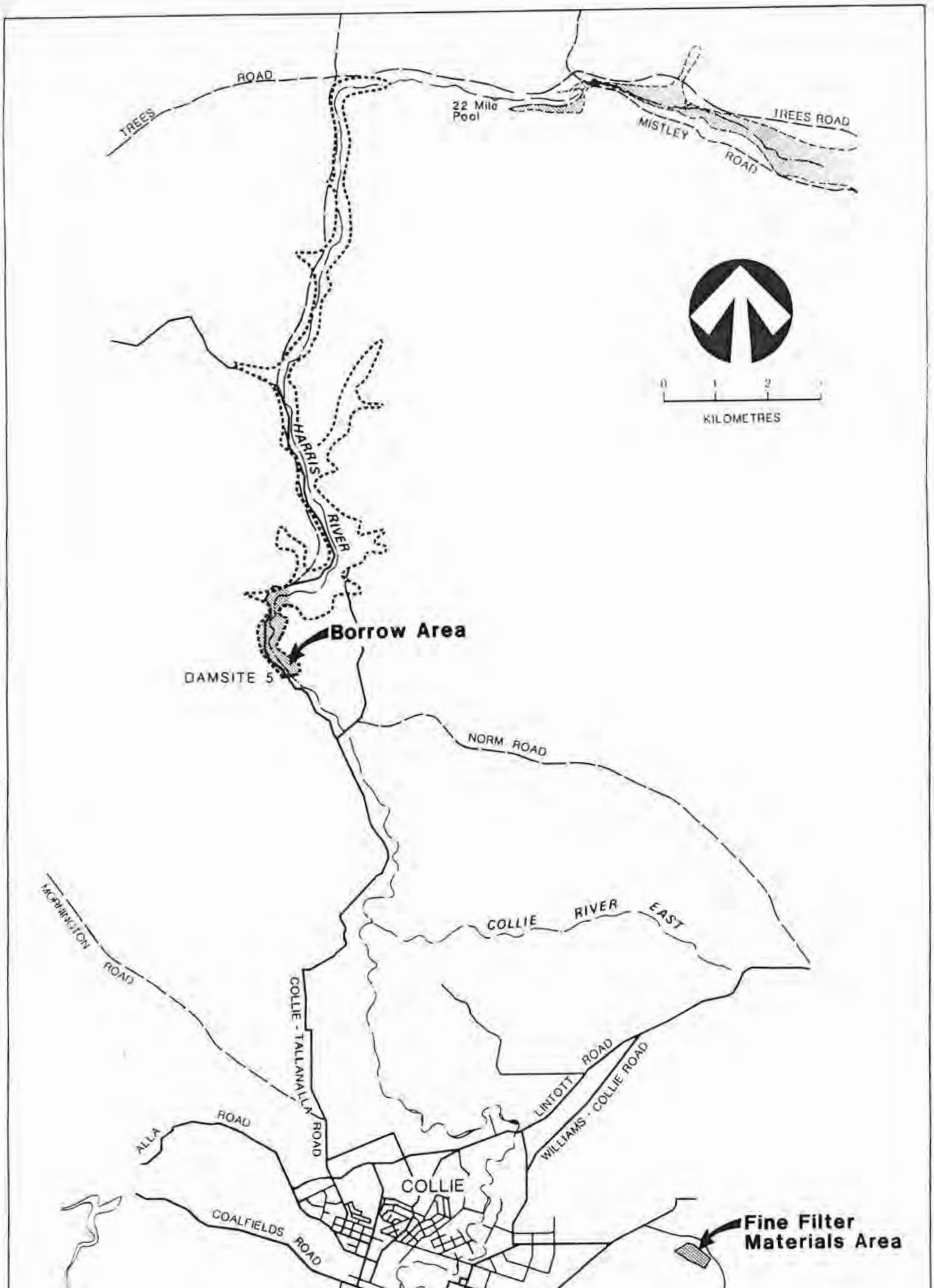
HARRIS RIVER DAM - CATCHMENT AREA

Figure 5
Dames & Moore



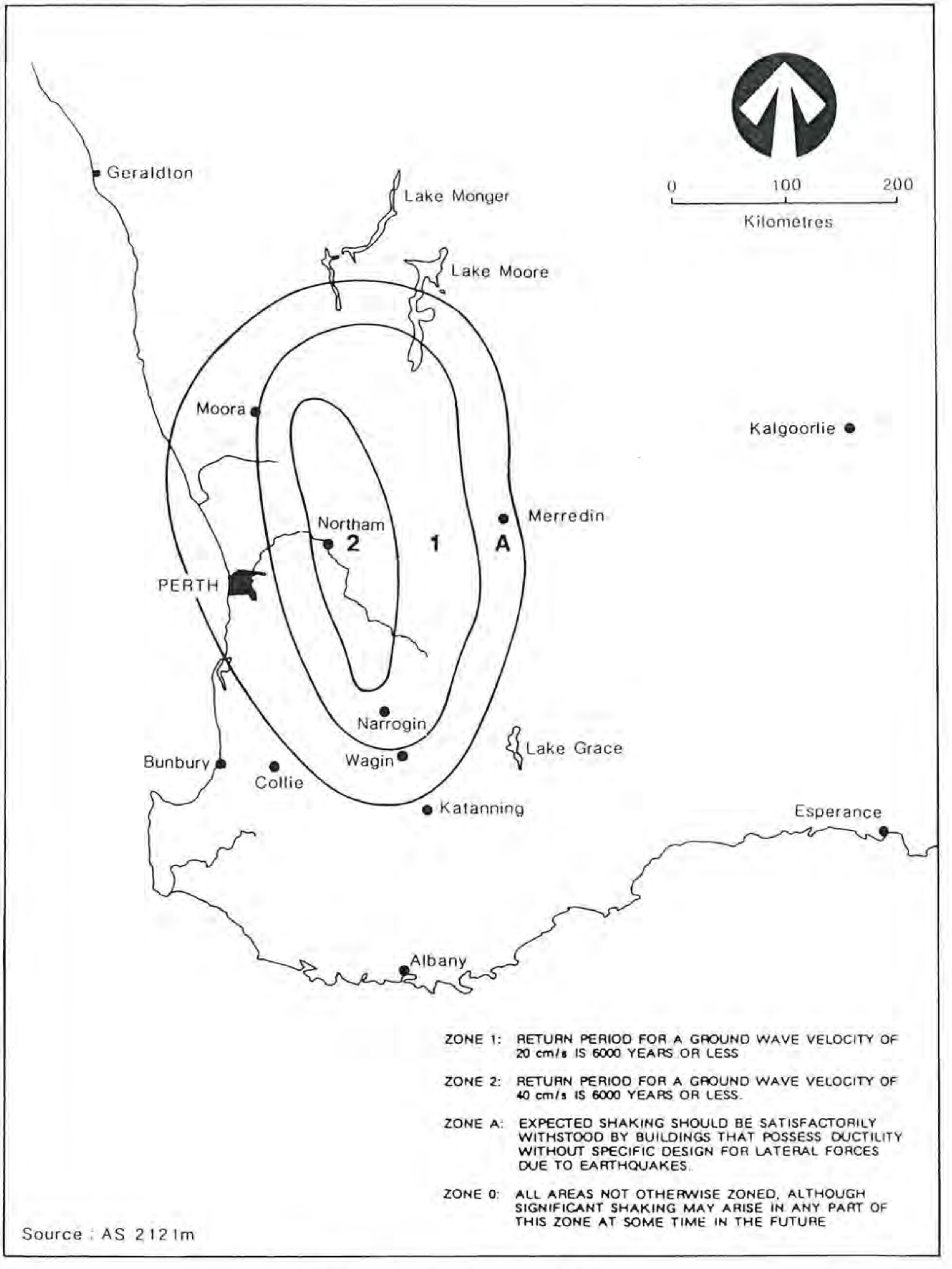
PROPOSED PIPELINE ROUTE

Figure 6



SOURCES OF CONSTRUCTION MATERIALS

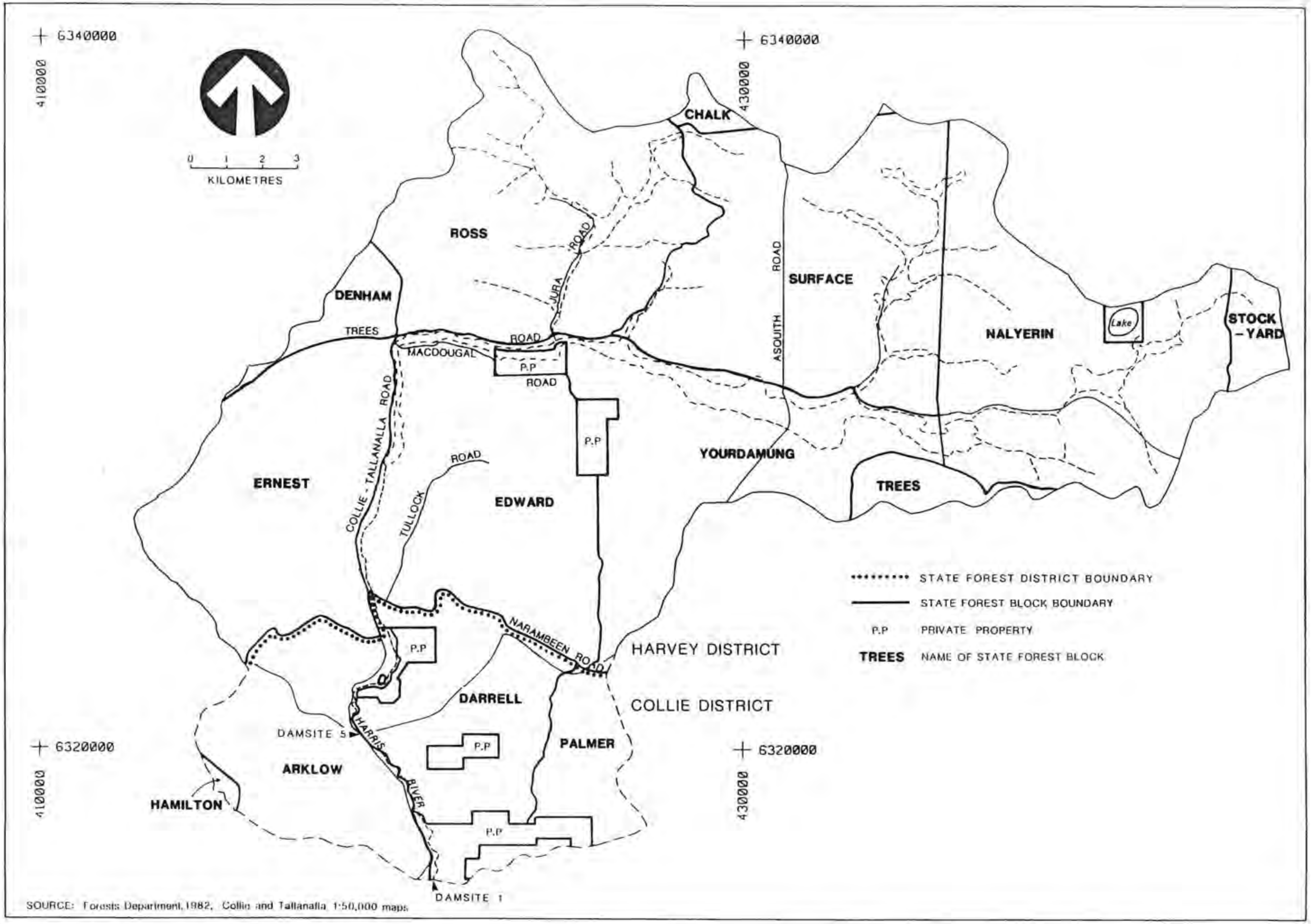
Figure 7
Dames & Moore



EARTHQUAKE RISK ZONES
- SOUTH WEST OF WESTERN AUSTRALIA

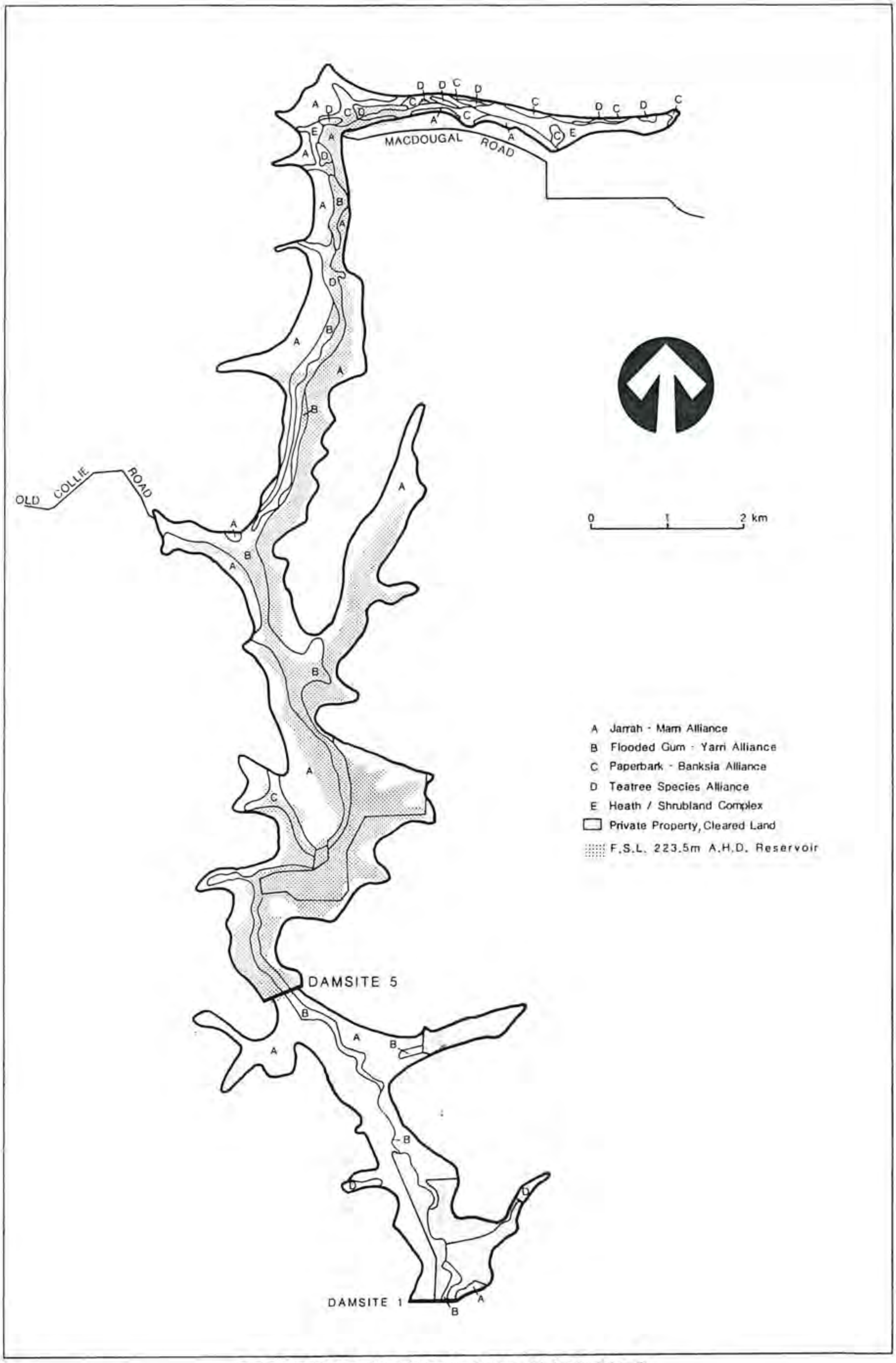
Figure 8

Dames & Moore



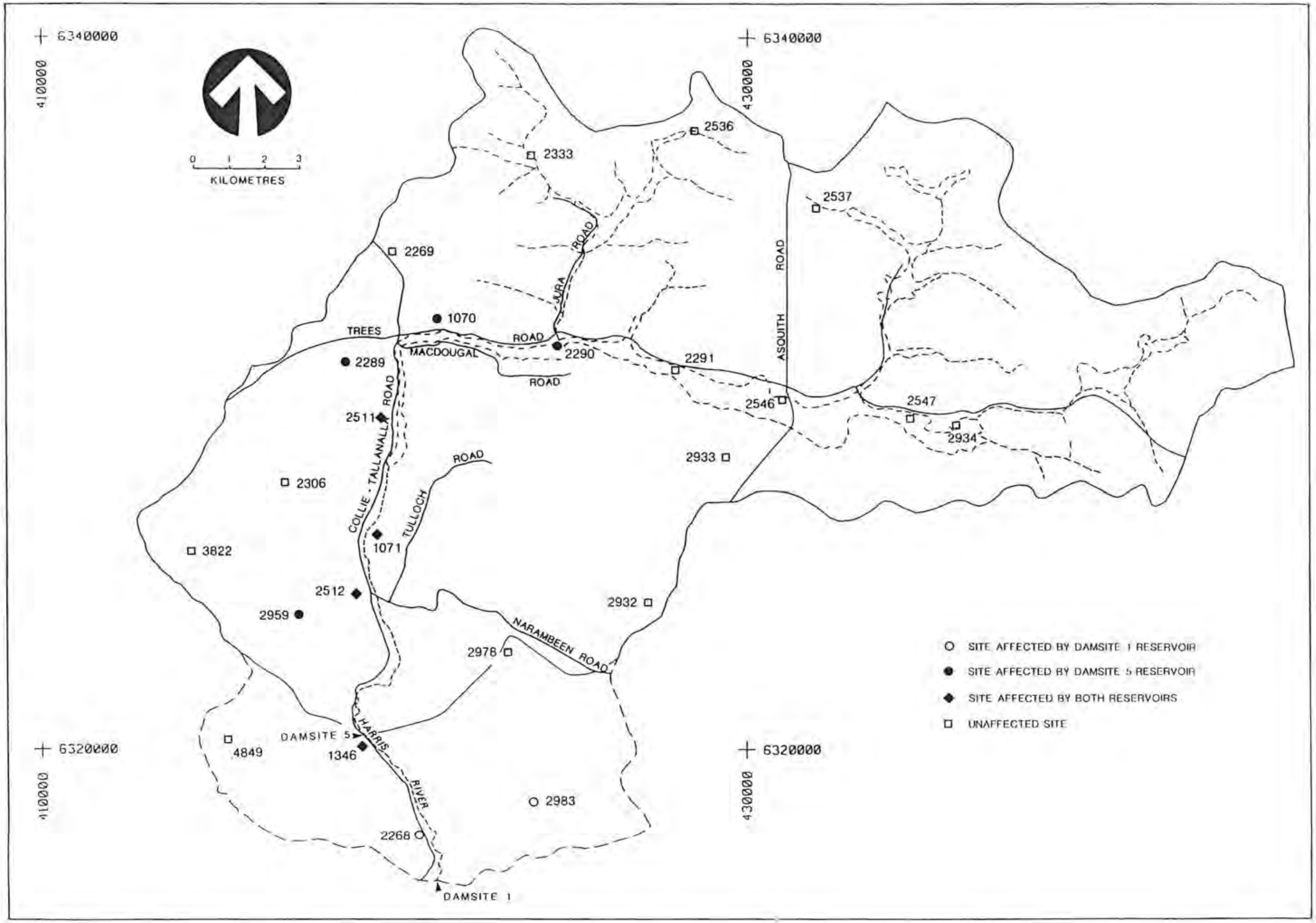
STATE FOREST BLOCKS AND DISTRICTS

Figure 9
Dames & Moore



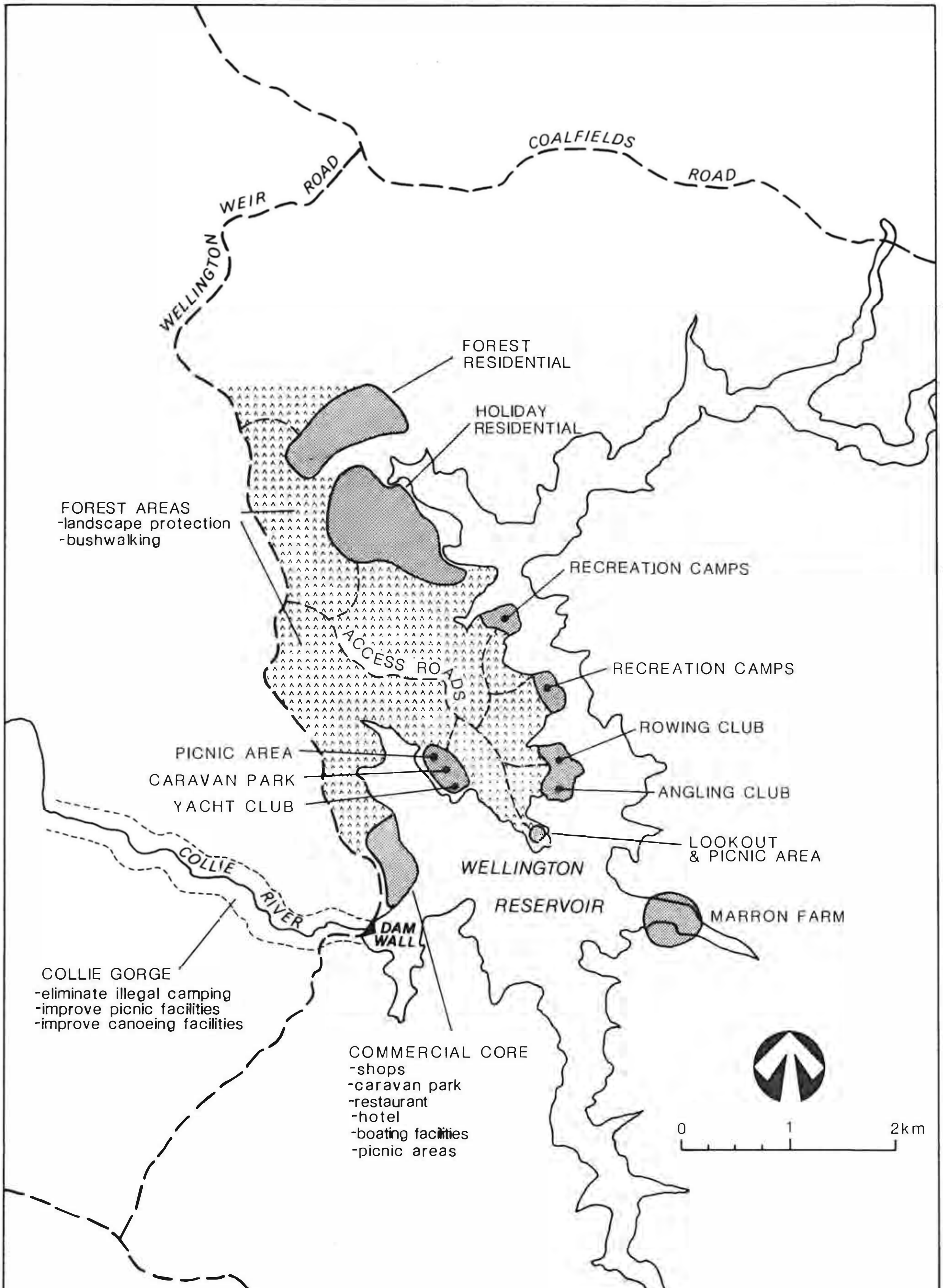
RESERVOIR VEGETATION ALLIANCES

Figure 10
Dames & Moore



HARRIS RIVER CATCHMENT BEEKEEPING SITES

Figure 11
Dames & Moore



WELLINGTON RESERVOIR RECREATION DEVELOPMENT CONCEPT

Figure 12
Dames & Moore