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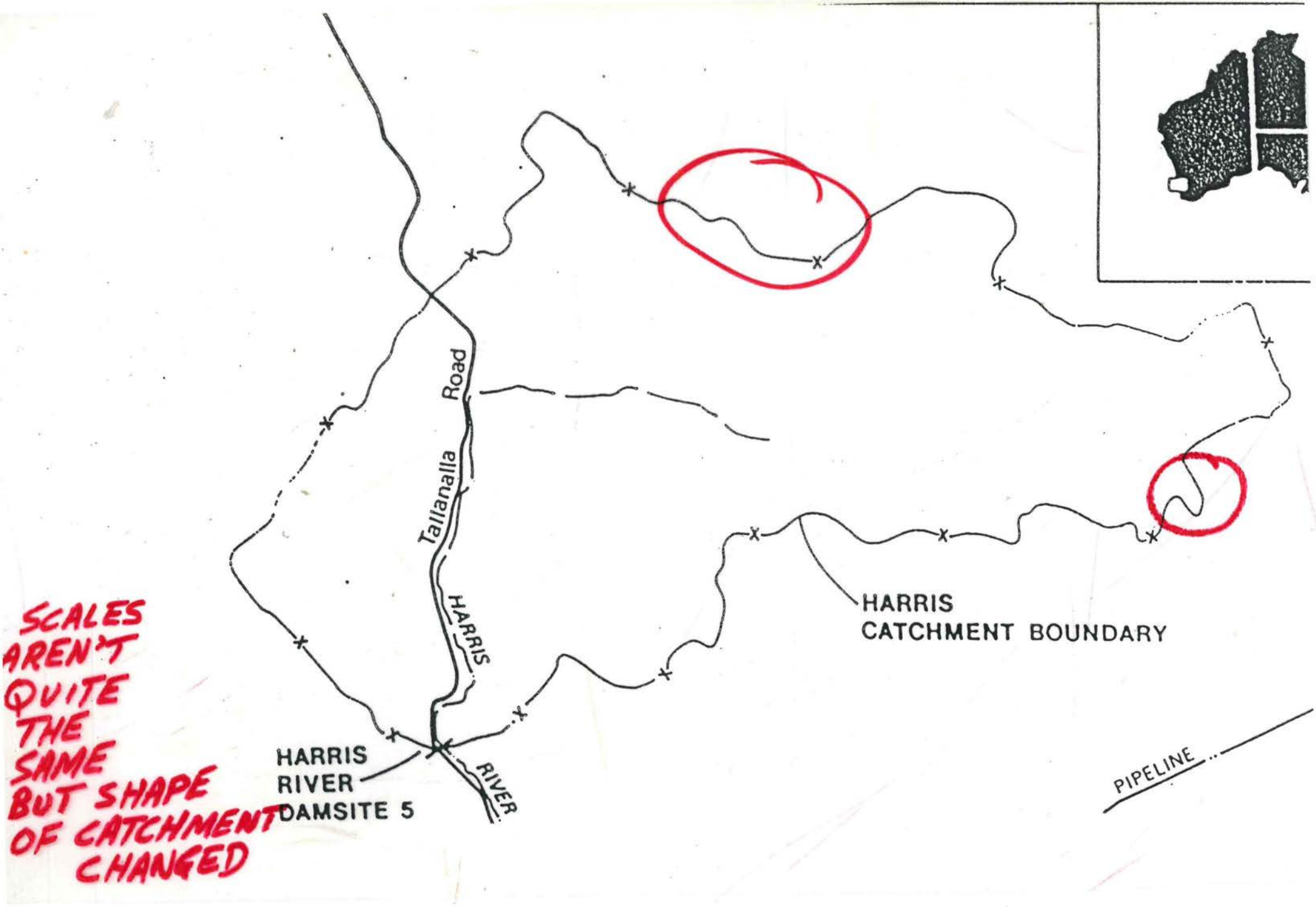
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DAMSITE 5
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CATCHMENT BOUNDARY
PIPELINE
SCALES AREN'T QUITE THE SAME BUT SHAPE OF CATCHMENT CHANGED

WATER AUTHORITY
of Western Australia

WATER RESOURCES DIRECTORATE
Water Resources Planning Branch

Harris Dam Project
Environmental Review and Management Programme
Appendices

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APPENDIX C	"Report on the Terrestrial Fauna of the Harris River Dam Reservoir Area" by G. Harold.
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APPENDIX G	"Report on the Preliminary Survey for Aboriginal Archaeological Sites at the Harris Dam Project Area, Collie: Including Regional Ethnohistorical Data" by P. M. Veth, K. Ward and M. Zlatnik; April 1984.
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APPENDIX K	"Simulation of Wellington Reservoir Supply Salinities for Selected Harris Storage Sizes". Internal Report, Water Authority of Western Australia;
APPENDIX L	"Harris River - Hydrology" by D. Salim (Report No.W.R.B. 114); December 1984.

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APPENDIX A

CLIMATE, LANDFORM, SOILS AND EROSION STATUS STUDIES

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1.0 CLIMATE

1.1 REGIONAL CLIMATE

The damsite is located approximately 50km from the Indian Ocean at an altitude of 200m (AHD). The close proximity of the ocean causes temperate climatic conditions with predominantly winter rainfall. The seasonal rainfall distribution results from winter frontal systems off the oceans.

Collie Post Office has been recording climatic data for the Bureau of Meteorology since 1899, until 1982. Worsley Alumina Refinery has been recording meteorological data since 1980. These two sites are both located within 11km of the damsite. The Collie station is taken as being representative of local climatic conditions. Data from the Darkan meteorological station (which has been recording since 1898) has been included in this report to enable comparison with data recorded at Collie.

1.2 RAINFALL

Figure 1 shows the mean monthly rainfall and number of wet days for Collie. The late autumn, winter and early spring predominance is indicated with the peak occurring in June - July. The summer growing season from November to March receives less than ten percent of the annual rainfall. Figure 2 shows the variability of the rainfall for Darkan. The Darkan station records an average of 13 wet days during June - July, whereas Collie experiences 21 wet days during June. The annual average rainfall for Collie is 971mm and mean annual rainfall decreases rapidly towards the east. Darkan, 60km east from Collie, has an average annual rainfall of 569mm (Figure 3).

Table 1 lists the highest 24 hour rainfall recorded in each month and the year of recording for Collie from 1957 to 1975. The highest 24 hour total recorded at Collie was 73.7mm in March 1971.

Rainfall intensity - duration curves have been prepared by the Bureau of Meteorology for Collie and for Worsley Refinery (Tables 3 and 4). The critical six minute intensity for Collie has been calculated to be 74mm/h and 82mm/h for return periods of 1 year in 10 and 1 year in 100 respectively. The data for Worsley contrasts to the Collie data but are based on fewer observations. The six minute intensities for Worsley for 1 in 10 year and 1 in 100 year periods are 100mm/h and 130mm h/ respectively.

1.3 TEMPERATURE

The temperatures recorded for Collie are moderate with the highest mean monthly maximum recorded in January (30.5°C) and the lowest mean monthly minimum being recorded in July (4.2°C). The mean diurnal range in January is 17.3°C and in July 11.3°C. Temperature data for Collie are shown in Figure 4.

1.4 HUMIDITY

Atmospheric humidity is often measured as the relative humidity, a quantity which varies diurnally with changes in temperature of the air and with changes in air mass characteristics. Figure 4 shows the mean relative humidities at 0900 hours and 1500 hours. The low summer rainfall and associated low humidity levels indicate that humidity would rarely be oppressive or have an adverse impact on construction activities.

1.5 EVAPORATION

The Harris River catchment is contained within the isopleths indicating the 1200 and 1600 millimetres of annual average evaporation and evaporation from a free water surface in the Harris River catchment exceeds the annual average rainfall at Collie by a factor of 70%.

No evaporation data is recorded at the Collie Post Office. Extrapolation of evaporation figures for Western Australia shows that evaporation is least in the winter months, amounting to about 50mm, and is highest in January when it totals approximately 275mm (Department of Science and Technology, 1981).

1.6 FROSTS

Frosts occur throughout the winter from May to September with rare occurrences recorded in April, October and November. The frequency of frost occurrence is recorded in Table 5.

1.7 WINDS

From frequency data supplied by the Bureau of Meteorology, a wind rose was computed and plotted for data collected at Collie Post Office from 1957 to 1975 (Figure 5). The wind rose 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/h, and 24.6% are in the 6-10 km/h speed range. Only 1.2% of winds exceed a constant speed of 41km/h.

TABLE 1

HIGHEST 24 HOUR RAINFALL TOTAL (mm) AND YEAR RECORDED FOR COLLIE (1957 to 1975)

PARAMETER	J	F	M	A	M	J	J	A	S	O	N	D
HIGHEST 24 HOUR RAINFALL	44.2	21.3	73.7	41.7	61.7	68.6	51.8	73.2	57.7	48.5	31.5	32.0
YEAR RECORDED	1960	1970	1971	1969	1958	1961	1967	1964	1971	1970	1971	1959

(Source: Bureau of Meteorology)

TABLE 2

MEAN, HIGHEST AND LOWEST FREQUENCY OF FROST OCCURRENCE AT COLLIE (1957 to 1975)

PARAMETER	J	F	M	A	M	J	J	A	S	O	N	D
MEAN OCCURRENCE	0	0	0	0	3	5	5	7	3	1	0	0
HIGHEST OCCURRENCE	0	0	0	3	11	13	12	12	8	4	1	0
LOWEST OCCURRENCE	0	0	0	0	0	0	0	0	0	0	0	0

(Source: Bureau of Meteorology)

TABLE 3

RAINFALL INTENSITY (COLLIE - PREPARED FEBRUARY 1976)

Expressed in mm/h

	RAINFALL DURATION (HRS)						
RETURN PERIOD	0.1	0.5	1.0	2.0	12.0	24.0	72.0
1 in 2 years	68	33	21	14	4.6	2.8	1.4
1 in 10 years	74	35	23	15	4.8	3.0	1.5
1 in 20 years	79	39	25	16	5.0	3.1	1.6
1 in 50 years	80	41	26	17	5.4	3.4	1.7
1 in 100 years	82	42	27	18	5.6	3.5	1.8

(Source: Bureau of Meteorology)

TABLE 4

RAINFALL INTENSITY (WORSLEY - PREPARED AUGUST 1980)

Expressed in mm/h

	RAINFALL DURATION (HRS)						
RETURN PERIOD	0.1	0.5	1.0	2.0	12.0	24.0	72.0
1 in 2 years	75	32	24	15	4.2	2.6	1.5
1 in 10 years	100	48	31	20	5.6	3.5	1.7
1 in 20 years	105	54	36	22	6.4	4.0	1.9
1 in 50 years	120	65	40	25	7.2	4.5	2.1
1 in 100 years	130	70	44	27	8.0	5.0	2.2

(Source: Bureau of Meteorology)

2.0 LANDFORM

From published data, five landform mapping units have been identified within the Harris River catchment (Department of Conservation and Environment, 1980). The landform units are described as being within three landscapes and contained within the "Darling Plateau of Precambrian crystalline rocks" geomorphological province. Table 5 indicates the breakdown of the three levels of landform analysis.

TABLE 5

LANDFORM ANALYSIS

GEOMORPHOLOGICAL PROVINCE	LANDSCAPE	LANDFORM UNIT
Darling Plateau of Precambrian Crystalline Rocks	Lateritic Uplands Goonaping	Dwellingup
	Minor Valleys Yarragil Pindalup	
	Major Valleys combining Slopes and Floors	Murray

(Source: Department of Conservation and Environment, 1980)

The Darling Plateau geomorphological province is described as a plateau with gentle slopes and occasional prominent hills or monadnocks rising above it. The valleys are usually broad, flat-floored and swampy and change to deeply incised, V-shaped valleys towards the Darling Scarp (Department of Conservation and Environment, 1981).

2.1 LANDFORM UNITS

The landform units have been delineated by landform - soil relationships in Department of Conservation and Environment (1980) and the following description has been derived from McArthur, et al., (1977) and from site inspections (Figure 6).

2.1.1 Dwellingup Unit (Lateritic Upland Landscape)

An undulating landscape of the majority of the catchment which includes shallow depressions in the heads of drainage lines and several hills which project above the general landscape level. Elevation varies between 250 to 300m (ASL).

2.1.2 Goonaping Unit (Lateritic Upland Landscape)

This unit occurs as shallow upland valleys in the heads of drainage lines and contain some swamps. This unit contains internally drained lakes such as Lake Nalyerin, and is a minor unit in the catchment.

2.1.3 Yarragil Unit (Minor Valleys Landscape)

This unit covers a large section of the catchment and comprises floors and streams of minor valleys. The valleys are broad and flat-floored with low slope gradients. Swamps occur in many valley floors.

2.1.4 Pindalup Unit (Minor Valleys Landscape)

Comprises valley floors and slopes and has affinity with the Dwellingup and Yarragil units. Slopes are moderate, broken by erosion scars producing steeper elements, and a broad valley floor. This unit is shown in the higher reaches of the Harris River as the upper section of Trees Plain.

2.1.5 Murray Unit (Major Valleys Combining Slopes and Floors)

This unit occurs in the lower reaches of the Harris Catchment and encompasses the damsite analysed by the Water Authority of Western Australia. The unit comprises deeply incised valleys and sideslopes with slope gradients up to 30%. In this section of valley, a narrow alluvial floodplain occurs.

2.2 LANDFORM - GEOLOGY RELATIONSHIPS

The upland plateau has been developed from erosion of the Archaen granites with the landscape being extensively mantled by laterite. The present land surface is the result of long-continued differential stripping, movement, and sorting of detritus, and exposure of variously weathered and unweathered substrata (McArthur et al., 1977).

In general, the interfluves have been least affected by erosion and are dominated by lateritic materials. Erosional modification is often dependent on features of slope, declinity and available relief, while areas of low slope gradient offer zones of deposition of detritus (McArthur et al., op cit.)

3.0 SOILS

3.1 SOIL MORPHOLOGY

The soils of the project area have been identified using the Northcote (1979) system of soil classification. This system is based on recognition of various soil features by observation, handling or by simple chemical tests. Principal profile form is the ultimate coding of a soil under this system and each letter and number has a precise meaning within the coding system. Accordingly, soil identification is almost completely objective. The system divides a soil type into division (based on texture), sub-division, section, class and principal profile form. A letter-number combination is utilised to code the soil.

The system of Great Soil Groups prepared by Stephens (1962) is based on a morphological approach related to genetic development. The system is based on the dominant soil forming process, the soil colour, texture, structure and consistence. This system enables various soil types with similar morphological characteristics to be grouped under one classification. Thus, a classification of red-brown earth may contain soils of varying principal profile forms.

Although Northcote (1979) was used to identify the soil types in the Harris River catchment area, the various soils have been combined under their individual Great Soil Group (Stephens, 1962) to form "soil mapping units".

At Harris River, six distinct soils, each covering a minimum area of five hectares have been identified. It is expected that other soil types with an areal extent less than five hectares do occur, but these were too small to be mapped. Great Soil Group names were applied to the six Northcote (1979) codings. The Great Soil Group names (Stephens, op. cit.) were extended by additional work completed by Stace, et al., (1972). Small scale mapping at a scale of 1:2,000,000 of catchment soils had previously been undertaken by Northcote, et al., (1967).

Mapping the six Great Soil Groups at the published scale of 1:100,000 could not be considered because of scale problems. Consequently, the Great Soil Groups have been combined under four soil mapping units. Erodibility ratings for the soil mapping units are described in Section 3.3.

The soils of the study area are directly related to landform and parent material. Soils in the plateau uplands have been eroded and washed downslope. The sand depth increases downslope as materials washed from higher slopes are deposited. Throughout the catchment on the plateau surfaces (uplands), duricrusts occur which are blocky recemented lateritic gravels. Their occurrence is variable and is dependent on the degree of site erosion.

3.2 SOIL MAPPING UNITS

Soil types identified in the catchment area are listed in Table 6 and mapped as soil mapping units (Figure 7). Descriptions of typical soil profiles are included as Addendum I and particle size distributions are contained in Addendum II.

3.2.1 Gravelly Earthy Sands

This soil type is the major unit in the catchment area. It occurs on the plateau uplands in particular, on the colluvial slopes along Tallanalla Road. Typical profile form is KS-Uc4.22. These units contain more than 60% lateritic gravel and the finer materials are coarse textured sands with an earthy fabric. These soil units have formed from weathering of the laterite duricrusts, have been transported downslope by colluvial action, and are free of salts and calcium carbonate. Weathering granite rock was identified at 80cm depth, and breakdown of feldspars to kaolinitic clays was occurring on exposure of the rock to the elements.

TABLE 6

SOIL TYPES AND SOIL MAPPING UNITS

Principal Profile Form (Northcote, 1979)	Great Soil Group (Stephens, 1962)	Great Soil Group Extension (Stace et al., 1972)	Soil Mapping Unit
KS-Uc4.22	Lateritic Podzolic Soils	Gravelly Earthy Sand	Gravelly Earthy Sands
Uc1.22 (Associated Soil)	Alluvial Soil	Alluvial Soil	
Uc5.23	Yellow Earths	Earthy Sand	Earthy Sand
Um1.42	Yellow Podzolic Soils	Siliceous Sand	Lithosols
KS-Uc1.23	Lateritic Podzolic Soils	Lithosol	
-	Acid Swamp Soil	Acid Peats	Swamp Soils

KS = More than 60% of the soil texture is lateritic gravel of a size greater than 2mm.

Associated with the gravelly earthy sands and the lithosols soil mapping unit (Section 3.2.3) are alluvial soils with a principal profile form of Uc1.22. These soils have coarse sandy loam textures and an earthy fabric. They encompass small areas restricted to small floodplains which are usually one to two metres above the base level of the stream. This uniform soil contains less than 1% lateritic gravel and is well graded. The lineal extent of this soil, and with its restriction to narrow floodplain areas, prevents the mapping of this unit on Figure 7.

3.2.2 Earthy Sands

This soil mapping unit occurs throughout the catchment area but is more prominent along Asquith Road (eastern) section. The textures are coarse loamy sands with an earthy fabric. The principal profile form for this soil is Uc5.23. Lateritic gravel occurs in the profile but totals less than 30% of the texture class.

Some quartz fragments were identified in the lower profile and are weathering products from the granite bedrock. These fragments were transported by slope wash from higher upslope.

The principal feature of this soil unit is the bleached B horizon (Northcote, 1979) which is overlain by a darker coloured horizon containing organic matter. There is little colour variation in the bleached horizon between the dry and moist state (Addendum I).

3.2.3 Lithosols

This soil mapping unit occurs on sideslopes and footslopes throughout the eastern section of the catchment. The unit comprises two principal profile forms - Um1.42 and KS-Uc1.23.

The former soil type is a medium - textured (silty loam) uniform soil overlying a recemented lateritic gravel (duricrust). The fabric of the A_1 and A_2 horizons is earthy and both are free of gravel. The duricrust is usually found at depths between 150 and 200cm.

The second soil type is a coarse-textured uniform soil with more than 65% of the profile containing laterite nodules. The finer textured part of the soil (less than 2mm diameter) has an earthy fabric and is up to 80cm deep.

3.2.4 Swamp Soils

No profiles were described for this soil mapping unit but observations of road drain excavations disclosed a profile comprising organic matter (peat) to 30cm deep, overlying a mottled clay B horizon. This unit was observed in the broad swamp of "Trees Plain" in the upper reaches of the Harris River catchment.

Stephens (1962) describes acid swamp soils as consisting "of a variable mixture of organic and mineral matter of acid reaction under the influence of a water-table that periodically is at, above, or near the surface of the profile".

3.3 SOIL ERODIBILITY

Soil erodibility is a function of soil texture, soil structure, aggregate stability, infiltration and permeability rate, and water holding capacity. The resistance of a soil to water erosion depends on:

- The ability of surface aggregates to withstand raindrop impact
- The ability of surface aggregates to withstand transportation in overland flow
- The ability of sub-surface aggregates to withstand disruption caused by rapid wetting
- The rate at which the surface can absorb water
- The internal permeability of the profile
- The amount of water each soil horizon or layer is capable of absorbing (Charman, 1978).

The water erodibility of soil can be based on its texture, structure, depth of soil horizons and some measure of aggregate stability. For instance, the coarse (sand) texture and apedal structure of the lithosols soil mapping unit will give this soil a high rating for these two factors alone. The individual sand grains lack coherence and are, therefore, easily detached. These soils can give rise to high rates of soil loss when saturated under heavy rainfall conditions.

Based on an index in use (and under trial) by the Soil Conservation Service of N.S.W., the project area soils are rated in terms of their erodibility (Table 7). However, the erodibility ratings of the soils at the project area were assessed on a subjective basis and not by the objective system proposed by Charman (1978).

The ratings shown in Table 7 are based on the soil units remaining in their natural undisturbed state. If any disturbance of these soil types occurs, soil erodibility rating will increase to the very high to extreme level. Disturbance will alter soil structure, permeability and infiltration rate. This will enable runoff flows to easily detach and transport soil particles.

Because of the rainfall characteristics in this area, notably rainfall events of long duration which results in soil saturation, minimal disturbance of these soil mapping units will increase soil erodibility and areas which were previously relatively stable will become potential non-point sources of sediment.

TABLE 7

SOIL ERODIBILITY RATINGS

Soil Mapping Unit	Erodibility Rating
Gravelly Earthy Sands	Very High
Earthy Sands	High
Lithosols	High
Swamp Soils	Low

3.4 SOIL EROSION HAZARD

The erosion hazard rating is a subjective assessment derived from an interaction between soil erodibility, rainfall erosivity, the steepness and length of slope, vegetative cover and management of the site.

Soil erodibility has been described in Section 3.3. Rainfall erosivity relates to the erosion potential of rain and is a function of intensity and duration of rain, raindrop size and impact. The action of raindrops falling on soil is a work process and all work processes involve energy being expended. The kinetic energy of falling raindrops is a function of raindrop size and velocity and this energy is expended in detachment of soil particles in raindrop splash. Storms of high intensity rainfall and of short duration will have larger raindrop sizes than low intensity rainfall, long duration storms. The larger drop sizes will cause more detachment and probable surface sealing.

Slope steepness and length affects the velocity of the runoff which in turn affects the detachment and transporting ability of the runoff on soil particles. A long steep slope will accumulate runoff thus increasing depth and velocity as a function of the flow becoming channelised.

Vegetative cover protects the soil surface from raindrop impact and the transporting energy of runoff flows. A soil surface with bare patches between clumps of vegetation is more prone to detachment by raindrop impact and runoff flows and lacks the plant root holding ability of vegetated units.

Management of a site has one of the major effects on erosion hazard. A well vegetated (undisturbed) site will be less prone to erosion than a disturbed, unvegetated site. If a programme of works requires disturbance of the soil surface, management of the site must involve the introduction of soil erosion control measures to reduce erosion hazard in the disturbed state.

Consequently, a landform unit with an erosion hazard of "low" under natural conditions may be coverted to "high" or "extreme" under disturbed management conditions.

Table 8 lists the erosion hazard ratings for the landform mapping units within the project area under the pre-existing undisturbed state.

Under the existing land use and hydrologic regimens, the catchment area is classified as stable and there is no evidence to indicate massive erosion or soil movement. However, the dominance of earthy fabrics and the presence of highly erodible sands on steep sideslopes, has the potential to contribute to gross soil erosion if the runoff coefficient is increased by clearing or poor drainage design.

TABLE 8

EROSION HAZARD RATINGS

Landform Mapping Unit	Erosion Hazard Rating
Dwellingup	High
Yarragil	High
Murray	Moderate
Goonaping	Low
Pindalup	Low

4.0 EROSION STATUS

4.1 HARRIS RIVER CATCHMENT

Techniques used to assess erosion status in the catchment included examination of existing colour aerial photography, field examination of contemporary geomorphic processes and their relationship with geology, landform, soils and land use.

The most significant aspect of this investigation is the paucity of quantitative data available on sediment yield rates, spatial soil loss, documentation of severity and distribution of erosion types, and the significance of various land management strategies in the overall control of erosion.

There are two types of erosion occurring within the catchment area - geological and accelerated. Geological erosion is the detachment and removal of particles that occurs under natural conditions. Thus, the chemical weathering and mechanical disintegration of rocks and the removal of the resultant debris by raindrop action and running water is natural erosion. This phenomenon is ubiquitous throughout the area and is responsible for providing sediment for reworking by the various processes operating on the land surface. Accelerated erosion is the detachment, transport and deposition of material at a faster rate than would occur in an undisturbed or natural state.

There are two principal provinces of accelerated erosion in the catchment and they are:

- o Forested lands
- o Agricultural lands.

As would be expected, there is no evidence of massive erosion on forested lands in the catchment. The canopy of forest and understorey plants prevents raindrop impact and the majority of rainfall percolates into the landsurface. Spatially discrete areas of soil erosion occur along roads within the forest and these are contributing minor amounts of sediment to the system.

The agricultural lands are contributing sediment from erosion of cleared farmland. This is particularly the case on private land between Damsites 1 and 5. Although there is little evidence for gully erosion, sheet erosion is contributing sediment to the Harris River system.

In terms of the present investigation, all these indicators suggest that soil erosion in the catchment is negligible under the current land management practices.

4.2 EFFECT OF PRESENT LAND USE ON CONTEMPORARY GEOMORPHIC PROCESSES

The effect of present land use on erosion processes is expressed by two major parameters:

- o Ground cover
- o Hydrologic response.

These two parameters are directly related and the former cannot be modified without modifying the latter. Under current management practices, the small area used for agriculture and the large area within State forest is ensuring minimum hydrologic response. This is having two effects:

- o Rainfall is very effective
- o Runoff and channelised flow have a long period time of concentration for given rainfall events.

The occurrence of forests ensures good retention of rainfall and ensures low energy input into stable drainage lines providing low kinetic energy for transport of sediment.

5.0 BIBLIOGRAPHY

Charman, P.E.V. (1978). Soils of New South Wales. Sydney: Soil Cons. Serv. of N.S.W. Tech. Handbook No.1.

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

_____(1981). The Darling System of Western Australia: The System 6 Report. Perth: Dept. of Conservation & Environ. 347 pp.

Department of Science and Technology (1981). Climate of Australia. Canberra: Bureau of Meteorology. 34 pp.

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 Resources Management Series No.3.

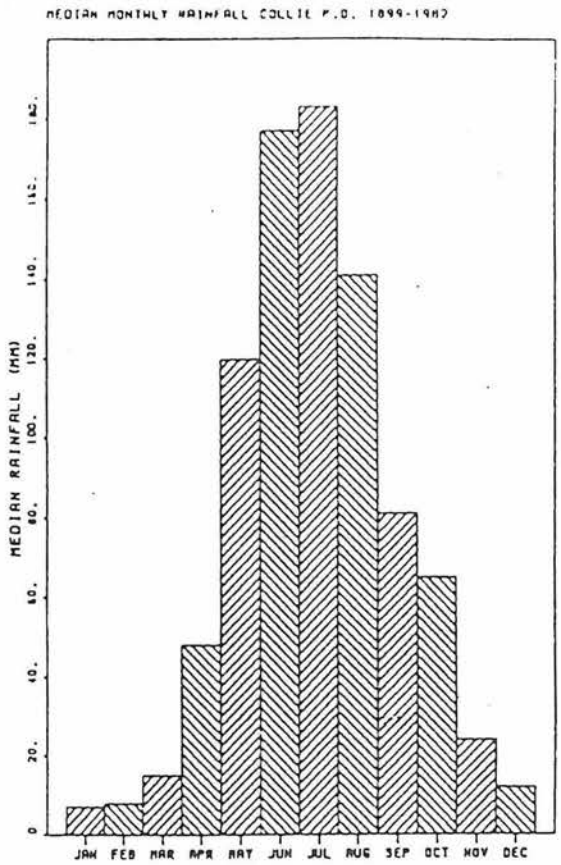
Northcote, K.H. (1979). A Factual Key for the Recognition of Australian Soils. Adelaide: Rellim. 124 pp.

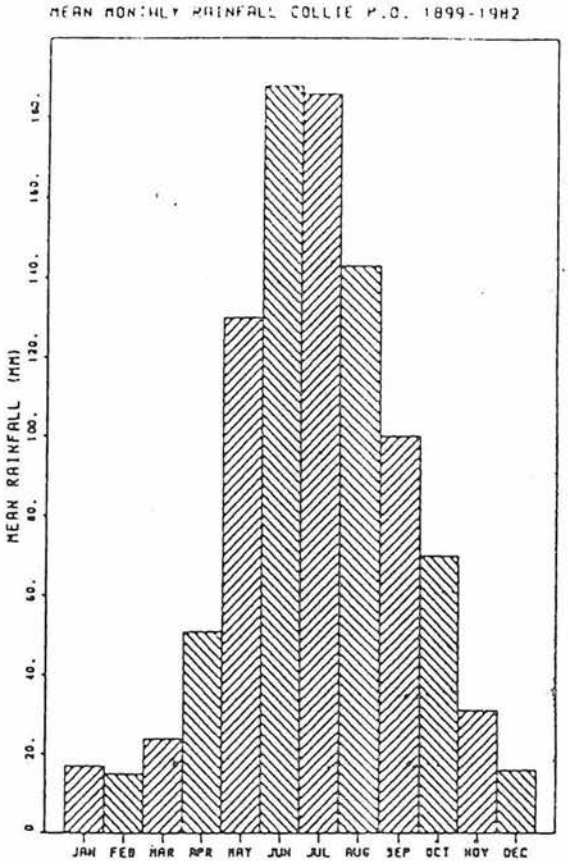
Northcote, K.H., Bettenay, E. Churchward H.M. and McArthur, W.M. (1967). Atlas of Australian Soils: Explanatory Data for Sheet 5 Perth - Albany - Esperance Area. Melbourne: C.S.I.R.O. and Melb. Uni. Press. 52 pp and accompanying map (1:2,000,000).

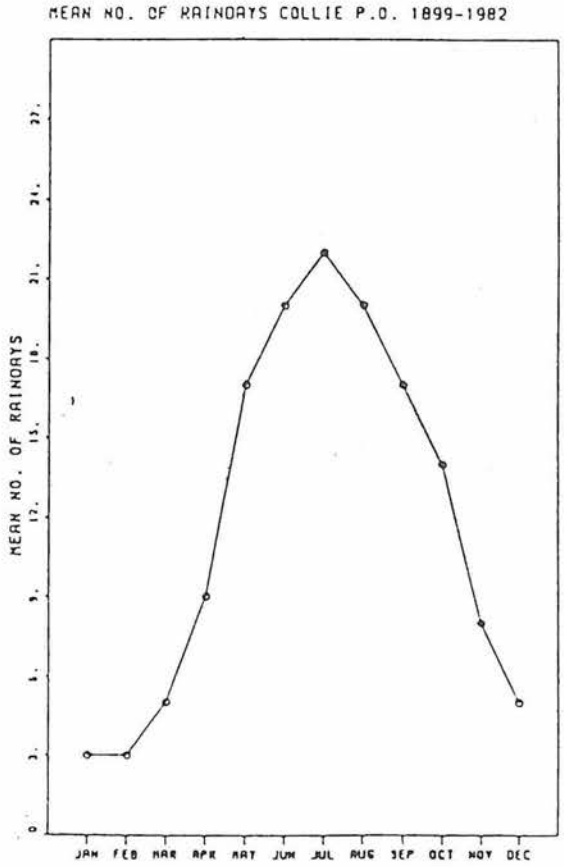
Stace, H.C.T., Hubble, G.D., Brewer, R., Northcote, K.H., Sleeman, J.R., Mulcahy, M.J. and Hallsworthy E.G. (1972). A Handbook of Australian Soils. Adelaide: Rellim. 435 pp.

Stephens, C.G. (1962). A Manual of Australian Soils. Melbourne: C.S.I.R.O. 3rd Ed. 61 pp.

FIGURES

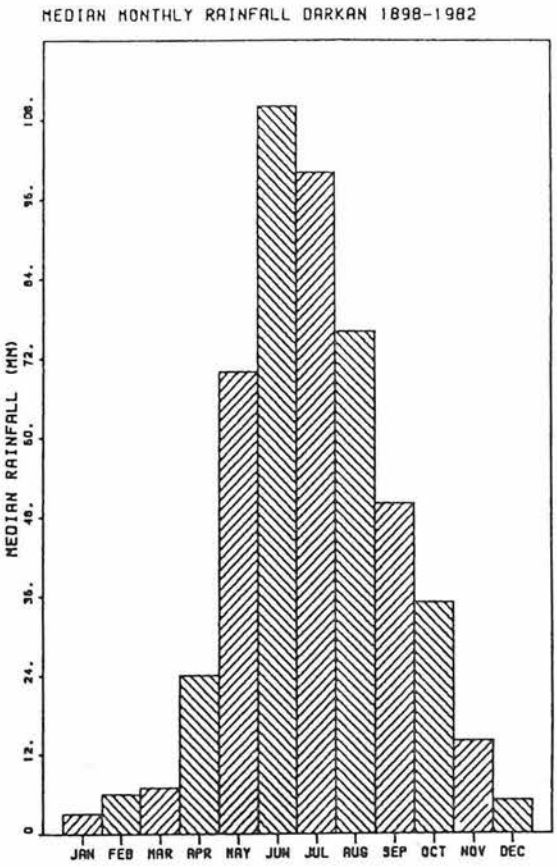


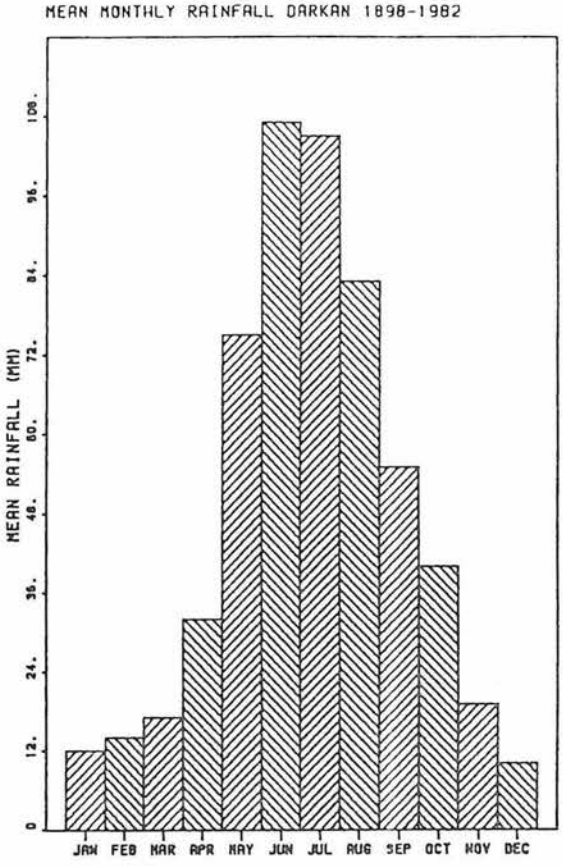


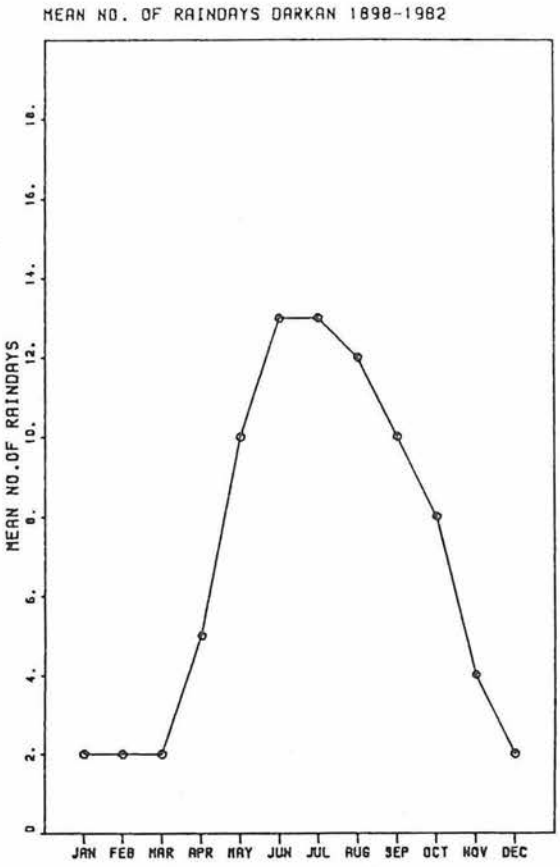


RAINFALL-COLLIE

Figure 1
Dames & Moore

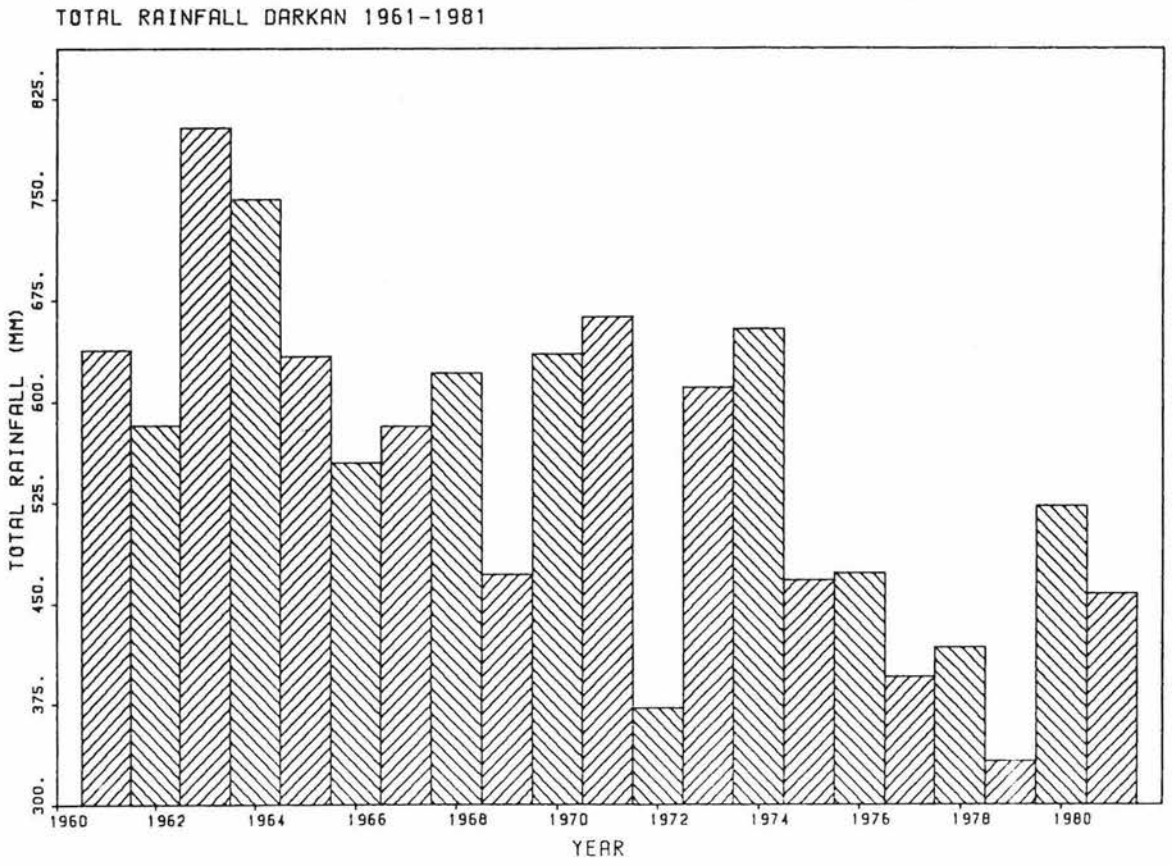


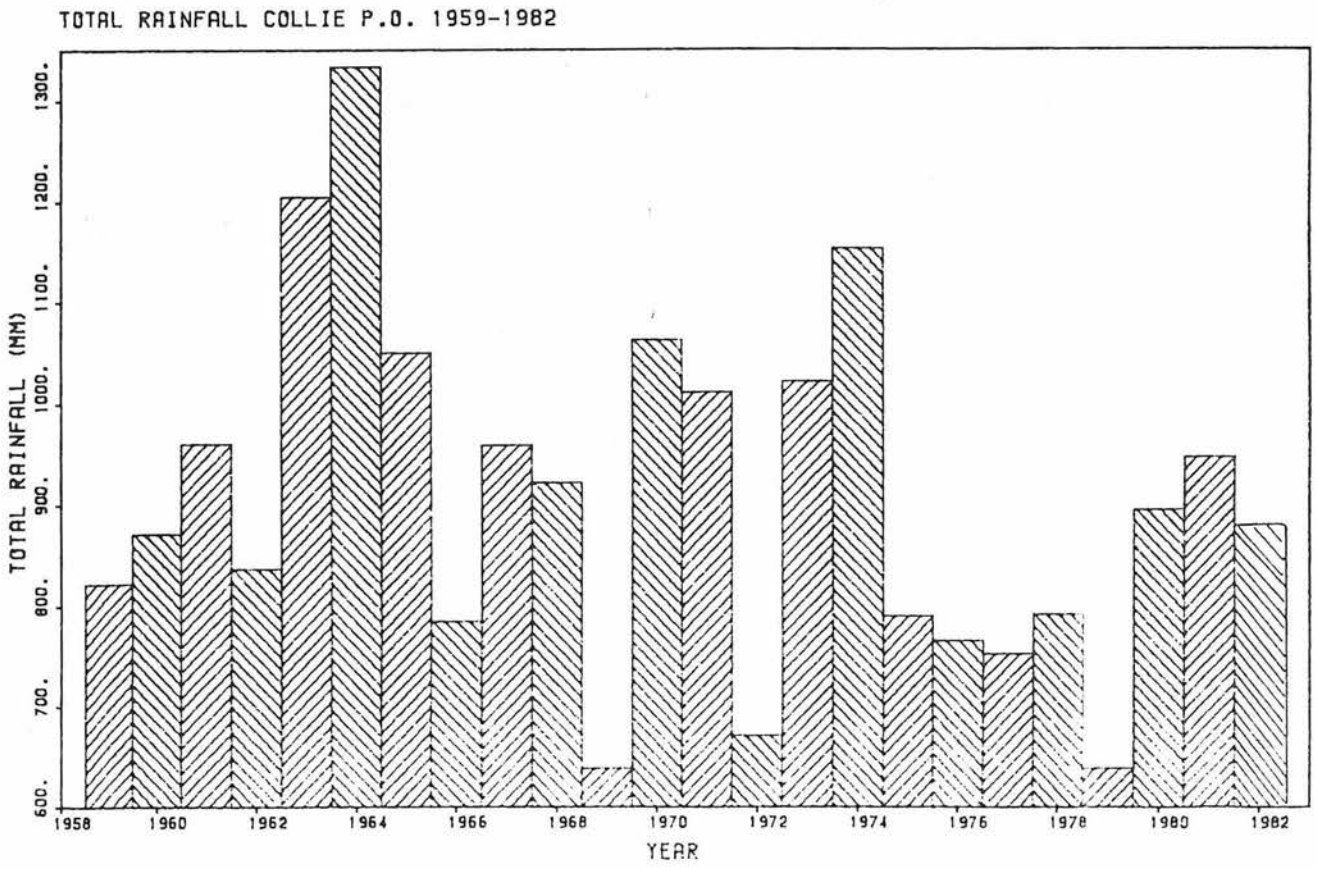




Rainfall - Darkan

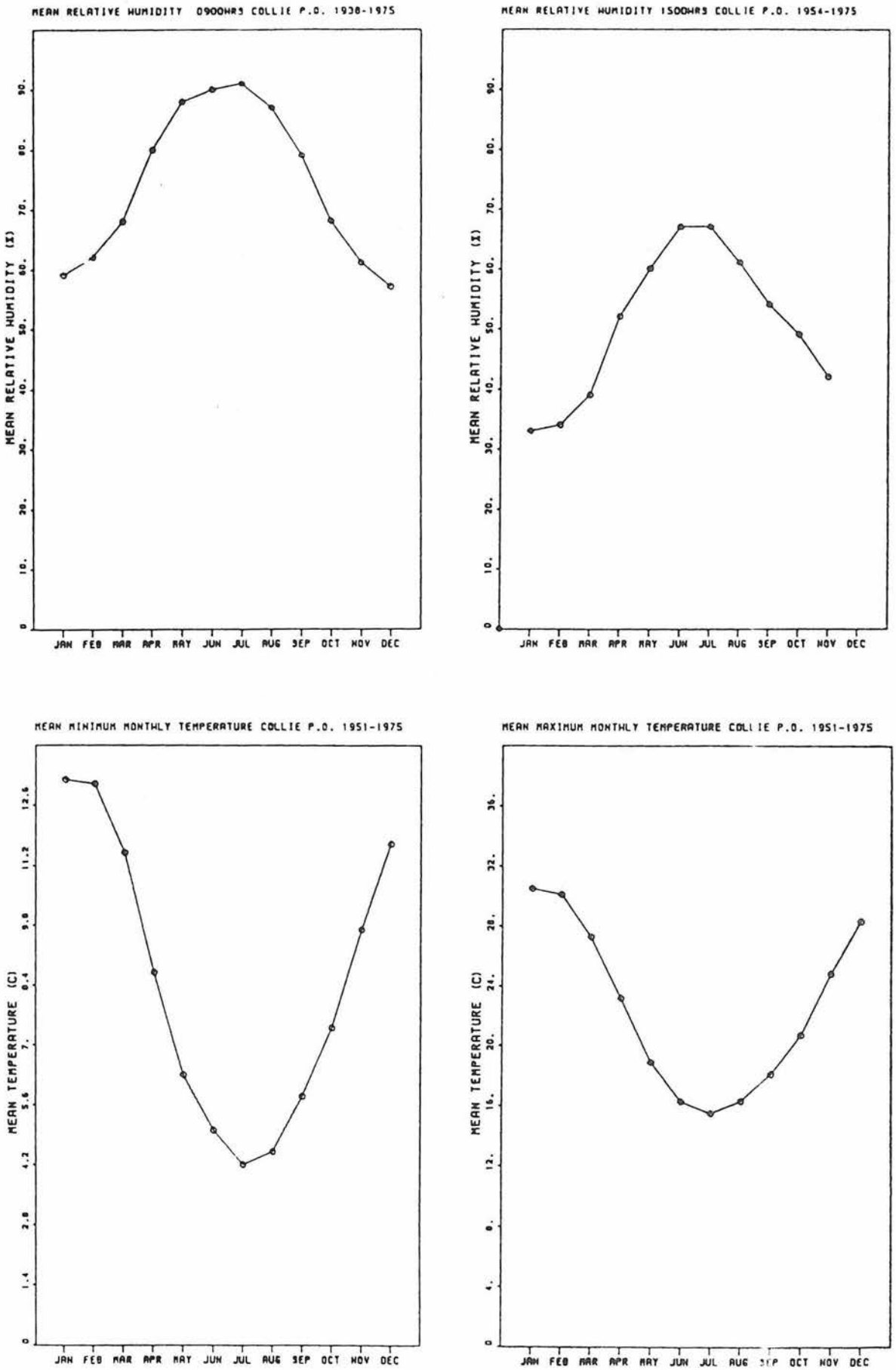
Figure 2
Dames & Moore





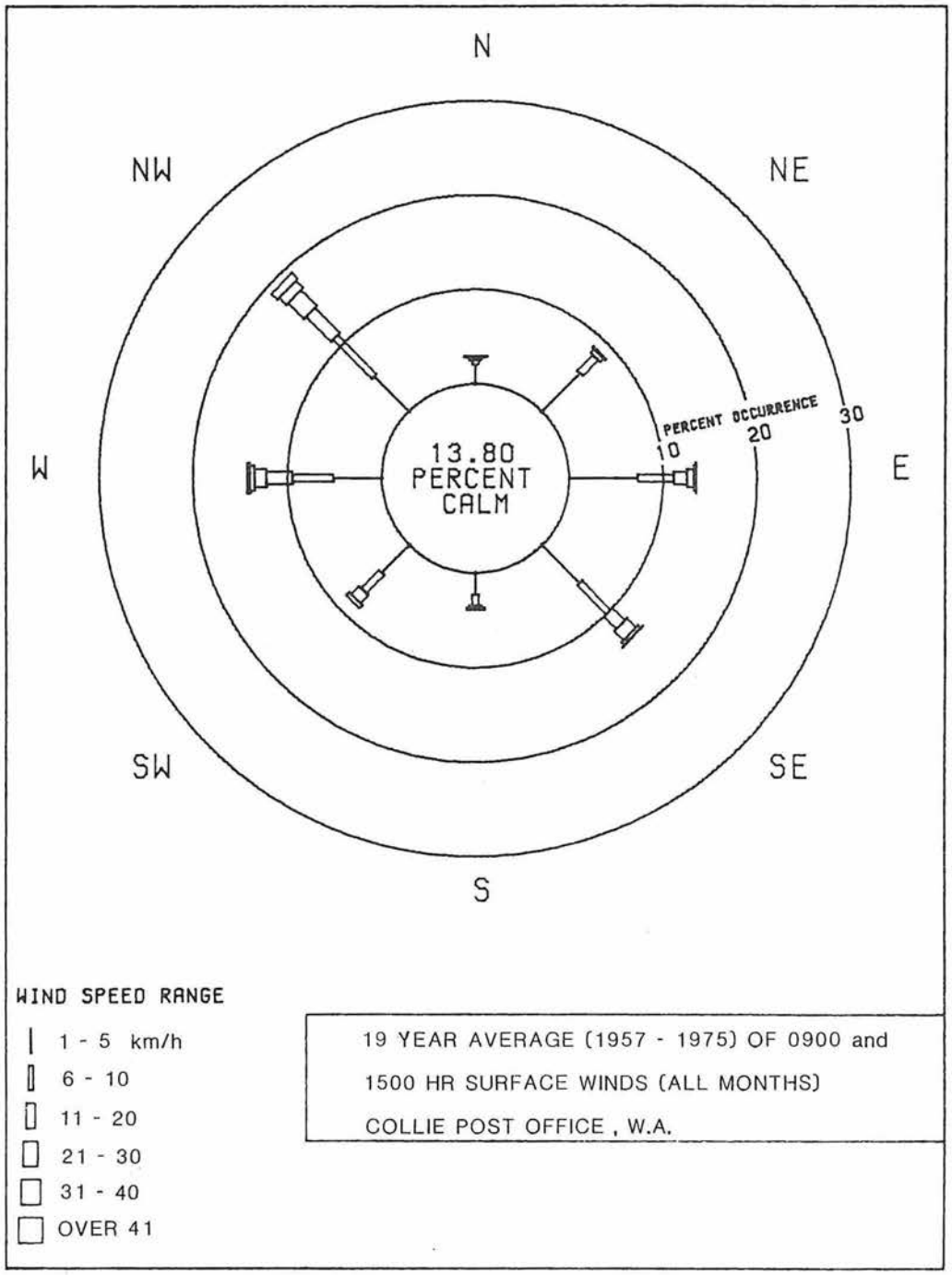
TOTAL RAINFALL-DARKAN & COLLIE

Figure 3
Dames & Moore



TEMPERATURE & RELATIVE HUMIDITY-COLLIE

Figure 4
Dames & Moore



(Source : Bureau of Meteorology)

Figure 5
Dames & Moore

LANDFORM

Figure 6
Dames & Moore

SOILS

Figure 7
Dames & Moore

ADDENDUM I

SOIL PROFILE DESCRIPTIONS

SOIL PROFILE DESCRIPTIONS

GRAVELLY EARTHY SANDS (KS-Uc4.22)

Depth (cm)	Horizon	Description
0-3	O	Organic layer-leaf litter, twigs, grass.
3-6	A_1	brownish black (5YR 2/1) moist - 7.5YR 2/2 dry) organic, loamy sand, apedal, earthy fabric, laterite abundant 70%, gradual change to -
6-22	A_2	dark reddish brown (5YR 3/6 moist - 5YR 5/8 dry) loamy sand, apedal, earthy fabric, laterite abundant (70%), pH 6.0, gradual change to -
22-35	A_3	dark reddish brown (2.5YR 3/6 moist - 5YR 5/8 dry) sandy loam, apedal, earthy fabric, laterite abundant (70%) , ph 6.5, gradual change to -
35-80	B	reddish brown (2.5YR 4/8 moist - 5YR 5/8 dry) sandy loam, apedal, earthy fabric, laterite abundant (70%), pH 6.0, sharp change to -
80-200+	C	weathering granite

ALLUVIAL SOIL (Uc1.22)

Depth (cm)	Horizon	Description
0-15	A_1	reddish brown (5YR 4/8 moist - 5YR 5/8 dry) sandy loam, apedal, earthy fabric, few stones, pH 6.0, sharp change to -
15-20	A_2	dark reddish brown (5YR 3/3 moist - 5YR 4/2 dry) sandy loam, apedal, earthy fabric, few stones, pH 5.5, sharp change to -
20-30	A_3	reddish brown (5YR 4/8 moist - 5YR 5/8 dry) loamy sand, apedal, earthy fabric, few stones, pH 5.5 gradual change to -
30-50+	B	bright brown (7.5YR 5/6 moist-7.5 YR 6/6 dry) loamy sand, apedal, earthy fabric, few stones, pH 6.0.

EARTHY SAND (Uc5.23)

Depth (cm)	Horizon	Description
0-30	A	brownish black (2.5Y 3/1 moist - 2.5Y 5/1 dry) loamy sand, apedal, earthy fabric, no stones, pH 6.0, gradual change to -
30-200+	B	bleached dark greyish yellow (2.5Y 5/2 moist - 10 YR 7/2 dry) loamy sand, apedal, earthy fabric, quartz fragments (1%), pH 5.0.

SILICEOUS SANDS (Um1.42)

Depth (cm)	Horizon	Description
0-20	A_1	reddish brown (5YR 4/6 moist - 7.5YR 5/6 dry) silt loam, apedal, earthy fabric, no stones, pH 6.0, gradual change to -
20-35	B_1	bright brown (7.5YR 5/8 moist - 10YR 7/8 dry) silt loam, apedal, earthy fabric, no stones, pH 5.5, sharp change to -
35-200+	B_2	recemented lateritic gravel (duricrust)

LITHOSOL (KS - Uc1.23)

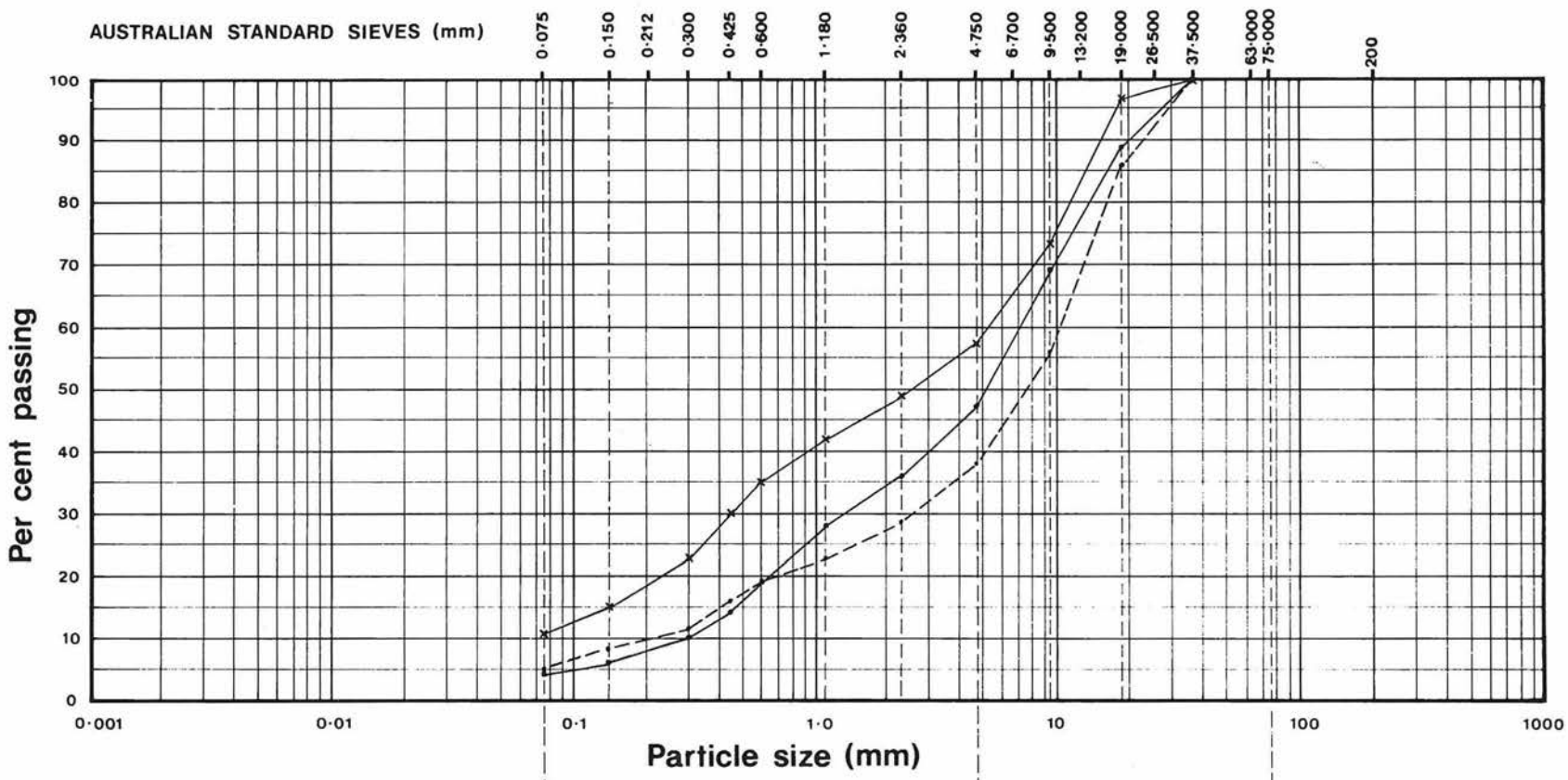
Depth (cm)	Horizon	Description
0-80+	A	brown (7.5YR 4/6 moist - 10YR 6/6 dry) sandy loam, fabric, abundant laterite (70%), pH 6.0.

ADDENDUM II

PARTICLE SIZE DISTRIBUTIONS

FILE 8076-024 DRAWN MWR CHECKED KEL DATE 27/4/84

PARTICLE SIZE DISTRIBUTION



UNIFIED SOIL CLASSIFICATION	CLAY & SILT	Fine	Medium	Coarse	Fine	Coarse	COBBLES
		SAND			GRAVEL		

A.S.1289(1977) PARTICLE SIZE LIMITS	CLAY	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	COBBLES	BOULDERS
		SILT			SAND			GRAVEL				

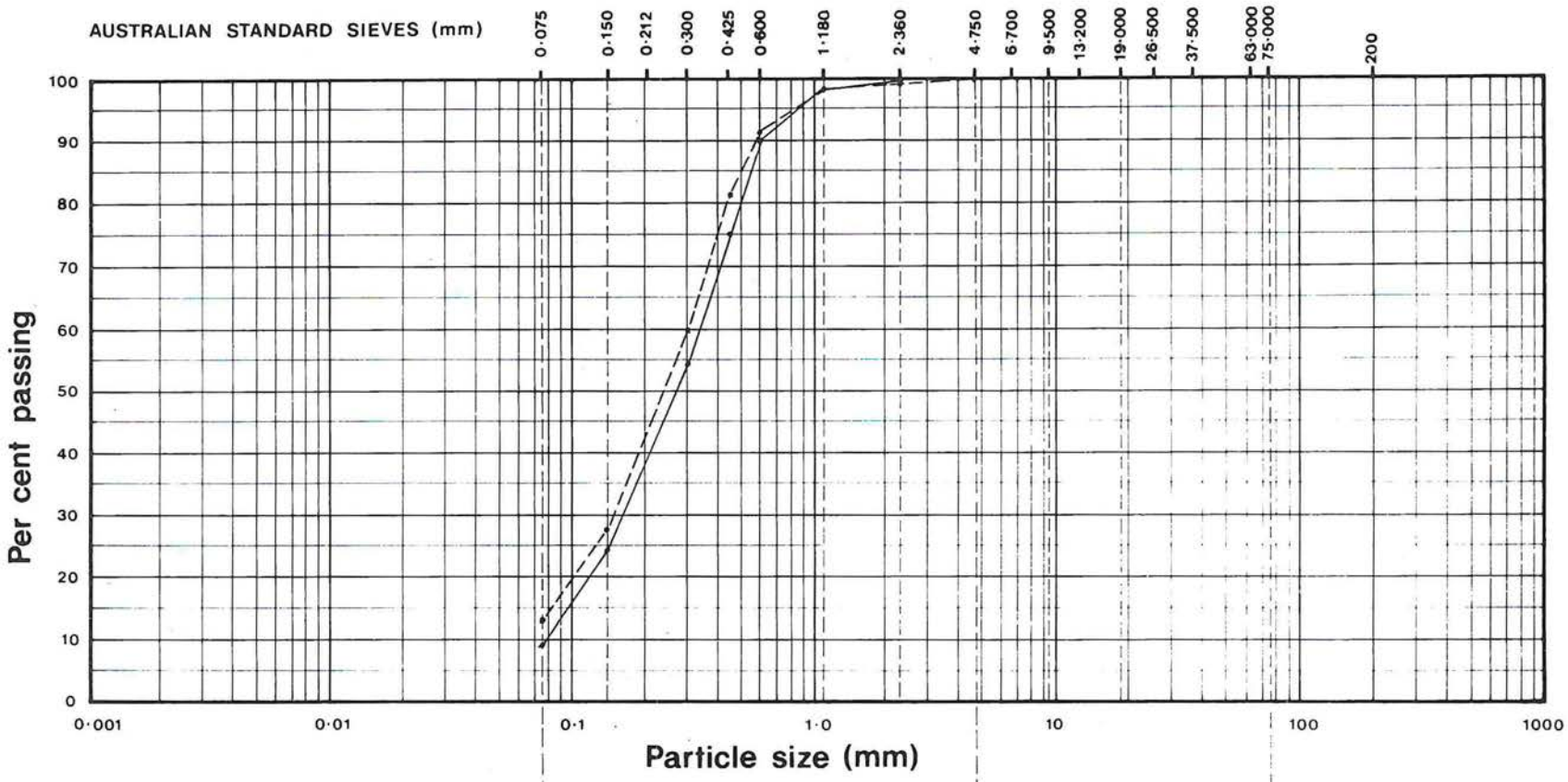
GRADING CURVE LEGEND	SAMPLE NO	DEPTH(cm)	CLASSIFICATION
———	1	3-22	KS-Uc 4.22 (Northcote, 1979)
- - - - - -	2	22-35	Lateritic Podzolic Soils(Stephens,1962)
——×——×	3	35-80	

FIGURE 2-A

Dames & Moore

FILE 8076-024 DRAWN MWR CHECKED KEL DATE 27/4/84

PARTICLE SIZE DISTRIBUTION



UNIFIED SOIL CLASSIFICATION	CLAY & SILT	Fine	Medium	Coarse	Fine	Coarse	COBBLES
		SAND			GRAVEL		

A.S.1289(1977) PARTICLE SIZE LIMITS	CLAY	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	COBBLES	BOULDERS
		SILT			SAND			GRAVEL				

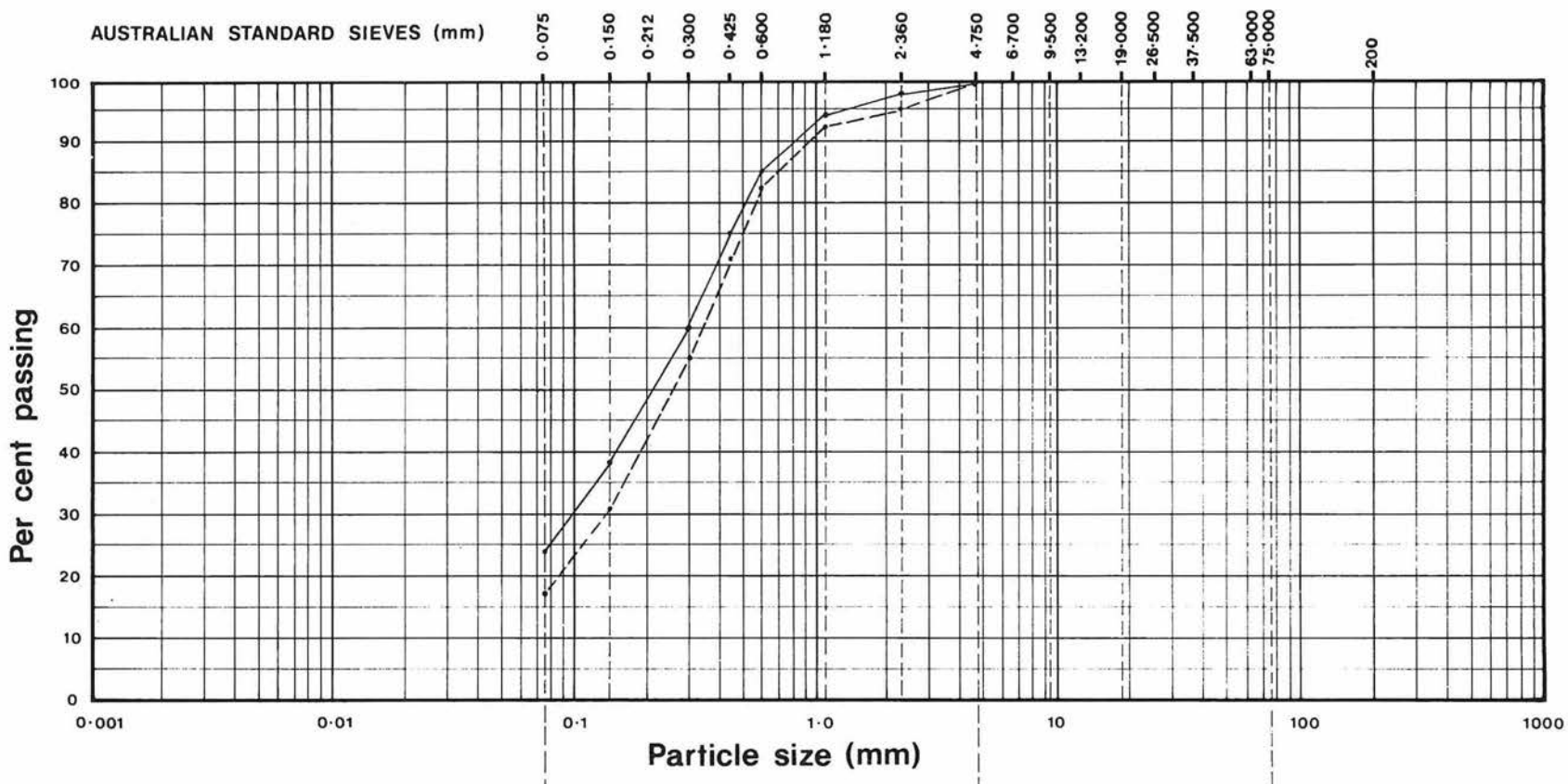
GRADING CURVE LEGEND	SAMPLE NO	DEPTH (cm)	CLASSIFICATION
———	4	5-20	Uc 1.22 (Northcote, 1979)
- - - - - - - - - -	5	20-50+	Alluvial Soil (Stephens, 1962)

FIGURE 2-B

Dames & Moore

FILE 8076-024 DRAWN MWR CHECKED KEL DATE 27/4/84

PARTICLE SIZE DISTRIBUTION



UNIFIED SOIL CLASSIFICATION	CLAY & SILT	Fine	Medium	Coarse	Fine	Coarse	COBBLES
		SAND			GRAVEL		

A.S.1289(1977) PARTICLE SIZE LIMITS	CLAY	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	COBBLES	BOULDERS
		SILT			SAND			GRAVEL				

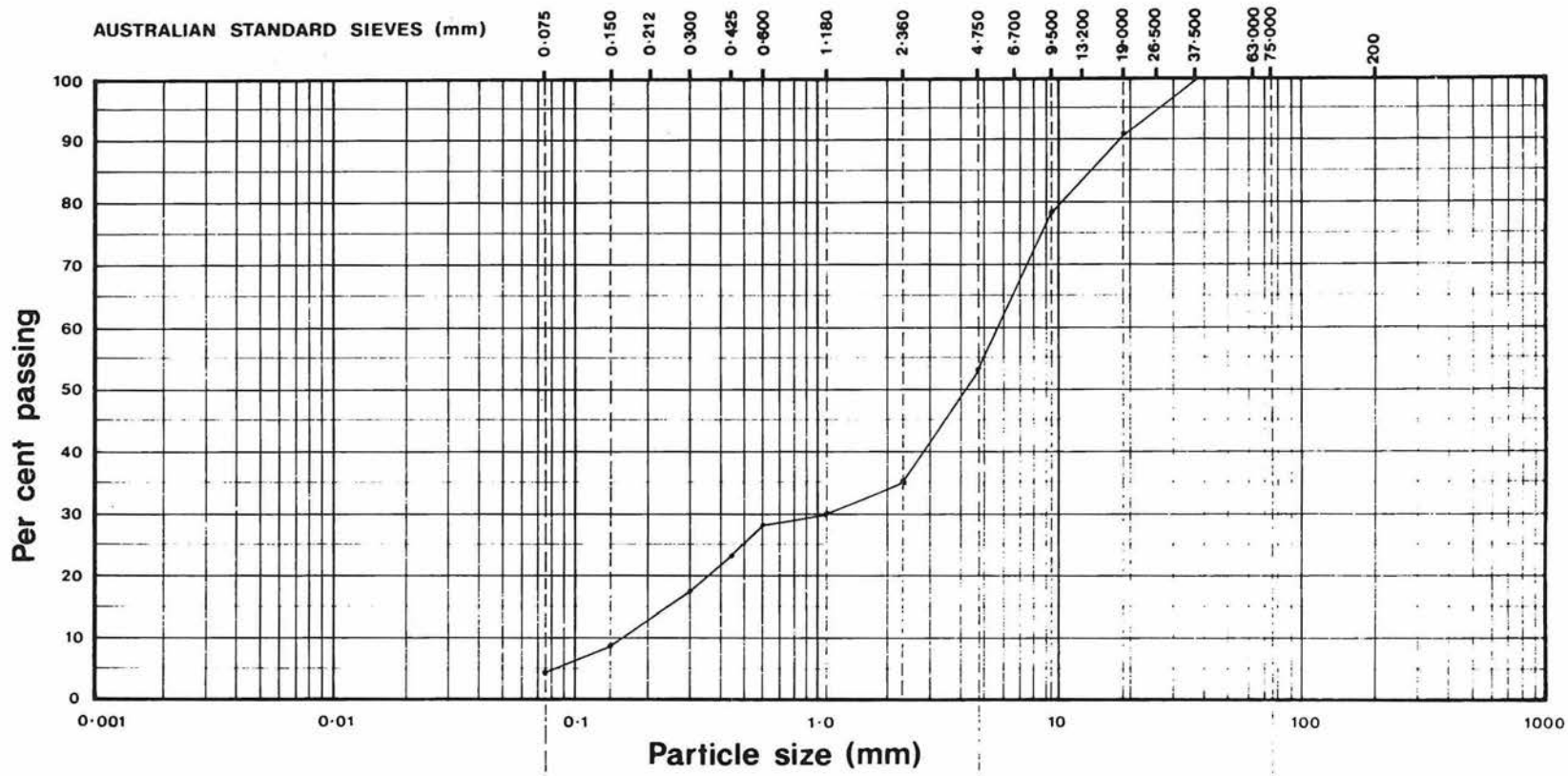
GRADING CURVE LEGEND	SAMPLE NO	DEPTH (cm)	CLASSIFICATION
——•——	6	0-20	Um 1.42 (Northcote, 1979)
- - •- - -	7	20-35	Yellow Podzolic Soil (Stephens, 1962)

FIGURE 2-C

Dames & Moore

FILE 8076-024 DRAWN MWR CHECKED KEL DATE 27/4/84

PARTICLE SIZE DISTRIBUTION



UNIFIED SOIL CLASSIFICATION	CLAY & SILT	Fine	Medium	Coarse	Fine	Coarse	COBBLES
		SAND			GRAVEL		

A.S.1289(1977) PARTICLE SIZE LIMITS	CLAY	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	COBBLES	BOULDERS
		SILT			SAND			GRAVEL				

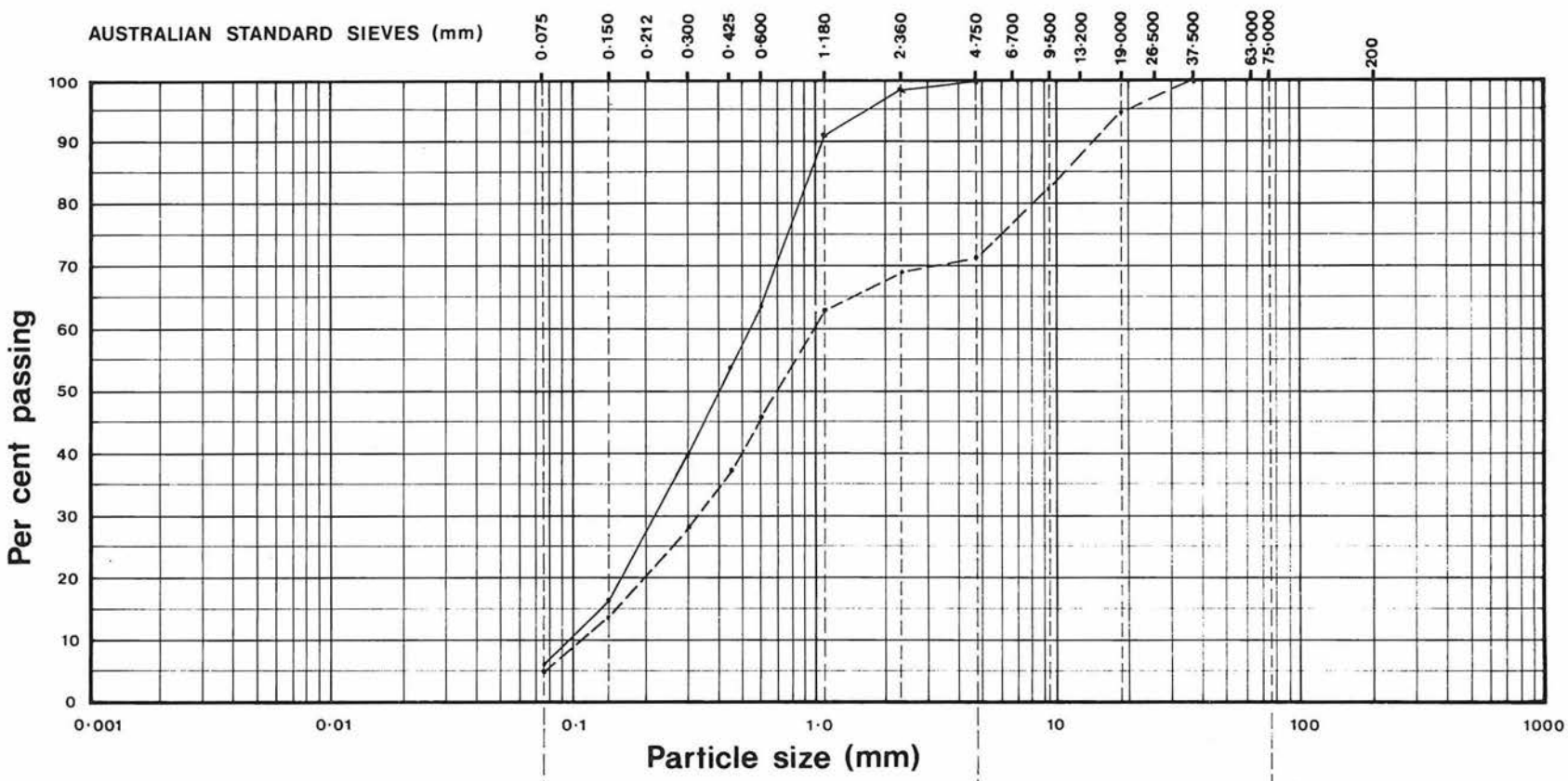
GRADING CURVE LEGEND	SAMPLE NO	DEPTH (cm)	CLASSIFICATION
——•——	8	10-80+	KS-Uc 1.23 (Northcote, 197°) Lateritic Podzolic Soils (Stephens, 1962)

FIGURE 2-D

Dames & Moore

FILE 8076-024 DRAWN MWR CHECKED KEL DATE 27/4/84

PARTICLE SIZE DISTRIBUTION



UNIFIED SOIL CLASSIFICATION	CLAY & SILT	Fine	Medium	Coarse	Fine	Coarse	COBBLES
		SAND			GRAVEL		

A.S.1289(1977) PARTICLE SIZE LIMITS	CLAY	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	COBBLES	BOULDERS
		SILT			SAND			GRAVEL				

GRADING CURVE LEGEND	SAMPLE NO	DEPTH (cm)	CLASSIFICATION
———	9	5-30	Uc 5.23 (Northcote, 1979)
- - - - - -	10	30-200+	Yellow Earths (Stephens, 1962)

FIGURE 2-E

Dames & Moore

APPENDIX B

VEGETATION AND VASCULAR PLANT FLORA OF THE HARRIS RIVER CATCHMENT

Prepared by
Dr. A.S. Weston
Senior Botanist
Dames & Moore

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1.0 INTRODUCTION

The Harris River originates in the central Darling Range east of Harvey and joins the Collie River immediately north of Collie. The Water Authority of Western Australia (Water Authority) proposes to dam the river to augment town and irrigation water currently supplied by Wellington Dam. Two suitable sites for a dam were selected (Damsite 1 and Damsite 5) as outlined in Figures 1 through 6. Damsite 5 has been selected by the Water Authority as the site for construction. This report describes the vegetation and flora of the river's catchment above the two damsites.

Approximately 99% of the Harris River catchment above Damsite 1 is covered in native, uncleared vegetation that is structurally diverse and comprises a flora rich in native species. Both the flora and the vegetation have been described at relatively small scales in published and unpublished articles and reports dealing with the plant cover of larger segments of the Darling Range. Although there are no detailed descriptions of the flora and vegetation in the catchment, reports centred on nearby areas do have some relevance.

The descriptions of the vegetation and flora given below are based upon a variety of reports, articles and published maps, upon unpublished maps and information provided by the Department of Conservation and Land Management (CALM) and upon field work undertaken by several members of the Dames & Moore study team and subconsultants. During field trips between April 1983 and January 1984 flora and vegetation were observed and specimens collected. Specific study sites sampled by Harold and by Davies are indicated in their reports, Appendix C and Appendix D, respectively. Other observations were made along tracks in the catchment and along walked traverses, particularly in the reservoir area and in the heathland and swampy plains bordering its upper end.

2.0 VEGETATION

The native vegetation of the Harris River catchment above Damsite 1 is, considered on a broad scale, of two types:

- Jarrah forest on the plateaux and slopes, sometimes with marri as a co-dominant or sub-dominant, and with yarri intergrading into
- Flooded gum-paperbark-shrub complexes that are highly variable and diverse, and often very dense, in depressions and valleys.

The vegetation of the entire catchment has been mapped at scales of 1:1,000,000 (Beard, 1981) and 1:250,000 (Smith, 1974; Heddle et al. 1980b), and parts of the catchment have been mapped at larger scales (Dames & Moore, 1981; CALM API sheets). Although the maps are based upon different scales and systems of vegetation classification, they all recognise as key elements the dominant species, their heights and their densities.

For the purposes of this report the vegetation of the catchment is mapped at a scale of 1:100,000 (Figure 1) and vegetation units which occur within the reservoir site are indicated on a 1:50,000 scale map Figure 2). These two Harris River vegetation maps are based upon the other maps referred to above, upon interpretation of stereo pairs of 1:20,000 scale coloured aerial photographs and upon site inspections. The vegetation units mapped are described below.

2.1 VEGETATION OF THE HARRIS RIVER CATCHMENT

Heddle et al. (1980b) mapped vegetation complexes, i.e. groupings of structural formations, plant associations and site-vegetation types. Their descriptions and maps of the relevant complexes and component units form the model for the following description of Harris River catchment vegetation. Table 1, reproduced from Forest Focus No.22 (Heddle et al. 1980a), indicates which plant species define each site-vegetation type. Figure 1, which maps the nine site-vegetation type complexes occurring in the catchment area, was produced from a CALM computer-generated map of vegetation complexes and from the map by Heddle et al. (1980b).

COMPLEX 1 Dwellingup and Hester Complex in the High Rainfall Zone

The vegetation of the central/southern Dwellingup and Hester Complex is, for the most part, the jarrah (Eucalyptus marginata) open forest and jarrah-marri (Eucalyptus calophylla) open forest that is widespread on and typical of the lateritic slopes and uplands in the western, high rainfall zone of the Northern Jarrah Forest between Dwellingup and Collie. Blackboys (Xanthorrhoea preissii), she-oaks (Allocasuarina fraserana), bull banksias (Banksia grandis) and Macrozamia riedlei are conspicuous and widely distributed understorey species. Clematis pubescens forms thickets with

widely distributed understorey species. Clematis pubescens forms thickets with Bossiaea aquifolium and Acacia drummondii on some lower slopes. Bracken (Pteridium esculentum), Hibbertia hypericoides, Hakea sp., Dryandra nivea, Lasiopetalum floribundum and a variety of other species are also widely dispersed through the forest.

The principal site-vegetation types in this vegetation complex are S (on mid-slopes, upper slopes, plateaux and ridges), T (upper slopes and ridges) and P (lower and middle slopes), with less common occurrences of types O and R.

Complex 1 and Complex 11 are the two best-represented vegetation complexes in the Harris River catchment and would be the two affected most extensively by inundation behind the proposed damsites. A stand of Complex 1 jarrah-marri open forest is illustrated in Plate 1-2, Appendix C.

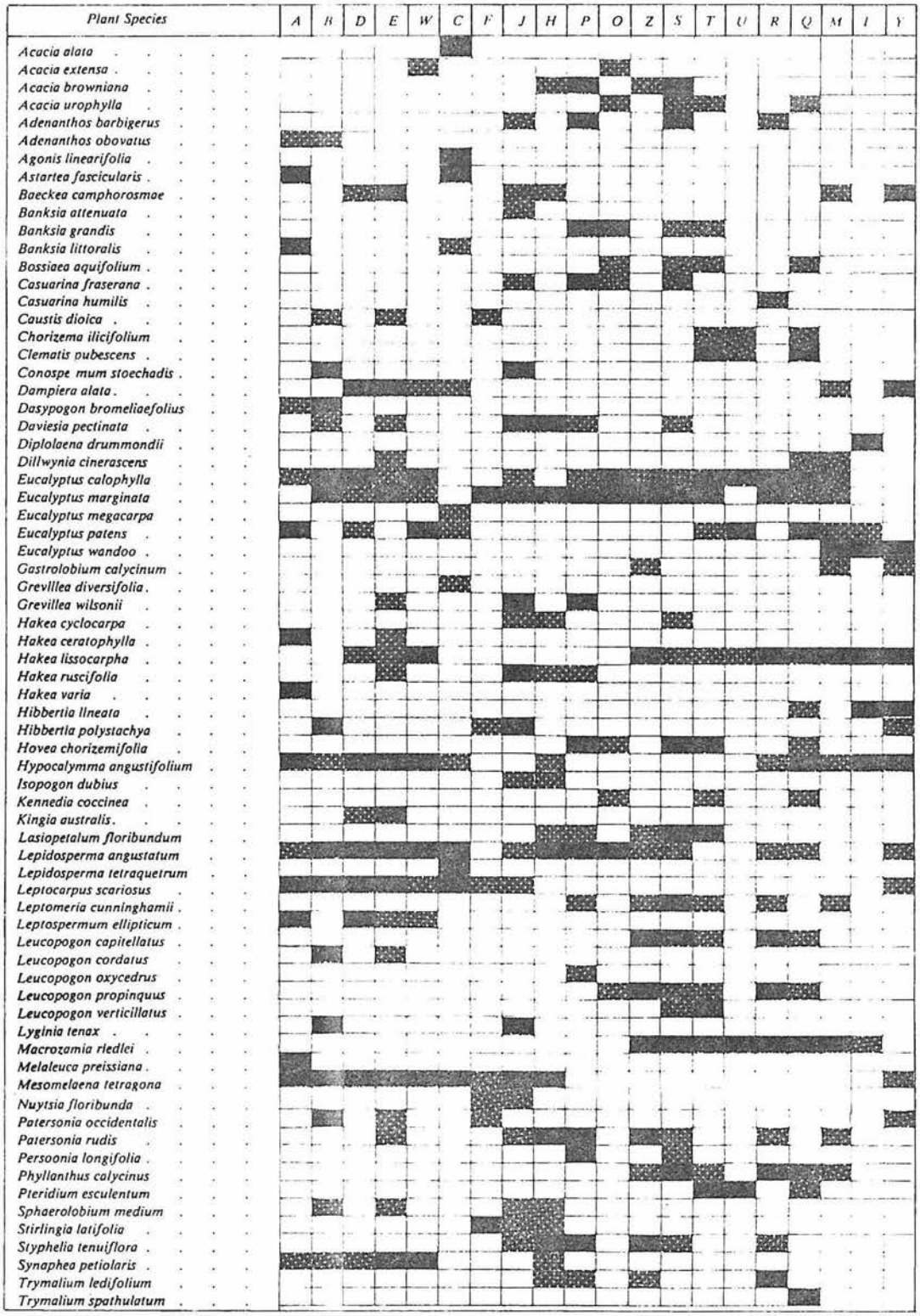
COMPLEX 2 Dwellingup Complex in the Medium to High Rainfall Zone

In common with Complexes 1, 4, 8, 10, 11, 13 and 20, Complex 2 has jarrah-marri open forest as a principal type of vegetation. Like Complexes 1, 4 and 11 this complex is composed primarily of jarrah and jarrah-marri open forest which, as in Complexes 1 and 4, occurs on lateritic (or, especially towards the east, sandy) slopes, plateaux and ridges. The Dwellingup complex of the medium to high rainfall zone north of Collie differs from the Dwellingup and Hester Complex of the high rainfall zone and the Dwellingup, Yalanbee and Hester Complex of the low to medium rainfall zone in having different floristic and structural features in the understorey.

Complex 2 jarrah-marri open forest is transitional between the jarrah-marri open forests of Complex 1 and Complex 4 in terms of its understorey; although the principal site-vegetation types are P and S (as in Complex 1), types H and Z (the principal types in Complex 4) and O and R (shared with Complex 1) are common. This Dwellingup Complex is extensive east of Perth but has a restricted distribution between Serpentine Dam and Collie.

Occurrence of Complex 2 in the catchment area is limited to six areas in its eastern third, mainly east of Asquith Road.

TABLE B-1 - Definition of Site Vegetation Types
Northern Jarrah Forest (Darling Plateau)



J. J. Havel, Forests Department Bulletin No. 87; 1975

Species generally absent.

Species should be present, but absence not critical.

Species should be present.

TYPE G was defined subsequently. It has a variable and unique set of indicator species which are characteristic of granite outcrops and their surroundings in low to medium rainfall zone, such as lichens, *Borya nitida, Grevillea bipinnatifida, Hakea elliptica, Hakea undulata, Eucalyptus laeliae, Eucalyptus wandoo* and *Casuarina huegeliana.*

COMPLEX 4 Dwellingup, Yalanbee and Hester Complex in the Low to Medium Rainfall Zone

This complex is similar to the first two in that it is confined to upland sites and is composed primarily of jarrah and jarrah-marri open forest. The understorey, comprising in part a different suite of species, is what distinguishes this complex from others. For instance, Bossiaea aquifolium, Pteridium esculentum and Lasiopetalum floribundum are uncommon or absent while Bossiaea ornata, Styphelia tenuiflora and Isopogon dubius are abundant and widespread or locally common.

The principal site-vegetation types in the complex are H and Z. Site-vegetation type P is less common.

Complex 4 occurs as four sets of bands in the eastern quarter of the catchment.

COMPLEX 8 Goonaping Complex

The Goonaping Complex embraces a wide range of structural formations and plant associations, mostly in shallow depressions at the heads of drainage lines and often on deeply leached, compacted soils that are saturated during much of the wet season. In the Harris River catchment the vegetation of the complex varies from jarrah-marri open forest through paperbark (Melaleuca preissiana) - swamp banksia (B. littoralis) low open woodland and Banksia attenuata low open woodland to low shrub and heath associations.

The most extensive occurrence of the Goonaping Complex in the Darling Range south of the Brookton Highway lies south of the upper Harris River around Lake Yourdamung. This occurrence differs from any north of the Brookton Highway in the commonness of Banksia attenuata, virtual absence of Banksia menziesii and other floristic features.

The principal site-vegetation types in the complex are F and J, but types A and, especially, B are also well-represented.

The Goonaping Complex merges with the Trees Plain Swamp Complex on the south, east and west of Asquith Road and continues south of the catchment.

COMPLEX 10 Yarragil Complex (Minimum Swamp Development) in the Medium to High Rainfall Zone

This minimum swamp development form of the Yarragil Complex is common north, south and west of the Harris River catchment above the proposed damsite but is probably not well-represented in the catchment itself. This form of the complex is predominantly jarrah-marri forest with yarri (Eucalyptus patens) and bullich (E. megacarpa), the yarri being widespread and the bullich being restricted to upper valleys and gullies.

The site-vegetation types included in this form of the complex include, primarily, C, D and W and, secondarily, Q, T and U.

The 1980 map by Heddle et al. shows four areas of Complex 10 in the southern fifth of the catchment, but the more recent, CALM, computer-generated map shows these four areas as Complex 11.

COMPLEX 11 Yarragil Complex (Maximum Swamp Development) in the Medium to High Rainfall Zone

This form of the Yarragil Complex differs from the previous one, Complex 10, in several respects. It generally occurs in areas having a somewhat lower rainfall, swamps are more abundant and often larger, bullich is absent, swamp banksia-paperbark low open woodland replaces the jarrah-marri (-yarri) open-forest on moist valley floors, and there is a well-defined lower tree layer of two or three banksia species in the open forest. This complex is well-represented in the medium rainfall zone of the Harris River catchment, especially along tributaries, where yarri is the dominant species.

The principal site-vegetation types in Complex 11 are D, E and W. Site-vegetation type E occurs only in this complex and, to a lesser extent, in Complex 13 and Complex 9. The last complex does not occur in the Harris River catchment. Site-vegetation types P, F, J, A and B are less widespread in the complex.

Complex 11 and Complex 1 are the two best-represented vegetation complexes in the Harris River catchment and would be the two most extensively affected by inundation behind the proposed dam sites. A Complex 11 mixed open forest and other Complex 11 vegetation are illustrated in Plate 1, photographs 1, 4, and 5 (Appendix C) and Plate 1 (Appendix D).

COMPLEX 12 Swamp Complex

Swamp complex vegetation is highly variable and diverse and ranges from low open woodlands to scrub, heath, shrublands and sedgelands, primarily on swampy valley floors. A variety of species of Melaleuca are the main dominants, but species of Hakea, Verticordia and Banksia are often co-dominants. The most extensive, most diverse and best-developed Swamp Complex vegetation between Dwellingup and Collie occurs along the Harris River above MacDougal Road. Smaller stands of Swamp Complex type vegetation occur in Complex 11.

The principal site-vegetation type occurring in the Swamp Complex is A.

Smith (1974) takes the larger areas of Swamp Complex type vegetation out of his counterparts of Complex 11 and Complex 8 and groups them, along with Complex 12, into paperbark and paperbark-Melaleuca low open woodland, myrtaceous open heath, paperbark-banksia low woodland, closed scrub and closed herbland (Lake Nalyerin and Lake Yourdamung). By far the largest areas of myrtaceous open heath and paperbark-banksia low woodland east of the scarp shown on Smith's Collie vegetation map are in Harris River valleys upstream of the dam's full supply level.

This complex of swamp and seasonal wetland vegetation in the Harris River valleys is the only occurrence of teatree low woodland scrub in jarrah-marri forest shown by Beard (1981) at a scale of 1:1,000,000 and segments of the complex east of the full supply level are considered by foresters familiar with the area to be unique (The West Australian, Saturday October 29 1983, p.20).

Swamp Complex vegetation is illustrated in photographs 1,3,4,5 and 6 in Plate 1 (Appendix C) and in Plates 2 and 3 (Appendix D).

COMPLEX 13 Pindalup and Yarragil Complex in Low to Medium Rainfall Zone

This vegetation complex is characterised by wandoo (Eucalyptus wandoo) open-woodland in the valleys and jarrah-marri open forests on slopes above the wandoo. Jarrah, marri and yarri also occur with the wandoo in various proportions and densities. In the eastern part of the catchment, where the complex occurs, it is commonly upstream and upslope of Complex 12 and merges above with Complex 4 jarrah and jarrah-marri open forest.

The principal site-vegetation types represented in the complex are H, M and Y. Site-vegetation types A, K, Z and E are less commonly represented.

COMPLEX 20 Murray Complex in Medium to High Rainfall Zone

Murray Complex vegetation occurs in moderately incised valleys of the Murray landform - soil units. The medium to high rainfall form of this complex is mostly restricted to the western fringes of the Darling Plateau, where the majority of its major areas of occurrence outside the Murray Valley have been inundated behind dams (Heddle et al. 1980b).

The dominant vegetation in the co ıplex is jarrah-marri open forest on upper and middle valley slopes and jarrah-marri-yar open forest on lower slopes. Fringing woodlands of flooded gum (Eucalyptus rudis) a ıd swamp paperbark (Melaleuca rhaphiophylla) are common along streams and rivers.

Complex 20 is represented in the catchment by a broad band between Damsite 1 and Damsite 5.

The principal, most consistent site-vegetation types in the complex are C, Q, U and T. Site-vegetation types D, O, R and W are less consistent.

2.2 VEGETATION OF THE RESERVOIR AREA

The vegetation of the reservoir areas, as shown in Figure 2, comprises five variable plant alliances belonging to Vegetation Complexes 1, 10, 11 and 12:

A - Jarrah-Marri Alliance
B - Flooded gum-Yarri Alliance
C - Paperbark - Banksia Alliance
D - Teatree Species Alliance
E - Heath/Shrubland Complex

2.2.1 Jarrah - Marri Alliance

Jarrah-marri alliance vegetation occurs on all the slopes and hillsides within the full supply levels above the flats and stream channels (Photograph 2). Like the other reservoir alliances, this one is variable in height, density and predominance of component species in both overstorey and understorey. The variation is affected not only by permanent natural factors such as climate, soil, slope and exposure but also by irregular, periodic events such as burning and logging and by dieback disease. Marri and jarrah are most commonly the dominants, but in several places, particularly on forested slopes between the damsites, yarri is dominant with or without marri. The principal site-vegetation types in this reservoir alliance are P, D, W and E, with less common occurrences of O, R, Q, B, A, U and J.

2.2.2 Flooded Gum - Yarri Alliance

The most widespread and conspicuous species in the fringing woodland and forest along the Harris River is flooded gum, but both swamp paperbark and yarri often occur with it and in some places replace it. In the upper end of the reservoir, flooded gum occurs as a scattered mallee among teatree (Melaleuca spp.) thickets and dense sedge and shrubland vegetation. South of the Old Collie Road it occurs with yarri open forest and woodland that is continuous across the Harris River and onto the flats on either side. River banksias and peppermints are common understorey trees and often occur as dominants in dense, tall thickets that also comprise Astartea fascicularis, Agonis linearifolia, Acacia extensa and various sedges. Below Damsite 5, the alliance is mainly restricted to narrow fringing bands bordering the river.

2.2.3 Paperbark - Banksia Alliance

Swamp paperbarks (Melaleuca rhaphiophylla), Melaleuca preissiana and river banksias occur separately and in combination as low open woodland to low forest and low closed forest or scrub on open flats subject to seasonal flooding (Photographs 3 and 4). On flats and lower slopes on the margins of the Harris River valley, the understorey is often an open distribution of low shrubs. Nearer the river above MacDougal Road the understorey is often a very dense, tall thicket of shrubs and sedges that merges with the teatree species alliance. Below MacDougal Road the alliance often merges with the flooded gum - yarri alliance.

2.2.4 Teatree Species Alliance

On the flats above the Old Collie Road subject to inundation for relatively long periods there are very dense thickets of teatrees between 1m and 3m tall (Photograph 6). Agonis linearifolia is abundant near the margins of the thickets. Melaleuca polygaloides is the dominant shrub over the deepest water. Restionaceous sedges are also abundant and widespread in the stands, and various shrubs are locally dominant. These include Melaleuca viminea, M. leptoclada and Kunzea recurva. Gahnia trifida, Borya scirpoidea, Microtis orbicularis, M. atrata, Polypompholyx multifida and Utricularia hookeri are all common in Melaleuca viminea thickets in the north-eastern arm of the reservoir.

2.2.5 Heath/Shrubland Complex

The eastern end of the reservoir contains the western reaches of the Trees Plain complex of heaths and shrublands that complement the teatree alliance on drier sites (Photographs 4 and 5). Although the majority of dominant species in the complex are myrtaceous (Kunzea recurva, Melaleuca spathulata, Verticordia acerosa, V. plumosa, Pericalymma ellipticum) and proteaceous (Petrophile seminuda, H. marginata, Hakea sulcata), some other species are also prominent. These other species include Oxylobium reticulatum, Labichea punctata, Andersonia aristata and A. involucrata. The mouse-like odour of Andersonia involucrata suggests that it might be pollinated by small mammals.

2.3 DOWNSTREAM RIVERINE VEGETATION

The lower damsite, Damsite 1, is located approximately one kilometre upstream from the confluence of the Harris and Collie Rivers. The vegetation in the strip between the damsite and the Collie River is flooded gum fringing forest along the river, which is mostly flanked by agricultural clearings. The fringing forest understorey in the strip has been partially degraded by the trampling of livestock.

2.4 RARE VEGETATION COMMUNITIES

Although there are many published and unpublished lists, surveys and reports on rare and restricted plant species that have some relevance to the Harris River catchment, there is no comparable work on vegetation. The only comprehensive survey of major Australian plant communities and their conservation status (Specht et al. 1974) suffers from a complete absence of information about the areal extent of any alliance listed. Furthermore, the data from which the report was compiled was collected prior to the availability of medium scale vegetation maps and descriptions for most of Western Australia, including the Darling Range, and before a system of conservation Management Priority Areas (MPA's) in State forests and the Lane - Poole Reserve were publicly mooted. Nor are most of the forest, woodland, shrub and sedge alliances referred to by Specht et al. broken down into the communities that occur in the catchment.

Some indication of the rarity of shrub and sedge (cyperaceous and restionaceous) communities found in the catchment can be drawn from inspection of 1:250,000 and 1:1,000,000 vegetation maps. For example, at a scale of 1:1,000,000 the only occurrence of teatree (Melaleuca) low woodland scrub shown in the Northern Jarrah Forest is along the Harris River (Beard, 1981). It extends from MacDougal Road, in the upper reservoir area, to above Treesville.

3.0 FLORA

The northern jarrah region, between Collie in the south and Mundaring in the north, probably has at least 1,000 species of vascular plants. During CALM's reconnaissance and survey for site-vegetation mapping of the State forest portion of the region, approximately 600 species were collected (Havel, 1975). More recently, 412 species were recorded in a relatively small area touching the Harris River catchment in the north (Dames & Moore, 1981), the Worsley Alumina project area. This list has been substantially increased by subsequent collecting, principally in the heathlands and forest understorey on Mt Saddleback (Worsley Alumina Pty Ltd,1985).

3.1 FLORA OF THE HARRIS RIVER CATCHMENT

Table 2 lists approximately 190 species of vascular plants recorded in the Harris River catchment. The list is a preliminary, partial list and far from comprehensive. Furthermore, as it comprises entries from unverified lists as well as determinations of collections made during the survey, some of the names may be incorrectly used. The second column of Table 2 gives five-letter abbreviations indicating the family to which each species belongs. X's in the last three columns indicate the species' principal habitats. The term "forests" includes all eucalypt woodlands, open forests and forests in the catchment. The term "heath/shrublands" refers to heath/shrubland complexes, particularly on Trees Plain, and teatree shrubland and other thickets along the streams. Both aquatic and semi-aquatic species are checked under "water". Some species are not checked under any habitat type because their principal habitats are not listed (e.g. paperbark - banksia woodland), because they have more than one principal habitat (or none), or because of uncertainty.

The number of species of vascular plants in the Harris River catchment may be, owing to the contributions of the Harris River heathland and seasonal wetlands, comparable to the Worsley Project area. However, a large proportion of the Harris River flora listed in Table 2 was not encountered in the Worsley Project area. This may be because many Harris River catchment species may be restricted to the heathlands and swampy plains of the Harris River valley bordering on the reservoir site (Complex 12), habitats not found in the Worsley Project area.

This swamp vegetation is estimated to have "three times the number of wildflowers found in the jarrah" (The West Australian, Saturday October 29 1983, p. 20) and contains species that are uncommon and poorly represented elsewhere on the Darling Plateau.

TABLE 2

VASCULAR PLANT SPECIES OF HARRIS RIVER DAM CATCHMENT (Partial)

SCIENTIFIC NAME	FAMILY	HABITAT		
		FORESTS	HEATH/ SHRUBLANDS	WATER
Acacia dentifera Benth.	MIMOS			
Acacia divergens Benth.	MIMOS		X	
Acacia drummondii Lindl. ssp. candolleana	MIMOS	X		
Acacia extensa Lindl.	MIMOS	X	X	
Acacia pulchella R. Br.	MIMOS	X		
Acacia saligna Wendl.	MIMOS			
Acacia urophylla Benth. ex Wendl.	MIMOS	X		
Acacia willdenowiana Wendl.	MIMOS	X		
Actinostrobus pyramidalis Miq.	CUPRE		X	
Adenanthos barbigerus Lindl.	PROTE	X		
Adenanthos obovatus Labill.	PROTE		X	
Agonis flexuosa (Spreng.) Schauer	MYRTA	X		
Agonis linearifolia Schauer	MYTRA		X	
Albizia lophantha (Willd.) Benth.	MIMOS		X	
Allocasuarina fraserana (Miq.)	CASUA	X		
Andersonia aristata Lindl.	EPACR		X	
Andersonia involucrata Sond	EPACR		X	
Anigozanthos flavidus Redoute & DC.	HAEMO		X	
Anigozanthos manglesii D. Don	HAEMO	X		
Anigozanthos? viridis Endl.	HAEMO			
Astartea fascicularis (Labill.) DC.	MYRTA		X	
Astroloma humifusum (Cav.) R. Br.	EPACR			
Banksia attenuata R. Br.	PROTE			
Banksia grandis Willd.	PROTE	X		
Banksia littoralis R. Br.	PROTE		X	
Baumea? acuta (Labill.) Palla	CYPER			X
Baumea vaginalis (Benth.) S.T. Blake	CYPER			X
Boronia dichotoma Lindl.	RUTAC		X	
Boronia spathulata Lindl.	RUTAC	X		
Boronia sp.	RUTAC		X	
Borya scirpoidea Lindl.	LILIA		X	
Bossiaea aquifolium Benth.	PAPIL	X		
Bossiaea eriocarpa Benth.	PAPIL	X		
Bossiaea linifolia R. Br.	PAPIL	X		
Bossiaea ornata (Lindl.) Benth.	PAPIL	X		
Caladenia longiclavata E. Colem.	ORCHI	X		
Caladenia uliginosa A.S. George	ORCHI		X	
Calothamnus lateralis Lindl.	MYRTA		X	
Calytrix flavescens A. Cunn.	MYRTA	X	X	
Cassytha glabella R.Br.	LAURA			
Caustis dioica R. Br.	CYPER			
*Centaurium erythraea Rafn.	GENTI			
Centella asiatica (L.) Urban	APIAC			X
Chorizema ilicifolium Labill.	PAPIL	X		
Chorizema rhombeum R.Br.	PAPIL			

TABLE 2 CTD

SCIENTIFIC NAME	FAMILY	HABITAT		
		FORESTS	HEATH/ SHRUBLANDS	WATER
Clematis pubescens Hueg. ex Endl.	RANUN	X		
Compeserma virgatum Labill.	POLYG		X	
Conostylis aculeata R. Br. ssp. aculeata	HAEMO	X		
Conostylis setosa Lindl.	HAEMO	X		
Conostylis serrulata R. Br.	HAEMO			
Cyathochaeta avenacea Benth.	CYPER			
Dampiera linearis R. Br.	GOODE			
Dasypogon bromeliifolius R. Br.	LILIA			
Daviesia hakeoides Meisn.	PAPIL			
Daviesia juncea Sm.	PAPIL			
Daviesia pectinata Lindl.	PAPIL			
Daviesia polyphylla Benth.	PAPIL			
Dianella revoluta R. Br.	LILIA			
Diplolaena microcephala Bartl.	RUTAC			
Diuris longifolia R. Br.	ORCHI			
Drosera spp.	DROSE			
Dryandra nivea (Labill.) R. Br.	PROTE	X		
Eucalyptus calophylla Lindl.	MYRTA	X		
Eucalyptus decipiens Endl.	MYRTA			
Eucalyptus marginata Donn ex Sm.	MYRTA	X		
Eucalyptus megacarpa F. Muell.	MYRTA	X		
Eucalyptus patens Benth.	MYRTA	X		
Eucalyptus rudis Endl.	MYRTA	X		
Eucalyptus wandoo Blakely	MYRTA	X		
Eutaxia virgata Benth.	PAPIL		X	
Gahnia decomposita Benth.	CYPER		X	
Gahnia trifida Lindl.	CYPER		X	
*Gladiolus angustus L.	IRIDA			
Gompholobium capitatum A. Cunn.	PAPIL		X	
Gompholobium knightianum Lindl.	PAPIL			
Gompholobium preissii Meisn.	PAPIL			
Gonocarpus hexandrus (F. Muell.) Orchard	HALOR			X
*Gratiola peruviana L.	SCROP			X
Grevillea drummondii Meissn.	PROTE	X		
Grevillea paniculata Meisn.	PROTE			
Grevillea sp.	PROTE			
Grevillea wilsonii A. Cunn.	PROTE	X		
Haemodorum simplex Lindl.	HAEMO		X	
Hakea cyclocarpa Lindl.	PROTE			
Hakea aff. lasiantha R. Br.	PROTE	X		
Hakea lissocarpha R. Br.	PROTE	X		
Hakea marginata D.C.	PROTE		X	
Hakea prostrata R.Br.	PROTE		X	
Hakea ruscifolia Labill.	PROTE			
Hakea sulcata R. Br.	PROTE		X	
Hakea trifurcata (Sm.) R. Br.	PROTE			
Hakea varia R. Br.	PROTE			

TABLE 2 CTD

SCIENTIFIC NAME	FAMILY	HABITAT		
		FORESTS	HEATH/ SHRUBLANDS	WATER
Helipterum manglesii (Lindl.) Benth.	ASTER	X		
Hemigenia pritzelii S. Moore	LAMIA			
Hibbertia amplexicaulis steud.	DILLE	X		
Hibbertia hypericoides (DC.) Benth.	DILLE	X		
Hibbertia montana Steud.	DILLE	X		
Hibbertia polystachya Benth.	DILLE			
Hibbertia racemosa (Endl.) Gilg	DILLE			
Hibbertia stellaris Endl.	DILLE		X	
Hibbertia subvaginata (Steud.) F. Muell.	DILLE	X		
Hybanthus debilissimus F. Muell.	VIOLA	X		
Hypocalymma angustifolium Endl.	MYRTA		X	
Hypocalymma cordifolium (Lehm.) Schauer	MYRTA		X	
Isopogon dubius (R.Br.) Druce	PROTE			
*Ixia maculata L.	IRIDA			
Jacksonia capitata Benth.	PAPIL		X	
Kingia australis R. Br.	LILIA			
Kunzea recurva Schauer	MYRTA		X	
Labichea punctata Benth.	CAESA		X	
Lasiopetalum floribundum Benth.	STERC			
Laxmannia minor R. Br.	LILIA		X	
Lechenaultia biloba Lindl.	GOODE	X		
Lepidosperma angustatum R. Br.	CYPER			
Lepidosperma longitudinale Labill.	CYPER		X	
Lepidosperma tenue Benth.	CYPER			
Leptocarpus scariosus R. Br.	RESTI			
Leptocarpus tenax (Labill.) R.Br.	RESTI			
Leptomeria cunninghamii Miq.	SANTA			
Leptospermum erubescens Schauer	MYRTA		X	
Leucopogon capitellatus DC.	EPACR	X		
Leucopogon strictus Benth.	EPACR			
Leucopogon verticillatus R. Br.	EPACR	X		
Lobelia alata Labill.	LOBEL			X
Lomandra glauca (R. Br.) Ewart	LILIA	X		
Lomandra sonderi (F. Muell.) Ewart	LILIA	X		
Lomandra sp.nov.	LILIA	X		
Loxocarya fasciculata (R. Br.) Benth.	RESTI	X		
Melaleuca lateritia A. Dietr.	MYRTA		X	
Melaleuca leptoclada Benth.	MYRTA		X	
Melaleuca polygaloides Schauer	MYRTA		X	
Melaleuca preissiana Schauer	MYRTA			
Melaleuca rhaphiophylla Schauer	MYRTA		X	
Melaleuca spathulata Schauer	MYRTA		X	
Melaleuca viminea Lindl.	MYRTA		X	
Mesomelaena tetragona (R.Br.) Benth.	CYPER	X		

TABLE 2 CTD

SCIENTIFIC NAME	FAMILY	HABITAT		
		FORESTS	HEATH/ SHRUBLANDS	WATER
Microtis atrata Lindl.	ORCHI		X	
Microtis orbicularis Roger	ORCHI		X	
Mirbelia dilata R. Br.	PAPIL	X		
Nuytsia floribunda (Labill.) R. Br. ex Fenzl	LORAN		X	
Opercularia echinocephala Benth.	RUBIA			
Opercularia hispidula Endl.	RUBIA			
Oxylobium reticulatum Meisn.	PAPIL		X	
Oxylobium linearifolium D. Don	PAPIL		X	
Patersonia occidentalis R. Br.	IRIDA			
Persoonia longifolia R. Br.	PROTE	X		
Pericalymma ellipticum (Endl.) Schauer	MYRTA		X	
Petrophile linearis R. Br.	PROTE			
Petrophile seminuda Lindl.	PROTE		X	
Phlebocarya ciliata R. Br.	LILIA			
Phyllanthus calycinus Labill.	EUPHO	X		
Pimelea imbricata R. Br.	THYME		X	
Polypompholyx multifida (R.Br.) F. Muell.	LENTI		X	
Poranthera huegelii Klotsch	EUPHO			
Prasophyllum macrostachyum R. Br.	ORCHI		X	
Pteridium esculentum (Forst. f.) Nakai	DENNS	X		
Pterostylis nana R. Br.	ORCHI			
Scaevola striata R. Br.	GOODE	X		
Scaevola sp. ASW 13623	GOODE		X	
Senecio leucoglossus F. Muell.	ASTER	X		
Sollya heterophylla Lindl.	PITTO			
Stackhousia huegelii Engl.	STACK		X	
Stirlingia latifolia (R.Br.) Steud.	PROTE	X		
Stylidium spp.	STYLI			
Styphelia tenuiflora Lindl.	EPACR	X		
Tetraria octandra (Nees) Kuecken.	CYPER			
Tetratheca sp.	TREMA			
Thomasia grandiflora Lindl.	STERC			
Thomasia pauciflora Lindl.	STERC			
Thysanotus dichotomus (Labill.) R. Br.	LILIA			
Tribonanthes violacea Endl.	HAEMO		X	
Triglochin procera R. Br.	JUNCA			X
*Tritonia sp.	IRIDA			
Utricularia hookeri Lehm.	LENTI		X	
Velleia trinervis Labill.	GOODE		X	
Verticordia acerosa Lindl.	MYRTA		X	
Verticordia plumosa Desf.	MYRTA		X	
Villarsia albiflora F. Muell.	MENYA			X
Villarsia parnassifolia R. Br.	MENYA		X	
Villarsia sp.	MENYA		X	
Viminaria juncea (Schrad. & Wendl.) Hoffm.	PAPIL			
Xanthorrhoea gracilis Endl.	LILIA	X		
Xanthorrhoea preissii Endl.	LILIA	X		
Xanthosia huegelii (Benth.) Steud.	APIAC	X		
Xanthosia sp.	APIAC	X		
Xylomelum occidentale R. Br.	PROTE			

* Established alien species

3.2 AQUATIC AND SEMI-AQUATIC FLORA

The aquatic and semi-aquatic species of vascular plants recorded in the catchment during the survey are indicated in Table 2 in the "Water" habitat column. The term "water plants" refers to both algae and vascular plants, and to submerged, floating and emergent life forms.

Like the river itself, the submerged and floating plants it supports are ephemeral or seasonal. They disappear during summer and autumn except as seeds, or dormant buried structures. Only one species of submerged or floating aquatic plant, water ribbon (Triglochin procera; in Plate 3, Appendix D), was identified in the catchment during the survey, but pond weed (Potamogeton tricarinatus) has been recorded in the region.

Emergent plants are those that are rooted beneath the water and with plant parts emerging above the water's surface. Several species are emergents when the river is full but are rooting in river bed mud as the river flow diminishes. The five commonest species of this type in the Harris River below MacDougal Road (Figure 2) are Gonocarpus hexandrus, Lobelia alata, Centella asiatica, Myriophyllum aquaticum and Baumea vaginalis. All are more or less rhizomatous. The first four species are weak-stemmed, spreading and loosely decumbent. The fifth, Baumea vaginalis, occurs in erect clumps. The villarsias and most of the species in the teatree alliance above MacDougal Road could also be considered emergent semi-aquatics.

Aquatic and semi-aquatic plant communities are illustrated in Plates 1, 2, and 3, Appendix D.

3.3 RARE OR GEOGRAPHICALLY RESTRICTED SPECIES

At least seven sets of lists and descriptions of rare and endangered vascular plant species occurring in the Northern Jarrah Forest (and elsewhere) have been produced in the last ten years (Specht et al. 1974; Hartley and Leigh, 1979; Marchant and Keighery, 1979; Rye and Hopper, 1981; Leigh et al. 1981; Patrick and Hopper, 1982; Leigh et al. 1984). The first of these, published in 1974, is based upon botanists' personal knowledge and herbarium surveys for particular groups. The others are based, either directly or indirectly, upon comprehensive herbarium surveys, often augmented by detailed field surveys for selected species.

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* Lists of protected rare species are printed in the Western Australian Government Gazette from time to time. The most recent such list was printed in 1983.

detailed field surveys for selected species.

All of these lists suffer from a common, unavoidable deficiency, namely that the intensity and uniformity of herbarium collections is insufficient to distinguish between genuinely rare (and restricted) species and species that appear to be rare (or restricted) because they have been poorly collected. Furthermore, lists are incomplete in that they do not contain undescribed species, some of which are rare. Other sources of ambiguity are inaccurate determinations of herbarium specimens and the treatment of groups of species as single species. For example, one of the Harris River swamp species, Borya scirpoidea, has been identified in the past as Borya nitida, a species of south coast granite outcrops, and is not listed in the 1981 herbarium census (Green, 1981).

The most recent, though unpublished, detailed herbarium survey of jarrah forest species that might be rare or geographically restricted includes 11 which might possibly occur in the Harris River catchment. These are:

Acacia flagelliformis
Acacia semitrullata
Adenanthos teges
Grevillea drummondii
Grevillea ripicola
Hemigenia microphylla
Pultenaea skinneri
Senecio leucoglossus
Stylidium rhipidium
Synaphaea pinnata
Tetratheca pilifera

Two species, Senecio leucoglossus and Grevillea drummondii, were found in eucalypt forest in the reservoir site, and a third, Pultenaea skinneri, was previously found a few kilometres west of the catchment. Both the Grevillea and the Pultenaea are on the most recent list of declared (gazetted) rare flora (1983). The Pultenaea is described by Leigh et al. (1984).

Some other species that occur in the catchment, such as swamp cypress (Actinostrobus pyramidalis), woody pear (Xylomelum occidentale) and limestone marlock (Eucalyptus decipiens), are uncommon, rare or restricted in the Darling Plateau jarrah forest but are reasonably well-represented elsewhere.

4.0 CONSERVATION RESERVES

One large conservation reserve, the southern section of CALM's Lane - Poole reserve, occupies approximately one-third of the Harris River catchment. The Lane - Poole Reserve is a recreation and conservation reserve comprising major portions of pre-existing MPA's and sections of state forest linking them. Most of the Lane - Poole Reserve lies within a potential regional park outlined by the Environmental Protection Authority (1983). With the exception of Samson MPA, boundaries of the potential regional park closely correspond to those of the proposed Jarrah Reserve (Conservation Council of Western Australia, 1980).

The boundaries of that part of the Lane - Poole Reserve occupying the Harris River catchment are shown in Figure 3, along with the boundaries of the three pre-existing MPA's of which it is composed. The boundaries of these latter three MPA's-Surface, Nalyerin and Trees - and of their core areas are taken from the System 6 Study Report (Department of Conservation and Environment, 1981). The northwestern part of Surface MPA which was deleted as a conservation management priority area when the Lane - Poole Reserve was created is indicated in Figure 3. The areas of the three MPA's in the catchment prior to amalgamation are shown in Table 3. The figures given are for the total areas of the MPA's, not just the sections contained within the catchment.

TABLE 3

TOTAL AREAS OF MPA'S

AREA	SURFACE	NALYERIN	TREES
CORE	5480 ha		
BUFFER	9645 ha		
TOTAL	15125 ha	10400 ha	7800 ha

Source: CALM, Harvey.

Three-quarters of the Lane - Poole Reserve is devoted to the conservation of flora, fauna and landscape, primarily in the former Surface, Nalyerin and Trees MPA's, now part of Lane - Poole Reserve. This contiguous trio of MPA's, with their well-developed open forest, including the largest remaining stand of uncut jarrah north of the Blackwood River, and a variety of remarkable seasonal lake and swamp vegetation units, is one of the largest and most important conservation reserves in State forest, and the most important parts of the reserve complex are the Surface and Nalyerin MPA core areas, major portions of which are situated in the Harris River catchment.

Although there is no area of overlap between the reservoir site and any part of Surface MPA, or of any other reserve, elements of the heterogeneous swamp vegetation preserved in Surface MPA extend westward to below the full supply level of the reservoir. Furthermore, while there can be no direct impact of the reservoir upon the conservation reserve, there is a possibility that the full reservoir would influence the water table level in the Trees Plain area of the MPA. If subsurface water in the MPA is continuous with the water in the reservoir a high reservoir level could prevent or inhibit seepage flows through the swamp. This could keep the height of the water table beneath the swampy plains in the MPA higher in late spring and early summer than it would normally be, and the vegetation in that area could be altered.

5.0 MODIFYING AGENTS

The vegetation and flora of any area are dynamic, not static, but since European settlement the vegetation and its flora in all parts of Australia are being altered fundamentally and at an unprecedented rate (Adamson and Fox, 1982). The Northern Jarrah Forest is no exception.

The nature of the pre-Aboriginal vegetation of the Darling Range can now only be conjectured but, thanks to early botanical collections and journal entries, it is still possible to draw a much clearer picture of the vegetation at the time of European settlement. While the magnitude and rate of changes in the vegetation and flora of the continent as a whole since settlement have been cataclysmic for more than a century, major irreversible alterations in the Darling Plateau's central and western areas have begun relatively recently. The alterations are due to a series of interacting modifying agents introduced by Europeans that include and are related to timber-felling, removing timber, cropping, construction of roads, powerlines and dams, travelling across the plateau on foot and by vehicle, reducing the risk of uncontrollable wild fires, bringing in exotic plants, animals and diseases, and mining. Four sets of past and probable modifications and agents of botanical change are mapped and discussed in this section.

5.1 BURNING

Although major changes in plant adaptations and the vegetation have developed in response to the Aboriginal use of fire almost throughout Australia, the application of this tool for vegetational control was not uniform, even in the Darling Range. It is likely that the interior of the jarrah forest south of the Murray River was not burnt frequently or extensively (Hallam, 1975, pp. 26-27), though probably fierce, summer wildfires occasionally raged through it.

Since 1962, the year after Dwellingup was devastated by wildfire, a CALM policy of rotational prescribed fuel-reduction burning has been implemented for almost all of the jarrah forest (Underwood and Christensen, 1981).

CALM burns to reduce the risk of uncontrollable wildfires in State forest. Generally these prescribed burns are carried out in spring and autumn during cool, dry weather and when wind speeds are low. In order to restrict the buildup of fuel under the vegetation, attempts are made to burn areas of forest every four to eight years. Figure 4 shows the boundaries of burn areas in the Harris River catchment, years when they were last burnt and, in most cases, the years of planned future burns. One area shown in the figure is being exempted from the sequence of cool season, prescribed, fuel-reduction, control burns. This is a conservation MPA section that borders Lake Nalyerin and is being used for fauna research. The map in Figure 4 is based upon unpublished CALM maps and verbal communications.

The effects of the frequent, cool season burning practised in the Harris River catchment are undoubtedly different from the effects of pre-settlement forest burning. For example, regeneration of proteaceous plants and sedges and other geophytes and chamaephytes is favoured by low intensity, cool season burns, while regeneration of leguminous plants from seed is favoured by high intensity, mid-summer burns (see Underwood and Christensen, 1981). Frequent fires appear to promote the spread of various species of introduced weeds in the Perth metropolitan area (Bridgewater and Zammit, 1979) and probably also in the catchment.

Much of the contemporary jarrah forest also differs from its 19th century antecedents in having an abundance of logging debris on the forest floor. This debris would have some effect on the duration, local intensity and aftermath of any fire, but the effects on low and high intensity burns would differ markedly.

5.2 LOGGING

Although timber-felling in the Northern Jarrah Forest began soon after settlement in 1829, it was many years before timber in the Harris River area began to be logged, and it was many years after that that systematic recording of areas logged was initiated.

The map of State forest logging history in the Harris River catchment is based upon unpublished CALM logging history maps that are being continually up-dated to show the type, purpose, time and extent of logging (Figure 5). The CALM logging history maps show the major portion of the Harris River catchment as having been logged sometime before 1976. Cutting was probably selective and appears to have included an area in the northwest corner of the catchment shown on CALM's Tallanalla map as virgin jarrah forest.

Other areas are shown as unlogged or with no recorded history of logging. The core area of Surface MPA (Figure 3) is for the most part an area of unlogged jarrah forest. Most of the other areas in the category have been logged in the past, probably before the inception of relevant systematic record-keeping (there are apparently no records of it in CALM files).

All of the State forest area east of the Tallanalla - Collie Road has been classified as dieback (Phytophthora cinnamomi) Disease Risk Area or Quarantine area since 1976. Consequently, access to the area is restricted and logging within it has been deferred until the distribution of dieback is mapped and effective measures to contain the spread of dieback are developed.

5.3 DIEBACK

The Northern Jarrah Forest is being radically altered by jarrah dieback, an exotic plant disease caused by the fungus Phytophthora cinnamomi. This is a soil-borne pathogen that can be carried long distances on the mudguards, wheels and tracks of vehicles and probably on the feet of large birds and hoofed animals. Once introduced to a site, it spreads slowly through the soil and among root systems of susceptible species. It may also be washed downslope during storms. In southwestern Australia the disease is most devastating to plants on poorly drained sites in the high rainfall areas of the jarrah forest and in vegetation dominated by proteaceous species. The biology of dieback disease in jarrah forest is described in greater detail by McKinnell (1981).

By 1982 more than 223,000 hectares of State forest were diseased and an additional 119,000 hectares were considered to be unprotectable from the fungus by virtue of being downslope from existing infections. CALM is currently engaged in programmes of surveying and mapping the incidence and spread of dieback in State forests. The Department is also studying the behaviour of the disease and potential methods for controlling its spread.

Research carried out during the last decade indicates that fire intensity may have direct effects on dieback spread (Underwood and Christensen, 1981). Low intensity fires promote regeneration of species of Proteaceae which are particularly sensitive to attack by the fungus, while high intensity fires favour leguminous plants which tend to be resistant or even, in a few cases, antagonistic to the pathogen.

The incidence of jarrah dieback in the Harris River catchment is shown in Figure 6 which is taken from unpublished maps provided by CALM. Figure 6 is taken from recently produced 1:25,000 scale maps based upon CALM field surveys and interpretation during 1979-1981 of 1:4,500 scale 70mm colour aerial photographs. These maps cover only the part of the catchment mapped for dieback in Figure 6. Dieback infection for the remainder of the catchment is mapped as an overlay which was taken from 1:50,000 scale maps prepared by the CALM from less sophisticated sources in 1976.

Assessment of dieback presence and risk potential in State forest is a difficult process that requires specialised training and experience possessed by few outside CALM. Consequently, CALM assessments are accepted here. No attempt has been made to assess dieback infestation or risk potential, but deaths of banksias along the Harris River probably caused by the dieback fungus were noted.

5.4 MINING

Surface mining, next to the creation of reservoirs, has the most drastic effect on the Darling Plateau vegetation of any human activity. Both activities totally destroy all vegetation. Although there is relatively little removal of soil or physical alteration of the soil profile in reservoirs, flooding destroys the pre-existing vegetation and prevents recolonisation for at least the life of the reservoir. Surface mining involves the removal of the substrate, as well as of all plants, until mining is completed. Subsequently soil profiles may be restructured and the surface recontoured.

The entire Harris River catchment shown in Figures 1 through 6 is within Alcoa's bauxite mining lease, and Harris River catchment bauxite deposits are included in Alcoa's area of highest interest for mining (Dames & Moore, 1978, Figure 1). It is anticipated that these deposits will eventually be mined and revegetated according to techniques being used further north in the Darling Range, or similar ones. The sequence of bauxite mining techniques currently in use starts with the removal of topsoil and its transfer to another site that is being rehabilitated. Then the overburden is removed and stockpiled and the bauxite stripped and transported to the refinery. Rehabilitation begins with replacing the overburden and contouring it to merge with the surrounding surfaces. A layer of topsoil recently removed from another site is then spread uniformly across the contoured surface before revegetation begins. Basically,

revegetation depends upon regeneration from seed and other perennating plant structures present in the topsoil, upon broadcasted seed and upon planted seedlings. Although attempts are often made to establish species that are native locally, the floristic richness and diversity of the new vegetation is reduced and its nature altered compared to the vegetation that precedes the mining.

6.0 REFERENCES

Adamson, D.M. and Fox, M.D. (1982). Change in Australasian vegetation since European settement. In Smith (ed.). 1982.

Beard, J.S. (1981). Swan, The Vegetation of the Swan Area. Sheet 7, 1:1,000,000 Vegetation Series and Explanatory Notes. Univ. of West Austr. Press, Nedlands. 221pp.

Bridgewater, P.B. and Zammit, C.A. (1979). Phytosociology of southwest Australian limestone heaths. Phytocoenologia 6:327-343.

Conservation Council of Western Australia (1980). Jarrah Reserve, a Proposal for Major Reserve in the Jarrah Forest of Western Australia C.C. of W.A., Perth. 71pp.

Dames & Moore (1978). Wagerup Alumina Project. Environmental Review and Management Programme. Alcoa Australia, Perth. 486 pp.

----------(1981). Worsley Alumina Project: Flora and Fauna Studies, Phase One. Worsley Alumina Pty Ltd., Perth. 251 pp.

Department of Conservation and Environment (1981). The Darling System, Western Australia - Proposals for Parks and Reserves. The System 6 Study Report D.C.E. Report No. 8. Perth.

----------(1980). Atlas of Natural Resources Darling System Western Australia. Dept. Cons. & Env. 86pp. and maps.

Environmental Protection Authority (1983). The Darling System - System 6. Part I: General Principles and Recommendations. D.C.E. Report No 13. Perth.

Green, J.W. (1981). Census of Vascular Plants of Western Australia. Western Australian Herbarium, Perth. 115 pp.

Hallam, S.J. (1975). Fire and Hearth. Australian Institute of Aboriginal Studies, Canberra. 150 pp.

Hartley, W. and Leigh, J.H. (1979). Plants at Risk in Australia. Australian National Parks and Wildlife Service Occ. Paper No.3.

Heddle, E.M., Havel, J.J. and Loneragan, O.W. (1980a). Focus on Northern Jarrah Forest conservation and recreation areas. Forest Focus 22: 3-27.

Heddle, E.M., Loneragan, O.W. and Havel, J.J. (1980b). Vegetation complexes of the Darling System, Western Australia. In Department of Conservation and Environment (1980). Text and 1:250,000 scale map.

Havel, J.J. (1975). Site-vegetation Mapping in the Northern Jarrah Forest (Darling Range) II. Location and Mapping of Site-vegetation Types. Forests Department Western Australia Bull. No. 87.

Leigh, J., Briggs, J. and Hartley, W. (1981). Rare or Threatened Australian Plants. Australian National Parks and Wildlife Service Spec. Publ. No.7.

Leigh J., Boden, R. and Briggs, J. (1984). Extinct and Endangered Plants of Australia. Macmillan, South Melbourne. 369pp.

Marchant, N.G. and Keighery, G.J. (1979). Poorly Collected and Presumably Rare Vascular Plants in Western Australia. Kings Park Res. Notes No. 5.

McKinnell, F.H. (1981). Review of the Dieback Disease Situation 1981. Forests Department of Western Australia Tech. Paper No.2.

Patrick, S.J. and Hopper, S.D. (1982). A Guide to the Gazetted Rare Flora of Western Australia: Supplement 1. Department of Fisheries and Wildlife Rep. No. 54. Perth.

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

Smith, F.G. (1974). Vegetation Map of Collie. Western Australian Department of Agriculture, Perth. 40pp. and 1:250,000 scale map.

Smith, J.M.B. (ed.) (1982). A History of Australian Vegetation. McGraw-Hill, Sydney. 168 pp.

Specht, R.L., Roe, E.M. and Boughton, V.H. (eds.) (1974). Conservation of Major Plant Communities in Australia and Papua New Guinea. Australian Journal of Botany Supplementary Series, Suppl. No. 7.

Underwood, R.J. and Christensen, P.E.S. (1981). Forest Fire Management in Western Australia. Forests Department of Western Australia Special Focus No. 1.

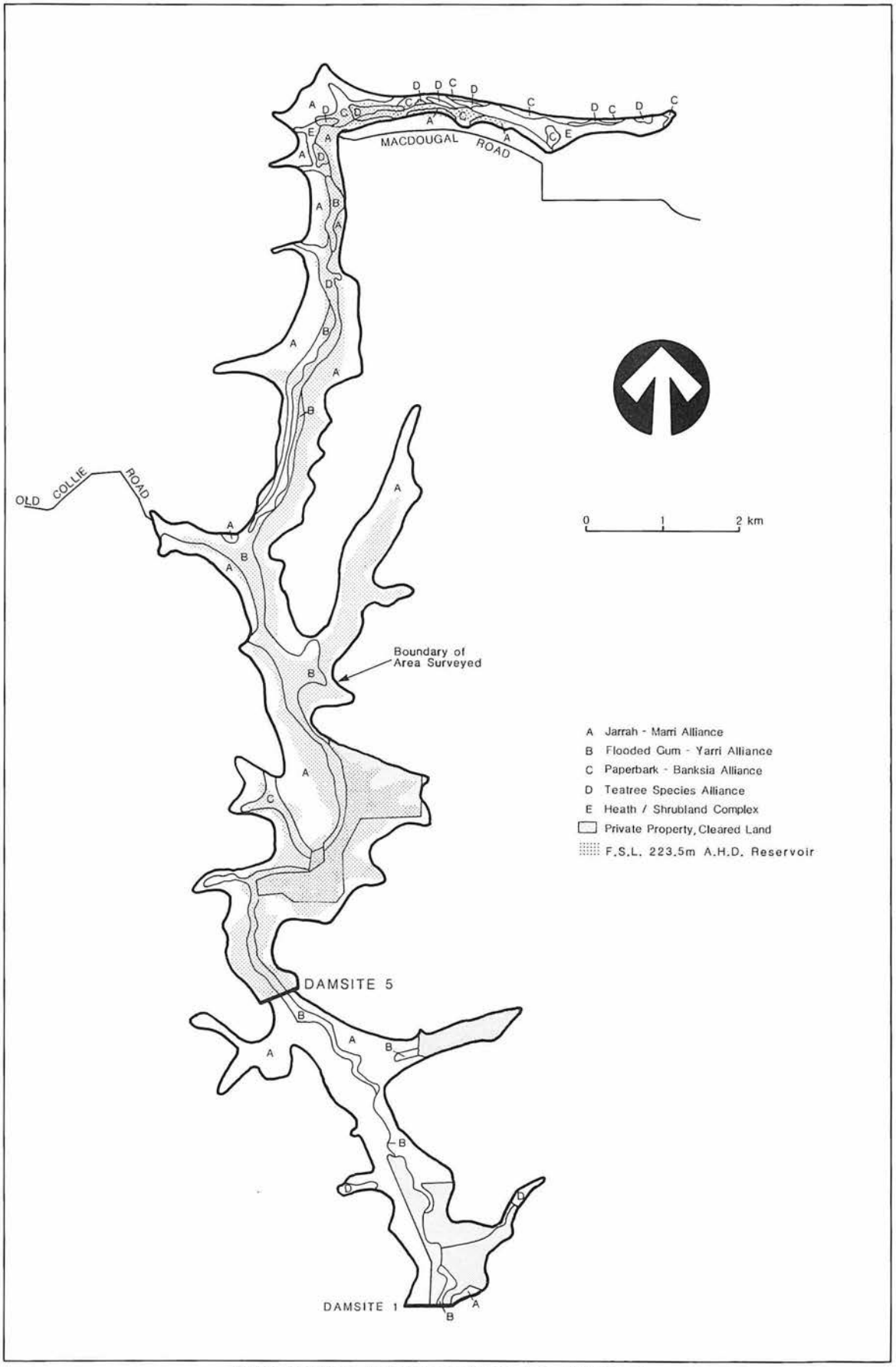
Worsley Alumina Pty Ltd (1985). Worsley Alumina Project. Flora and Fauna Studies, Phase two, pp.348. Worsley Alumina Pty Ltd, Perth

FIGURES

VEGETATION COMPLEXES

SOURCE: Heddle et al., 1980 and Forests Department of W.A.

Figure 1
Dames & Moore



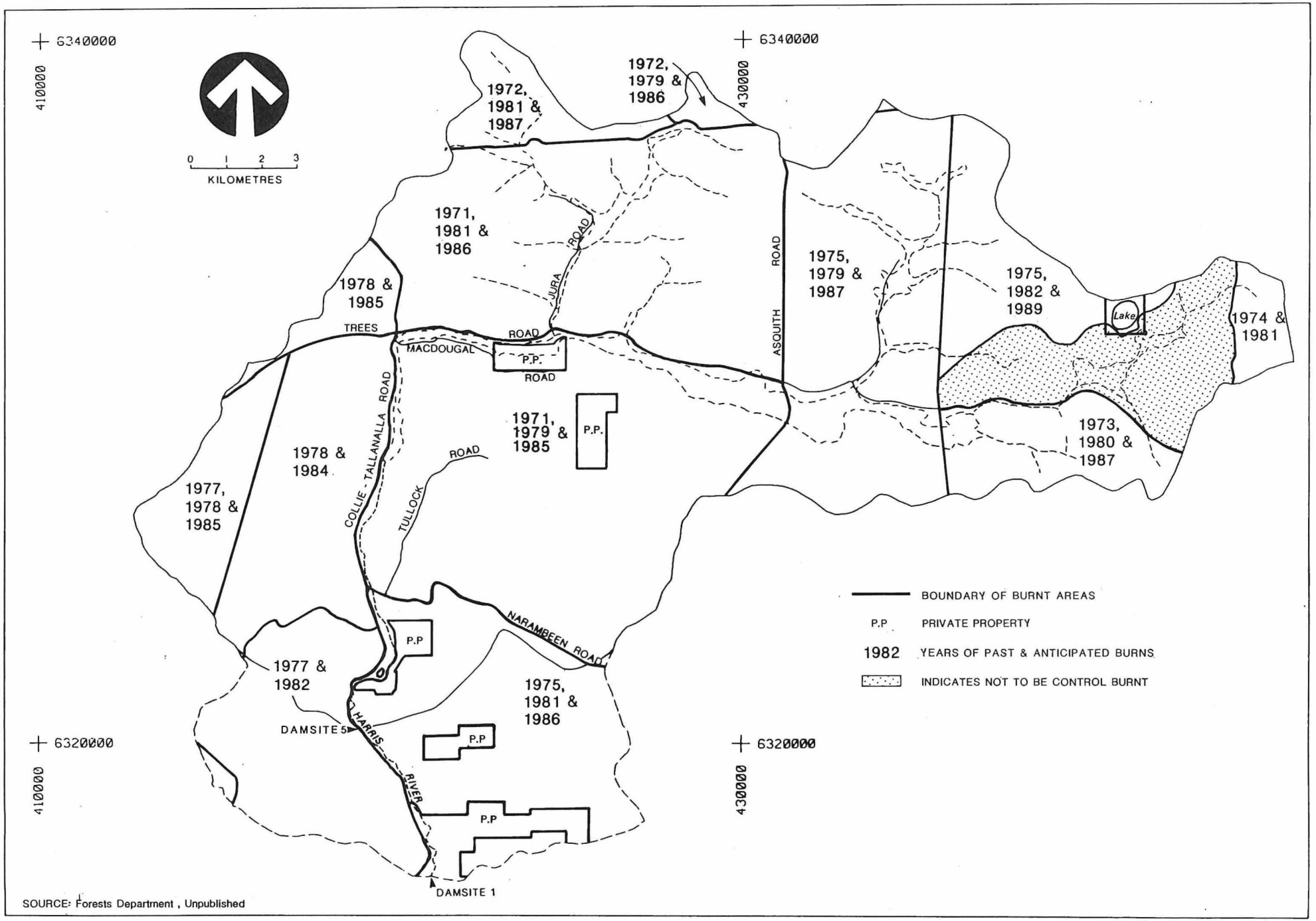
RESERVOIR VEGETATION ALLIANCES

Figure 2
Dames & Moore

LANE-POOLE RESERVE AND PREVIOUS CONSERVATION MANAGEMENT PRIORITY AREAS IN THE CATCHMENT AREA

Figure 3
Dames & Moore

BURN HISTORY IN CATCHMENT



SOURCE: Forests Department , Unpublished

Figure 4
Dames & Moore

SOURCE : Forests Department, Unpublished

STATE FOREST CUTTING HISTORY IN CATCHMENT

Figure 5
Dames & Moore

SOURCE: Forests Department, Unpublished

AREAS OF DIEBACK

Figure 6
Dames & Moore

PLATE

PLATE - CAPTIONS - VEGETATION AND FLORA

1. Aerial view of Harris River vegetation looking southwest across Asquith Road. Trees Plain Swamp Complex vegetation (Complex 12) in centre and arms, and, principally, jarrah-marri forest (Complex 8 and Complex 13) around it.

2. Jarrah open forest with a prominent understorey of Xanthorrhoea preissii.

3. Zonation of vegetation around Lake Nalyerin.

4. Mixed proteaceous - myrtaceous heath in the Trees Plain Swamp Complex (Complex 12) and paperbark (Melaleuca preissiana) low open woodland (Complex 8).

5. Calytrix flavescens, Labichea punctata and other heath shrubs in flower on Trees Plain.

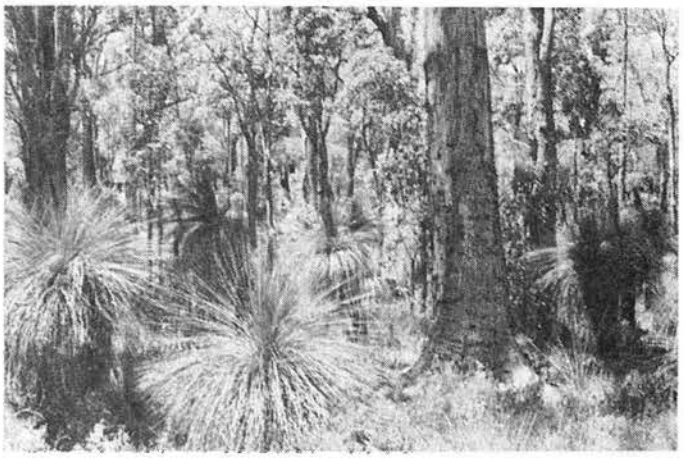
6. Dense Melaleuca spp. shrubland on Trees Plain. The emergent mallee-like eucalypt is a flooded gum (Eucalyptus rudis).

7. Pale pink Polypompholyx multifida and violet Utricularia hookeri, locally common in the Harris River Swamp Complex.

8. Grevillea drummondii, a gazetted rare species, growing near the Harris River near the Old Collie Road.



1.



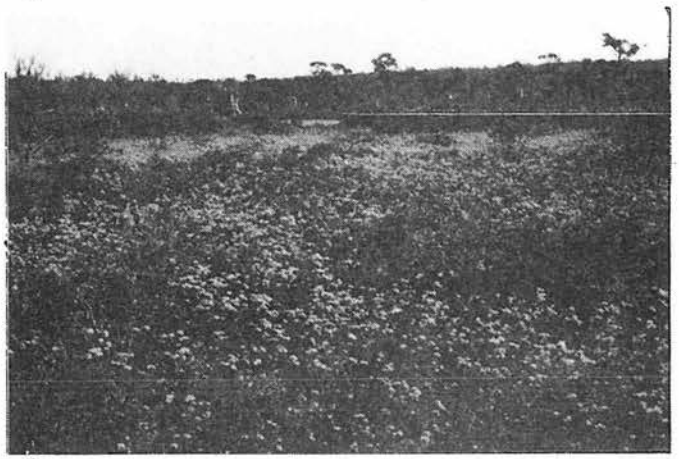
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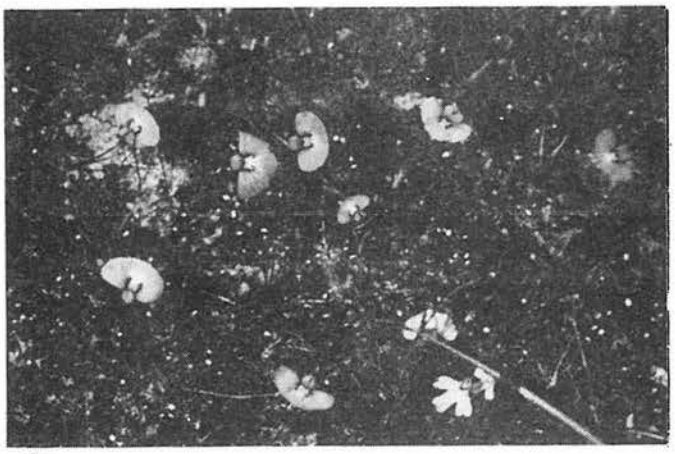
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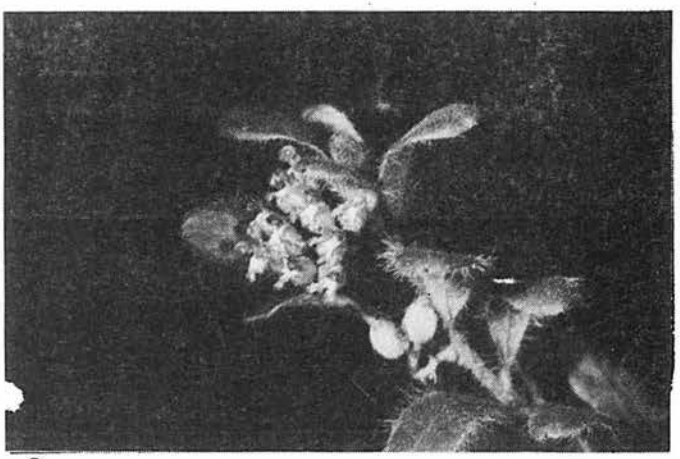
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6.



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Plate
Dames & Moore

APPENDIX C

REPORT ON THE TERRESTRIAL FAUNA OF THE HARRIS DAM RESERVOIR AREA

Prepared by
G. Harold
Consulting to Dames & Moore

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SUMMARY

The Harris River lies in the Darling Range and flows in a southerly direction until it becomes the Collie River East Branch immediately north of Collie in the southwest of Western Australia. The survey area comprises the middle reaches of the Harris River.

Habitats occurring at the site consist of Jarrah-Marri woodlands with a variety of understories and dense riverine thickets. These habitats are typical of the extensive southwest forest belt.

A moderately diverse fauna was found in the survey area comprising 9 mammals (including 3 feral species), 46 birds, 18 reptiles and 8 frogs. In view of the habitats present it is considered that another 22 species of mammals (including 8 bats) possibly also occur in the study area. All species listed in Addenda I-IV have substantial distributions; some are restricted to the southwest, but the geographic range of most extend into north and/or eastern Australia. No extensions of known range were established and all species recorded have been previously recorded in the southwest. No unique faunas or relic populations of very rare species were detected.

One species found in the study area and listed for protection under the Western Australian Wildlife and Conservation Act (1950) was a bird, the Red-eared Firetail. This species occurs in coastal and gully habitats, and is distributed from Perth in the north to beyond Esperance in the east. The construction of the dam is not expected to have an affect on this bird species.

The main effect of the dam will be the destruction of the valley habitats which are, however, well represented elsewhere in the southwest.

1.0 INTRODUCTION

1.1 AIMS OF THE SURVEY

The aims of the survey were to:

- o Assemble an inventory of the terrestrial vertebrates present
- o Obtain information on their abundance and habitat preferences.

These aims were expected to reveal the presence or absence of species regarded as rare and endangered, and to identify special habitats important for the regional survival of species.

As it was not possible to survey the whole area that would be affected by the dam, study areas were selected as representative samples of the local range of habitats (Figure 1). The likely effects of the dam upon the local wildlife were also assessed.

1.2 SURVEY OF THE HARRIS RIVER AREA

The fauna survey was carried out in two parts (14th - 21st October and 17th - 23rd December 1983) as wet weather prevented access into the quarantine areas east of Tallanalla Road during October.

2.0 HABITATS

2.1 INTRODUCTION

A total of nine areas were designated for sampling during the survey (Figure 1). Areas 1-5 were sampled in October and Areas 6-9 during the December survey.

The following descriptions of the study areas have been derived from the vegetation complexes described in Appendix B of the volume of appendices.

2.2 STUDY AREA DESCRIPTIONS

Area 1 (Plate 1.1) 'Riverine flat', Jarrah - Marri - Yarri - Flooded Gum open forest.

Eucalyptus marginata, E. calophylla to about 20m in height, less than 30% canopy cover over Xanthorrhoea preissii to 2m in height, less than 20% canopy cover, over sparse sedges with sparse litter on pale brown sandy loam.

Area 2 (Plate 1.2) 'Lateritic hillslope', Jarrah - Marri open forest.

Eucalyptus marginata, E. calophylla to about 20m, less than 30% canopy cover, over Banksia grandis to about 5m, less than 30% canopy cover, over sparse Xanthorrhoea preissii, Macrozamia reidlei and regenerating B. grandis with deep litter on gravelly brown loam.

Area 3 (Plate 1.3) 'Valley hillslope', Jarrah - Marri open forest.

Eucalyptus marginata, E. calophylla to about 20m, less than 50% canopy over regenerating E. marginata, E. calophylla, and Macrozamia reidlei, Bossiaea aquifolium, Xanthorrhoea gracilis and Pteridium esculentum with sparse litter on brown sandy loam.

Area 4 'Alluvial flat', Jarrah - Marri - Yarri open forest.

Eucalyptus marginata, E. calophylla and E. patens to about 25m, less than 20% canopy cover over Xanthorrhoea preissii to 1.5m, less than 10% canopy cover over sedges and low shrubs with sparse litter on brown sandy loam.

Area 5 (Plate 1.4) 'Creek habitat', Jarrah - Marri - Yarri open forest/shrubland.

Eucalyptus marginata, E. calophylla and E. patens to about 25m, less than 10% canopy cover over Leptospermum erubescens, Agonis linearifolia, Acacia extensa, Mesomelaena tetragona, Mirbelia dilatata to 3m, less than 50% canopy cover over sedges with moderate litter on pale brown loam.

Area 6 (Plate 1.5) 'Gentle valley slope', Jarrah - Marri open forest.

Eucalyptus marginata, E. calophylla to about 20m, less than 20% canopy cover over Xanthorrhoea preissii, Hakea aff. lasiantha to 2m, less than 10% canopy cover over sparse low shrubs to about 0.5m in height with moderate litter on pale brown loam.

Area 7 'Gentle valley slope', Jarrah - Marri open forest.

Eucalyptus marginata, E. calophylla to about 25m, less than 20% canopy cover over Hakea aff. lasiantha and Xanthorrhoea preissii to 3m, less than 30% canopy cover over low sparse shrubs with sparse litter on gravelly brown loam.

Area 8 'Gentle valley slope', Jarrah - Marri open forest.

Eucalyptus marginata, E. calophylla to about 20m, less than 20% canopy cover over Xantherrhoea preissii and regenerating eucalypts, Dryandra sp. and small shrubs to 2m, less than 30% canopy cover with moderate litter on hard gravelly brown loam.

Area 9 (Plate 1.6) 'Permanant waterhole', Flooded Gum fringing forest.

Eucalyptus rudis to about 10m, less than 10% canopy cover over Acacia divergens and Leptospermum erubescens to 2m, less than 30% canopy cover over sedges to 0.5m in height, less than 60% canopy cover with moderate litter on grey brown loam.

3.0 METHODS

3.1 DATA COLLECTION TECHNIQUES

The following field techniques were employed for the collection of data.

3.1.1 Observation

During traverses by vehicle and on foot sightings of vertebrates and signs of their activity were recorded for each of the vegetation associations selected for sampling.

3.1.2 Headtorching

During nocturnal searches, the presence of animals was revealed by the reflection of a light in their eyes. The animals were inspected more closely and identified and recorded, or collected by hand or by using other methods.

3.1.3 Litter Search

A three pronged fork was used to rake over and dig through litter to expose cryptic animals sheltering in the litter, or in burrows hidden underneath the litter.

3.1.4 Stalking and Stunning

Fast running lizards were stunned by 'shooting' with a heavy elastic band. These were then picked up by hand, identified, and collected or released.

3.1.5 Mist Netting

A five tier nylon net with a 3cm mesh was set to catch bats during the night.

3.1.6 Trapping

A plastic cone 45cm in depth and with a 20cm base diameter, was inverted in the ground to form a pit trap and set at a spacing of 5m beneath a drift fence of flywire which was 25cm high. The pits were set in pit lines of ten beneath a 50m long fence.

A series of ten Elliott traps located 5m apart were set in conjunction with each of the pit lines. A cage trap was located at each end of the Elliott trap lines with the exception of lines at Areas 5 and 9.

3.2 IDENTIFICATIONS

The field identification of all retained specimens was checked by the Western Australian Museum. Birds were identified due to previous experience with most species in the southwest. The identification of birds which proved difficult to identify was confirmed by reference to Pizzey (1980).

3.3 EFFORT AND APPLICATION

A total of fifteen man-days was spent collecting field data between 14-21st October and 17-23rd December 1983. Observational traverses of all major habitat types were made by day and at night. Observational effort was concentrated at water bodies, especially at 22 Mile Pool at MacDougal Road bridge (Figure 1), where some birds and large mammals congregate to drink.

Careful observation during the day provided almost all of the data on birds and large mammals, and capture methods used for small nocturnal mammals, as well as for most reptiles and frogs. Many of the smaller animals are difficult to identify, because they tend to be cryptic and/or nocturnal, and in many cases the retention of specimens is necessary to ensure correct identifications.

Spotlighting was undertaken during vehicle traverses and headtorching was carried out through all major habitat types on five evenings for each of the techniques. A mist net was set up at October camp for three evenings and two mist nets set up over water at MacDougal Road bridge for three evenings in December (Figure 1).

Pit fences and combination Elliott and cage traplines were set for six nights in Areas 1-4 and 6-8 and combination Elliott/cage lines were set for five nights at Areas 5 and 9. A further five Elliott traps were set for three days in a successful attempt to catch a skink, Egernia luctuosa, which had been sighted under MacDougal Road bridge.

The total number of trapnights was 1059 and the breakdown is shown in Table 1.

TABLE 1

TRAPLINES SET AT EACH AREA

Area	Pits	Nights	Elliotts	Nights	Cages	Nights	Trap Nights
1	10	6	10	6	2	6	132
2	10	6	10	6	2	6	132
3	10	6	10	6	2	6	132
4	10	6	10	6	2	6	132
5	-	-	10	5	2	5	60
6	10	6	10	6	2	6	132
7	10	6	10	6	2	6	132
8	10	6	10	6	2	6	132
9	-	-	10	5	2	5	60
MacDougal Bridge			5	3			15
				TOTAL TRAP NIGHTS			1059

4.0 RESULTS

All specimens retained during the surveys were lodged with the Western Australian Museum.

4.1 MAMMALS

4.1.1 Nomenclature

Scientific names and order follows Strahan ed (1983).

4.1.2 Species Recorded

Six native mammal species were recorded. They consisted of the Echidna (a monotreme), one carnivorous marsupial, two kangaroos, a bat and a rat. Three introduced species, the Fox, Rabbit, and Feral Pig were also recorded. Details of the records are presented in Addendum I.

4.1.3 Comments

The full documentation of the status and abundance of the mammalian fauna of any area is a long term project. Although the relative abundance of macropods and the larger feral mammals can be ascertained by a short field study, this is not the case with the smaller marsupials and bats. A large number of trap nights in different seasons are required and the low results of a mammal trapping programme can not be interpreted as a true reflection of their abundance. Accordingly a short annotated list has been drawn up reviewing the distribution and/or abundance of species that may occur at the site but have not yet been recorded.

Some of these species here have been recorded at Lake Nalyerin (CALM; unpublished data) and in the Worsley Refinery Lease Area (Worsley Alumina Pty Ltd., unpublished data) to the east and west of the survey area respectively. It is probable that species recorded at each or both of these areas are also present in the survey area.

o DASYURIDAE

Western Quoll Dasyurus geoffroii

Described by Christensen and Kimber (1977) as being widely distributed, but nowhere very common. In view of this, it has recently been placed on the Rare and Endangered List. Recorded from the Worsley Refinery Lease area.

Brush-tailed Phascogale Phascogale tapoatafa

Ranges widely in the southwest of Western Australia. Also occurs in the southeastern, eastern, and northern coastal and adjacent regions of Australia. Recorded from the Worsley Refinery Lease area.

Yellow-footed Antechinus Antechinus flavipes

In the southwest of Western Australia this species occurs in a wide variety of habitats from Karri forest, Jarrah forest to coastal heath. Also recorded from large areas of New South Wales, Victoria and Queensland.

Fat-tailed Dunnart Sminthopsis crassicaudata

Occurs over vast areas of southern Australia, almost coast to coast but not usually in forested areas.

o MYRMECOBIIDAE

Numbat Myrmecobius fasciatus

Formerly ranging widely through southern Australia. 'Today the main populations of Numbats seem to be confined to the Wandoo bearing country of the south-west of Western Australia' (Ride, 1970) though CALM at Manjimup have found populations in Jarrah woodland in the Perup area.

o PARAMELIDAE

Southern Brown Bandicoot Isoodon obesulus

Widely distributed in the southwest of Western Australia in dense understorey, especially in swampy areas. Also occurs in southeast New South Wales and Victoria. Fresh diggings attributed to this species have been found in the Worsley Refinery Lease area and probably also occurs in the survey area. Dell (1971) has indicated the need for litter for nest construction by this species.

o PHALANGERIDAE

Common Ringtail Possum Pseudocheirus peregrinus

In Western Australia this species inhabits dense vegetation in sclerophyll forest or woodland, expecially peppermint, Agonis spp. (Ride, 1970). Although it has been found as close as 24km to the east of Collie, it is considered unlikely to occur in the study area because of the absence of its preferred habitat.

Common Brushtail Possum Trichosurus vulpecula

Widely distributed in eastern and central Australia as well as in the southwest of Western Australia. Almost certainly present in the survey area, although population levels are probably low.

Western Pygmy Possum Cercartetus concinnus

Widespread in the southwest of Western Australia and also southern South Australia. Its presence at Lake Nalyerin and at the Worsley Refinery Lease area indicates that it probably also occurs in the survey area.

o TARSIPEDIDAE

Honey Possum Tarsipes rostratus

Ranges widely in the southwest of Western Australia from Shark Bay in the north to Israelite Bay in the east. Although possibly occurring in the survey area its preferred habitat, heath, is absent.

o MACROPODIDAE

Tammar Wallaby Macropus eugenii

With the closest known W.A. Museum specimen approximatley 50km to the east northeast of the study area, this species, if present, would be at the southwestern limit of its natural distribution.

Western Brush Wallaby Macropus irma

Almost certainly occurs in the survey area. Recorded from Lake Nalyerin and the Worsley Refinery Lease area.

o POTOROIDAE

Brush-tailed Bettong Bettongia penicillata

The last remaining populations in Western Australia are in the Perup and Dryandra forests and the Tuttanning Reserve (Christensen, 1983)

Burrowing Bettong Bettongia lesueur

Presumed extinct on mainland (Burbidge, 1983) where it has not been collected for over 80 years.

The bat species recorded in Table 2 are expected to occur within the study area and most have been collected at Lake Nalyerin or in the Worsley Refinery Lease area.

TABLE 2

BAT SPECIES EXPECTED TO OCCUR IN STUDY AREA

SPECIES	LOCATION	
Tadarida australis - White Striped Mastiff Bat	W	LN
Mormopterus planiceps - Little Mastiff Bat		LN
Nyctophilus timoriensis - Greater Long-eared Bat	W	
N. gouldii - Gould's Long-eared Bat		LN
N. geoffroyi - Lesser Long-eared Bat	W	
Chalinolobus gouldii - Gould's Wattled Bat		LN
C. morio - Chocolate Wattled Bat		LN
Pipistrellus tasmaniensis - Great Pipistrelle		LN

W = Worsley Refinery Lease Area

LN = Lake Nalyerin

(Sources : Worsley Alumina Pty Ltd., Unpubl. Data; CALM, Unpubl. Data)

All of the species recorded in Table 2 are distributed widely in Australia including Gould's Long-eared Bat (Nyctophilus gouldii) which is the only species so far not recorded from either of the above localities.

The Quokka (Setonix brachyurus) is nowdays considered to be moderately common in the moister parts of the southwest where it inhabits densely vegetated swamps (Kitchener, 1983). This species also occurs on Rottnest and Bald Islands. The record of this mammal in the survey area is of interest although more intensive surveys would be necessary to establish its status.

The Common Dunnart (Sminthopsis murina) recorded from the survey area was a female with 7 pouch young. This species is currently under taxonomic investigation by Dr. D. Kitchener of the W.A. Museum.

4.2 BIRDS

4.2.1 Nomenclature

Scientific and common names for all birds has been based on the system used by Pizzey (1980).

4.2.2 Species Recorded

A total of 46 species of native birds was recorded during the surveys. The species compromised 19 species of non-passerines which represented 13 families and 27 species of passerines representing 14 families. A full systematic list of the species, with detailed notes on the habitats and number of observations, is given in Addendum II.

4.2.3 Comments

The Harris River survey area has a mean average rainfall of 1000mm and lies towards the wetter limits of the southwest division of Western Australia. The results of the surveys need to be considered in that context.

All of the species found in the survey have been previously recorded from the southwest (Pizzey, 1980; Serventy and Whittell, 1976), and none are restricted to the Jarrah - Marri forest block.

With the exception of seven species, all are widely distributed across Australia. The exceptions are: the White-tailed Black Cockatoo (Calyptorynchus baudinii); Red-capped Parrot (Purpureicephalus spurius); Western Rosella (Platycercus icterotis); Western Spinebill (Acanthorynchus superciliosus); Red-winged Wren (Malurus elegans); White-breasted Robin (Eopsaltria georgiana); and the Red-eared Firetail (Emblema oculata). The latter three species have southwest forest and coastal distributions and the remainder have more extensive distributions over southern Western Australia. Of these species only the Red-eared Firetail is on the Rare and Endangered List (Section 5.0.)

Habitats within the study area consist of lowland Jarrah-Marri woodland and dense riverine shrubland (Appendix B). Although pools were present along the Harris River, they were narrow and densely vegetated and ephemeral (except for 22 Mile Pool) and they do not provide adequate long term habitat for waterbirds.

Because of the absence of a wide diversity of habitats, especially the absence of Wandoo woodland (which has a rich avifauna), the total number of the bird species recorded is low, although it is considered that most residents and the more common nomadic and migrant bird species have been recorded.

This low total number of species is typical of a Jarrah forest bird assemblage and compares favourably with birds recorded from similar habitats such as the Worsley Refinery Lease area where 50 species were recorded (Worsley Alumina Pty. Ltd., unpublished data). The bird assemblages from the Worsley Refinery Lease area and the survey area have an absence of open country species such as the Magpie (Cracticus tibicen), Magpie Lark (Grallina cyanoleuca), and Richards Pipit (Anthus novaeseelandiae), a typical feature of continuous, dense forest.

No breeding activity was observed, due to the lateness of the survey, although some young of the Scarlet Robin (Petroica multicolor), were seen on a number of occasions.

4.3 REPTILES

4.3.1 Nomenclature

Australian reptiles are not as well known as the mammals or birds. Their taxonomy is incomplete and less stable with a large number of species still being described. For these reasons, published checklists quickly become out of date. To overcome this

problem, the basis for scientific names for reptiles used in this report is the unpublished checklist prepared by the Western Australian Museum (Storr, 1983 unpublished). Most species do not have common names, but common names have been given to the families (Addendum III).

4.3.2 Species Recorded

The survey recorded a total of 18 species of reptiles, which consisted of 15 lizards representing 3 families and 3 snakes from 1 family. A full systematic list of the species, with notes on observations and the species habitats, and an assessment of abundance, is given in Addendum III.

4.3.3 Comments

Distributional data in Storr, et al. (1981), Storr (1979) and Cogger (1979) indicate that all the reptiles recorded during the survey are widely distributed in the southwest division of Western Australia, and that only two, the skink Egernia luctuosa and the gecko Diplodactylus polyophthalmus, are restricted to that division.

One reptile recorded was the infrequently collected skink Egernia luctuosa. This species prefers densely vegetated drainage lines and swamps, and extensive collecting in this habitat throughout the southwest may reveal that the species is more common than current records indicate.

The 18 species of reptiles recorded during the surveys represent half of the predicted total for the area. Records in the Western Australian Museum show that an additional 16 species have been collected from similar habitats in the southwest. These additional species include:

The turtle-	Chelodina oblonga
The gecko-	Phyllurus milii
The legless lizards-	Aprasia pulchellus
	A. repens
	Lialis burtonis
The skinks -	Ctenotus delli
	Egernia kingii
	E. pulchra
	Leiolopisma trilineatum
	Sphenomorphus australis

The snakes - Ramphotyphlops australis
R. pinguis
Python spilotes imbricatus
Notechus curtus
Rhinoplocephalus gouldii
R. nigriceps

Thus nine lizard and six snake species are listed as not recorded though probably occurring in the study area. In order to rectify this situation, greater time needs to be expended in summer and especially winter when many snake and lizard species are more easily collected from their habitat; under logs, stones, in rotten stumps and abandoned ant nests and other litter. During the survey period, most night time temperatures were low, which would have restricted the activity of nocturnal species.

4.4 FROGS

4.4.1 Nomenclature

Scientific names of species used here follow Storr (unpublished). Common names are only given for families in Addendum IV.

4.4.2 Species Recorded

The survey recorded eight species of frogs representing two families. A full systematic list of the species, with notes on observations, habitats, and an assessment of their abundance, is given in Addendum IV.

4.4.3 Comments

All eight species recorded are widespread in the southwest of Western Australia (Cogger, 1979) and they are within their previously recorded geographic range limits.

The diversity and abundance of species of the large burrowing frogs (Heleioporous) was low. These frogs spend much of the year underground and only occasionally come to the surface at night to feed.

As most frogs are more active when breeding commences at the onset of the first winter rains, further collecting at this time would probably reveal more species. With the type of habitats occurring in the study area, one species, Heleioporous psammophilus, is almost certainly present. Two other species, Ranidella pseudinsignifera and Pseudophryne guentheri, may also be present despite the site being located at the southwestern limits of their known geographic range.

5.0 DISCUSSION

5.1 ASSESSMENT OF THE SURVEY

A high proportion of vertebrates which could be expected to occur in the survey area have been recorded by these surveys. Those recorded so far fall into one of the following categories: larger animals occurring in low densities, such as wallabies, native cats and other marsupials and snakes, for which the probability of observation increases with the time spent searching; those species whose activity (for example, ground frogs), or location (for example, migrant birds) is affected by season.

5.2 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 (1950) 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 Hamersly River near Hopetown. Also Lucky Bay, Mississippi and Duke of Orleans Bays east of Esperance. Common to uncommon, sedentary and often very local'.

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. An increase in native sedges (Lepidosperma spp.) around the margins of the dam will provide increased food sources for the Red-eared Firetail. This bird utilises a range of seeds of native plants as a food source.

6.0 CONCLUSIONS

6.1 ZOOLOGICAL SIGNIFICANCE OF THE SURVEY AREA

The survey area forms a small portion of the extensive Jarrah - Marri forest block which stretches from New Norcia in the north to Mt Barker in the southeast and the habitats recorded in the Harris River area were typical of this forest belt. A diverse vertebrate fauna was found in the survey area with all of the component species having substantial geographic ranges. While a few are restricted to the southwest of Western Australia, many extend into northern and/or eastern Australia. No extensions of known range were established and all species recorded were already known to occur in the Jarrah - Marri belt.

6.2 EFFECTS OF THE DAM

The most significant effect upon the local wildlife by the formation of the dam will be the drowning of the valley habitats. Animals will be drowned or displaced by the advancing water which will lead to competition with neighbouring populations and eventually may result in a death rate similar to that of the number of animals displaced.

The creation of a large body of water will create an environmental niche for many waterfowl such as the Black Swan (Cygnus atratus), Black Duck (Anas superciliosus), Coot (Fulica atra), and the Musk Duck (Biziura lobata). Other open country bird species such as the Willie Wagtail (Rhipidura leucophrys), Tree Martin (Cecropis nigricans), and Welcome Swallow (Hirundo neoxena), will benefit from the increased supply of insects and more open waterside vegetation. Populations of some native fish will also rise making the dam attractive to Herons (Ardeidae) and Cormorants (Phalacrocoracidae). Cormorants will especially benefit if dead trees are left standing in the water (as at Mundaring Reservoir) as these provide vantage points for fishing and perching. If the water level remains constant, dense vegetation such as reeds and sedges will inevitably grow creating a niche for the Clamourous Reed Warbler (Acrocephalus stentoreus), and Little Grassbird (Megalurus gramineus) as well as providing food resources for the Red-eared Firetail (Emblema oculata).

The long term effect of the dam will be to destroy some wildlife habitats though this will not present a threat to any of the animals detected, as species, all of which have already been recorded elsewhere in the southwest of Western Australia.

7.0 BIBLIOGRAPHY

Burbidge, A.A. (1983). Burrowing Bettong. In Strahan, R. (ed). Complete Book of Australian Mammals. Sydney: Angus and Robertson. 187-189 pp.

Christensen, P. (1983). Brush-tailed Bettong. In Strahan, R. (ed). Complete Book of Australian Mammals. Sydney: Angus and Robertson. 184-185 pp.

Christensen, P.E.S and Kimber, P.C. (1977). Mammals of Western Australian Forests. Forests Dept. Information Sheet, No 5.

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

Dell, J.D. (1971). Notes on the Quenda, Isoodon obesulus. West. Aust. Nat. 11:191.

Ford, J.R. (1983). Morphological and ecological divergence and convergence in isolated populations of the Red-tailed Black Cockatoo. Emu. 80:103-120.

Kitchener, D. (1983). Quokka In Strahan, R. (ed). Complete Book of Australian Mammals. Sydney: Angus and Robertson. 259-260pp.

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

Ride, W.D.L. (1970). A Guide to the Native Mammals of Australia. Melbourne: Oxford University Press.

Serventy, D.L. and Whittell, H.M. (1976). Birds of Western Australia. Perth: University of Western Australia Press. 4th ed.

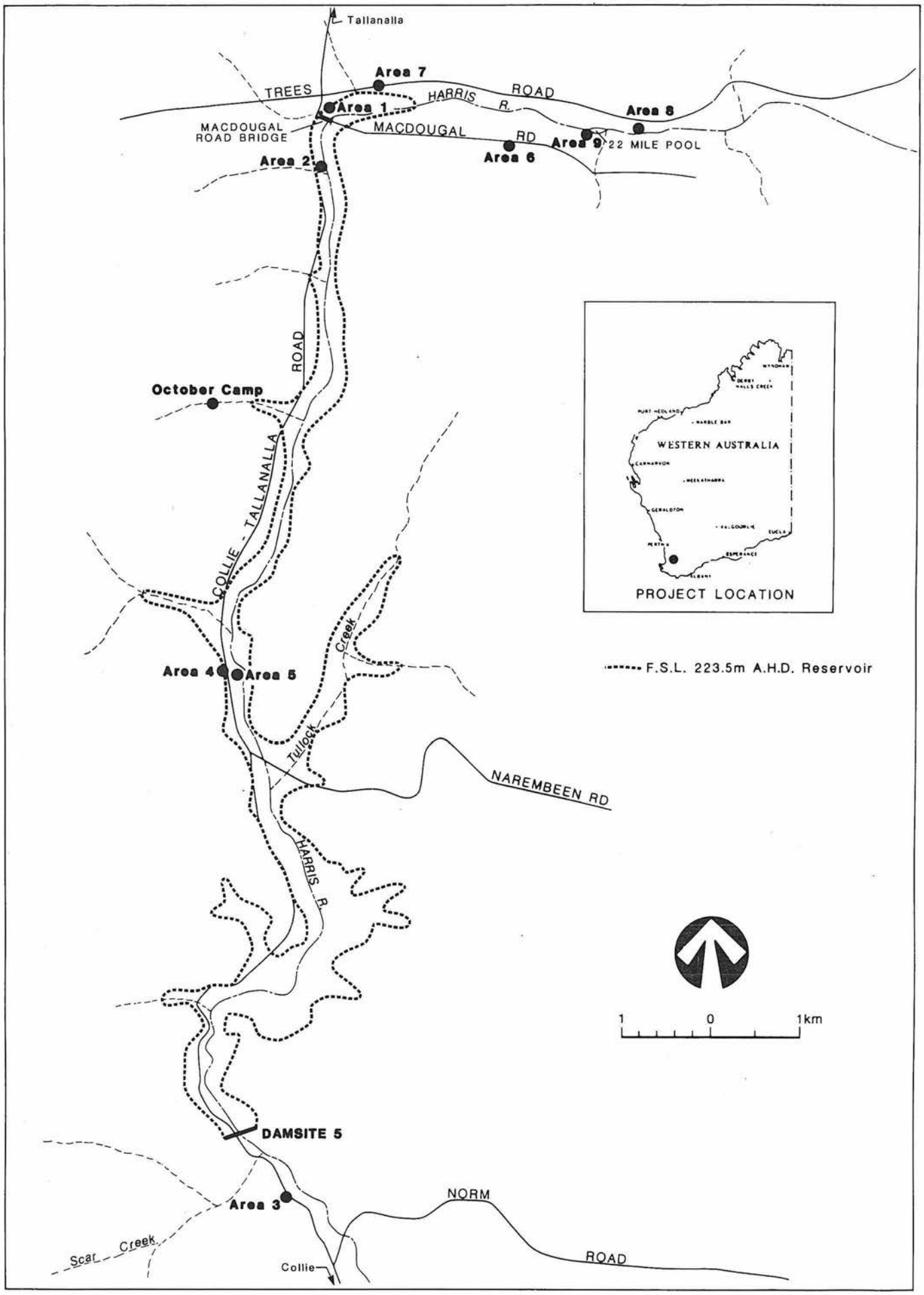
Storr, G.M. (1979). The Diplodactylus vittatus complex (Lacertilia, Gekkonidae) in Western Australia. Rec. West. Aust. Mus. 7:391-402.

Storr, G.M. (1983). Checklist of the Amphibians and Reptiles of Western Australia. (Unpbl. Memeo).

Storr, G.M., Smith, L.A., and Johnstone, R.E. (1981). Lizards of Western Australia Pt. 1 Skinks. Perth: University of Western Australia Press.

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

FIGURE



FAUNA STUDY AREAS

Figure 1
Dames & Moore

CAPTIONS - PLATE 1- STUDY SITES

1. Area 1 Riverine flat with Jarrah-Marri-Yarri-Flooded Gum open forest over Blackboys on pale brown sand loam.

2. Area 2 Lateritic hillslope with Jarrah-Marri open forest over Banksia on gravelly brown loam.

3. Area 3 Valley hillslope with Jarrah-Marri open forest with regeneration after fire.

4. Area 5 Creek habitat with Jarrah-Marri-Yarri open forest over shrubland.

5. Area 6 Gentle valley slope with Jarrah-Marri open forest over Blackboys and shrubs on pale brown loam.

6. Area 9 Permanant waterhole with Flooded Gum fringing forest.



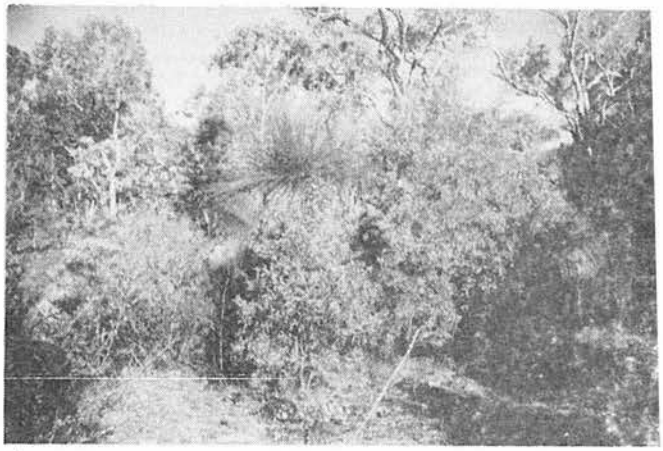
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Plate 1

CAPTIONS - PLATE 2 - FAUNA

1. A skink, Egernia luctuosa, found in dense streamside vegetation and restricted to the southwest of W.A.

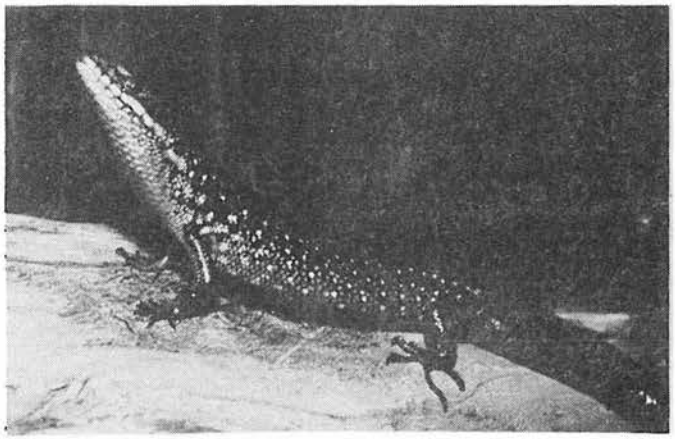
2. The skink, Ctenotus labillardieri, very common and located in most habitat types and restricted to the wetter areas of the southern half of W.A.

3. Varanus rosenbergi, a goanna which is common in woodland areas.

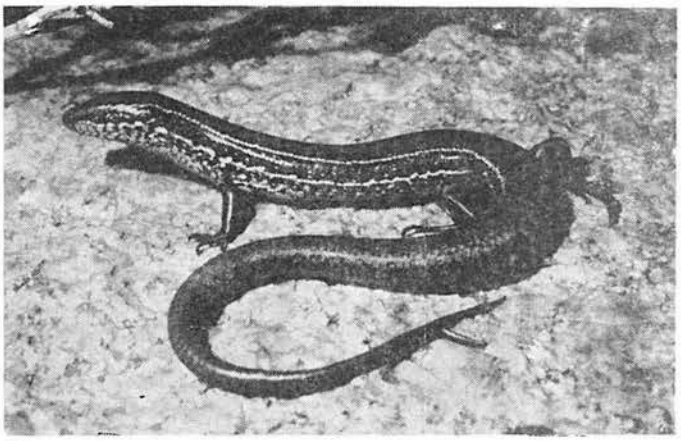
4. Notechis scutatus occidentalis (Western Tiger Snake), a frog eating, front fanged snake and more commonly found in the vicinity of swamps and rivers.

5. Notechis coronatus (Crowned Snake), a front fanged snake relatively uncommon in the area.

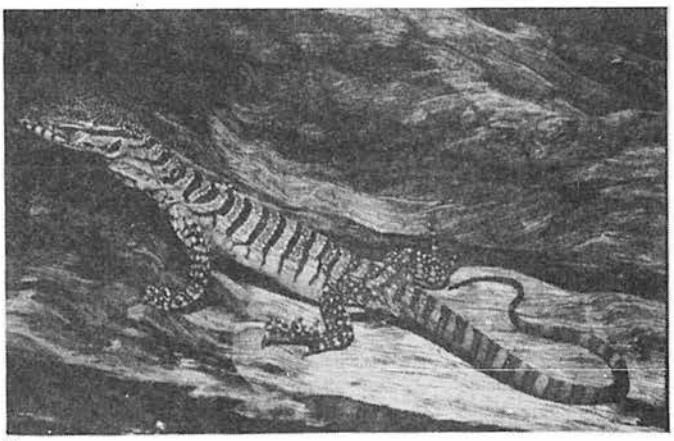
6. The bull frog (Litoria moorei), moderately common in waterside vegetation.



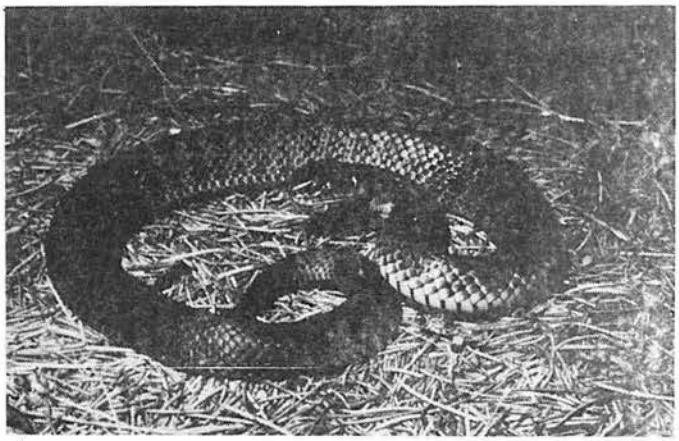
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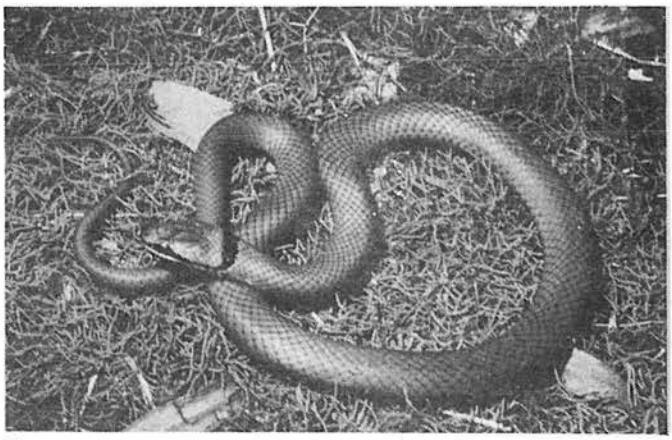
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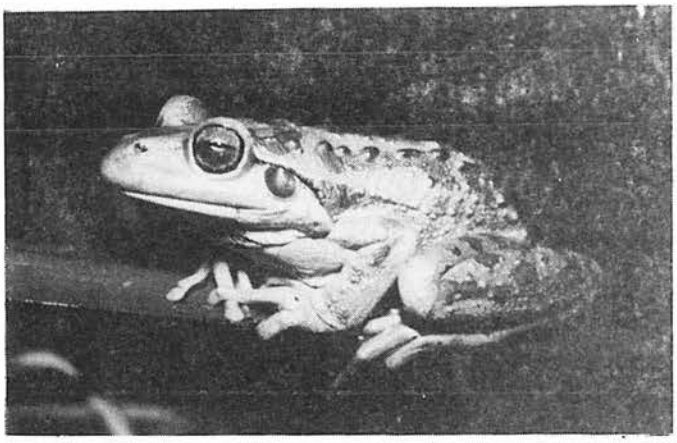
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Plate 2

ADDENDA

ADDENDUM I

SYSTEMATIC LIST OF MAMMALS RECORDED FROM THE HARRIS RIVER SURVEY AREA

Mammals that were collected and retained are lodged in the Western Australian Museum.

MONOTREMATA - MONOTREMES

Tachyglossidae

Tachyglossus aculeatus (Shaw, 1792) - Short beaked Echidna

Diggings observed in side of anthill	MacDougal Road bridge
Diggings observed in side of anthill	Area 4

MARSUPIALIA - MARSUPIALS

Dasyuridae

Sminthopsis murina (Waterhouse, 1838) - Common Marsupial Mouse

A female with seven pouch young in pit trap in Jarrah-Marri woodland	Area 2

Macropodidae

Macropus fuliginosus (Desmarest, 1817) - Grey Kangaroo

Moderately common. Woodland habitats

2	October camp
Fresh scats and 1 animal observed	Area 5
1 observed	3km north of October camp
1 observed	Area 7

Setonix brachyurus (Quoy and Gaimard, 1830) - Quokka

Reported by CALM officers as present in the swamps of the upper Harris River.

CHIROPTERA - BATS

Vespertilionidae

Eptesicus regulus (Thomas, 1906) - King River Eptesicus

One in mist net MacDougal Road bridge

RODENTIA - RODENTS

Muridae

Hydromys chrysogaster Geoffroy, 1804 - Water Rat

One specimen observed at MacDougal Road bridge by CALM officers

CARNIVORA - CARNIVORES

Canidae

Vulpes vulpes Linnaeus - Fox

Fresh tracks observed Area 4

Fresh tracks observed Area 6

ARTIODACTYLA - CLOVEN HOOVED MAMMALS

Suidae

Sus scrofa Linnaeus - Pig

Scats Area 4

A few diggings Area 8

Many diggings Area 9

LAGOMORPHA - RABBITS AND HARES

Leporidae

Oryctolagus cuniculus Linnaeus - Rabbit

Moderately common along flats along Harris River and also at Area 9 (22 Mile Pool)

ADDENDUM II

SYSTEMATIC LIST OF BIRDS RECORDED FROM THE HARRIS RIVER SURVEY AREA

Following each species name are the numbers of sighting and brief notes on habitat

CASUARIIDAE

Dromaius novaehallondiae (Latham) - Emu

Two road kills in woodland along Tallanalla Road. Four along Trees Road east from Asquith Road.

ARDEIDAE

Ardea novaehollandiae Latham - White-necked Heron

Single bird fishing in shallow pool at Asquith Road causeway.

ANATIDAE

Anas superciliosa Gmelin - Black Duck

Single bird feeding at 22 Mile Pool.

PANDIONIDAE

Accipiter fasciatus (Vigors & Horsfield) - Australian Goshawk

Single bird over swamp near 22 Mile Pool.

Aquila morphnoides Gould - Little Eagle

Two observations of single birds over woodland along Tallanalla Road.

COLUMBIDAE

Phaps chalcoptera (Latham) - Common Bronzewing

Seven observations of single birds in woodland along Tallanalla Road and one group of three at dusk at 22 Mile Pool.

CACATUIDAE

Calyptoryhnchus magnificus (Shaw)-Red-tailed Black Cockatoo

Fourteen observations, mainly in groups of up to ten birds plus one group of about twenty, high numbers by forest standards (Ford, 1983).

Calyptorynchus baudinii Lear - White-tailed Black Cockatoo

Ten observations, mainly small groups of up to about ten birds. One flock of about 80 individuals. Some groups feeding on flowering Banksia grandis in Jarrah-Marri woodland.

PLATYCERCIDAE

Purpureicep alus spurius (Kuhl) - Red Capped Parrot

Sixteen observations, mainly single birds, pairs and two groups of five birds. In Jarrah-Marri woodland.

Platycercus icterotis (Kuhl) - Western Rosella

Three observations, one individual and two pairs in woodland along Tallanalla Road.

Barnardius zonarius (Shaw) - Port Lincoln Parrot

Seventeen observations, mainly pairs and flocks of up to ten in woodland.

CUCULIDAE

Cuculus pyrrhophanus Latham - Fan-tailed Cuckoo

Nine recordings of single birds and pairs in woodland during the October survey.

Chrysococcyx lucidus (Gmelin) - Shining Bronze Cuckoo

One observed and two calling in Jarrah-Marri woodland during the October survey.

STRIGIDAE

Ninox novaeseelandiae (Gmelin) - Boobook Owl

Two heard calling from Jarrah-Marri Woodland.

PODARGIDAE

Podargus strigoides (Latham) - Tawny Frogmouth

One heard calling and two observed. All in Jarrah-Marri woodland.

AEGOTHELIDAE

Aegotheles cristatus (White) - Owlet-nightjar

One heard calling from Jarrah-Marri woodland during the December survey.

ALCEDINIDAE

Dacelo gigas (Boddaert) - Laughing Kookaburra

Fifteen observations, mainly small groups of about five birds in Jarrah - Marri woodland.

Halcyon sancta Vigors & Horsfield - Sacred Kingfisher

Fifteen observations of mainly single birds in Jarrah-Marri woodland.

MEROPIDAE

Merops ornatus Latham - Rainbow Bee-eater

Six observations, three groups of five, one pair and one single bird. All hawking for insects along the upper Harris River east of MacDougal Bridge.

HIRUNDINIDAE

Cecropis nigricans Vieillot - Tree Martin

Twenty one observations of one to ten birds. Also three groups of fifteen and one of twenty were observed over Jarrah-Marri woodland.

CAMPEPHAGIDAE

Coracina novaehollandiae (Gmelin) - Black-faced Cuckoo-shrike

Eight observations, all of single birds except for one pair. Jarrah-Marri woodland.

MUSCICAPIDAE

Petroica multicolor (Gmelin) - Scarlet Robin

Four observations of single birds and one pair in Jarrah-Marri woodland.

Eopsaltria georgiana (Quoy & Gaimard) - White-breasted Robin

Seven observations of single birds. All in dense low riverside vegetation.

Pachycephala pectoralis (Gmelin) - Golden Whistler

Twenty observations, nine single birds, six pairs, two groups of three and three groups of about five. Mainly confined to the denser areas of Jarrah-Marri woodland.

Colluricincla harmonica (Latham) - Grey Shrike-thrush
Thirteen observations of one or two birds in the more thickly vegetated areas of Jarrah-Marri woodland.

Rhipidura fuliginosa (Sparrman) - Grey Fantail
Sixteen observations of mainly single birds and pairs. In Jarrah-Marri woodland.

MALURIDAE
Malurus splendens (Quoy & Gaimard) - Splendid Wren
Four observations, three single males and one male and two females. All in dense vegetation adjacent to streams and the Harris River.

Malurus elegans Gould - Red Winged Wren
Five observations of groups of up to five birds in dense streamside vegetation.

ACANTHIZIDAE
Sericornis frontalis (Vigors & Horsfield) - White-browed Scrub Wren
Four observations of one to three birds in dense streamside thickets.

Smicrornis brevirostris (Gould) - Weebill
Two observations of single birds and one pair in Jarrah-Marri woodland, and a single bird in open Marri woodland over tall Melaleuca on a river flat.

Gerygone fusca (Gould) - White-tailed Warbler
Twenty seven observations of one or two birds in Jarrah-Marri woodland.

Acanthiza apicalis Gould - Broad-tailed Thornbill
Nine observations of pairs and single birds in dense streamside thickets.

NEOSITTIDAE
Daphoenositta chrysoptera (Latham) - Varied Sittella
Seven observations of two to five birds, in Jarrah-Marri woodland.

CLIMACTERIDAE

Climacteris rufa Gould - Rufous Tree-creeper

One observation of a single bird in riverside Jarrah-Marri woodland.

MELIPHAGIDAE

Anthochaera chrysoptera (Latham) - Little Wattlebird

Twenty four observations of mainly one to five birds in dense tall riverside and swampy tall thickets and one group of fifteen in riverside Jarrah-Marri woodland.

Melithreptus lunatus (Vieillot) - White-naped Honeyeater

Six observations of single birds and one pair feeding in Jarrah - Marri woodland. All records except for one, from the October survey.

Lichmera indistincta (Vigors & Horsfield) - Brown Honeyeater

Fourteen observations of one to six birds plus one group of about twenty at 22 Mile Pool. Only observed during the December survey.

Phylidonyris novaehollandiae (Latham) - New Holland Honeyeater

Eighteen observations of one to five birds in dense streamside vegetation.

Acanthorhynchus superciliosus Gould - Western Spinebill

Five observations of single birds in Jarrah-Marri woodland.

PARDALOTIDAE

Pardalotus punctatus (Shaw) - Spotted Pardalote

One bird in low eucalypts at 22 Mile Pool.

Pardolotus substriatus (Gemlin) - Striated Pardalote

Thirty-eight observations of mainly single birds and pairs. Also one group of six. Jarrah-Marri woodland.

ZOSTEROPIDAE

Zosterops lateralis (Latham) - Grey-breasted White-eye

Four observations of one to ten birds in dense streamside thickets.

FRINGILLIDAE

Emblema oculata (Quoy & Gaimard) - Red-eared Firetail

One single bird bathing in 22 Mile Pool.

ARTAMIDAE

Artamus cyanopterus (Latham) - Dusky Wood Swallow

Six observations, four single birds, one pair and a group of six. Flying over stream and swamp vegetation.

CRACTICIDAE

Strepera versicolor (Latham) - Grey Currawong

Four observations, two single birds and a pair in dense Jarrah-Marri woodland.

CORVIDAE

Corvus coronoides Vigors & Horsfield - Australian Raven

Seven observations of single birds and pairs. Jarrah-Marri woodland.

ADDENDUM III

SYSTEMATIC LIST OF REPTILES RECORDED FROM THE HARRIS RIVER SURVEY AREA

Reptiles collected and retained as specimens have been lodged in the Western Australian Museum.

Following each species name is a short summary which includes an estimate of local abundance, short notes on habitat preferences, and the location and total number of individuals observed or collected and locations.

LACERTILIA - LIZARDS

GEKKONIDAE - GECKOS

Diplodactylus polyophthalmus Gunther, 1867
Uncommon. Jarrah-Marri woodland.

1 in a pit trap	Area 8

Phyllodactylus marmoratus (Gray, 1845)
Uncommon. Jarrah-Marri woodland.

1 headtorched on a tree	October camp
1 headtorched on ground	Area 6
2 in pit traps	Area 6

SCINCIDAE - SKINKS

Cryptoblepharus plagiocephalus (Cocteau, 1836)
Uncommon. Jarrah-Marri woodland.

1 on log	Area 1
1 in pit trap	Area 6

Ctenotus labillardieri (Dumeril & Bibron, 1839)
Uncommon. Jarrah-Marri woodland and low streamside vegetation.

1 under log	October camp
1 under log	Area 2
1 active in low streamside vegetation	MacDougal Road bridge
1 under log	About 1km east of Area 7

Egernia luctuosa (Peters, 1866)

Uncommon. Dense streamside vegetation

1 in Elliott trap	MacDougal Road bridge

Egernia napoleonis (Gray, 1839)

Very common. All woodland habitats. Usually observed on large dead logs and stumps where they take refuge in deep cracks when disturbed.

4 on logs and stumps	Area 1
4 on logs and stumps	Area 2
5 on logs and stumps	Area 3
1 on log	Area 4
3 on logs and stumps	October camp
3 on logs	About 1km east of October camp
1 on log	1km south of Area 2
1 on stump	Scar Road creek crossing
1 on log	Area 7
1 on log	Area 8
1 on log	MacDougal Road bridge
1 on log	1.5km west of Area 8
1 on log	0.5 km west of Area 6

Hemiergis i. initialis Werner, 1910

Common. Woodland habitats. Under logs.

2 in pit traps	Area 1
3 in pit traps	Area 2
4 under logs	Area 2
1 in pit trap	Area 8
7 under logs	Area 8

Hemiergis peronii (Fitzinger, 1826)

Uncommon. Jarrah-Marri woodland.

1 under log	Area 3

Lerista distinguenda (Werner, 1910)

Common. Jarrah-Marri woodland.

1 in abandoned stick-ants nest	Area 2
1 in abandoned stick-ants nest	Area 3
1 in pit trap	Area 3
2 in pit traps	Area 4
2 in pit traps	Area 6
1 under log	Area 8

Lerista microtis (Gray, 1845)

Uncommon. Jarrah-Marri woodland.

3 in pit traps	Area 3
1 in pit trap	Area 6

Menetia greyii Gray, 1845

Uncommon. Jarrah-Marri woodland.

1 in pit trap	Area 1
2 in pit traps	Area 4
3 active in litter	Area 4
1 active in litter	Area 5

Morethia obscura Storr, 1972

Very common. In litter woodland habitats.

2 in pit traps	Area 1
1 in pit trap	Area 2
5 active in litter	Area 3
11 in pit traps and active	Area 4
3 in pit traps and active	Area 6
3 active in litter	Area 7
4 active in litter	Area 8
4 active in litter	October camp

Tiliqua r. rugosa (Gray, 1827)
Uncommon. Woodland habitats.

1 in pit trap	Area 3
1 active	2km south of October camp turn-off
2 active	1km south of Area 4
1 active	1km south of October camp turn-off
1 active	Damsite

VARANIDAE - GOANNAS

Varanus gouldii (Gray, 1838)
Uncommon. Woodland.

1 dead on road	10km south of Area 1

Varanus rosenbergi Mertens, 1957
Moderately common. Woodland.

1 active	Area 1
1 active	1km south of Area 4
1 active	1km east of Area 6
1 active	7km south of MacDougal Road bridge

SERPENTES - SNAKES

ELAPIDAE - FRONT-FANGED SNAKES

Notechis coronatus (Schlegel, 183)
Uncommon. Melaleuca shrubland over heath.

1 active on road through swamp	Asquith Road causeway

Notechus scutatus occidentalis Glauert, 1948

Uncommon. 1 active	MacDougal Road 5km east from Tallanalla Road

Pseudonaja a. affinis (Gunther, 18 2)
Uncommon. Woodland habitats.

2 active	Area 6

ADDENDUM IV

SYSTEMATIC LIST OF FROGS RECORDED FROM THE HARRIS RIVER SURVEY AREA

Frogs collected and retained for specimens have been lodged in the Western Australian Museum.

Following each species name is a short summary which includes an estimate of local abundance, short notes on habitat preferences, and the location and total numbers of individuals observed, collected or heard calling.

ANURA - FROGS

LEPTODACTYLIDAE - GROUND FROGS

Crinia georgiana Tschudi, 1838

Very common. On alluvial flats along the Harris River.

39 in pit traps and up to about 30 calling	Area 1
24 in pit traps and up to about 30 calling	Area 2
2 in pit traps	Area 3
19 in pit traps and up to about 5 calling	Area 4
Up to about 30 calling	Area 5
1 in pit trap	Area 6
Up to 20 calling from creek	MacDougal Road bridge
2 calling	October camp

Geocrinia leai (Fletcher, 1898)

Very common. On alluvial flats along the Harris River.

17 in pit traps	Area 1
2 in pit traps	Area 2
2 in pit traps	Area 3
10 in pit traps	Area 4
Up to 20 calling	Area 5
About 10 calling	1 km south of MacDougal Road bridge
One calling	2km south of MacDougal Road bridge
One calling	3km south of MacDougal Road bridge
Two calling every day	October camp

Heleioporus eyrei (Gray, 1845)
Uncommon. Jarrah-Marri woodland.

1 in pit trap	Area 6

Heleioporus inornatus Lee and Main, 1954
Uncommon.

1 headtorched in dense forest	October camp

Limnodynastes dorsalis (Gray, 1841)
Uncommon in pools.

1 calling from creek	October camp
1 calling from creek	MacDougal Road bridge
1 calling	22 Mile Pool

Ranidella glauerti (Loveridge, 1933)
Very common. Calling from shallow pools.

Up to 20 calling	Area 1
About 10 calling	Area 2
Up to about 50 calling	Area 5
About 20 calling	Corner of Norm and Tallanalla Roads
About 20 calling	22 Mile Pool

HYLIDAE - TREE FROGS

Litoria adelaidensis (Gray, 1841)

Very common along Harris River.

1 in pit trap and up to 50 calling from river	Area 1
Up to about 30 calling	Area 2
About 5 calling	Area 5
2 in pit traps	Area 7
Up to about 20 calling	MacDougal Road bridge
Up to about 20 calling	1km south of MacDougal Road bridge
About 10 calling	2km south of McDougal Road bridge
About 10 calling	4km south of MacDougal Road bridge
2 calling	October camp
About 5 calling	1km east of October camp
About 5 calling	Corner of Norm and Tallanalla Roads

Litoria moorei (Copland, 1957)

Moderately common. In waterside vegetation along Harris River.

1 in pit trap	Area 5
2 active on track in dense forest	October camp
About 5 calling nightly	MacDougal Road bridge
About 5 calling nightly from river	Area 6
About 5 calling nightly	Corner of Norm and Tallanalla Roads

APPENDIX D

REPORT ON THE SURVEY OF THE AQUATIC FAUNA OF THE HARRIS RIVER

Prepared by
P. M. Davies
Consulting to Dames & Moore

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1	Aquatic Fauna Study Areas

SUMMARY

The Harris River was surveyed for aquatic macroinvertebrates and fish fauna at the different habitat types present.

A total of 75 taxa of invertebrates and 5 species of fish was recorded. Analysis of the ecological requirements of the macroinvertebrates sampled, revealed a mixture of pond and true stream species. This mixture possibly was due to preliminary work at Damsite 5 which had effectively stopped water flow.

Two of the five fish collected were introduced species - Gambusia affinis (Mosquito Fish) and Perca fluviatilis (Redfin). With dam construction and consequent valley inundation, these species are expected to prosper in the altered habitat with concommitant reduction in the numbers of the native fish present, particularly the members of the Galaxidae.

1.0 INTRODUCTION

1.1 THE INVERTEBRATE FAUNA

The Harris River survey was undertaken to provide a baseline inventory of the resident aquatic invertebrate fauna and to provide background data which will enable an assessment of the impact of the Harris Dam on the aquatic fauna.

There are two deficiencies which have major effects on the successful completion of an aquatic invertebrate fauna survey. First, with the exception of the Odonata, usable keys to many important freshwater groups are unavailable and identifications are usually left to specialist taxonomists. Second, there is a paucity of baseline ecological data for aquatic communities (Lake,1982). As no literature relating to previous aquatic invertebrate surveys in the Harris River area was found, this short period survey was a baseline survey rather than adding to available data.

1.2 THE FISH FAUNA

The construction of a dam and the infilling of a valley with water causes changes in physical attributes of the aquatic system and may produce changes to the fish habitat. However, the effect of these changes on natural fish populations is uncertain, although it has been shown that introduced species such as trout and redfin prosper in the altered habitats to the disadvantage of the native galaxiid species (Frankenberg, 1966). Similarily the loss of stream habitat and streamside vegetation may adversely affect native fish populations (Cadwallader et al., 1980).

The impact of the Harris Dam on the resident fish populations will be dependant on the species present and the degree to which their habitat is changed.

1.3 AIMS AND WORK EFFORT

The aims of this study were to survey the resident native and introduced fish fauna and to obtain an inventory of the aquatic macroinvertebrates present in the various habitats in the Harris River. Particular emphasis was placed on the unconfirmed presence of the native migratory minnow or spotted minnow (Galaxias maculatus). This species spawns in tidal estuaries during the spring tides (McDowall, 1978) and migrates many kilometres upstream to mature in the headwaters of small streams and rivers. There was concern that the weirs of stream gauging stations and dam walls may be detrimental to the completion of this species' life cycle.

The work effort was concentrated on the reservoir area from the damsite upstream to and including 22 Mile Pool (Figure 1).

2.0 MATERIALS AND METHODS

2.1 SURVEY AREA

The Harris River is a tributary of the Collie River within the Wellington Dam catchment, and the catchment vegetation consists predominately of Jarrah (Eucalyptus marginata) forest. The upper reaches of the river comprise peaty swamps which form a succession of pools in summer.

Preliminary clearing work at the damsite has reduced river flow below the site and water was retained in a pool upstream from the site to 22 Mile Pool. Flow upstream from the pool could be measured only in two riffle zones.

2.2 DESCRIPTION OF SAMPLING STATIONS

Six stations were chosen to include a cross-section of the aquatic habitat types which occurred in the Harris River (Figure 1).

Station 1 - a pool habitat, average depth less than 20cm with no stream flow. This station was downstream from the damsite.

Station 2 - at the damsite, a pool of water 70-85cm deep with no stream flow. Organic detritus including leaf packs and inorganic sediment was present.

Station 3 - approximately 1km above the damsite, a shallow gravel pool (depth 5-10cm), with low velocity of flow (20 - 25cm/sec).

Station 4 - a meandering, slow moving (flow velocity less than 14cm/sec) backwater area, pool depth between 2 and 8cm.

Station 5 - shallow pool (5-10cm deep) and swampy, flow nil, evidence of inorganic sediment and organic detritus.

Station 6 (22 Mile Pool) - the most upstream habitat chosen, this pool was approximately 25 metres wide and 120 metres long, depth generally greater than 120cm, flow nil and the station was located at the upper reach of the reservoir area.

2.3 SAMPLING METHODS

2.3.1 Invertebrates

The six stations were sampled for aquatic macroinvertebrates on 19th and 20th December 1983 and for fish fauna on 29th December 1983.

At Station 3, a riffle zone, a Surber sampler (Surber, 1970) with dimensions of $0.1m^2$ and incorporating a 500μm mesh net was used to sample benthic invertebrates. All the other stations were sampled for invertebrates with sweep nets (500μm mesh) by vigorously agitating the benthic detritus and vegetation. This technique qualitatively samples species in the plankton and among the vegetation and detritus. All invertebrates were preserved in a solution of 4% formalin.

2.3.2 Fish

Fish samples were obtained by using sweep nets with a mesh size of 250μm and held by three people. All fish specimens were labelled and preserved in a solution of 4% formalin.

2.4 SORTING OF INVERTEBRATES

All invertebrate samples were washed through two sieves with mesh apertures of 3.35mm and 475 m. Animals smaller than 3.35mm and larger than 475 m were sorted at 12 times magnification under a binocular microscope. Invertebrates larger than 3.35mm were picked from material spread on white trays. All invertebrates were removed and preserved in a solution of 70% ethyl - alcohol.

2.5 IDENTIFICATIONS

Invertebrates and fish were identified to the lowest taxon using available keys of the Australian fauna. Specimens of Chironomids (non-biting midges) were forwarded for indentification to a specialist taxonomist.

3.0 RESULTS AND DISCUSSION

3.1 INVERTEBRATE FAUNA

3.1.1 Results

A total of 75 taxa of macroinvertebrates were identified, of which 52 were insects, 8 were crustaceans, 4 were molluscs, 3 were arachnids, and the remainder were minor phyla (Table 1). No rare or endangered invertebrates were recorded.

The number of taxa collected would be expected to be higher during the winter months as many groups such as the Plecoptera had completed their aquatic (larval) stages. The following is a brief summary and description of the species found at the Harris River pools. It must be stressed that many other taxa maybe present in the Harris River, but the description below is confined to those species caught by the sampling techniques.

Nematoda - With the literature available it is not possible to identify nematodes ('round worms') to a lower taxon than the familial level. The animals sampled were free-living and characteristically associated with the substratum (Williams,1980).

Mollusca - The freshwater limpets (Ancylidae) are abundant in southwestern Australia (Williams, 1980), and Ferrissia and the native planorbid, Physastra, were both common. The fresh water mussel, Westralunio carteri was only found at Station 1.

Oligochaeta - Oligochaetes or worms present difficulties in identification, however they formed a dominant component of the fauna at all Stations, with the exception of Station 4.

Hirudinea - One species of leech, Richardsonianus australis, was found in the still pools. The Richardsonids (true blood - suckers) feed on the blood of vertebrates.

Hydracarina - A minimum of three species of water - mites were present, with identification only to the order level. Hydracarines are predators of small invertebrates.

Cladocera - One species of Cladoceran (Daphnia carinata) was sampled in the Harris River. Cladocerans are generally found in still freshwater but some species can tolerate slightly saline conditions (Edward, 1983).

Ostracoda - Two species of Ostracods were recorded from 22 Mile Pool (Station 6). Ostracods favour habitats that have a mud bottom (Williams, 1980).

Copepoda - One species of cyclopoid Copepod (Macrocyclops albidus) was present.

Amphipoda - The Amphipod species, Perthia branchialis, was recorded from all Stations. The inland Gammaridae are generally restricted to freshwater habitats and are adversely affected by an increase in salinity levels.

Decapoda - Gilgies (Cherax quinquecarinatus) were present in all Stations, except Station 4. In the headwaters (Station 6) both the gilgie and the koonac (C. plebejus) were recorded. Koonacs are freshwater crayfish that dig burrows to the level of the water table. These burrows are significant in being a part of a defended territory (Horwitz and Knott, 1983). Marron (Cherax tenuimanus) were expected to be found at the sampling stations, however none were caught. This can be explained by the sampling technique used and the duration and timing of the sampling (during the daytime). The estuarine shrimp, Paleomonetes australis was common in the still waters. It has been shown to have an avoidance response to strong water flow and a salinity tolerance from 0.2 parts per thousand (p.p.t.) to 44 p.p.t. (Bray, 1978). P. australis is heavily predated by fish and survives by utilizing algal and macrophytic cover (Bray, op cit).

Ephemeroptera - Little data exists on the nymphs of the Australian Ephemeroptera. Species identification of the family Leptophlebiidae is presumptive and based on voucher specimens. In the family Caenidae, Tasmanocoensis tillyardi was located at the damsite (Station 2). Earthworks in the area resulted in inorganic sediment being present. Edward and Bunn (1983) showed this species to be a possible indicator organism for excessive sedimentation, as it possesses gill plates to protect the gills from sediment. This enables the species to survive in areas of high turbidity.

Odonata - Six species of dragonflies (Anisoptera) were recorded. Acanthaeschna anacantha and Aeshna brevistyla inhabit slow flowing rivers or pools and are associated with weeds and leaf litter and contrasts with Orthetrum caledonicum which generally inhabits mud (Watson, 1962).

At Station 6, two damselfly species, Ischnura aurora and Austroagrion coeruleum were recorded. Both species are associated with lakes or permanent pools and I. aurora also occurs in muddy conditions (Watson, 1962).

Hemiptera - The Notonectidae, or backswimmers, are frequently associated with small freshwater lakes and ponds (Williams, 1980). Corixids are also common under these conditions. One species from the family Veliidae was recorded, with members of this family commonly found on the surface film of swamps and pools (Williams, 1980).

Coleoptera - Watts (1978) has recently revised the Australian Dytiscidae. Six species of Dytiscids (water beetles) were found to occur in the Harris River. Adults and larvae of this species are voracious predators and occur in a wide range of habitat types. The families Helodidae and Hydrophilidae were recorded with each preferring standing water pools. Gyrinids ('whirly-gig beetles') are gregarious and frequently occur at the edges of small lakes, ponds, dams and sheltered areas (Williams, 1980).

Diptera - Four families of Dipterans were recorded including a few Simuliidae, Empididae and Ceratopogonidae (biting - midges). By far the most diverse family of invertebrates was the Chironomidae with 16 species which included Peramerina levidensis, Cricotopus annuliventris, Stempellina sp., Rheotanytarsus sp., and Thienemanniella sp. which are all true stream forms (Edward, 1964). In contrast Cryptochironomus griseidorsum, Dicrotendipes conjunctus, Chironomus alternans (complex), Cryptochironomus curtivalva and Procladius sp. are all still water species (Edward, op. cit.).

Trichoptera - Seven species of larval caddis flies were recorded. Members of the family Hydroptilidae are small caddis flies and the larvae in later instars construct a characteristic glass shaped case.

The Leptoceridae is the largest families of Trichoptera in the southwest. Triplectides sp. is a widespread genera occurring mainly in slow moving rivers and lentic water bodies throughout Australia (Morse and Neboiss, 1982). Two species of Hydrobiosidae were present and common in the pharate (sub-adult) stage.

3.1.2 Discussion

The invertebrate fauna in the Harris River at the time of sampling contained a combination of stream and pool, freshwater species.

At the proposed damsite large amounts of inorganic sediment and allochthnous litter were present. The mayfly, Tasmanocoensis tillyardi, was found at this station and is a possible indicator organism of excessive sediment.

3.2 FISH FAUNA

3.2.1 Results

Five fish species were recorded in the Harris River (Tables 2 and 3). Two of the five species, the mosquito fish (Gambusia affinis) and redfin (Perca fluviatilis, are introduced.

TABLE 1

SYSTEMATIC LIST OF MACROINVERTEBRATE FAUNA AND THEIR DISTRIBUTION

PHYLUM / CLASS / SUB-CLASS / Order / Sub-Order / Family / Genus species	STATION 1	2	3	4	5	6
NEMATODA						
Mermithidae		x			x	x
indet.					x	
MOLLUSCA						
BIVALVIA						
Hydriidae						
Westralunio carteri	x					
GASTROPODA						
Planorbiidae						
Physastra sp			x			
Ancylidae						
Ferrissia sp		x	x			x
indet.	x					x
ANNELIDA						
OLIGOCHAETA (? 3sp)	x	x	x		x	x
HIRUDINEA						
Richardsonianidae						
Richardsonianus australis	x			x		
ARTHROPODA						
ARACHNIDA						
Hydracarina (? 3sp)		x		x		x
CRUSTACEA						
BRACHIOPODA						
Cladocera						
Daphniidae						
Daphnia carinata					x	x
OSTRACODA						
Ostracoda						
Cypridae indet.						x
Cypridopsidae indet.						x

	1	2	3	4	5	6
COPEPODA						
COPEPODA						
Cyclopoida						
Macrocyclops albidus		x			x	x
MALACOSTRACA						
AMPHIPODA						
Gammaridae						
Perthia branchialis	x	x	x	x	x	x
Decapoda						
Parastacidae						
Cherax quinquecarinatus	x	x	x		x	x
Cherax plebejus						x
Palaemonidae						
Palaemonetes australis	x	x		x		x
INSECTA						
Epnemeroptera						
Leptophlebiidae						
(New genus) H3	x		x			x
(N genus allied to) Thaulophlebia sp	x	x	x			x
(N genus allied to) ? Atalonella sp	x	x	x			x
Caenidae						
Tasmanocoenis tillyardi		x				
Odonata						
Zygoptera						
Coenagrionidae						
Ischnura aurora						x
Austroagrion coeruleum						x
Anisoptera						
Gomphidae						
Hemigomphus armiger				x	x	
Libellulidae						
Orthetrum caledonicum		x				x
Aeshnidae						
Acanthaeschna anacantha	x					
Aeshna brevistyla						x
Synthemidae						
Synthemis ? macrostigma occidentalis				x		x
Synthemis ? spiniger?						x
Hemiptera						
Heteroptera						
Notonectidae Anisops sp					x	
indet (nymph)					x	x
Corixidae						
? Micronecta					x	x
Veliidae						
indet					x	x

		1	2	3	4	5	6
Coleoptera							
	Hydrophilidae		x		x	x	x
	indet						
	Helodidae						x
	indet						
	Gyrinidae						
	Macrogyrus sp						x
	Aulonogyrus strigosus	x					
	Dinetus sp	x					
	Dytiscidae						
	indet	x			x		x
	Rhantus sp	x	x			x	
	Platynectus decempunctatus					x	
	Hypodes tambreyi						x
	Necterosoma darwini				x	x	x
	Sternopriscus browni (Adult)	x	x	x	x	x	x
	Sternopriscus browni (nymph)		x		x		x
Diptera							
	Simuliidae						
	indet		x				
	Empididae						
	indet.	x	x	x	x		
	Ceratopogonidae						
	indet.			x			
	Chironomidae						
	Peramerina levidensis	x	x	x	x		x
	Cricotopus annuliventris	x					
	Stempellina sp				x		
	V12	x					
	V14	x			x		
	V15	x			x		
	Rheotanytarsus sp	x	x	x	x		
	Thienemanniella sp				x	x	
	V27		x	x	x		x
	Tanytarsus sp	x	x	x	x	x	x
	Polypedilum sp		x			x	
	Cryptochironomus griseidorsum	x	x	x			
	Dicrotendipes conjunctus						x
	Chironomus alternans (complex)		x	x		x	x
	Cryptochironomus curtivalva					x	
	Procladius sp		x	x		x	x
Trichoptera							
	Leptoceridae						
	Lectrides parilis		x				
	Condocerus optus				x		x
	Triplectides sp		x		x		x
	Hydrobiosidae						
	Apsilochroema urdalum	*x	*	*	*		
	Taschorema pallescens	*x	*		*		*x
	Hydroptilidae						
	Oxyethira retracta	x	x		x		x

* Pharates

x Larvae

indet = indeterminate.

TABLE 2

FISH SPECIES OCCURRING IN HARRIS RIVER

FAMILY (Common Name)	SCIENTIFIC NAME
GALAXIIDAE (Western Minnow)	Galaxias occidentalis (Ogilby, 1899)
PERCICHTHYIDAE (Nightfish)	Bostockia porosa (Castelnay, 1873)
KUHLIIDAE (Western Pigmy Perch)	Edelia vittata (Castelnay, 1873)
POCCILLIDAE (Mosquito Fish)	Gambusia affinis (Baird and Girard, 1854)
PERCIDAE (Redfin)	Perca fluviatilis (Linnaeus, 1758)

3.2.1.1 Western Minnow (Galaxis occidentalis)

This indigenous species is the most common freshwater fish in the southwest of Western Australia and is found in a variety of habitats including ponds and lakes (Allen, 1982). In disturbed habitats, it is one of the first species to disappear due to its low tolerance to high levels of turbidity and temperature and oxygen fluctuations (Coy, 1979).

TABLE 3

FISH SAMPLED AND THEIR DISTRIBUTION

SPECIES	STATION					
	1	2	3	4	5	6
Galaxias occidentalis	x			x	x	
Bostockia porosa	x	x	x	x	x	x
Edelia vittata	x	x		x	x	x
Gambusia affinis						x
Perca fluviatilis						x

The low tolerance of this species is reflected by its present distribution in the Harris River. Minnow were present and common at all Stations except 2 and 3 where sedimentation has increased turbidity and reduced flow.

The Minnow is not compatible with Gambusia affinis and is the first indigenous species to be competitively excluded (Coy, 1979). This may explain the Minnow's absence from Station 6 as this was the only site where Gambusia affinis were sampled.

During the juvenile stages, G. occidentalis exhibits many colour variations and may be easily confused with other galaxiid species. This may explain the unconfirmed report of the presence of G. maculatus (the Migratory Minnow). The present distrubution of G. maculatus in Western Australia is in coastal streams and swamps from Esperance to Albany (Allen, 1982) and was not found in the Harris River or been reported in the Collie River.

3.2.1.2 Nightfish (Bostockia porosa)

The nightfish is unique to southwestern Australia. The species occurs from Albany to Gingin Brook and is common in coastal streams and ponds. It is a solitary, nocturnal fish and is carnivorous and aggressive. It was present, but uncommon, at all Stations.

3.2.1.3 Western Pigmy Perch (Edelia vittata)

A widespread, very common and agressive species occurring over most of the southwest and is often found in association with Gambusia. The Western Pigmy Perch frequents the edges of still pools among weed cover and streamside vegetation. The diet of this fish consists mainly of caddis fly larvae (Trichoptera) and other insects which fall from the stream side vegetation (Allen, 1982).

3.2.1.4 Mosquito fish (Gambusia affinis)

This species was introduced into W.A. in 1934 and now is widespread and prolific in warmer waters. This species adversly affects native species by directly competing for food resources and habitat and is a predator on the fry of many indigenous species. In the Harris River this species was sampled only in the warm, still, higher pools and was absent from the faster flowing lower sites.

3.2.1.5 Redfin (Perca fluviatilis)

This species is native to Europe and was introduced to Western Australia for sport fishing. Redfin predominately eat other fish species and freshwater crayfish. P. fluviatilis was only recorded in the headwater pool (Station 6).

3.2.2 Discussion

With construction of the dam, Stations 2 to 6 will be inundated and the diversity and abundance of fish species may possibly change.

Knowledge of the ecology of Galaxis occidentalis and Edelia vittata suggests that these species will become greatly reduced as the habitat is changed (loss of stream side vegetation) and the introduced species (Mosquito Fish and Redfin) may prosper in the new habitat.

Downstream from the damsite, fish populations would be directly affected by changes in water temperature and flow.

4.0 RECOMMENDATIONS

During dam construction, sedimentation should be kept to a minimum, to reduce the effect of turbidity on downstream species. It has been hypothesized that sedimentation may stop the normal aerobic breakdown of allochthnous detritus (S. Bunn, pers. comm.) which is at the base of the trophic pyramid.

If stream flows from the dam can be maintained at present levels, water temperatures will remain low. These temperatures are not suitable to the Mosquito Fish and this may reduce its ability to colonize and to actively compete against native fish species.

Installation of stream gauging weirs are not expected to have any affect on the movement of native species of fish present in the Harris River. The Night Fish and Western Pigmy Perch do not migrate while the Western Minnow may migrate during years of widespread flooding (Coy, 1979). It is not anticipated that obstacles such as gauging weirs will prevent the Western Minnow from completing its life cycle as it may reproduce locally.

5.0 BIBLIOGRAPHY

Allen, G.R. 1982). A Field Guide to Inland Fishes of Western Australia. W.A. Museum, Perth 86 pp.

Bray, D.M. (1978). The biology of the estuarine shrimp, Palaeminetes australis (Decapoda: Palaemonidae) in South-western Australia. Unpub. PhD Thesis, Zool. Dept. U.W.A.

Cadwallader P.L., Eden A. K. and Hook, R.A. (1980). Role of streamside vegetation as a food source for Galaxias olidus Gunther (Pisces: Galaxiidae). Aust. J. Mar. Freshwater Res. 30:257-62.

Coy, N.J. (1979). Freshwater Fishing in South West Western Australia. Perth.

Edward, D.H.D. (1964). The Biology and taxonomy of the Chironomidae of south-western Australia. Unpub PhD Thesis, Zool. Dept. U.W.A.

---------- (1983). Inland Waters of Rottnest Island. Jour R. Soc. W.Aust. 66:41-46.

Edward, D.H.D. and Bunn S.E (1983). Invertebrate faunal study of Jarrah forest streams. Unpub. Report to Dept. of Conservation and Environment, Perth.

Frankenberg, R. (1966). Fishes of the Galaxiidae. Aust. Nat. Hist. 15: 161-164.

Horwitz, P. and Knott, B. (1983). The Burrowing habit of the Koonac Cherax plebejus (Decopoda: Parastacidae). W.A. Nat. 15: 113-117.

Lake, P.S. (1982). Ecology of the Macroinvertebrates of Australian Upland Streams. A review of current knowledge. Bulletin of the Aust. Soc. for Limnology. 8:1-15 (1981 Jolly Award Address).

McDowall, R.M. (1978). New Zealand Freshwater Fishes. Heinemann Educational Books, Auckland.

Morse, J.C. and Neboiss, A. (1982). Triplectides of Australia. (Insecta: Trichoptera Leptoceridae). Memoirs of the National Museum 43: 61-98.

Surber, E. (1970). Procedure in taking stream bottom samples with the stream square foot bottom sampler. Proc 23rd Annual Conf Southeastern association of Game and Fish Commissioners, Oregon U.S.A.

Watson, J.A.L. (1962). The Dragonflies of South Western Australia. W.A. Naturalists Club, Perth. Handbook No 7.

Watts, C.H.S. (1978). A revision of the Australian Dytiscidae Aust. J. Zool. Supp. 57: 1-66.

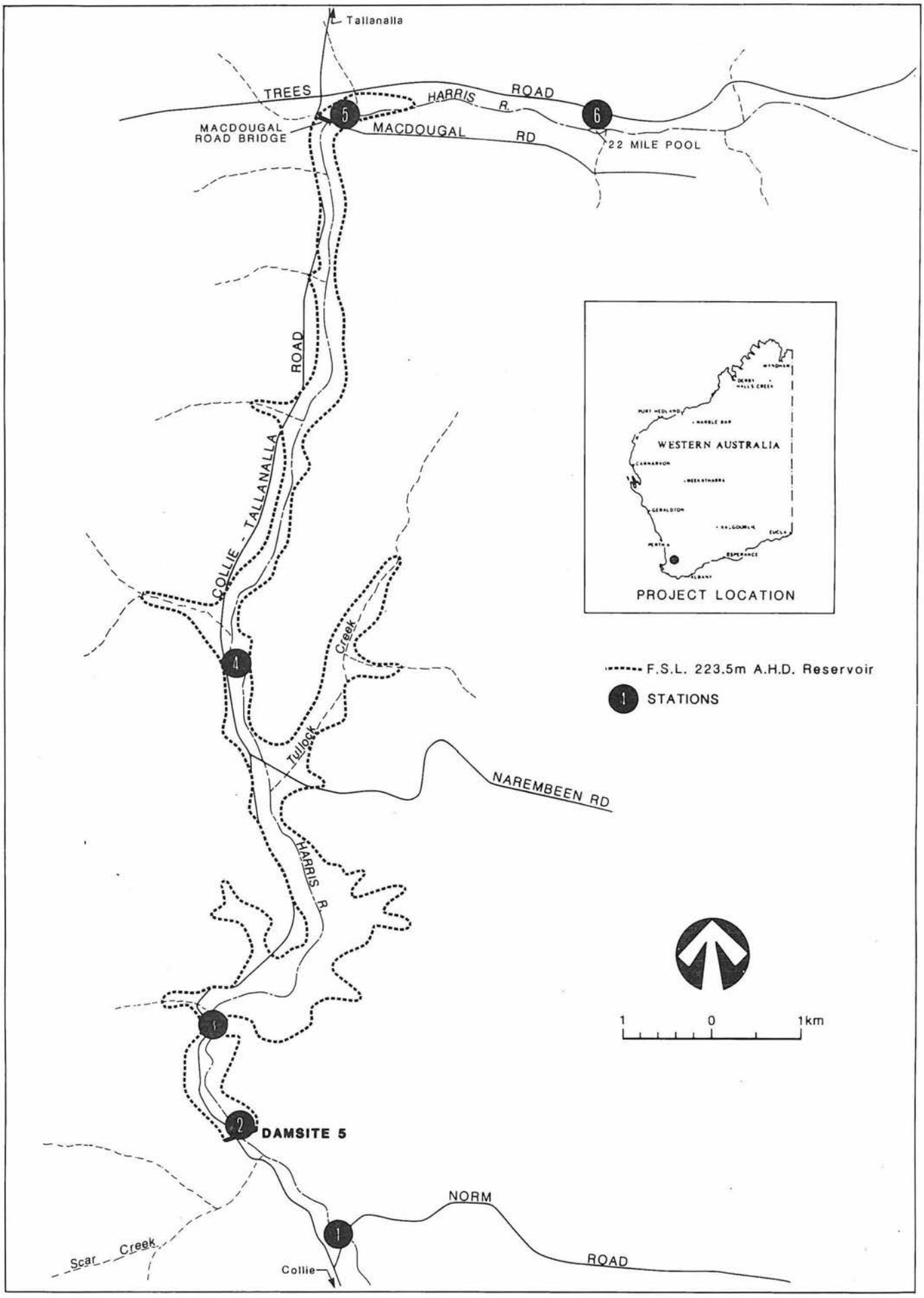
Williams, W.D. (1980). Australian Freshwater Life. Macmillan, Melbourne. 2nd Ed.

6.0 ACKNOWLEDGEMENTS

I would like to thank Garry Connell and Alan Kendrick for enthusiastic assistance in the field and Dr. D.H. Edward and S. Bunn for providing identifications.

* * *

FIGURE



AQUATIC FAUNA STUDY AREAS

Figure 1
Dames & Moore

PLATES



Plate 1 - Station 1 below Damsite 5. The pool is 0.1m deep and a Surber sampler is behind and to the left of the technician.



Plate 2 - Station 4. The stream consists of a series of pools overgrown by brush and containing many aquatic plant species.

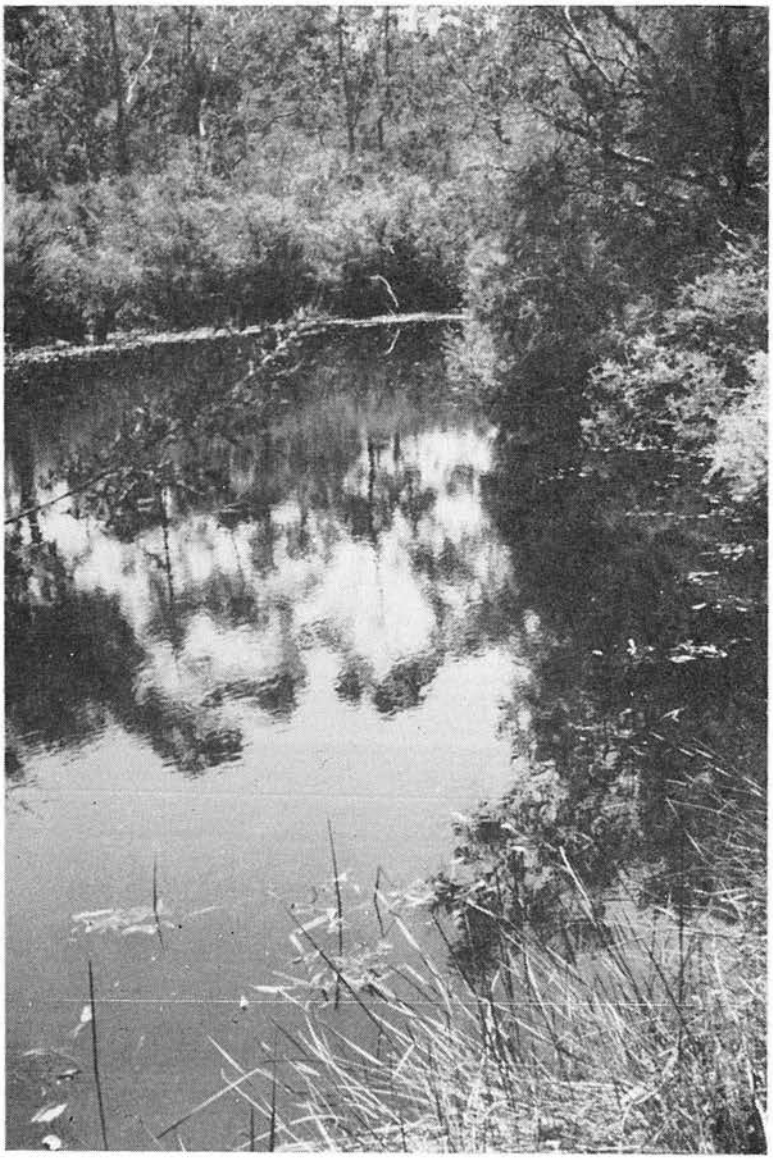


Plate 3 - Station 6 or 22 Mile Pool. This pool is the deepest of the Harris River pools and the most extensive.

APPENDIX E

SOCIO-ECONOMIC PROFILE
HARRIS RIVER DAM PROJECT

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1	Primary Survey Area

1.0 INTRODUCTION

The objective of this survey was to develop a socio-economic profile of the existing environment for the Collie and Harvey Shire areas which encompass the Harris River project site and conduct a preliminary assessment of the socio-economic effects of the project in this study area.

It is important to point out that the area has experienced the development of a significantly larger project - the Worsley Alumina Refinery project. During the peak construction period, the on-site construction workforce was approximately 3200 workers and 50% of these workers were reported to have been recruited from sources outside the Bunbury region. In contrast, the construction workforce for the Harris River dam should not exceed 200 workers. The major economic effects of the Worsley project were experienced in Collie township where there was an extreme shortage of rental and other short-term accommodation. Consequently, there was a short-term boom in the service industries providing accommodation and entertainment, but other sectors of the local economy were not substantially affected by this large-scale construction project. As the large items of capital plant and equipment for the Worsley project were not purchased locally, no substantial secondary industry servicing the site was developed. The effect of the Worsley project on the local quality of life and community structure has not been considered.

From the fieldwork carried out to date in the area, community and social services appear adequate, but have been stressed with the increase in demand generated by the Worsley project. At the completion of the project, many of the construction workers and their dependents chose to stay in the region due to the areas perceived quality of life. Significant numbers of these are presently unemployed or underemployed. The existing community needs of the Bunbury and surrounding areas are being assessed in a study commissioned by the South West Development Authority. This study is due for release in late September 1985.

Given the fact that the area appears to have coped with the construction impacts of the Worsley project, there is sufficient evidence to suggest that the Harris River project should not cause significant adverse economic and social effects on the Collie - Harvey Shire areas.

The Harris River dam will probably have the majority of its direct socio-economic effects during the construction phase and the area should be able to absorb the project with only limited short-term impacts. This report has been divided into the following sections:

- Definition of the study area
- The local economy
- Population and housing
- Other community and social infrastructure
- Transportation
- Relationships with existing regional and town planning schemes.

2.0 DEFINITION OF THE SURVEY AREA

The survey region was divided into a primary and secondary area. The primary area was defined by the census collection district (no. 051101) which includes the proposed sites of the dam. The collection district is the lowest level of aggregation of Australian Bureau of Statistics census data. This collection district has an area of 41,204 ha, which is slightly larger that the catchment area of the proposed dam (31,200 ha). The secondary area was defined as the Collie and Harvey Shire areas.

The primary area has its southern boundary on the outskirts of Collie township and encompasses the entire northwestern portion of the Shire of Collie (Figure 1).

It should be noted that the catchment area takes in a small portion (approximately 5,000 ha) of Harvey Shire, and less than 1,000 ha of Williams Shire. These portions appear to be uninhabited by permanent residents.

3.0 THE LOCAL ECONOMY

3.1 ECONOMIC STRUCTURE

The economic structure of the secondary survey area is one of contrast between Collie Shire and Harvey Shire. Collie Shire's economy is primarily based on coal mining and electricity generation, whereas Harvey Shire is dependent upon its agricultural and processing industries. As the commuter areas of Harvey Shire have attracted more population, there is census evidence in the 1976-1981 period of a significant shift in importance to the service industries. These service industries cater to the regional centre of Bunbury. For example, growth in Harvey Shire's service industries has outstripped growth in agriculture and processing by more than three times during the inter-censal period.

Table 1 shows the changes in structure that have occurred during the 1976-1981 period. Of particular importance to Collie Shire is the construction of the Worsley Alumina Refinery. This project workforce peaked with 3,200 people on site in the early part of 1983 and is now completed and in operation. In Table 1, the effect of this project on Collie Shire in June 1981 is apparent, with an increase in the relative importance of the construction industry rising from 6.1% in 1976 (170 people) to 14.6% (518 people) in 1981.

Growth in the other basic sectors of the economy, such as mining, has been significant but their relative importance has declined due to the increase in the construction sector.

3.2 EMPLOYMENT MULTIPLIERS

Employment multipliers were calculated for the Preston Statistical Sub-Division and the Collie and Harvey Shires. The multiplier used is called the "total employment multiplier" and measured the change in service industry jobs that resulted from changes in the economy's basic industries. A larger region or "benchmark" economy is used to divide each of the economies in question into their basic and service components (Weiss and Gooding, 1966).

The results of the multiplier analysis based on 1976 and 1981 data show a total employment multiplier for the Preston Statistical Sub-Division of 2.86 and for Collie Shire 1.5. Results for Harvey Shire were compounded by substantial growth in service industries in the City of Bunbury and consequently reported an unreasonably high multiplier. For the purposes of this project, the results for Collie Shire and the Region are sufficient to estimate multiplier effects of the dam construction. In Collie Shire, the addition of one job to the construction industry would lead to 0.5 service jobs whereas at the regional level, an increase in one construction job would lead to 1.86 service jobs.

TABLE I

ECONOMIC STRUCTURE OF STUDY AREA, REGION AND WESTERN AUSTRALIA
1976 - 1981

	Collie Shire		Harvey Shire		Preston Statistical Sub-Division		Western Australia	
Industry	1976	1981	1976	1981	1976	1981	1976	1981
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Agriculture	5.0	3.3	28.1	20.6	13.6	11.1	9.0	7.9
Mining	27.9	26.4	0.5	0.7	6.7	6.6	3.4	4.0
Manufacturing	5.1	4.7	19.1	20.2	12.9	11.9	13.5	12.5
Electricity, Gas, Water	10.8	10.1	3.4	3.9	4.2	4.5	1.5	1.7
Construction	6.1	14.2	7.1	7.4	9.1	10.6	8.5	7.5
Wholesale, Retail Trade	14.3	10.6	11.0	11.4	17.1	16.2	18.3	17.8
Transport & Storage	7.1	4.1	4.0	4.0	6.3	5.4	5.3	5.8
Communications	0.9	0.9	1.2	1.1	1.6	1.6	1.9	1.8
Finance, Property & Business Services	2.3	3.8	2.8	4.3	4.1	5.3	7.0	8.5
Public Administration & Defence	1.5	2.0	3.1	3.2	2.5	2.5	5.1	4.3
Community Services	11.1	10.3	11.5	12.3	12.0	12.7	14.7	16.3
Recreation, Personnel Other Services	3.2	3.3	2.6	3.1	4.2	4.6	5.2	5.3
Other/N.C. *	4.7	6.4	5.6	7.8	5.9	7.0	6.5	6.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Not Classified or not reported

(Source: Australian Bureau of Statistics)

4.0 POPULATION AND HOUSING

4.1 REGIONAL AND LOCAL TRENDS

The estimated resident population and private dwellings for the survey area, region and state for 1976 and 1981 are recorded in Table 2. From the table, the importance of Bunbury is evident, with 21,749 people or 45.2% of the regional population. Collie Shire, the focus of the present study has the second highest population with 8,947 and Harvey Shire, the other main area affected by the project, is third with 8,027. However, when annual growth rates of the above areas are considered, the Shire areas surrounding Bunbury have been growing faster than the City itself.

Reasons for this trend were suggested in the Bunbury Regional Plan and are:-

- Less expensive land in a rural setting
- Better than average services, ie. scheme water, shops, primary schools, community facilties, power and telephones
- Increased demand due to increasing basic industry employment, and in some instances, reduced travel time to work.

Collie Shire has not grown as quickly as Harvey Shire because of the latter's adjacent suburban areas to the City of Bunbury. However, it is noteworthy that Collie Shire has still grown faster than the City of Bunbury and comparative growth rates are shown in Table 3.

4.2 SITE VICINITY

The population in the immediate vicinity of the site defined by the surrounding 1981 census collection district was 334 (Figure 1). More than half of this population were not permanent residents of the area. A breakdown of the district's workforce indicates that 113 men were working in construction and were most probably living in a construction camp for the Worsley Alumina project. This was confirmed by the number of occupied private dwellings being recorded at 49.

TABLE 2

ESTIMATED RESIDENT POPULATION AND PRIVATE DWELLINGS, 1976-1981

Statistical Division, Sub Division and Local Govt. Area (a)	Area at 30 June 1981 (square kilometres	Census 30 June 1976 Census Counts	Census 30 June 1976 Estimated Resident Population	Census 30 June 1976 Private Dwellings	Census 30 June 1981 Census Counts	Census 30 June 1981 Estimated Resident Population	Census 30 June 1981 Private Dwellings	% Change 1976/1981 Census Counts	% Change 1976/1981 Estimated Resident Population	% Change 1976/1981 Private Dwellings
SOUTH-WEST										
PRESTON STATISTICAL SUB-DIVISION										
Bunbury (C)	61.2	19,513	20,600	6,102	21,749	22,630	7,235	11.4	9.8	18.6
Capel	554	2,302	2,470	705	2,913	2,920	868	26.5	18.2	23.1
Collie	1,662	7,540	8,080	2,459	8,947	9,200	2,816	18.6	13.9	14.5
Dardanup	529	2,702	2,910	835	3,419	3,640	1,078	26.5	25.1	29.1
Donnybrook-Balingup	1,540	2,827	3,030	1,039	3,202	3,350	1,093	13.2	10.6	5.2
Harvey	1,766	6,704	7,110	2,146	8,027	8,280	2,750	19.7	16.4	28.1
TOTAL	6,112	41,588	44,200	13,286	48,257	50,020	15,840	16.0	13.2	19.2
SOUTH WEST										
TOTAL, DIVISION	26,661	81,666	86,500	31,024	97,834	102,250	38,694	19.8	18.2	24.7
WESTERN AUSTRALIA										
TOTAL	2,525,000	1,1448,857	1,178,340	370,941	1,273,624	1,299,090	445,700	11.2	10.2	20.1

(Source: Australian Bureau of Statistics)

Further inspection of the industry of employment census data revealed that only 15 persons worked permanently in either agriculture or forestry. Consequently, it can be assumed that the upper limit to the number of households directly affected by the project is 15. According to discussions with Shire Council personnel, this number is no more than 10-12 households and are smaller marginal rural properties.

TABLE 3

ANNUAL GROWTH RATES,
POPULATION AND HOUSING
1976 - 1981

LOCAL GOVERNMENT AREA	POPULATION	HOUSING
Bunbury City	3.4 %	1.8 %
Harvey Shire	5.1 %	3.0 %
Capel	4.2 %	3.4 %
Collie	2.7 %	2.6 %
Dardanup	5.2 %	4.6 %
Donnybrook - Balingup	2.0 %	1.0 %
Preston Sub-Division	2.5 %	3.6 %
South-West Division	3.4 %	3.7 %
Western Australia	2.0 %	3.7 %

(Source: Australian Bureau of Statistics)

4.3 COMPARISON OF SOCIO-ECONOMIC CHARACTERISTICS

Comparison of the socio-economic characteristics of the site vicinity, Collie and Harvey Shires, the Preston Statistical Sub-Division, and the State, is complicated by the presence of the Worsley construction camp. Inspection of Table 4 shows the population near the site to be better educated, middle-aged, with very low percentages of dependent population, and with a high percentage of employed married women for a rural area.

Both Shires have similar characteristics to the Region but the increasing urban orientation of Harvey Shire is shown in the higher percentage of employed married women. This percentage is approaching the State level of 44.9%.

TABLE 4

SOCIO-ECONOMIC INDICATORS
SITE VICINITY, SHIRES, REGION AND STATE, 1981

SOCIAL INDICATOR	SITE VICINITY	COLLIE SHIRE	HARVEY SHIRE	PRESTON SUB-DIVISION	W.A.
% Over 65 years	3.0	6.6	8.4	8.7	8.5
% 0 - 14 years	25.0	28.2	29.2	28.2	26.1
% Tertiary Educated	31.3	21.9	19.8	21.7	25.5
% Employed Married Women	45.6	28.5	41.8	38.6	44.9
% Home Ownership	71.4	67.5	67.4	67.2	65.6

(Source: Derived from Australian Bureau of Statistics Census, 1981)

4.4 PERMANENT HOUSING

As shown in Table 3, growth in housing has managed to keep slightly ahead of population growth, in all local government areas except the Donnybrook-Balingup Shire. Discussion with Shire and City personnel have indicated that there has been very sluggish regional demand for housing during 1982-1983. These sources also suggested that there is adequate land available in both Bunbury and the surrounding Shires to cater for demand in the foreseeable future. In Collie Shire, the picture was found to be substantially different because of the Worsley Alumina project. Local Shire personnel indicated that there were shortages of land suitable for residential development around the townships. One of the recommendations of the Darling Range Study Group's Report on land use in the Darling Range, May 1982, was that an interdepartmental committee be convened to look further into this problem. The draft town planning scheme (No.2), under consideration by the Town Planning Department, has identified a number of possible areas for future residential rezoning. If constraints imposed by Government departments can be resolved, it is considered that there would be adequate land for expansion of the township of current growth rates.

4.5 NON-PERMANENT ACCOMMODATION

In the immediate vicinity of the project there has been an shortage of short-term and rental accommodation. This was mainly due to the Worsley Alumina project. At the peak of construction there were three construction camps housing over 1,500 persons and catering to single and non-accompanied married personnel. Private accommodation in Collie is presently at a premium with several older hotels being renovated to provide extra, but very basic, accommodation. The Shire Council has also developed a caravan park on the southern side of town near the old Forestry Commission headquarters. This caravan park was constructed to accommodate 80 sites for caravans or tents.

Temporary accommodation in the broader Bunbury region is more plentiful because of the tourist areas along the adjacent coastline. In the 1985 Royal Automobile Club of Western Australia accommodation directory some 1,035 private caravan park sites and 696 units in hotel, motel or guesthouses were recorded in the region. In the township of Collie, there were 120 caravan park sites, and 94 hotel, motel and guesthouse units (RAC, 1985). These figures have probably grown significantly over the past years as some of the older hotels have developed additional basic facilities. It is estimated that the supply of caravan park accommodation available to construction workers during peak tourist season would be adequate within the region. This is based on a construction workforce of 200 and a mean total occupancy rate of approximately 45% (South West Development Authority, unpubl. rep.) This does not take into account any concurrent developments or tourism booms, such as the America's Cup Challenge.

5.0 OTHER COMMUNITY AND SOCIAL INFRASTRUCTURE

Discussion with local Shire Councils, City of Bunbury and State Government Departments confirmed that there is an adequate supply of educational and health services in the region. In an interview with officers of the State Department of Education regional office, the effect of the Worsley Alumina project was raised. It was found that even though there were significant short-term additions to class sizes in the Collie area, there had been considerable excess capacity in the system prior to the project. Also, a high percentage of the non-local construction personnel were either single, non-accompanied or couples without children. There were also substantial numbers of workers commuting to the site on a daily or weekly basis. Such groups have very low demand for local educational services. Social problems arising in the construction camps were reported to be minor because of the characteristics of the camp population, rigid enforcement of camp rules and provision of active recreation facilities.

One area of concern voiced by Shire personnel was the increase in family related social problems in the suburban growth areas around Bunbury. These areas include Australind and Brunswick Junction. Causes for the increase were thought to be:

- The high number of new arrivals from other parts of Australia with its attendent loneliness
- Limited opportunities for female employment, especially married female employment
- Lack of adequate community infrastructure where affected families could seek assistance.

This type of problem, referred to as 'suburban syndrome', is typical of rapid growth areas where community development has not kept pace with physical expansion. Such a problem was felt to be more associated with the urban development of Bunbury rather than individual resource projects.

An inventory of existing facilities has been produced by the Department of Industrial, Commercial and Regional Development (1982).

6.0 TRANSPORTATION

6.1 EXISTING ROAD NETWORK

The main highway servicing the project area (State Highway No. M037) runs east-west from Bunbury to the township of Collie and is a standard two-lane sealed rural highway. Traffic counts taken along the M37 to the west of the Collie townsite show the annual average daily traffic (AADT) counts to be 1,700 vehicles per day. The AADT count in the Collie township peaks at 6,000 vehicles per day and decreases east of the townsite to approximately 400 vehicles per day.

Access to the site from the south is by Tallanalla Road. This road runs from the State Highway over a railway level crossing through the main commercial area of Collie and through its northern residential area. As soon as this road leaves the township area it is unsealed and is a low standard shire road (Figure 1).

Tallanalla Road runs north through the proposed site to a junction at Tallanalla where the Harvey-Quindanning Road runs east-west and Tallanalla Road continues north through Hoffman's Mill to Wagerup. The other connection between Collie and the Harvey area to the west, is called Mornington Mills Road and is also of low standard and provides local access to both Collie and Harvey. Existing traffic volumes on all of these local access roads are less than 100 vehicles per day. The area to the east of Tallanalla Road is criss-crossed with forestry roads and tracks which do not connect the project area with any significant population centres. These roads are located within the Forests Department dieback quarantine areas and are not open to general public usage.

6.2 EXISTING RAIL NETWORK

The project area is served by an existing 3'6" gauge railway line (known as the Narrogin Railway) which runs east-west in close proximity to the main highway. The principal function of the railway is to service the coal mining areas around Muja and Collie and agricultural areas further to the east.

6.3 EXISTING AIR NETWORK

The project area is served by an aerodrome 10km northeast of the Collie townsite. The Collie Shire is currently upgrading the aerodrome to cater for six to seven seated passenger aircrafts. The length of the landing ground will be increased to 1,000 metres.

7.0 RELATIONSHIP WITH EXISTING REGIONAL AND TOWN PLANNING SCHEMES

7.1 REGIONAL PLANNING

The only regional planning documents that have been produced in the vicinity of the site are the Bunbury Region Plan (Taylor and Burnel, 1980) and the Bunbury 2000 Strategy. These documents do not include Collie Shire in their study area but the agency set up as a result of the plan, the South West Regional Authority, has a task force to consider development issues arising in the Collie area.

A recommendation to the former State Premier by the Darling Range Study Group (1982), which prepared a document concerning land use in the Darling Range, was to set up a Land Use Advisory Committee made up of senior officers of all relevant government departments.

The initial task of this group was to incorporate the framework plans of relevant departments, such as the Water Authority of Western Australia and major land users into a single integrated framework plan. Such an exercise may involve further discussion and planning for the Harris River dam project in its regional context.

7.2 LOCAL TOWN PLANNING SCHEMES

There are three local government areas affected by the project. The Harvey Town Planning Scheme No. 10 was finalised late in 1983 and is now operational.

A proposed draft Planning Scheme No. 2 is proposed for the urban areas of Collie Shire and was finalised at the end of 1984.

8.0 BIBLIOGRAPHHY

Australian Bureau of Statistics Census Statistics for 1981 and 1976. Prepared by the Australian Bureau of Statistics.

Bunbury and Districts Steering Committee, Bunbury Region Plan. Internal Report - Schedule of Submissions (undated).

Commonwealth Employment Services Quarterly Transactions, June, September and December Quarters, 1982 and 1983.

Darling Range Study Group (1982). Land Use in the Darling Range, Western Australia. A Report prepared by the Darling Range Study Group Study for the Premier of W.A., May 1982.

Department of Industrial, Commercial and Regional Development South West Office (1982). Bunbury, July 1982,. Bunbury Directory, Town Planning Department, W.A.

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

Taylor, R. and Burnel, W. (1980). Bunbury Region Plan, June 1980. A Report on Regional Planning for Bunbury and Parts of Harvey, Dardanup and Capel. Report prepared for Town Planning Department, W.A.

Technical Committee Report. Internal Report. Bunbury Region Plan (undated).

Weiss, S.J. and E.C. Gooding (1966). "The Estimation of Differential Employment Multipliers for a Small Regional Economy". Research Report to the Federal Reserve Park of Boston No. 37. November 1966.

FIGURE

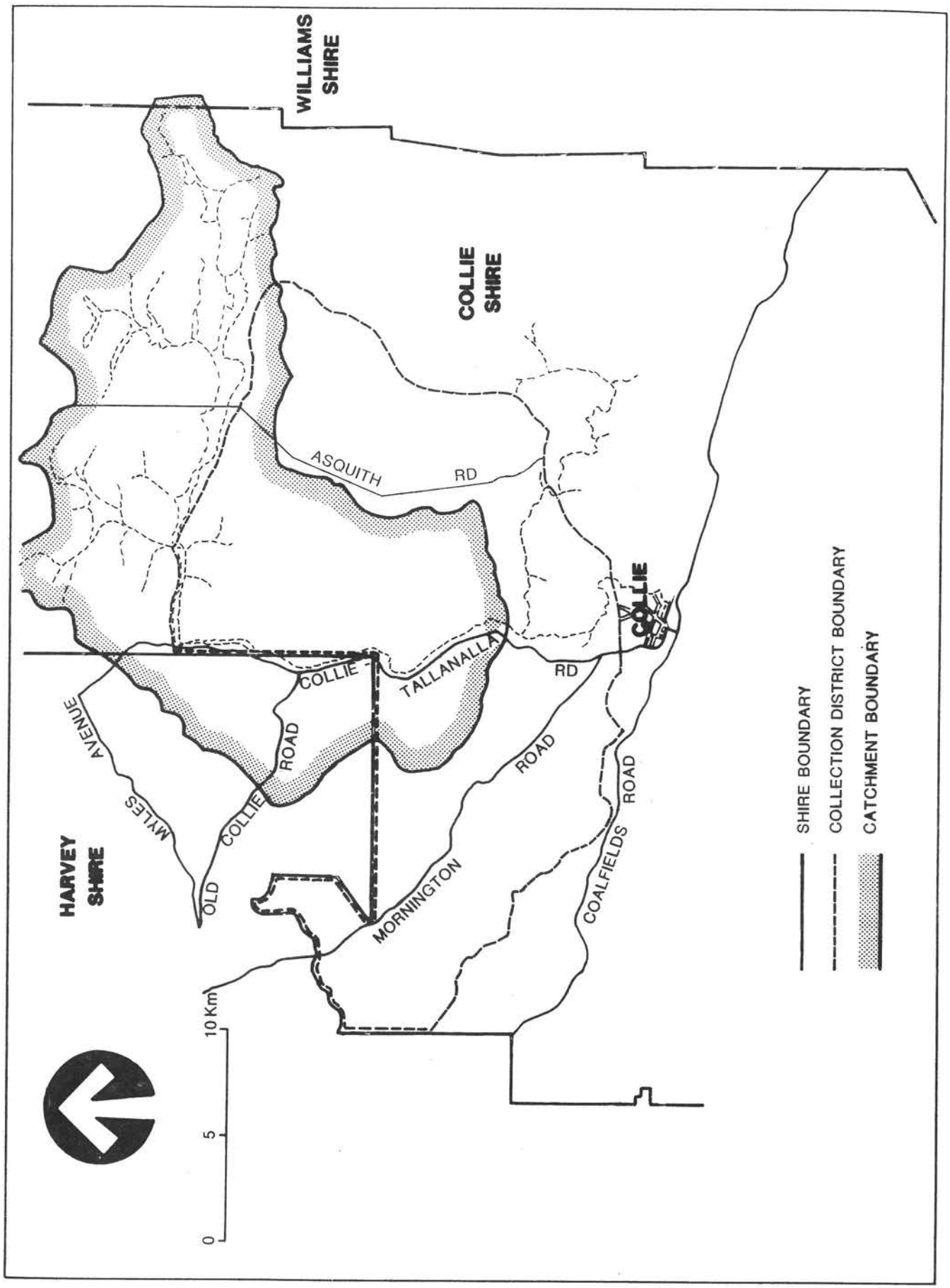


Figure 1 – Primary Survey Area

APPENDIX F

REPORT AND SUPPLEMENT ON THE RECREATION SURVEY FOR THE HARRIS DAM ENVIRONMENTAL REPORT

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30th April, 1984

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1.0 PRELIMINARY

The Water Authority of Western Australia* is examining the Harris River for its potential as a water supply reservoir. This is particularly important to the Southern Wheatbelt areas (Katanning, Narrogin, etc.) which derives its water from the Wellington Reservoir. The catchment area of the Wellington (Collie River) includes large areas of farmland and a major urban and mining area (Collie). These pose risks for the Reservoir and an alternative storage is desirable.

The study of the Harris covers both the engineering and economic feasibility of the dam and also the environmental consequences of the reservoir.

1.1 OBJECTIVE

The environmental review of the reservoir includes recreation and the Recreation Survey has three objectives:

- To describe the existing recreation use of the study area.
- To describe the potential recreational use of the study area.
- To make recommendations about recreational research and development in the study area.

1.2 SURVEY AREA

The survey area is shown on Plan 1.

It comprises three sub units:

- The Harris River downstream of Trees Road.
- The Wellington Reservoir.
- The Collie River downstream of the Wellington Dam to River Road.

Three Local Authorities have responsibilities:

1.2.1 Harris River

It is a major tributary of the Collie and joins the latter some 6 km north of the town of Collie. The river is an annual stream and most of its bed is overgrown with dense understorey vegetation.

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* Since the completion of this Recreation Survey, the Public Works Department has become the Water Authority of Western Australia and the Forests Department has become part of the Department of Conservation and Land Management.

Therefore any reference to the old Department names in this report should be read in the light of the new Department's name.

1.2.2 Wellington Reservoir

The Wellington Reservoir is an artificial lake held back by a concrete wall 34 metres high. It is principally an irrigation dam but also supplies domestic water to Collie and the Great Southern Towns Area (Narrogin, Katanning, etc.).

1.2.3 Collie River Gorge

The Collie River Gorge is a very steep sided valley extending below the dam.

1.3 METHODOLOGY

The time frame and budget limited the survey to the following elements:

- Desk research and analysis of data collected by Forests Department, Department of Youth, Sport and Recreation, Shires, Public Works Department, etc.
- Off peak field surveys to collect data on location and intensity of use. This involves:
  - A two day reconnaissance survey at Easter, 1983
  - A one day detailed survey, 24th April, 1983 (Anzac Day Long Weekend)
  - Two days of detailed surveys on 21st and 22nd April, 1984 (Easter).
- Meetings with Collie Shire and other local officials.

2.0 FINDINGS AND RECOMMENDATIONS

2.1 FINDINGS

1. Recreational pressures on the area are likely to increase as the population of the Bunbury Region grows to 50,000 by 1990-2000.

2. The recreational and tourist resources of the area are substantial and comprise natural assets (forest, rivers, scenery, etc.) and man-made features (coal mines, refineries, dams, etc.). Overall the potential of these resources has not yet been recognised.

3. The developed tourist and recreation facilities in the study area are minimal and concentrated at the Wellington Dam site and of the Wellington Mills Holiday Camp.

4. The users of the recreation resources fall into a defined seasonal pattern. Summer users are predominantly non family groups from the Metropolitan area. Winter users are predominantly family groups from Bunbury and the nearby south-west.

5. No significant recreational use of the Harris River Valley was observed.

6. The shorelines of the Wellington Reservoir receive minor night time seasonal use for marron and redfin perch fishing, and minor summer and winter picnics. The latter activity is confined to the upper reaches (Mungalup Plantation and Bussell Brook) where picnic facilities have been provided. Occcasional camping occurs.

7. The excellent facilities at the Wellington Dam site are intensively used for day visitor activities (picnics, sight seeing, bush walking, etc.). Substantial overcrowding occurs at peak times.

8. The Collie River Gorge below the dam wall is intensively used for a variety of recreational activity:

   - sightseeing overspill from the dam site facilities
   - touring, driving the narrow tracks. (Collisions occur)
   - hiking and bushwalking
   - camping in designated "picnic" grounds
   - marroning in season
   - swimming and canoeing.

   This activity is concentrated between the dam wall and the River Road Bridge but extends downstream (recreation vehicles, canoeing and shooting) and may be inconsistent with the ecological value of the area.

9. The dam wall and reservoir on the Harris River will create an additional tourist attraction in the region with the same sightseeing and picnic activities that occur at most dams in the Darling Range (e.g. Canning, Serpentine, Stirling, Wellington). The attraction will depend upon the scenic quality of the dam and the facilities and access provided.

10. More regular flows in the Harris River below a dam would increase the recreation potential of the downstream river,providing such activity was consistent with water quality standards for the Wellington Reservoir.

11. The reservoir lake that will result in the Harris River Valley will inundate the Tallanalla Road which has some current use and significant potential as a Tourist/Recreation route from Dwellingup to Collie.

12. The construction of the Harris River Dam could enable the Wellington Reservoir to be used for recreation activity which would be of significant value to both local recreation opportunity and the regional tourism industry.

A resource suited to a very wide range of recreational/tourist activity would become available:

- unpowered boating of various kinds (yachting, canoeing, rowing, etc.)
- power boating and perhaps houseboating under certain circumstances
- boat and shoreline fishing (marron and redfin perch)
- shoreline hiking and recreational driving
- shoreline picnic and casual swimming and other sporting activities.

The forest and lake scenery and the indented shoreline would enable a variety of tourist and recreation accommodation to be provided:

- camping
- caravan park
- holiday cabins
- guest house/lodge
- motel
- club camps.

13. Most of the land surrounding the Wellington Reservoir is privately owned. Development of recreational and tourist facilities will depend upon a positive approach by the landowner or acquisition by the Crown.

2.2 RECOMMENDATIONS

1. That provision be made at the Harris River damsite for public sight seeing and picnic facilities.

2. That once the water flows downstream of the dam are determined, the suitability of the area for camping and picnics be examined.

3. That an alternative route be investigated for the section of the potential scenic tourist road from Dwellingup to Collie that will be inundated by the reservoir. The overall tourist route should be planned to link all the dams and reservoirs between South Dandalup and the Wellington including the new Harris Dam.

4. That in the event of the Harris River Dam proceeding and the domestic water supply function of Wellington Reservoir being replaced, the latter should be made conditionally available for recreation.

5. A Comprehensive Development Plan for the shorelines and backup forest around the Wellington Reservoir should precede any recreational activity or development. Such a plan should be similar to those prepared for Lake Eildon and Lake Hume in Victoria.

   The Development Plan should indicate the locations and densities of recreational facilities and activities, taking account of:

   - engineering services and access
   - environmental issues - water quality
     - erosion
     - flora and fauna
   - landscape quality
   - conflicts in recreation use
   - finance, management and maintenance
   - public attitudes to development of the area.

6. That in the event that 4. be agreed to, the owner of the land surrounding the Wellington Reservoir should be approached to determine their preparedness to participate in a Development Plan.

7. That the ecological and landscape damage being caused by wild camping in the Collie Gorge be closely monitored. Any solution should ensure that provision for camping and picnicing be conveniently located.

3.0 FACTORS AFFECTING RECREATION ACTIVITY

3.1 REGIONAL RECREATION ISSUES

The Harris River Valley and the Collie River/Wellington Dam are in an area of significant tourism and recreation potential. It is generally considered that this potential has not yet been recognised. The specific items that comprise the tourism/recreation resource are documented in Section 3.2 of this report. There are a number of general characteristics which influence recreational activity in the area now and will have a major impact in the future.

3.1.1 Economic Activity

Collie and its nearby coal province has had a spasmodic history of growth. Before the 1950's coal mining was a labour intensive industry and the population of the area was high.

The conversion of power generation plants in the City to oil in the 1950's and 1960's saw a rapid decline in activity on the coalfields and a consequential population reduction in Collie. In the last 5-10 years international oil shortages have resulted in a major rejuvenation of coal mining in the area and a slight jump in the population.

TABLE 1

POPULATION HISTORY COLLIE AND BUNBURY

	COLLIE	BUNBURY
1954	9882	9869
1959	11034	12234
1961	8486	13186
1964	9200	14800
1966	8544	15459
1968	8500	16450
1971	7535	17779
1976	7800	20150
1981	9200	22630

The return to 1950's population levels in Collie has been assisted by the construction and operating workforce of the Worsley Alumina Refinery and consequential employment.

By contrast, Bunbury has grown steadily from an equal level with Collie in 1954 to a population of more than twice that of Collie now.

Industrial activity in the South-West Region such as:

the Worsley Alumina Refinery
the Wagerup Alumina Refinery

Mineral sands mining and refining
Woodchip manufacturing and exporting
Various manufacturing plants such as particle board, etc.

have contributed to the rapid growth of Bunbury. The population statistics in Table 1 do not reflect the total growth of the subregion because considerable urban development has occurred in adjoining municipalities such as Australind (Harvey Shire) Eaton (Dardanup Shire) and Gelorup (Capel Shire).

The Bunbury Region Plan 1980 prepared for the Bunbury and Districts Planning Committee indicated the urban planning for Bunbury, Australind and Gelorup.

Based on the effects of the Wagerup and Worsley Alumina refineries and other general economic growth (agriculture, tourism, forestry, coal, mineral sands, etc.) the Report suggests that the urban region population will be 50,000 by 2001 and 100,000 by 2034.

The Bunbury Region Plan Report emphasises that these forecasts take no account of a possible aluminium smelter between Australind and Brunswick Junction.

The construction and operation of such a plant could result in the population reaching 50,000 by 1990. The consequential industrial growth thereafter is difficult to forecast.

Plan 3 shows the elements of the economic activity.

3.1.2 Sub Regional Tourism/Recreation Assets

The industrial activity itself is a potential tourism asset. The coal mines (disused and operational) are of significant interest as are the large alumina refineries and associated conveyor belts through the forest.

Bunbury Town and associated beaches and bays are a major tourist destination. Leschenault Inlet is heavily used by both residents and visitors from all parts of the State for recreational fishing and boating.

The forests, rivers and reservoirs of the southern portion of the Darling Range are a major recreational asset which are only lightly used at present.

The Collie Gorge or Lennard Forest Block (Coalfields Highway south to the Ferguson River and west of the Wellington Dam) is part of this area which has outstanding natural scenery and thus tourism and recreation potential.

The Leschenault Inlet is heavily used in the summer season and as a shallow estuarine environment is potentially at risk of degradation from misuse.

The Darling Range rivers and reservoirs have some capacity for further use but that capacity is limited because of the need to protect the scenic and environmental qualities of those water bodies. There is little evidence that State Forests, apart from those areas adjoining the reservoirs or major rivers, are used for picnicing or hiking, etc.

Thus there are a number of natural and man-made recreation and tourist assets in the region.

i.e. Mining Areas
Major Industrial Plants
Major Urban Centres
Estuaries and Rivers
Excellent Forest Scenery and Reservoirs.

The economic activity of the region in buoyant. Population growth is rapid and potential economic activity (Alumina Smelter) will increase the rate of growth.

Pressures on the study area for forest, recreation and tourism, will thus increase.

3.2 THE RECREATION RESOURCE

Plan 4 shows the main resources of the immediate study area and the elements which limit the useability of those resources.

3.2.1 General Features

(a) State Forest

As can be seen from Plan 4 a large proportion of the general study area is State forest. The forest areas are being logged in accordance with Forests Department programmes. The significant features of the State forest that affect recreational and tourist use are the quarantined (no access) areas and the areas planted with softwoods.

Large areas of the forest have been quarantined for dieback control. The most significant of those areas includes all the forest east of the Harris River/Tallanalla Road. This places severe limits on the access to and useability of the Harris River for recreation.

Quarantine areas also surround Wellington Reservoir and except for the freehold land immediately abutting the reservoir, would probably extend to the shoreline.

Two large areas adjoining the Wellington Reservoir have been planted with softwoods.

The resulting access tracks and open character of the plantations have encouraged casual use for camping and fishing.

(b) A similarly large proportion of the general area is freehold land which is partly cleared and farmed and partly held in large parcels as timber reserves.

The most important impact of the freehold ownership is the area almost totally surrounding the Wellington Reservoir.

Crown Grant 56 is owned by the Worsely Timber Company.

3.2.2 Resources of Study Area Units

(a) Harris River Valley

The valley that would be inundated by the proposed dam is 14 km long extending from just north of Norm Road to Trees Road in the north. Apart from the actual site(s) of the dam(s) the valley is relatively wide and shallow.

The Harris is an annual stream and is a major tributary of the Collie River.

Much of the streambed comprises dense thickets of understorey vegetation, while medium Eucalypt forest occupies most of the wide shallow valley on each side.

The section of valley immediately north of Norm Road where the potential damsites arise is steep sided and is a localised area where the Eucalypt forest has higher scenic qualities.

In general terms however the valley is not considered to have any special scenic value.

It would probably rank 48 on a scale of Visual Landscape Quality (20-78) developed by the Darling Range Study Group and published in their report "Land Use in The Darling Range Western Australia", May 1982 p.217.

There are no discernable pools that would form the basis of active picnic/camping areas although in winter the flowing stream would no doubt be of interest if picnic spots were developed in the more attractive parts of the valley.

(b) The Wellington Reservoir

The reservoir occupies several steep sided valleys and has a basin area (maximum water surface area) of 1610 hectares. It is thus the second largest reservoir in the Darling Ranges. Only the new South Dandalup Reservoir is larger at 1960 hectares.

Annual variation in water level (5 - 10 metres) leaves the typical barren, tree stump fringe around the shore, except at the end of winter. The water is deep (about 30 metres) in the body of the reservoir. The trunks of drowned trees still occupy the water.

Most of the valley slopes are in a relatively virgin condition with dense Eucalypt forest. Extensive pine forests have been planted along the southern arm of the reservoir (Bussell Brook) and upstream of the main water body on the Collie River (Mungalup Plantation).

Despite the barren fringe around the water body in summer there are many sections of the shoreline which are attractive and suited to recreational access and use. The extremely indented character of the shoreline means that there is in excess of 50 km of shoreline. Most water areas are relatively narrow (200-400 metres) but several large expanses of water with dimensions exceeding 1000m by 1000m occur.

The whole basin occupied by the reservoir has high scenic value.

The Public Works Department which controls the use of the reservoir,has policies which ban the use of boats on the reservoir and shore fishing within 1.6 km of the dam wall.

Except in a few locations, gaining access to the reservoir shoreline involves trespassing on private property.

(c) The Collie River Gorge

The gorge is a very steep sided valley extending some 22 km downstream of the Wellington Dam to Roelands on the Coastal Plain.

The valley is probably the most scenic and visually exciting of the river valleys in the Darling Range.

The river plunges through steep rain forested gorges punctuated by massive sheet rock outcrops. Pools occur along the total length of the gorge. 7,500 hectares on either side of the upper section of the Gorge is within State Forest and included within the Lennard Management Priority Area. The priority use set down for the area is Conservation of Flora and Fauna and it is considered to have the highest category of ecological importance. More than half of the total length of the gorge is in freehold ownership.

The Forests Department has provided access and facilities and thus does not discourage public use despite the M.P.A. classification.

3.3 FACILITIES

3.3.1 Harris River Valley

The only recreation facility serving or available in the valley is the Collie-Tallanalla Road with a number of minor forestry access roads.

The road is unsealed but of comparatively high standard. It is part of a longer forestry road system that connects Collie with Nanga Brook and Dwellingup in the Murray River recreation province.

A number of the lesser spur forestry roads such as the Old Collie Road and Trees Road can be used to gain access to the Brunswick River,the Stirling Dam and thence to Harvey Weir and the Harvey Town.

There are no other formal facilities such as picnic areas or scenic lookouts.

3.3.2 Wellington Reservoir and Dam

The Forests Department has established a number of relatively simple and low key picnic sites on the extremities of the reservoir (Mungalup Plantation and Bussell Brook) both in areas of softwood plantations.

Plan 5 which shows the locations of these sites suggests that it was ownership rather than land management criteria that decided their location. Most other shorelines of the reservoir are privately owned. The picnic areas contain concrete and steel barbeque and some rudimentary picnic furniture.

Most of the picnic spots attract campers despite the absence of ablution facilities.

The major facilities at the dam itself are quite substantial although at peak periods are insufficient.

The facilities comprise:

- car parks
- shop/kiosk
- toilets
- major lookout and information bay
- limited BBQ/picnic facilities near the kiosk
- substantial BBQ and Picnic facilities in the quarry over looking the dam wall.

3.3.3 Collie River Gorge

A system of access tracks useable by normal motor vehicle serves a chain of picnic spots downstream of the dam wall.

These sites range from a small and simple site of one or two barbeques to a major site such as "Honeymoon Pool". The latter has numerous barbeques,and considerable bush picnic furniture.

As with the other bush picnic sites all these sites are occupied by campers in summer peak periods despite the absence of ablution facilities.

Thus the principal facilities are the natural assets of the area:

- the rivers and streams
- the scenery and the forest.

The only substantial specific purpose tourist and recreation facilities are those at the Wellington Dam activity node. An extensive network of forestry roads, mostly usable by standard motor vehicles, is a major asset to the recreational driver.

South west of the Wellington Dam, the Department of Youth, Sport and Recreation maintains a holiday/recreation camp at Wellington Mills. The camp can accommodate 80-100 persons. It is regularly used by school groups and by the general public at weekends. Commonly the occupants travel to the Collie Gorge for canoeing, etc.

4.0 RECREATION USE

4.1 CHARACTERISTICS OF USERS

On 12 separate days throughout 1978 representatives of the Forests Department toured the forest areas distributing questionnaires to forest users. The distribution was widespread in the Darling Range forestry area and users were required to return the questionnaire by mail.

The raw data from the Collie subset of this survey was obtained from the Forests Department and analysed.

The dates of the surveys are indicated in Table 2.

A total of 262 questionnaire forms were distributed and 129 or 49% were returned which is a relatively high rate of return for a mail survey.

All questionnaires were distributed in the Mungalup Plantation, Bussell Brook, Wellington Dam and Collie Gorge areas. None were distributed in the Harris River area because no significant use was noted.

4.1.1 Origin of Visitors

Tables 2 and 3 document the origin of the users of the area determined from the Forests Department sample survey.

TABLE 2

ORIGIN OF VISITORS IN EACH SURVEY DATE

	ORIGIN			
	PERTH METRO	SOUTH WEST	ELSEWHERE	TOTAL RETURNS
January 29	15	1	1	17
March 5	17	1	-	18
March 25	33	1	-	34
April 23	3	3	1	7
May 20	1	1	-	2
June 18	2	3	-	5
July 30	1	5	-	6
August 27	7	8	1	16
September 17	1	3	-	4
October 15	1	6	-	7
November 12	4	2	1	7
December 17	3	-	-	3

TABLE 3

ORIGIN OF VISITORS PER SEASON

	ORIGIN		
	PERTH METRO	SOUTH-WEST	ELSEWHERE
SUMMER	75	8	3
WINTER	13	26	1
TOTAL	88	34	4

Tables 2 and 3 illustrate two significant patterns.

Firstly, despite being 150 km from the Perth Metropolitan area, the total number of city visitors substantially exceeds those from Collie, Bunbury and other nearby population centres.

Secondly, the winter pattern is reversed. The proportion of local visitors is double those from the city.

4.1.2 Visitor Group

TABLE 4 documents the type of group of the visitors sampled in the 1978 Forests Department surveys. It compares the group type (family or non family) to the original of the visitors.

TABLE 4

VISITOR GROUP TYPE ACCORDING TO ORIGIN

ORIGIN	FAMILY GROUP	NON FAMILY GROUP	TOTAL
PERTH METRO	38 (44% of TOTAL METRO)	49 (56% OF TOTAL METRO)	87
SOUTH WEST	24 (67% of TOTAL SOUTH-WEST)	12 (33% OF TOTAL SOUTH-WEST)	36
ELSEWHERE	2	0	2
TOTAL	64	61	125

The emphasis of non family groups from the Perth Metropolitan area reflects a fairly large number of groups of **young adults** who visit the area for camping and canoeing expeditions. The dominance of the family group use from the south-west arises from the Winter time day trip and picnic by families from Bunbury.

TABLE 5 compares the type of visitors sampled in the 1978 Forests Department surveys to the seasonal use of the area.

TABLE 5

VISITOR GROUP TYPE ACCORDING TO SEASON

SEASON	FAMILY GROUP	NON FAMILY GROUP	TOTAL
SUMMER	33	56	89
WINTER	31	5	36
TOTAL	64	61	125

The data in Table 5 confirms the user characteristics shown by Table 3.

4.2 DISTRIBUTION AND TYPE OF ACTIVITY

4.2.1 1983/4 Survey

Plan 6, - illustrates the distribution of people and their activities arising from observation survey conducted on Sunday 24th April 1983 and on Saturday and Sunday, 21st and 22nd April 1984. The first was part of a long weekend created by the Anzac Day holiday and the second two days part of the Easter Holiday.

The observation surveys were conducted on a route beginning at the Tallanalla/Trees Road intersection at 11.00 a.m. through Collie then along the eastern and southern shores of Wellington Reservoir to the Dam. The final section of the route included Lennard Drive and River Road in the Collie Gorge. The route was completed by 3.00 p.m.

The surveys documented numbers of cars and other vehicles, numbers of people and their activity.

Tables 6, 7 and 8 summarise these factors.

TABLE 6

RECREATION USE - 24TH APRIL, 1983

SURVEY SECTOR	PEOPLE	CARS	ACTIVITIES %				
			CAMPING	SIGHT SEEING	PICNIC	FISHING	OTHER
HARRIS RIVER VALLEY 11 a.m.	-	-	-	-	-	-	-
MUNGALUP PLANT-ATION 12 NOON	24	6	15%	-	75%	10%	-
EAST WELLINGTON 12.30 p.m	-	-	-	-	-	-	-
BUSSELL BROOK 1.00 p.m.	8	2	-	100%	-	-	-
WELLINGTON DAM 2.00 p.m.	89	38	-	50%	45%	-	5% Hiking
COLLIE GORGE 2.30 p.m.	76	29	65% (26Tents	15%	10%	5%	5% Hiking
TOTAL	197	75	33%	30%	33%	3%	1%

The distribution and type of recreation use determined by the survey is consistent with a reconnaissance survey carried out on Easter Sunday 1983 (April 3rd).

The essential features of the data are:

- Overall, recreation activity is evenly divided between camping, picnic and sightseeing.
- No recreational use of the Harris River Valley was observed on either 3rd April nor 24th April
- The activity is concentrated at the dam where facilities are provided and in the picnic areas of the Collie River Gorge.

TABLE 7

RECREATION USE - 21ST APRIL, 1984

SURVEY SECTOR	PEOPLE	CARS	ACTIVITIES				
			CAMPING	SIGHT SEEING	PICNIC	FISHING	OTHER
HARRIS RIVER VALLEY	-	-	-	-	-	-	-
MUNGALUP PLANT-ATION	3	1	-	3	-	-	-
EAST WELLINGTON	6	2	6	-	-	-	-
BUSSELL BROOK	14	8	14	-	-	-	-
WELLINGTON DAM	46	13	-	30	16	-	-
COLLIE GORGE	272	119	242	24	-	6	-
TOTAL	341	143	262	57	16	6	-

* WEATHER WAS COLD AND RAINY

Again, no recreational activity in the Harris River Valley was observed.

Because of the wet weather the number of day visitors (sight seeing and picnicing) was low, particularly at the Wellington Dam facilities.

Camping in the picnic grounds of the Collie Gorge predominated and the high total of users indicates very intensive use.

TABLE 8

RECREATION USE - 22ND APRIL, 1984

SURVEY SECTOR	PEOPLE	CARS	ACTIVITIES				
			CAMPING	SIGHT SEEING	PICNIC	FISHING	OTHER
HARRIS VALLEY RIVER	3	1	-	3	-	-	-
MUNGALUP PLANTATION	5	2	-	5	-	-	-
EAST WELLINGTON	8	3	8		-	-	
BUSSELL BROOK	21	10	16	5	-	-	
WELLINGTON DAM	97	27	-	34	51	-	12 HIKERS
COLLLIE GORGE	334	129	308	22	-	4	-
TOTAL	468	172	332	69	51	4	12

* WEATHER: FINE AND COOL

The predominance of camping in the Collie Gorge was once again evident. The total number in the Gorge had reached saturation point where the attributes that attract people to the Gorge were overwhelmed by cars, tents and people.

4.2.2 1978 Forests Department Survey Data

The sample survey of users conducted by the Forests Department collected substantial data on the general and particular activities of visitors.

Tables 9 and 10 show the general activity derived from the data.

(a) General Activity

TABLE 9

ACTIVITY BY SEASON 1978 FORESTS DEPARTMENT SURVEYS

SEASON	ACTIVITY (NO. OF GROUPS)		
	CAMPING	DAY TRIP	OTHER
SUMMER (NOVEMBER 17 - APRIL 23	67	13	2
WINTER (MAY 20 - OCTOBER 15)	2	30	7
TOTAL	69	43	9

The use pattern shown by the Forests Department sample survey reflects expected patterns with camping prevailing in summer and day trip/picnic excursions in the winter.

TABLE 10

ACTIVITY OF VISITORS BY ORIGIN AND SEASON

	PERTH METRO			SOUTH-WEST		
	CAMPING	DAY TRIP	OTHER	CAMPING	DAY TRIP	OTHER
Jan 29	15				1	
March 5	15		1		1	
March 25	24	8	1	1		
April 23	3	-	-	1	3	-
May 20			1		1	
June 18		1	1		3	
July 30		1			4	1
August 27		2	5		9	
September17		1			3	
October 15		1		2	4	
November 12	4			1	1	
December 17	3					

It is clear from the data in Table 10 that:

* Metropolitan Use of the area is strongly biased towards summer camping. The 300km round trip from the City is too long for significant day tripping.
* Local Use is lower and heavily biased towards the winter day trip.

The residents of Bunbury and the South-West clearly tend to use the Collie, Wellington Forests for winter picnics etc., in exactly the same way as the Metropolitan population uses the "Hills" east of the City.

(b) Detailed Activities

The activities of Day Trippers were limited almost exclusively to picnics and sightseeing.

The campers listed a wide variety of activities and/or reasons for visiting the area.

Canoeing/boating/tubing was most referred to as the primary activity.

It was followed by a group of activities:-

- Swimming, solitude, sightseeing and marroning - each with a similar ranking.

The predominance of canoeing reflects the value and importance of the Collie Gorge as a canoeing venue.

It is clear that the type of activities which predominate are water oriented. They are thus concentrated on the relatively permanent water of the Collie River above and below Wellington Dam.

The irregular and relatively low flow rate of the Harris River is such that these activities are unlikely to occur in its valley at present. There is no evidence that the river is used for such activities in any significant way.

4.3 ATTITUDES OF USERS

4.3.1 Respondents Attitudes

The 1978 Forests Department Surveys offered respondents the opportunity to express opinions about the area in which they were recreating.

Two questions in the questionnaire indicate their attitudes to the region.

Q14. was structured in that it invited choices for future development and gave a list of 14 possibilities to choose from. The choices ranged over mundane facilities such as litter bins and toilets through better recreation arrangements such as walking tracks and canoe courses. One option listed was "no development".

Table 11 indicates the outcome of that question. It shows 1st choices only.

TABLE 11 USER ATTITUDES TO DEVELOPMENT

DEVELOPMENT OPTION	% OF TOTAL (N = 123)
No Development	24.4
Litter Bins	22.0
Picnic Tables, etc.	16.0
Toilets	12.0
Walking/Driving Tracks	11.4
Open Spaces for Games	4.0
Signs	3.0
Swimming Areas	3.0
Canoe Courses	2.4
Other (Hotel) (Camping Area)	1.6
TOTAL	99.8

Thus nearly a quarter of the sample of users indicated no further development as their attitude to the area.

It is more significant to note that another 24 respondents (20%) listed the "no development" option as their 2nd or 3rd choice after listing essential facilities as litter bins and toilets.

Question 15 asked: "Is there anything that you like or dislike about the forest areas you have visited today?

Can you suggest how this or similar areas may be improved?"

The 111 responses ranged over a relatively short list of comments and attitudes. These are shown in Table 12.

TABLE 12 USER COMMENTS

COMMENT	% OF TOTAL COMMENTS (111)
Widen/Improve Roads more signposting	15.3
Keep Natural Beauty Re-vegetate No commercialisation	26.1
More areas/sites needed	10
Eliminate Trail Bikes	26.1
More facilities - Toilets, letter bins, etc. - Cleaning of area	22.5
TOTAL	100.0%

It is clear from the table and from the language used in the responses that the majority of users want to keep the areas as they are but certain improvements need to be made.

i.e. improve roads
provide and maintain more toilets, etc.
ban trail bikes.

4.3.2 The Local Community

The local community does not use the Harris River Valley for any significant or occasional activity. In discussions with Shire Councillors, the only minor occasional recreation activities known in the area were illegal pig shooting in the forest and the collection of minnows for bait in river pools. The Councillors and the local community appreciate the importance of the Harris River Dam to improving water supplies in the region. They do not attach any importance to the Harris as an existing or potential recreation resource.

5.0 EFFECT OF HARRIS RIVER DAM ON RECREATION

5.1 DIMENSIONS OF THE POTENTIAL RESERVOIR

The dam site north of Norm Road is situated in a narrow steep sided section of the valley. The wall proposed would be high. It would hold back a waterbody some 1530 hectares in area at top water level. The length of the main arm of the water would be some 14 kilometers with a typical width of 500 metres. Immediately north of the dam the waterbody widens out to a main basin 1.5 by 2.5 km.

Plan 7 shows the approximate dimensions of the reservoir. The area of the reservoir is significant, as can be determined by comparing its dimensions with those of the other reservoirs shown in Table 13 .

TABLE 13

DARLING RANGE RESERVOIR

RESERVOIR	BASIN AREA	PURPOSE	RECREATION ACTIVITY	ACCOMMODATION
HELENA	760 ha	Water Supply	Sightseeing and Picnic at Dam	Nil
CANNING	487 ha	"	" "	"
WUNGONG	350 ha	"	Sightseeing, Picnic and Marron Fishing	"
SERPENTINE	1,210 ha	"	" " "	"
SOUTH DANDALUP	1,960 ha	"	" " "	
WAROONA	144 ha	Irri-gation	Waterski, Fishing, Swimming, Camping	Caravan Park
SAMSON BROOK	106 ha	Water Supply & Irri-gation	Fishing	Nil
DRAKESBROOK	41 ha	Irri-gation	Picnic & Swimming	"
LOGUE BROOK	99 ha	"	Fishing, Sailing, Waterski, Picnic, Swimming,Camping,	Caravan Park
STIRLING	394 ha	" & Water Supply	Sightseeing,Camping Fishing	Nil
HARVEY WEIR	150 ha	"	Sightseeing, Picnic Fishing	"
WELLINGTON	1,610 ha	"	Picnic, Sightseeing Fishing	"

There is an alternative site for the dam further south nearer the junction of the Harris with the Collie River. It results in slightly different dimensions but not such that the overall effect of the dam is markedly different.

5.2 FUNCTION OF RESERVOIR

The proposed reservoir will be totally used to supply domestic water through the Great Southern Towns Water Scheme (Collie, Narrogin, Katanning, etc.). It is designed to replace this function at the Wellington Reservoir.

The freshwater stored in the Harris Reservoir will also be used to manage salinity levels in the Wellington. It is intended to discharge freshwater down the Harris River and Collie River at regular intervals to scour saline water from the Wellington.

Thus the lower reaches of the Harris River and the Collie River will receive regular flows of freshwater. The Harris River is an annual stream which virtually dries up in summer. Regular year round flow will significantly change its character and recreation potential.

5.3 RECREATIONAL POTENTIAL OF AREA AFFECTED

The surveys of the area have shown that there is no significant recreational use of the Harris River Valley at present.

The principal reasons for this are:

- the valley is relatively isolated and the route of the Tallanalla Road through Collie is complicated and deters tourist use.

- the valley has low scenic value by local standards and thus does not attract the attention of travellers.

- the Harris River is an annual stream which virtually dries up in the summer months, thus offering little for water-based recreation.

- there does not appear to be significant populations of marron in the river which forms the basis of much of the recreation in the South-West Forests.

These factors are such that it is unlikely to attract people using other areas should they be motivated by overcrowding to seek new areas.

The river valley is in fact an important part of the Wellington Reservoir catchment. It supplies freshwater to the Wellington Reservoir and clearly, is significant in balancing the slightly saline water arising from the other rivers feeding the Wellington.

Thus the water supply authority would be anxious to limit any activity in the Harris River catchment in order to protect the water quality of the Wellinton.

Thus the recreational potential of the Harris River is low because of its isolation, low environmental quality and high value for water catchment or water catchment protection.

5.4 CREATION OF RECREATIONAL DESTINATION

5.4.1 Dam Site

All the dams and reservoirs in the Darling Range are significant destinations for recreation activity.

Day visitors are naturally attracted to the water scenery of the artificial lake and the engineering achievements in the dam itself.

Traditionally the water supply authorities have provided excellent day visitor facilities at the dam sites and these account for a significant proportion of total forest activity.

The 1978 Forests Department random surveys documented in Section 4.2.2 show that there is significant day trip use of the forests of the Collie area - principally the Wellington Dam area.

The main source of the day tripping is from Bunbury and other areas and this source is predicted to grow substantially.

The construction of a dam on the Harris River will create an additional tourist/recreation foci in the region which will undoubtedly attract use. As with the protected metropolitan reservoirs, there is unlikely to be difficulty in containing that use to the dam wall and immediate areas.

The environmental health impact of a recreation node at a new dam upstream of the Wellington Dam wold need to be assessed depending on the future use of the latter. If its domestic water supply function is terminated, no problems should arise.

5.4.2 Downstream of Dam

Proposals by the water supply authority to release water into the lower Harris on a regular basis to control salinity in the Wellington, will make the river more attractive for camping and picnics.

Provided this activity will not prejudice the quality of water entering the Wellington, it could be planned for.

The Collie Gorge which is grossly overcrowded in peak periods seems to need respite. Facilities on the lower Harris could provide such a respite and absorb some of the growing demand for such recreation space.

A careful survey of the valley should occur after the water flows are established but before large numbers of people invade the area.

5.5 LOCATION OF REGIONAL RECREATION ROUTE

The Tallanalla-Collie Road is a good quality forestry road which links Nanga Brook (Dwellingup) with Collie through the centre of the Darling Range Forest.

Although not heavily used at present it has considerable potential as a recreational/tourist route. The proposed Harris River Dam will flood the whole of the section of the road between the dam and Trees Road i.e. some 10-12 km.

Clearly in the interests of water quality management a replacement public road along the full length of the reservoir is unacceptable.

The potential of a tourist road through the forest involves the progressive upgrading and signposting of roads which link:

- South Dandalup Dam
- Nanga
- Waroona Dam
- Logue Brook Dam
- Harvey Weir
- Stirling Dam
- Worsley Alumina Refinery
- Harris Dam (Proposed)
- Collie
- Wellington Dam.

That potential route is shown on Plan 8. The alignment shown follows existing public roads and forestry roads of varying qualities. The overall route is capable of being broken into sections by existing connecting roads to SouthWestern Highway and the highway towns such as Waroona and Harvey.

5.6 RECREATION POTENTIAL - WELLINGTON RESERVOIR

One of the potential effects of a dam on the Harris River is that Wellington Reservoir could be carefully and conditionally made available for recreation.

On the assumption that the domestic water storage function is replaced by the Harris reservoir, and clear evidence that there is a need for additional forest recreation space, such a decision is recommended.

All characteristics of the reservoir and surrounding land (except ownership) favour the development of recreational and tourist facilities at carefully chosen locations around the shoreline and managed use of the water surface.

Table 13 indicates that at present only two reservoirs are used for active recreation - Waroona and Logue Brook. Both these areas have rudimentary accommodation facilities in the form of Caravan Parks both of which are consistently full at peak times.

Lakes Hume and Eildon in Victoria are major reservoirs with irrigation, flood mitigation, water supply and power generation roles.

Although much bigger in area and length, these reservoirs are used extensively for recreation. Both have urban and recreational settlements on their shores and farmland and forest surrounding them. Large sections of their shorelines are used for day visitor activities and the water surface is used for power boating and yachting.

Much of the development has occurred without the benefit of master plans, however in recent years the Victorian Authorities have moved to rectify that situation.

Further recreational development of reservoirs such as Waroona, Logue Brook, and Wellington in particular, should be preceded by the professional preparation of an appropriate management plan.

Such plan should balance:

- recreational demand and site location principles
- environmental quality (including landscape)
- financial consideration.

A reconnaissance of most of the shoreline of Wellington indicates numerous locations where recreational access involving day visitor use, tourist accommodation, boating access, could be attractively developed.

The principal recommendations of the investigation into Lakes Hume and Eildon could appropriately be applied to control recreational use plan for Wellington Reservoir, i.e:

- protect the water storage function of the reservoir
- cluster accommodation development to small intensive sites where scenic impact will be minor
- cluster day visitor use to small intensive sites where scenic impact will be minor
- control effluent disposal
- zone the water surface for the chosen boating activities
- establish a management authority.

A detailed study of the potential of the reservoir would no doubt reveal many detailed criteria that would need observance.

Recreational and tourist use of Wellington Reservoir is required because of:

(a) over use of existing desirable and accessible areas. i.e.Collie Gorge

(b) growing interest by the Metropolitan and regional population in forest recreation and camping

(c) substantial past and future growth in the Bunbury Region.

6.0 REFERENCES

1. A Study of Catchments and Recreation in Western Australia; Compiled for the Advisory Committee on Purity of Water, 1977.

2. Bents Basin State Recreation Area. Resource Inventory and Preliminary Development Strategy. Department of Lands N.S.W., 1980.

3. Bunbury Region Plan. A Report on Regional Planning for Bunbury and parts of Harvey, Dardanup and Capel, 1980. Russell Taylor & William Burrell.

4. Bunbury Water Use Survey. A Report to the State Energy Commission on the Use of Shorelines and Offshore Areas around the Bunbury Power Station; Feilman Planning Consultants, 1983.

5. Forest Visitor Survey. A Report on the Results of the State Forest Visitor Survey; Forests Department of W.A., 1980.

6. Lake Hume Recreation Study published by Lake Hume Recreation Co-ordinating Committee; Loder & Bayly, 1980.

7. Land Use in the Darling Range; A Report to the Premier of Western Australia by the Darling Range Study Group. May 1982.

8. Recreation in the Darling Range of Western Australia; A User Study. Carolyn Wilkin Lohr, 1976.

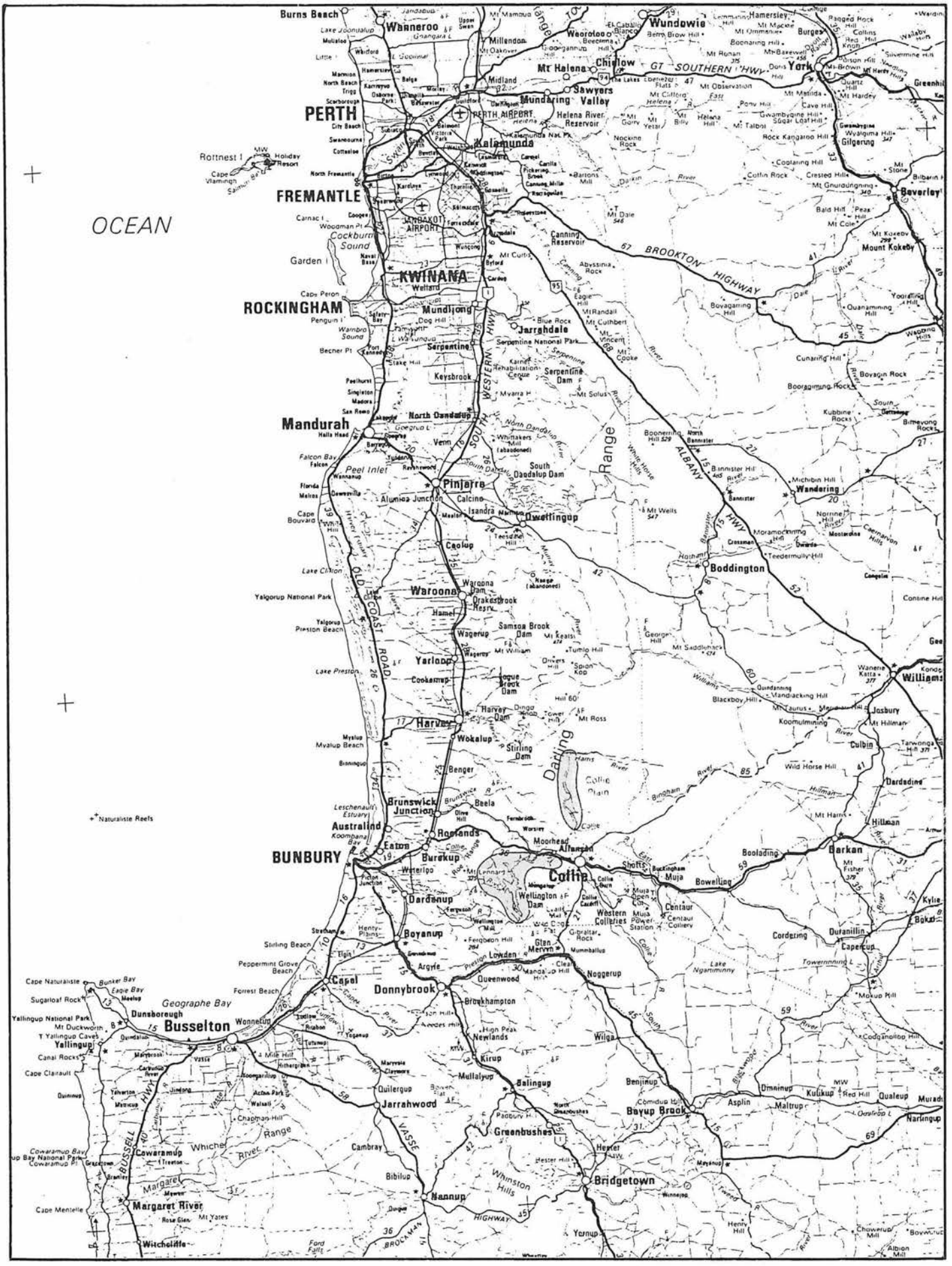
9. Recreation on Reservoirs and Rivers; Institution of Water Engineers London, 1972.

10. Study of Recreation and Land Use, Lake Eildon and Environs for State Rivers and Water Supply Commission of Victoria. May 1979.

11. The Amateur Marron Fishery in Western Australia. N.M. Morrissy. 1978. Fisheries Research Bulletin No.21.

12. The Collie Valley, Western Australia. A response to the proposed construction of a New Dam in the Collie Valley above Burekup, for the Conservation Council of Western Australia Inc. 1976.

FIGURES


OCEAN
PERTH
FREMANTLE
KWINANA
ROCKINGHAM
Mandurah
BUNBURY
Busselton
Margaret River
Cowaramup
Donnybrook
Bridgetown
Boyup Brook
Collie
Darkan
Williams
Wandering
Boddington
Dwellingup
Pinjarre
Waroona
Harvey
Australind
Brunswick Junction
Eaton
Burekup
Dardanup
Boyanup
Capel
Yarloop
Mundijong
Serpentine
Jarrahdale
Kalamunda
Mundaring
Chidlow
Wundowie
Mt Helena
Sawyers Valley
York
Beverley
Gilgering
Mount Kokeby
Canning Reservoir
Helena River Reservoir
Serpentine Dam
South Dandalup Dam
Samsoa Brook Dam
Wellington Dam
Stirling Dam
Harvey Dam
Logue Brook Dam
Waroona Dam
Drakesbrook Reserv.
Wagerup
Alumina Junction
Calcine
Isandra
Peel Inlet
Cockburn Sound
Geographe Bay
Naturaliste Reefs
Rottnest I
Garden I
Carnac I
Cape Peron
Penguin I
Becher Pt
Falcon Bay
Cape Bouvard
Lake Clifton
Yalgorup National Park
Lake Preston
Myalup Beach
Leschenault Estuary
Koombana Bay
Stirling Beach
Peppermint Grove Beach
Forrest Beach
Cape Naturaliste
Bunker Bay
Eagle Bay
Sugarloaf Rock
Yallingup National Park
Mt Duckworth
Yallingup
Canal Rocks
Cape Clairault
Cowaramup Bay
Cape Mentelle
Witchcliffe
Whicher Range
Darling Range
Blackwood River
Preston River
Collie River
Harris River
Murray River
Williams River
Albany Hwy
South Western Hwy
Brookton Highway
Great Southern Hwy
Old Coast Road
Russell Hwy
Vasse Hwy
Whinston Hills
Perth Airport
Jandakot Airport
Swan River
Canning River
Darling Scarp
Range
Mt Cooke
Mt Dale
Mt Vincent
Mt Randall
Mt Cuthbert
Mt Wells
Mt Saddleback
Mt Ross
Mt Lennard
Mt Observation
Mt Matilda
Mt Hardey
Mt Stone
Mt Gnurudingning
Mt Koseby
Mt Solus
Mt Keatsi
Mt Harris
Mt Fisher
Mt Hillman
Mt Taurus
Mt Curtis
Mt Talbot
Mt Billy
Mt Gorry
Mt Yetar
Mt Cutting
Mt Ommaney
Mt Mackie
Mt Roman
Mt Barlee
Mt Brown
Mt Mamaua
Mt Oakover
Mt Curtis
Mt Observation
Mt Cutting
Mt Ommaney



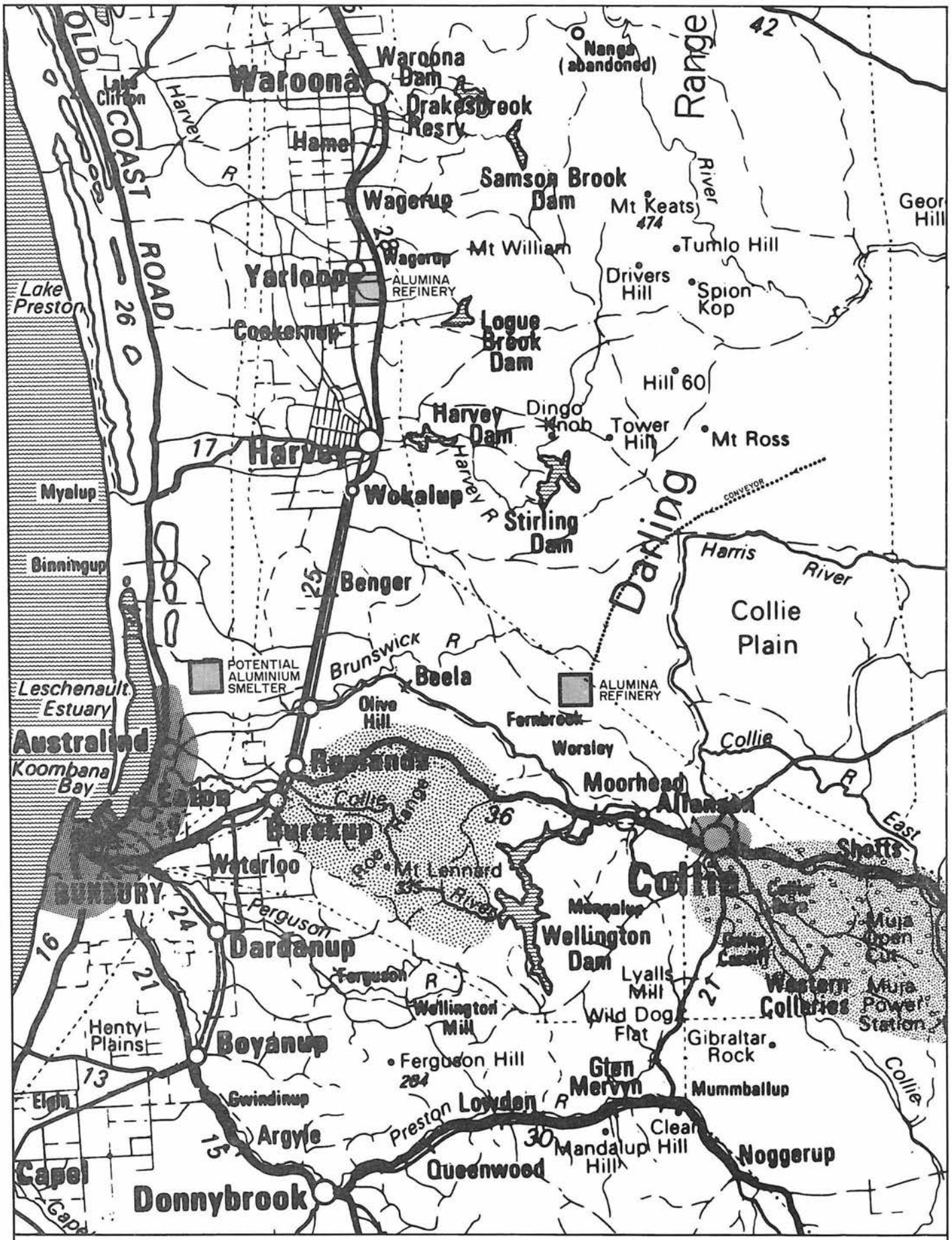
HARRIS RIVER DAM RECREATION SURVEY

SURVEY AREA

Scale-1:100,000 Date-April 1984
Feilman Planning Consultants Pty Ltd

Plan 2

Plan 2



HARRIS RIVER DAM RECREATION SURVEY

Urban .....

Area of Outstanding Scenery (including Hiking & Canoeing on River)

Coal Mining Province .....

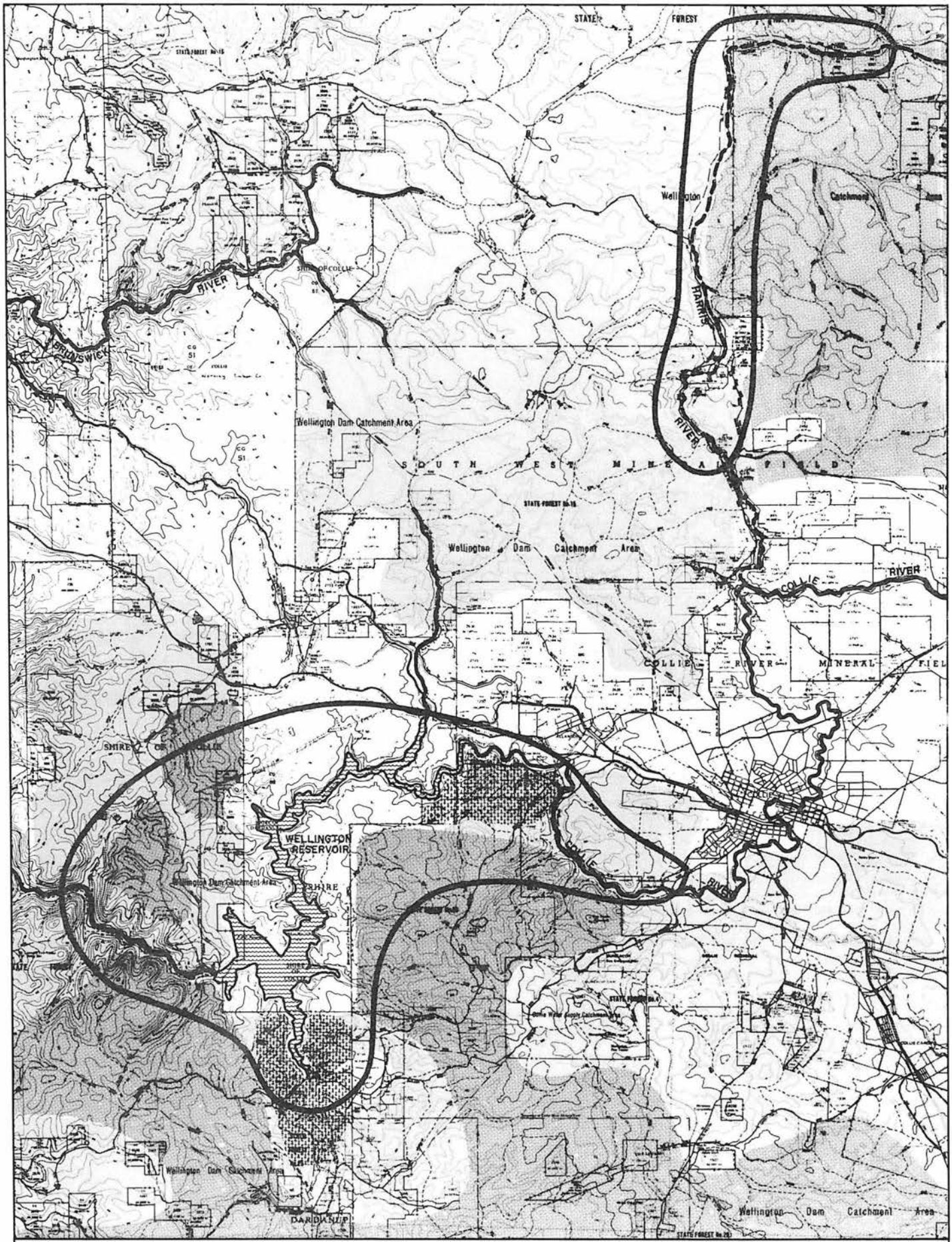
REGIONAL RECREATION FACTORS

Scale-1:250,000 Date-April 1984

Feilman Planning Consultants Pty Ltd

Plan 3

Plan 3



HARRIS RIVER DAM RECREATION SURVEY

Forest

Quarantined Forest

Pine Plantations

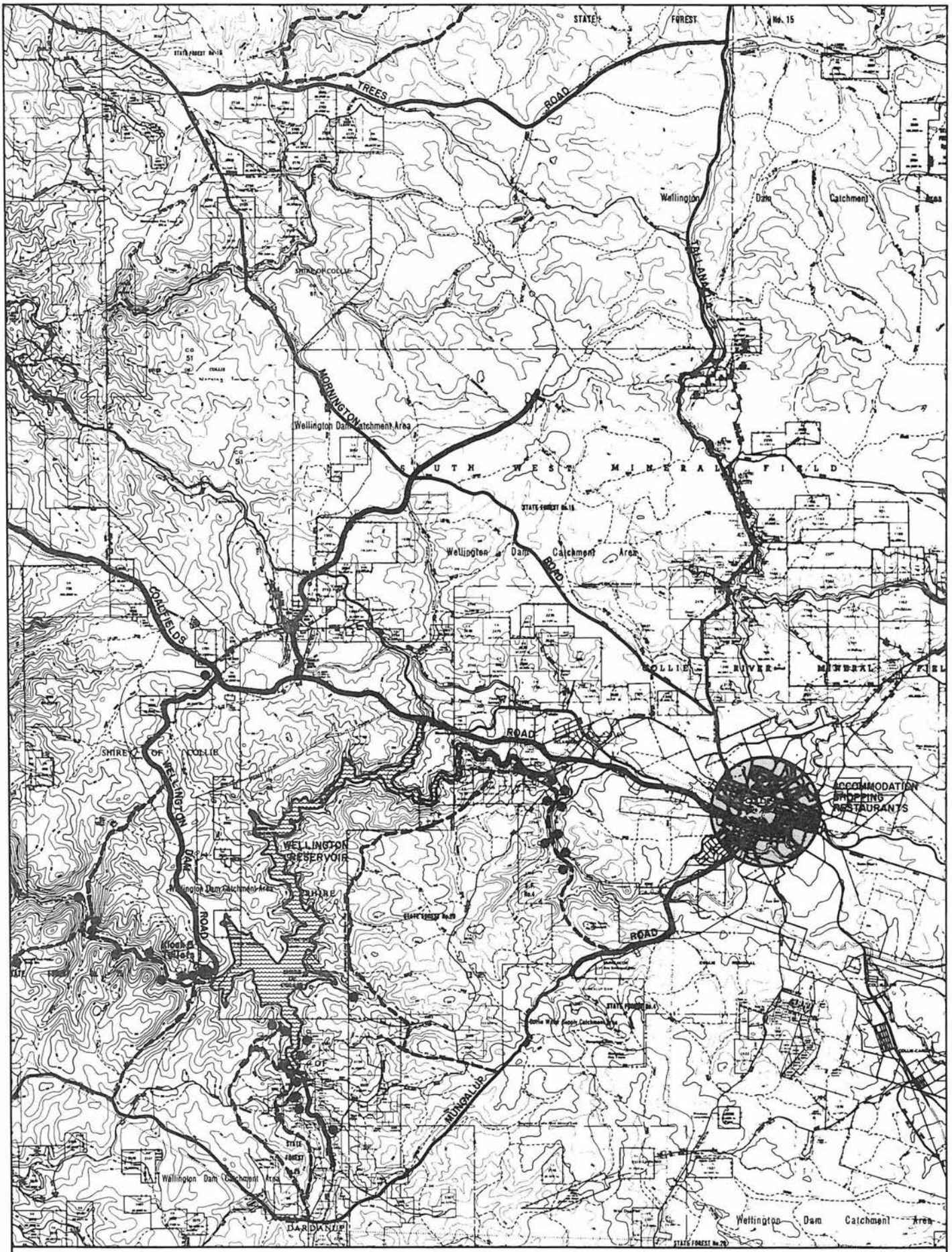
Freehold & Farmed

RECREATION RESOURCES

Scale-1:100,000 Date-April 1984
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Plan 4

Plan 4



HARRIS RIVER DAM RECREATION SURVEY

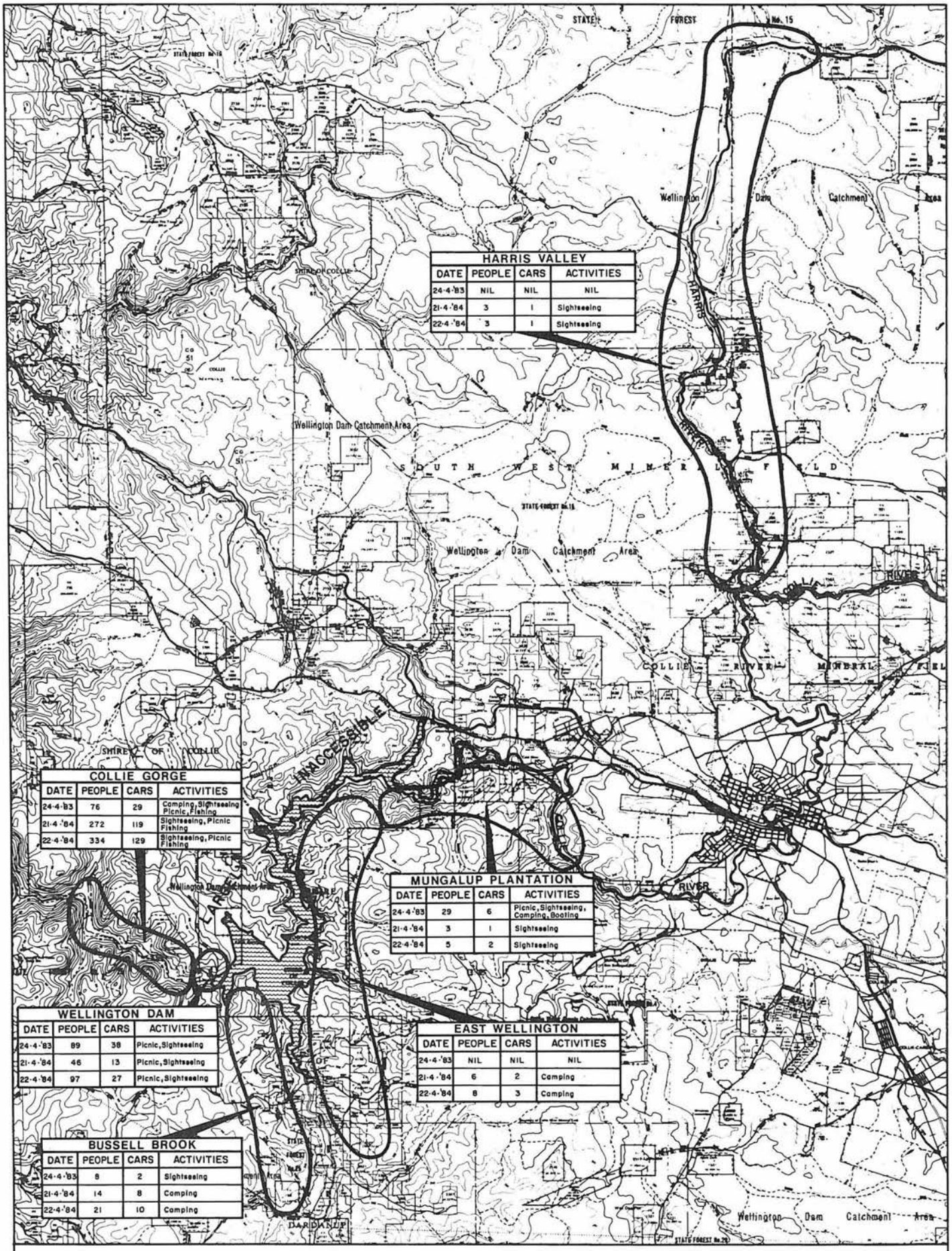
Main Sealed Roads .....
Main Unsealed Roads .....
Access Tracks .....
Minor Forestry Tracks. .....
Picnic & Wild Camping Sites ..

RECREATION FACILITIES

Scale-1:100,000 Date-April 1984
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Plan 5

Plan 5



HARRIS RIVER DAM RECREATION SURVEY

DISTRIBUTION OF RECREATION ACTIVITY

Scale-1-100,000 Date-April 1984
Feilman Planning Consultants Pty Ltd

Plan 6

Plan 6

62 Colin Street West Perth Tel. 322 3033

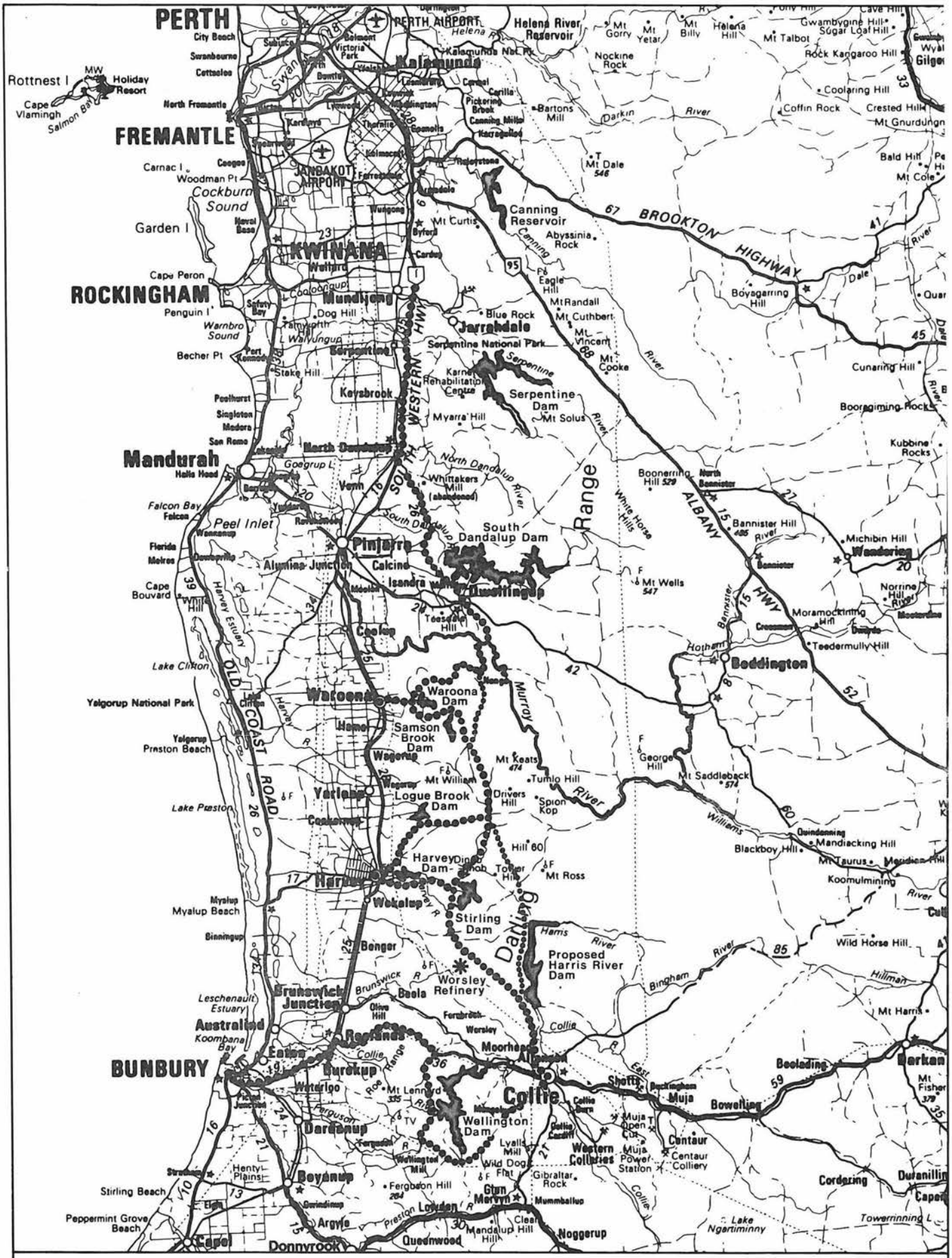


HARRIS RIVER DAM RECREATION SURVEY

DIMENSIONS OF PROPOSED HARRIS RIVER DAM

Scale-1:100,000 Date-April 1984
Feilman Planning Consultants Pty Ltd

Plan 7



HARRIS RIVER DAM RECREATION SURVEY

Existing Tallanalla Road .....

Potential Route(s) .....

FOREST/DAM RECREATION ROUTE

Scale-1:500,000 Date-April 1984

Feilman Planning Consultants Pty Ltd

Plan 8

HARRIS DAM ENVIRONMENTAL REPORT: RECREATION SURVEY

SUPPLEMENTARY REPORT

PRELIMINARY ASSESSMENT OF RECREATIONAL POTENTIAL OF WELLINGTON RESERVOIR

1.0 INTRODUCTION

In 1984 a limited survey of the recreation use of the Harris River valley, the shorelines of Wellington Reservoir and the Collie River gorge was carried out.

The survey formed part of an Environmental Review of the proposal to dam the Harris River for domestic water supply.

The principal findings of the survey were that:

- the Harris River valley has no significant recreation use and relatively low potential.

- the release of the Wellington Reservoir would result in a major addition to the recreational and tourist assets of the South-West of Western Australia.

The Report on the Survey recommended that a comprehensive plan of the Reservoir and its surrounds should precede any recreation or tourist development.

The West Australian Water Authority, which manages the reservoir and catchment, have sought a preliminary assessment of the likely development and the investment and return involved.

This report contains a superficial assessment of the development potential and provides approximate calculations of the investment and returns.

2.0 RECREATION AND TOURIST DEVELOPMENT

The potential recreation and tourist development around the reservoir will be a product of the:

(a) useability of the water, the shoreline and the forest frame.

(b) accessibility of various parts of the resource.

(c) availability of infrastructure and development finance.

Within obvious limits the market for recreation and tourist facilities based on the resource is assured. The recreation and tourism industry is supply led in the sense that the development of a resource or asset of resort generally creates a market.

Thus the establishment of facilities at the Wellington Reservoir will attract use from the Metropolitan Region principally in the summer period and from Bunbury and the South-West Region in the winter period.

2.1 USEABILITY OF THE RESOURCE

The Wellington Reservoir is a recreation resource of significant potential.

There are, however, a number of characteristics that influence both the type of use possible and the likely location of the use.

2.1.1. Water level fluctuation

The water level varies seasonally by up to 10 metres, resulting in a band of bare and often muddy ground between the waters edge and the permenent forest. Some of the upstream arms of the reservoir nearly dry up at the end of summer. Shoreline facilities should therefore be sited where slopes and water depths keep this band to a minimum.

2.1.2. Water Depth and Tree Stumps

Little of the reservoir floor was cleared before inundation. Thus the water has many tree skeletons projecting from the floor. Clearly therefore water-based activities must recognise the risks of this issue. i.e. power boating in shallow areas would be dangerous.

2.1.3 Reservoir Shape and Area

The water area is made up of a large central basin with several narrow arms. The effects of wind and wear action on, and the space or area available for, various forms of water-based activity needs to be taken into account. i.e. rowing and canoeing need different characteristics than power boating and sailing.

2.1.4. Land Conditions

The slope, vegetation type, environmental quality and existing use (e.g. pine plantation) of the land around the reservoir similarly controls the location, scale and type of development to support or provide an alternative to the water-based activity.

2.2 THE ACCESSIBILITY OF THE RESOURCE

The Reservoir has a maximum surface water area of 1600 hectares but it has more than 50 kilometres of indented shoreline.

Directionally simple and economic road access is a crucial element which controls recreation and tourist development.

The current road access to the Reservoir shoreline at present reflects the source of current use. Coalfields Highway and the Wellington Dam Road service the main source from the North and West.

A lower standard of access is provided via the Scenic Drive to the eastern arm of the reservoir which seems to primarily service Collie residents.

The remainder of the shoreline is accessed by a myriad of low grade forestry tracks requiring considerable local knowledge to navigate. These tracks are used only for forest management and marron fishing.

2.3 PROBABLE RECREATION USE

Based on consideration of the factors above, a review of literature on resevoir use in Australia and elsewhere, a potential development plan has been produced.

It has little status except that it has been used to indicate the value of investment possible and the likely returns from the recreational use of the reservoir.

The evolution of a real development plan for the reservior would require substantial research and a major policy decision by Government and the landowners.

2.3.1. Overall Concept

The principal elements of the overall concept are:

- All major activity is concentrated on the north-western sector of the reservoir. Existing access is good future access, economical environmental conditions for recreation and tourism are optimised.

- The remainder of the reservoir shoreline should remain largely in its current condition by sustaining the present accessibility.

2.3.2. Structure of Selected Area

The principal elements of the structure for Recommended Recreation Area are:

1. A Central Core Area abutting the existing Dam comprising:

   Major Public Recreation Facilities

   - Picnic areas
   - Lookouts
   - Boat launching
   - Swimming Sites i.e. floating jetties.
   - Active Recreation Areas (sport, etc.)

   Commercial Recreation Facilities

   - Shop and Restaurant
   - Boat Hire and Mooring (floating jetties)
   - Fuel Sales

   Recreation and Tourist Accommodation

   - Hotel/Motel/Guest House
   - Caravan Park and Cabins

2. An Outer Core Area opposite the main core comprising:

   Minor Public Recreation Facilities

   - Picnic and Recreation Areas
   - Boat launching and Yacht Club
   - Swimming

   Recreation Accommodation

   - Caravans, Cabins and Camping Area

3. A series of Camp Sites along the main arm of the Reservoir

   - Angling Club(s)
   - Rowing Club
   - Yacht Club
   - Scouts and Guides, etc.
   - Education Department/DYSR Camps

4. An optional part of the concept shows two areas for development i.e.

   Holiday Residential

   A self-contained village of approximately 300 low density residential lots (2000 sq.m. to 5000 sq.m.) isolated visually from the recreational core by forest terrain.

   Forest Residential

   A self-contained village of about 100 very low density retreat Residential lots (about one hectare) isolated visually from the recreation core by forest terrain.

The significance of these elements relates to the generation of revenue to meet the costs of the infrastructure and other public facilities in the area.

Clearly, other recreational and tourist facilities and activities could be established in place of or in addition to those set out in the concept. Other sites might be developed in place of or in addition to the locations suggested.

It is considered that the alternatives will make only a marginal difference to the overall investment and return.

3.0 VALUE OF INVESTMENT

The following section of the report itemises the value of investment for each of the core probable facilities identified in the Concept:

3.1 COMMERCIAL CORE

Public Recreation Facilities:

		$	
Boat Launching Ramps:	2 x $30,000 ...	.. $60,000	
Floating Jetties	4 x $30,000 ...	..$120,000	
Parking Areas (informal)	...	.. $50,000	
BBQ's and Picnic Area	...	.. $10,000	
Public Conveniences	...	.. $35,000	
			$275,000

Commercial Recreation and Tourism Facilities

Motel	40 units @ $40,000	$1,600,000	
Caravan Park	80 bays @ $8,000	$640,000	
Shop		$35,000	
Restaurant		$100,000	
Boat Hire and Fuel		$40,000	
			$2,415,000

Civil Works for Core

Internal Roads	$225,000	
Water Supply	$100,000	
Water Treatment	$250,000	
Electricity	$100,000	
		$675,000

TOTAL FOR COMMERCIAL CORE **$3,365,000**

3.2 OUTER CORE

Public Recreation Facilities

Boat Launching Ramp	$30,000	
Floating Jetty	$30,000	
BBQ and Picnic Facilities	$10,000	
Public Conveniences	$35,000	
Parking Area (informal)	$20,000	
		$125,000

3.2 OUTER CORE (CONTINUED)		B/Fwd	$125,000
Commercial Recreation and Tourism Facilities			
Chalet Park (30 Cabins)	$900,000		
Camping Area	$35,000		
			$935,000
Civil Works			
Internal Roads	$75,000		
Water Supply	$50,000		
Water Treatment	$50,000		
Electricity	$50,000		
			$225,000
Special Site			
Yacht Club (Building only - No pens)	$50,000		$50,000
TOTAL FOR OUTER CORE:			$1,335,000
3.3 CAMP SITES			
Three Camps for say Education Department, Department of Youth Sport and Recreation and say Scouts, at $500,000 each (10 cabins of 70 sq.m., Community Building and Kitchen, Floating Jetty)	$1,500,000		
Civil Works (Road Works, supply Electricity)	$200,000		
TOTAL FOR CAMP SITES			$1,700,000
3.4 CLUB SITES			
Two Clubs (say Angling and Rowing) comprising General Purpose Building, Boat Storage and Toilets and Ablution at $100,000 each			$200,000
3.5 GENERAL COSTS			
10km of Access Roads	$1,500,000		
Major Lookout and Carpark	$100,000		
			$1,600,000

Thus the total Investment that could occur in Tourist and Recreation Facilities would be of the order of $7,500,000.

3.6 HOLIDAY RESIDENTIAL

Civil Works

- Roads	$1,000,000	
- Effluent Treatment	$400,000	
- Water Supply	$300,000	
- Electricity	$300,000	
		$2,000,000
Buildings		
300 Cottages @ $30,000 each		$9,000,000
TOTAL INVESTMENT IN HOLIDAY RESIDENTIAL:		$11,000,000

3.7 FOREST RESIDENTIAL

Civil Works

- Roads	$500,000	
- Water Supply	$100,000	
- Electricity	$100,000	$700,000
Buildings		
100 Cottages @ $30,000 each		$3,000,000
TOTAL INVESTMENT IN FOREST RESIDENTIAL		$3,700,000

Thus a total of about $15,000,000 could occur in private recreational development.

4.0 REVENUE FROM DEVELOPMENT

The following section of this report analyses the income generated from the various facilities identified in the Concept Plan.

4.1 COMMERCIAL CORE

Sale of Hotel/Motel Site	$400,000
Sales of Caravan Park Site	$ 75,000
Sale of Combined Site for Shop/ Restaurant and Boat Hire	$200,000

TOTAL IMMEDIATE INCOME

Annual Income to Hotel/Motel/Restaurant	$1,226,400
Annual Income to Caravan Park	$ 131,000
Annual Income to Shop/Boat Hire	$ 600,00
TOTAL ANNUAL INCOME	$1,957,400

4.2. OUTER CORE

Sale of Site for Chalets	$250,000
Annual Income to operator of Chalets	$449,400

4.3 CAMPSITES

Sales of Sites $NIL

Thus the total income from sale of sites would be $925,000
and total annual income would be of the order of $2,406,800

4.4 HOLIDAY RESIDENTIAL

Sales of 300 lots
at $20,000 each $6,000,000

4.5 FOREST RESIDENTIAL

Scale 100 lots at $20,000 $2,000,000

The Total Income from the sale of the private recreation sites would be of the order of $8,000,000.

The Total cost of the public recreation facilities i.e. access road, picnic areas, launching ramps, jetties, lookouts, car parks, public conveniences, etc. is of the order of $2,000,000.

The Total cost of basic buildings, civil works for the Campsites is of the order of $1,700,000.

Thus the total cost of creating the public facilities is $3,700,000 - say $4,000,000.

The development and sale of the Holiday Residential and Forest Residential sites would generate a nett income of $5,300,000 - say $5,000,000 which covers the investment in public facilities.

Similarly the immediate income from the sale of Hotel/Motel site, etc., in the Commercial Core exceeds the cost of civil works to create the sites.

FEILMAN PLANNING CONSULTANTS

5th August, 1985

APPENDIX G

REPORT ON THE PRELIMINARY SURVEY FOR ABORIGINAL ARCHAEOLOGICAL SITES AT THE HARRIS DAM PROJECT AREA, COLLIE: INCLUDING REGIONAL ETHNOHISTORICAL DATA

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Consulting to Dames & Moore

26 April 1984

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ADDENDA:

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ABSTRACT

From the 30th June to the 3rd of July (1983) a preliminary archaeological survey for Aboriginal sites was conducted by P. Veth, M. Zlatnik and G. Quartermaine in the Harris Dam Project Area. This survey located 56 low to medium density stone artefact scatters. After analysis of these assemblages, a predictive statement for site location and type was formulated.

Subsequent to the July survey, the Water Authority redefined the reservoir basin as contained within the 218m contour (Damsite 1) as opposed to the previous FSL of 227m (Damsite 5). This resulted in an aerial extension of approximately 900 hectares, with the dam wall relocated to the south. A survey was conducted by P. Veth at the beginning of April (1984) in the new area and was designed to test the predictive statement for site location and type, discussed above. The survey located 11 small, low density surface artefact scatters and 8 isolated artefacts.

Almost all of the stone implements located are fashioned from quartz and are representative of known typologies and technological industries from the region.

1.0 INTRODUCTION

1.1 OBJECTIVES

The primary objectives of this project include:

- The surveying of the direct impact area which is defined as the land enclosed within the Full Supply Level (FSL) contour of 227m Above Sea Level (ASL).* The indirect impact area was identified as a 100m buffer zone around the perimeter of the FSL contour.

- The assessment of the nature and variability of Aboriginal cultural material with particular focus on site placement in relationship to landform, soil type, drainage characteristics and vegetation.

- The discussion of this data in a regional technological/temporal framework.

- To use this survey data to form a predictive statement about site placement in the entire reservoir basin.

- The provision of recommendations with a discussion of management options for future developments in the vicinity of the reservoir.

1.2 JUSTIFICATION

This preliminary survey is aimed at identifying the effects of proposed disturbance of the physical environment on historic and prehistoric Aboriginal sites. The Western Australian Aboriginal Heritage Act, 1972-80 makes provisions for the recording and preservation of places and objects customarily used by, or traditional to, the original inhabitants of Australia (see Addendum I for notes on the recognition of Aboriginal sites). In particular, the Act defines the obligations of the community to site protection (Addendum II). In addition to the requirements of this Act, Commonwealth environmental protection legislation requires that a survey of Aboriginal sites be undertaken as a component of an environmental study. Addendum III provides details on the recognition and procedure with human skeletal material. Addendum IV provides a glossary of terms used in the text.

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* Since the completion of the field survey, the Water Authority of Western Australia has decided the FSL for Damsite 5 to be 223.5m AHD.

Moreover, the data retrieved from archaeological surveys makes a valuable research contribution to the discipline of archaeology as well as to related multidisciplinary fields (see Schiffer and House, 1975).

1.3 SCOPE OF DEVELOPMENT

The surface area to be innundated is approximately 10.6km^2. The reservoir basin is approximately 12km north/south and 4.5km east/west at the widest point. The integrity of the archaeological material within this area will be lost through the proposed flooding. Loss of access to these sites essentially means the loss of important environmental/cultural data relevant to prehistoric adaptation to this inland valley system.

The results of other archaeological surveys for dam projects have shown that land in close proximity to the FSL is seriously disturbed, in the long term, by both human and natural agencies. In recognition of this long-term impact, a 100m buffer zone was identified as an indirect impact area around the perimeter of the FSL. It is expected that other facilities will be constructed in close proximity to the dam, although specific details of these are not available at present. It is expected that Tallanalla Road will be realigned to the west.

2.0 REGIONAL BACKGROUND

2.1 ENVIRONMENT

The Harris River lies in the Yilgarn Block, a stable shield area composed of Archaean crystalline rocks. Large areas of granite have invaded the original belts of metamorphosed sedimentary and volcanic rocks on the Block. Some reworking of the shield margins occurred during Proterozoic times. Phanerozoic sediments are restricted to local depressions and to drainage channels. The Harris River region is located in an area of Archaean granites with extensive covers of laterites (greater than 75%) of probably Tertiary age (Biggs et al., 1980).

The Harris River lies in the Darling Plateau geomorphological province. Weathering profiles on the Plateau may be as deep as 50m (Dimmock et al., 1974). Ferruginous and bauxite horizons in the upper portion of the weathered zone make up the lateritic profile. The Harris River basin is classified as a minor valley (Mulcahy et al., 1972). The basin belongs to the Yarragil Unit with narrow, flat swampy floors of orange earths and smooth slopes of gravelly sands (Churchward and McArthur, 1980).

The vegetation complexes of the Darling System approximate the Darling District of the South-West Botanical Province (Gardner, 1942). The proposed dam encompasses three types of vegetation complex. The valley bottom vegetation is termed the Yarragil Complex and is typified by open forest of Eucalyptus marginata - Eucalyptus calophylla with areas of low open-woodland of Melaleuca preissiana - Banksia littoralis. This complex has large areas of swamps having an average rainfall greater than 850mm. The maximum development of the swamps occurs in the upper reaches of the river where the vegetation varies from Melaleuca preissiana - B. littoralis to sedgelands. A variety of Melaleuca species occur in this area. The vegetation of the gravelly sand slopes of the valley is essentially an open-forest of jarrah-marri (Heddle et al., 1980). The proposed damsite is contained within State forest excluding a section of cleared farm land to the southeast of the basin.

2.2 PREVIOUS ARCHAEOLOGICAL WORK

No archaeological sites have previously been recorded within the area of the proposed dam. Contract surveys and reports by individuals have resulted in a number of sites being recorded in the Collie region (Novak, 1979; Pearce, 1981a, 1981b).

Thirty sites have been recorded in a 25km radius from the Harris River damsite (S0274, S0465 - S0468, S0959 - S0965, S0983 - S0991, S1352, S1514 - S1520). Site files are located with the Department of Aboriginal Sites, Western Australian Museum.

Site types include stone artefact scatters, stratified artefact assemblages, stone arrangements, quarry sites and one scarred tree. The majority of these sites consist of small, low density quartz artefact scatters. Importantly, however, are a number of large sites which represent the first documented evidence for relatively intensive use of the jarrah forests of the inland southwest (Pearce, 1981b).

Site distributions derived from reports and files place most of the recorded sites adjacent to drainage features. Of interest, is the tendency for the larger sites to occur adjacent to swamps and river pools (see Pearce 1981a: 57).

The oldest evidence for prehistoric occupancy in the southwest is dated to approximately 38,000 B.P. from the Upper Swan area (Pearce and Barbetti, 1981). Pleistocene dates have also been obtained from the Devil's Lair cave site in the Leeuwin-Naturaliste Block (possibly 33,000 years old) and from the Quinninup site complex (Dortch, 1977; Ferguson, 1977, 1981). A number of dated sequences falling within the Holocene period have yielded data on prehistoric adaptation and response to changing environmental parameters during the Recent transgression of the sea (Clarke and Dortch, 1977; Hallam, 1974; Pearce, 1978).

Prehistoric stone tool industries in the southwest have been classified into earlier and later phase industries (Dortch, 1977). The early phase industries have only been observed from a few well dated excavations. They include small, thick flake scrapers, bipolar cores, notched-denticulated pieces, flakes from discoidal cores, and single and multiplatform cores. These artefacts have been manufactured from a range of lithic materials including a distinctive fossiliferous chert. It appears that access to this chert was lost after the rise of the sea during the Recent period (Dortch, 1977; Glover, 1975; Ferguson, 1977).

Late phase industries generally found in archaeological contexts dating from 6,000 to 3,000 B.P. include the addition of geometric microliths, bladelets and backed blades (Dortch, 1975) and other componenets of the so-called "small tool tradition".

2.3 ETHNOHISTORICAL DATA

There is little historical literature referring to the Harris River area. To study its ethnohistory, therefore, it is necessary to study the historical literature from the Collie district in general.

The 1830's and 1840's in Western Australia was a period of great exploratory activity in the southwest regions. New areas were also being opened up for settlement in an effort to ease the congestion of eager settlers on the Swan River. The coast was followed, the rivers explored, the hills climbed in almost every direction, and every favourable report

was followed by a rush of pioneering settlers to the area. These settlers often recorded their experiences in the form of letters and diaries and it is from these, and the diaries of the explorers, that information about the earliest inhabitants, the Aborigines, can be gained.

Unfortunately, the Collie area, situated more than 60km inland in the heart of thick jarrah-marri forest, was not considered a promising area for settlement and, probably for this reason, was largely disregarded in exploratory adventures. The only real exploration of the area was carried out by John Septimus Roe, the Surveyor General, in March, 1830. He only went as far inland to what he named 'Roe Range' and 'Mount Lennard' (Roe, 1830). No Aborigines were seen on this journey although Roe noted that ".... the traces of them were evident and numerous in many places; and we passed several of their old habitations, which were of the usual temporary construction of boughs and grass" (ibid:85).

A settler, Mr Henty (1835) travelled from the Murray River to the Collie River, reaching it at a point 22 or 24km from the sea. But here he met only one Aborigine, and on his return journey, which took him a little further inland, no more Aborigines were seen until he reached the Harvey River.

Two years later Sir James Stirling, on his way back from Kojonup, cut westward across the hills towards the Leschenault Estuary from the Arthur River, but steered northward before reaching the Collie River, and by so doing crossed the Brunswick River. If he met any Aborigines on his route, or saw any sign of them, he made no note of it (Stirling, 1837).

These men, however, came the closest to Collie and the Harris River of any of the explorers, probably until Collie was finally settled in the 1880's (Williams, 1979). Others who explored the Coastal Plain stayed on the plain and the scarp but never ventured further inland (Dewar and Smith, 1833; Shenton and Wells, 1837). Those who crossed the Darling Range from Perth, to reach such places as Kojonup and King Georges Sound, generally did so by going due east from Perth or Pinjarra to Williams and then south (Bannister, 1833). Roe, in a later voyage to Albany, actually came back via Bunbury but passed quite a long way south of the Collie River, and made no note of the presence of any Aborigines (Roe, 1848).

By the time Collie was settled, the indigenous population of the southwest had been greatly reduced and their traditional way of life disrupted. If Aborigines did live in and use the Collie-Harris River area before European settlement, there is little mention of them in the historical records for the area.

This does not necessarily mean, however, that they were not there. Aboriginal groups of varying size and composition were encountered by explorers and settlers north, south, east and west of the Harris River-Collie district and there is no reason to suppose that this area in the centre was purposely avoided or ignored by Aboriginal groups. William Nairn Clark, for example, writes of numbers of Aborigines having been seen south-southeast of Kojonup and in the general area of Kojonup (cf. Bignell, 1971). John Bussell, an early settler at the Vasse, and between the Blackwood and Vasse Rivers, records meeting Aborigines and seeing signs of them both in the inland forest and on the coast (Bussell, 1833a; 1833b).

Bunbury, travelling in the hills near Harvey in 1836, met Aborigines dispersed over the hills searching for food (Bunbury and Morrell, 1930: 162-3) and on the coast in the summer months, met many more, much larger groups, fishing on the Leschenault Estuary and the rivers which ran into it (ibid: 76).

It is these coastal groups, between Harvey and Bunbury, which are probably of most significance in the study of Aborigines in the Collie area. Collie is situated in an area which is said to have been occupied by the 'Kaneang' or 'Ganeang' tribe, a tribe consisting of two matrilineal moieties - manitjmat or 'white cockatoo', and wardangmat or 'crow' - with a number of exogamous matrilineal divisions (or clans) under each moiety. The local descent group was patrilineal and each local group had ritual affiliations with totemic sites (Berndt, 1973: 50; Bates, 1906; Radcliffe Brown, 1930; Tindale, 1974). The area occuped by this tribe extended from the coast between Harvey and Bunbury in a southeasterly direction inland (Figure 1) and was bordered by the 'Bindjareb', 'Wilmen', 'Goreng', 'Mineng', 'Bibelmen' and 'Wadandi' tribes (Berndt, 1973: 51).

A closer inspection of the ethnohistorical sources, in conjunction with some environmental information from the coastal region around Bunbury, gives evidence that the coastal Aborigines moved quite regularly between the coast and the hills. These movements coincided with the availability of specific resources which changed with the seasons, and as the weather conditions improved or worsened. Groups encountered on the coast in summer were generally larger groups of 30 to 40 people, often only men and boys (the women remaining hidden). Bunbury, for example, while travelling around the Leschenault Estuary in December 1836, met a 'large' party of Aborigines in the north and another party of 100-200 men and boys a little further south (Bunbury and Morrell, 1930: 79). Likewise Collie and Preston (1829) travelling through the area in November had encountered a party of 30-40 on the mouth of the Collie and another, of at least 35 men and boys, on the mouth of the Preston.

Unfortunately, little exploration was attempted in the winter months. The only observations of Aborigines on the coast in winter, therefore, come from the journals of the early French explorers, Baudin (1800-1803) and Peron and Freycinet (1807) saw few Aborigines but noted their fires and on closer inspection found huts behind coastal sand dunes (Baudin, 1800-03: 173-4).

Some groups must, therefore, have stayed on the coast, at least until June. This coincides with the time the French explorers made their observations. Weather conditions in the region, however, make it unlikely that they would have stayed there throughout the winter, and certainly not in groups of the size encountered by summer time explorers. Bunbury, walking down the coast in November, had to detour inland to avoid large soaked areas, left so wet, he believe, by the October rains (Bunbury and Morrell, 1930: 92). In fact, a great proportion of the area would have been under water from June or July until October or November. Movement along the coast in these months would, therefore, have been both difficult and unpleasant for the Aborigines. It seems more than likely that they would have dispersed and travelled inland in the wet winter months, as the Aborigines on the Swan River are believed to have done (Hallam, 1975: 23-4).

Conversely the inland rivers are known to have dwindled to pools in summer (Roe, 1830: 83) as they do today. These pools are quite fresh but would have supported only a very small population, necessitating movement to more plentiful supplies - such as those on the coast.

Other resources would also have dictated movements to a great extent. Fish, an abundant resource around Bunbury in summer, was eaten in large quantities by the Aborigines who either speared them or caught them in specially constructed weirs in the estuary and rivers (Bunbury and Morrell, 1930: 87; Buller-Murphy, n.d.; Roth, 1902: 47). Other littoral resources such as ducks and swans (and their eggs) were also used (Bunbury and Morell, 1930: 74; Hammond, 1933: 16). These birds however, which still frequent the Leschenault Estuary and surrounding swamps today, fly inland to breed in winter (Frith, 1967). Similarly, the types of fish commonly caught by Aborigines - primarily sea mullet and 'pilchard' (probably yellow-eyed mullet) - swim out to sea at the end of summer (Thomson, 1974). Such large groups of Aborigines as were encountered by Bunbury and others in summer, therefore, could not have survived in such numbers between June and September.

The yam, or 'warryn' on the other hand - another resource said to have been used prolifically by the Aborigines in the Bunbury area - was found only in damp places in the hills during the winter (Hammond, 1933: 28-9; Meagher, 1973: 136ff.).

On this basis it seems reasonable to assume that the large summer coastal groups would have dispersed in smaller groups during winter, across the coastal plain and into the coastal uplands. Nor does it seem unreasonable to assume that some of these groups would have gone as far inland as the Harris River. Indeed the 'traces' and 'old habitations' found by Roe along the Collie River (1830: 85) were probably the remnants of groups who had spent the winter in the shelter of the hills.

According to Williams (1979: 121-2) there was a second phase of Aboriginal settlement in the Collie-Harris River area. This began in the 1930's with the growth of the timber industry. Men who had been to the Murchison in the hope of finding quick wealth in gold returned to Collie to work, bringing Aborigines from the north with them (presumably as labourers). These, according to Williams were 'Yamagee people' and they were later followed by other members of their tribe and by members of what Williams calls the 'Noonah tribe' from the east of the ranges. The two groups held joint corroborees, originally at Telfer's Pool near Collie and later at 'Woggary Pool' (8-Mile Pool) on the Darkan Road. Their main settlements were at 'Air Springs' on the Harris River, 'Twoup' on the Williams Road and, later, at Boronia Gully.

Aborigines of the south believed the 'Janga' or 'Kaanya' (spirits) lived. One such 'Kaanya' was a 'Wogal' or mythical snake, one of which inhabited part of the river near Busselton. Perth Aborigines also believed in a winged serpent or 'Waugal' (Berndt, 1973: 52). 'Woggary Pool' at Collie, Williams states, was believed to be inhabited by a 'Woggary', a nocturnal water snake, as was Minninup Pool. Whether this was a belief which developed after the arrival of the North-West Aborigines, or whether the belief was passed on by the southern groups who had passed through the area in earlier times is unknown. But it is possible that there were other such 'wynnitch' places on the Harris River of which Williams had no knowledge, a point which would probably become clearer in an ethnographic study of the area.

3.0 ARCHAEOLOGICAL RESEARCH FRAMEWORK

3.1 THEORY

Data derived from contract archaeological surveys can prove more analytically useful when evaluated in reference to a research framework (Goodyear, 1978). Given the preliminary nature of the present survey the following problem domains were addressed:

- To assess variability in the distribution and nature of Aboriginal cultural material within the FSL.

- To assess site placement in relation to:
  - drainage features
  - soil type
  - topography
  - vegetation type

- To relate the minimum computed density figure for the reservoir basin to other figures derived from similar surveys of inland forests

- To assess assemblage data within a regional technological and temporal framework.

3.2 METHODS

As no samples were collected from the field, it was important to standardise a recording format that would address these questions. Site data was recorded under the following categories:

- Site dimensions - criteria for dimensions
- Site zones - criteria for zones
- Assemblages - type/quantity/material/attributes
- Physiographic situation - landform type/land surface type/ aspect/slope/vantage
- Archaeological formation - soil/stratigraphy/exposure/visibility
- Environmental setting - local and regional flora/fauna, drainage features, surface visibility.

3.3 SITE DEFINITION

For the purposes of this survey a site was defined as two or more artefacts in close association in respect of open sites. Any clearly stratified cultural material was recorded as a site. Solitary artefacts, named Isolated Finds, were also recorded and plotted, although they will not be registered as sites.

3.4 SURVEY STRATEGY

The area surveyed (1,060ha) consists of a narrow band of land on each side of the Harris River and its main tributary, Tullock Creek (Figure 2). The main access road, Tallanalla Road, is located parallel to the western side of the Harris River until the eastern bend in the river at the northern end. This road and side-branching roads (Old Harris Road and Division Road) provided a useful broad baseline for regularly spaced transects across the western half of the proposed reservoir area. These transects were spaced at intervals of 250m along the north-south length of the survey area (Figure 2). Several areas on the western half were chosen for systematic quadrat sampling (the dam wall site, land surrounding several large swamps). A mixture of transect and quadrat surveying strategies were used (i.e. a multi-survey strategy) in order to assess different parameters. Transects are a more efficient means of estimating site variability in different ecotones to establish maximum site densities. The large quadrat samples aim to show clustering of elements, patterns of association and intersite

relationships (after Schiffer et al. 1978). At this preliminary stage these strategies aim to provide a predictive model by which subsequent survey and sampling can be conducted on a cost and in a research efficient manner.

The forest to the east of the Harris River is under dieback quarantine restrictions. As the river could only be crossed at several fords (due to high water conditions) and vehicular access was prohibited, the same degree of control could not be exercised as was possible on the western side. It was therefore decided that a system of zigzag transects would be the most efficient means for surveying this area.

In the southeast portion of the survey area, transects were limited by the boundaries of several farming properties. Paddocks were heavily grassed at the time of the survey, and visibility was minimal.

Surface visibility in the remainder of the survey area varied from almost zero in several swamp/river pool margins to as high as 70% in recently burnt areas. Average surface visibility in the valley bottom was approximately 20-30% while visibility of the valley slopes ranged from 30-40%. Visibility was highest in open laterite patches and in clearings, paths or roads. The south of the survey area has been subjected to controlled burning within the last two years. The northern zone was burnt earlier than the southern zone.

When exposed, the quartz artefacts were clearly visible on the varying backgrounds of leaf litter, orange/black earth or lateritic soil. Only one quartz outcrop was located during the survey (see Section 4.0 - Survey Results).

4.0 SURVEY RESULTS

4.1 DESCRIPTION OF SITES

A total of 53 sites were recorded within and adjacent to the proposed reservoir basin. Forty-eight of these sites consisted of surface scatters of quartz artefacts. The remaining sites included stratified artefacts which were located in road cuttings and in the matrix of upturned tree roots.

A summary of these sites is presented in Table 1.

As shown in Table 1, the majority of sites recorded contained 10 or less stone artefacts. Sites which contained between 11 and 100 pieces comprised 20.7% (N=11) of the sites while only 3.8% (N=2) contained over 100 pieces. Figure 3 indicates that the majority of the sites were located on relatively flat ground adjacent to the river system and its tributaries (67.9%, N=36). Only small, low density sites were recorded on high gradient valley slopes. The only outcrop of quartz in the survey area was located at point 47 (Figure 3) on a medium gradient valley slope. At that site where there appears to have been some quarrying activity and artefact manufacturing (e.g. several single platform and bladelet cores as well as associated debitage).

Most of the sites (71.7%, N=38) were located on areas of laterite. These areas are well drained and have good surface visibility. These factors obviously influence site recovery rates when compared to the rest of the survey area. It is significant that 60.4% (N=32) of all sites were located on, or closely adjacent to, forestry tracks and paths.

Five clearly stratified sites were located during the survey. These sites were visible due to ground disturbance (such as recent road construction, culvert construction and upturned trees with their root systems intact). The artefacts noted in situ were eroding from the orangey clay/earth that typifies the valley bottom of this area. A horizon of leached, yellow sand was noted in the vicinity of site 63 (S1878).

TABLE 1

SITE SUMMARY DATA (Key Overleaf)

SURVEY NO. (Figure 3)	W.A. MUSEUM NO.	GRID REF 1:250,000	SITE TYPE	ARTEFACT DENSITY	SOIL TYPE	TOPOGRAPHY
3	S1847	4189 3202	A.S.	L	Lateritic	VS - h/g
5	S1848	4192 3201	A.S./S.T.	M	Orange clay	VB - f
7	S1849	4191 3202	A.S.	L	Orange clay	VB - l/g
9	S1850	4188 3203	A.S.	L	Lateritic	VS - m/g
10	S1851	4189 3203	A.S.	L	Lateritic	VB - f
11	S1852	4185 3204	A.S.	L	Lateritic	VS - l/g
14	S1853	4184 3210	A.S.	L	Lateritic	VS - f
15	S1854	4184 3209	A.S.	M	Lateritic	VS - l/g
17	S1855	4186 3211	A.S.	L	Lateritic	VB - l/g
19	S1856	4186 3212	A.S.	L	Lateritic	VB - l/g
21	S1857	4179 3216	A.S.	M	Lateritic	VB - f
23	S1858	4182 3216	A.S.	L	Lateritic	VB - f
24	S1859	4186 3216	A.S.	L	Lateritic	VS - l/g
26	S1860	4194 3218	A.S./S.T.	L	Lateritic	VS - l/g
30	S1861	4197 3220	A.S.	M	Lateritic	VS - l/g
31	S1862	4195 3224	A.S.	M	Lat./Humic	VB - f
33	S1863	4216 3224	A.S.	M	Lateritic	VB
34	S1864	4211 3222	A.S.	L	Lateritic	VB
40	S1865	4182 3225	A.S.	H	Lateritic	VS
46	S1866	4187 3231	A.S.	L	Lateritic	VS - m/g
47	S1867	4191 3231	A.S.	M	Lateritic	VS - m/g
51	S1868	4200 3245	A.S.	L	Lateritic	VB - f
52	S1869	4196 3240	S.T.	L	Orange clay	VB - f
53	S1870	4194 3241	A.S.	L	Clay/silt	VB - f
54	S1871	4192 3242	A.S./S.T.	H	Lateritic	VB - f
55	S1899	4190 3243	A.S.	L	Sand/silt	VB - f
57	S1872	4187 3244	A.S.	L	Sand/silt	VB - f
58	S1873	4188 3242	A.S.	L	Sand/silt	VB - f
59	S1874	4189 3245	A.S.	L	Sand/silt	VB - f
60	S1875	4187 3247	A.S.	L	Sand/silt	VB - f
61	S1876	4187 3244	A.S.	L	Sand/silt	VB - f
62	S1877	4187 3244	A.S.	L	Sand/silt	VB - f
63	S1878	4189 3247	S.T.	L	Sand/silt	VB - f
64	S1879	4188 3248	A.S.	M	Lateritic	VB - f
65	S1880	4189 3248	A.S.	M	Lateritic	VB - f
67	S1881	4191 3252	A.S.	L	Lateritic	VB - f
70	S1882	4208 3268	A.S.	L	Lateritic	VB - l/g
71	S1883	4184 3258	A.S.	L	Lateritic	VS - l/g
79	S1884	4193 3266	A.S.	L	Lateritic	VB - f
80	S1885	4193 3265	A.S.	L	Lateritic	VB - f
87	S1886	4200 3288	A.S.	L	Lateritic	VB - f
89	S1887	4204 3294	A.S.	L	Lateritic	VS - f
91	S1888	4202 3299	A.S.	L	Lateritic	VS - f
91B	S1889	4196 3299	A.S.	L	Lateritic	VB - f

SURVEY NO. (Figure 3)	W.A. MUSEUM NO.	GRID REF 1:250,000	SITE TYPE	ARTEFACT DENSITY	SOIL TYPE	TOPOGRAPHY
92	S1890	4203 3302	A.S.	L	Lateritic	VS - f
95	S1891	4203 3306	A.S.	M	Clay/silt	VB
97B	S1891	4203 3309	A.S.	M	Clay/silt	VB
102	S1893	4201 3312	A.S.	L	Lateritic	VB - l/g
104	S1894	4208 3313	A.S.	L	Lateritic	VB - f
105	S1895	4209 3319	A.S.	L	Silt	VB - f
106	S1896	4210 3319	A.S.	L	Laterite	VB - f
109	S1897	4216 3318	A.S.	L	Laterite	VS - l/g
111	S1898	4250 3315	A.S.	L	Laterite	VS - f

KEY FOR TABLE 1

SITE TYPE	A.S.	Artefact Scatter
	S.T.	Stratified Site
ARTEFACT POPULATION	L (low)	0 - 10 pieces
	M (medium)	11 - 100 pieces
	H (high)	greater than 101 pieces
TOPOGRAPHY	VB - Valley Bottom	
	VS - Valley Slope	
	f - flat	
	l/g - low gradient slope	
	m/g - medium gradient slope	
	h/g - high gradient slope	

All of the artefacts, except one, were manufactured from quartz. One flake appears to have been manufactured from fossiliferous chert. Artefacts that could be viewed without disturbing the integrity of the site included bladelet cores, flaked pieces (amorphous cores), flakes and chips.

These sites are located in low, marshy areas, which are likely to be silted over during occasional high water events. The nature of the stone artefact assemblages and the geomorphic context indicate that these sites are highly suitable (and likely to be productive) for excavation (see Section 8.0 - Recommendations).

The assemblages of quartz stone artefacts consisted primarily of flakes, chips and flaked pieces. Several bladelet cores (discoidal) were noted in clear quartz. The range of formal tool types was large, although they were numerically small. Several ovate backed pieces were recorded, as well as naturally backed chips and flake fragments. Other tool types included notched and denticulate flake "scrapers" (Jones, 1971) as well as several bladelets that appeared to be unretouched under 10 times magnification. A burren type adze slug was recorded in one of the high density sites (location 47, S1867). Only several bipolar cores were noted during the survey. Extreme care was taken to identify this artefact as reports of its relative abundance varied greatly in several subsequent surveys of forests (Pearce, 1981b; Anderson, 1982). It is assumed that the bipolar core is a techno-morphological product which can best be identified using a class of experimentally tested damage attributes (Kamminga, 1978). Kamminga summarizes these damage attributes on bipolar cores of fine-textured silicates as:

- The appearance of percussion ridges and stubs
- The high frequency of step, retroflexed hinge and hinge fractures
- Internal cracking and undetached flakes
- The angle and positioning of the fractures along the margins of stubs and ridges
- Points and areas of intense crushing.

Although no systematic attribute analysis has been carried out at this preliminary stage, the intuitive impression is that less than 2% of the artefacts noted are visibly retouched or have macroscopic signs of use wear.

No grinding material was recorded during the survey.

4.2 DESCRIPTION OF ISOLATED FINDS

Figure 3 shows that all of the isolated finds are located in close proximity to the Harris River and its tributaries. These items mainly consist of quartz chips and flakes, although several clear examples of notched and steep-sided scrapers were recorded (Allen, 1972). Collectively these items are useful in explaining land use and settlement patterns.

5.0 CONCLUSIONS

The ethnohistorical evidence suggests seasonal use of the Collie-Harris River by small subsistence groups in the winter months.

The density of archaeological sites in the survey area ($5/km^2$) is extremely high in comparison to the results of several other surveys in the jarrah forest of the southwest (Anderson, 1982; Pearce, 1981b). For comparability, however, it is important to note that a site is defined in this survey as two or more artefacts in association. As discussed above, a majority of the surface scatters recorded in this survey contained 10 or less pieces. In contrast to Anderson's survey (1982) a considerable number of isolated finds (flakes, cores, scrapers) were also located.

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 valley-bottom vegetation (Section 2.1) of open forest/low open woodland. Only a few sites were located within the 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 chert in one stratified site and early Holocene dates from similar forest environments (B.Pearce, pers. comm.) suggest earlier material is likely to be found here. While bladelet and microlithic stone manufacturing techniques are assumed to date from the mid-Holocene, the bipolar core spans a long period in southwestern prehistory with an antiquity of over 19,000 B.P. (Ferguson, 1977).

Excavations at the three prime stratified areas (S1848, S1869 and S1878) could help to refine the broad two phase stone industrial sequence available at present.

6.0 DAM EXTENSION SURVEY

6.1 SURVEY STRATEGY - TESTING THE PREDICTIVE MODEL

Subsequent to the July (1983) survey, the Water Authority of Western Australia (Water Authority) decided to assess a new proposed damsite to the south (see Figures 3 and 4).* The FSL of 227m in the previous plan has now been altered to 218m. The proposed damsite (Damsite 1) was located close to the confluence of the Harris and Collie Rivers. This relocation resulted in an aerial extension to the reservoir basin of approximately 900 hectares.

The landforms and vegetation suites enclosed by Damsite 1 are largely similar to those within the previous survey area. This minor valley is characterized by flat swampy floors of orange earth and smooth slopes of gravelly sands (Churchward and McArthur, 1980). The valley bottom and gravelly sand slope vegetation is still broadly comparable in the south, however, with less well developed swamp complexes than found on the upper reaches of the Harris (Heddle et al., 1980).

A predictive statement of site location and type was used to direct surveys of the dam extension. The statement is based on the following significant results of the July survey:

- Most sites contained 10 or less pieces (75.5%, N = 40)
- The density of sites in this (July) survey area was high, in comparison to other southwest jarrah forest surveys (5/km^2). A site is defined as two or more pieces in close association
- Most of the sites (and isolated finds) are located adjacent to well developed drainage channels of the valley system on reasonably 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 product of increased surface visibility.

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* After the completion of this study, the Water Authority have decided that the original damsite (Damsite 5) would be the constructed at FSL 223.5m AHD. This information in Section 6.0 is retained to outline the Water Authorities' committment to archaeological surveys in new potential damsites.

To assess these problems, a two stage survey strategy was used.

Firstly, all areas in the dam extension with the attributes of low declination and proximity to well defined drainage were demarcated on 1:50,000 scale maps. Areas under present cultivation were excluded, given the present brief from the Water Authority. The three survey target areas are shown in Figure 4. Given that the study area is purely a minor valley system and topographic variation is limited to the slope variable, the resolution and predictive power achieved in larger, regional landform studies cannot be realised here. Therefore, target areas are relatively few in number with somewhat arbitrary boundaries. It is argued that the medium to high gradient slopes yielded little material in the July survey and are subsequently excluded from the first stage of the survey. The three largest target areas were intensively surveyed on foot using a combination of zigzag and evenly spaced linear traverses. In all cases, the creeks flowing into the Harris were used as datum reference lines.

The second survey strategy involved blocks of four evenly spaced traverses (at 10m intervals) - in an east/west direction - through several areas characterized by medium to high gradient slopes. This was carried out in areas of the proposed reservoir basin adjacent to the north-south Collie - Tallanalla Road. The aim of these traverses was eventually to act as a check on the predictive statement - which assumes that these areas should only have a very low density of small artefact scatters, with very occasional isolated artefacts.

Surface visibility was similar to that recorded from the previous damsite, ranging from 20-30% (on average) in valley bottoms up to as high as 70-80% in cleared areas, comprising previous forestry tracks, logging camps and gravel quarry pits.

6.2 SURVEY RESULTS

A total of 11 sites were located within the dam extension. All of these sites consisted on low density surface scatters of quartz artefacts. Eight isolated quartz artefacts were located and recorded in the field.

All of the clusters of stone artefacts, as well as the isolated finds, were located within the three target areas. No cultural material was located on the medium to high gradient slopes covered by systematic traverse.

A summary of the sites, and their context, is given below, with comments on the isolated finds. See Figure 4 for site and isolated find location.

S1966 G.R. SI50-6 1:250,000 420 324

Nine quartz artefacts were located adjacent to a fork of the Harris River Road (Protected Road Status), approximately 200m north of the point where it crosses the Harris River. The artefacts occur within a 7m diameter area, partially on the track and on its margin on a lateritic soil. The artefacts include 1 milky quartz bipolar core, 2 flaked quartz pieces, 4 fragments of pink quartz and a milky quartz flake.

S1967 G.R. SI50-6 1:250,000 418 319

This small site of 3 quartz artefacts is located 80m south of a small east/west bearing creek, 1.1km west from the Collie - Tallanalla Road, in the vicinity of Scar Road. Artefacts comprised one quartz flaked piece (measuring 5.2cm along its greatest axis) and three quartz chips (< 1.5cm). This material is located on a gentle slope of lateritic/humic soils adjacent to the thickly vegetated creek bed.

S1968 G.R. SI50-6 1:250,000 418 319

This site consists of two quartz primary flakes and a quartz fragment located in a similar environmental context to the above site, 400m to the east, adjacent to the creek.

S1969 G.R. SI50-6 1:250,000 418 319

A small outcrop of crazed quartz occurs approximately 100m east from the above site, approximately 100m south from the creek. One single platform core (quartz) and several primary flakes were located in the vicinity of the outcrop. Although the quartz appears to be largely fractured through natural agencies, several fragments in addition to the artefacts, showed signs of human alteration. The quartz outcrop is located on a medium gradient slope and downslope lateral movement of quartz fragments appears to be considerable. Vegetation, here, is less dense than the valley bottom associations (See Section 2.1) and is typified by the jarrah-marri open woodland.

S1970 G.R. SI50-6 1:250,000 418 319

This site is located approximately 200m east of the previous site occurring adjacent to Scar Road. Five quartz artefacts located comprised a single platform bladelet core, three primary flakes and a steep-sided scraper measuring 4.9cm along the longest axis of the flake blank. Vegetation at this site becomes more dense (with proximity to the Harris) with closer stands of jarrah and thick understorey associations dominated by B. littoralis. The soil in this low gradient area is predominantly lateritic.

S1971 G.R. SI50-6 1:250,000 419 320

Five quartz flakes were located within an area of $5m^2$, 50m west from the Collie - Tallanalla Road, 20m north of the Scar Road Creek. These flakes are located on lateritic gravels.

S1972 G.R. SI50-6 1:250,000 418 319

Five quartz pieces were located 500m west from the Collie-Tallanalla Road, approximately 100m north from the creek, over an area of $3m^2$. One of these artefacts is a steep - sided scraper, showing characteristic edge-crushing and step fracturing. The site occurs on lateritic gravels on a low gradient slope.

S1973 G.R. SI50-6 1:250,000 417 320

Three quartz primary flakes occur in an orange earth within the root matrix of an upturned jarrah tree. The site is situated approximately 700m west from the Collie - Tallanalla Road and approximately 20m north from the creek. Several quartz chips were noted in the vicinity of the tree base. The gently sloping ground is characterised by lateritic/sandy soils.

S1974 G.R. SI50-6 1:250,000 419 317

This site is located approximately 600m west of the Collie - Tallanalla Road on Saxa Road. Within a 5m section of this forest road, 1 quartz tula adze slug (3.1cm along its greatest axis), 3 milky quartz flakes and 2 quartz fragments were noted. The site occurs on lateritic gravel, surrounded by medium density jarrah-marri forest, with a relatively open understorey.

S1975	G.R.	SI50-6	1:250,000	419 317

One large single platform quartz core and three chips were located next to the intersection of Saxa Road and the SECWA transmission line. The material is located on a partially machine-scoured lateritic surface. This material is next to a low depression, which has swamp characteristics and is a potential soak.

S1976	SI50-6	1:250,000	419 317

Two quartz artefacts were located on the transmission easement, approximately 30m north of the Saxa Road intersection. Both artefacts are crystal quartz flakes, approximately 2.5 and 2.9cm along their greatest axis. The environmental context is similar to the previous site (S1975).

The location of the eight isolated finds are shown in Figure 4. Descriptions of these are summarized below:

- Quartz fragment with retouch along one edge. Approximately 1.5cm along the largest axis
- Amorphous conglomerate manuport, 5.1x5.2x4.1cm
- Clear quartz, single platform bladelet core 2.5cm along the greatest axis
- Milky quartz flaked piece 5.9cm along greatest axis
- Pink quartz multiplatform core 5.3cm along greatest axis
- A milky quartz flake, 1.9cm along greatest axis
- Two clear quartz chips.

6.3 DISCUSSION

In reference to the relevant probability statements outlined in Section 6.1, the following results were recorded from the sample of 11 sites:

- Prediction 1 - Sites will contain 10 or less pieces. All of the 11 sites recovered contained less than 10 pieces, with a mode of 3 pieces

- Prediction 2 - Most sites (and isolated finds) will be located adjacent to well developed drainage channels on flat ground. This guiding statement determined the three survey target areas. Sites were located in each of these areas 7,1 and 3 sites were located in target areas 1,2 and 3 respectively (See Figure 4).

- Prediction 3 - The majority of sites will be located on lateritic soils. All but three of the sites, S1967, S1968 and S1973 were located on lateritic soils, in several cases well exposed due to forestry tracks. Site S1973 occurs on a lateritic/sandy soil, characteristic of areas within the Harris basin, and areas to the south of Collie. Site S1967 is located on a laterite/humic soil horizon. The nine sites on purely lateritic soils are assumed to be well drained areas, yet in close proximity to a water supply.

- Prediction 4 - The majority of sites will be located on/or adjacent to forestry tracks and paths - this is seen largely as a product of increased surface visibility. Six of the 11 sites were located on, or adjacent to, forestry tracks/paths.

The range of tool types and lithic technologies evident in the small number of artefacts recorded are similar to those recorded in the July survey. The adze, and bladelets, are likely to be indicative of the mid - Holocene, or more recent age, of most of the assemblages (See Section 5.0).

The utility of the predictive guiding statement is shown by the fact that cultural material was located in all target areas, appearing to be similar in location and type to those in 227m FSL reservoir basin. Although no material was located in traverse surveys of the medium to high gradient slopes it is possible that more extensive (and time consuming) systematic traverses along the entire length of this area may have recovered several small sites and isolated finds, as described from the northern basin area. Repetitive and intensive surveying of non-target areas in zones adjacent to the originally systematically surveyed 227m FSL reservoir basin is considered to be limited in terms of the types of questions that can be answered.

7.0 SIGNIFICANCE OF SITES

The theoretical approach to site significance, adopted in this report, assumes that significance is only determinable in relation to some frame of reference, such as the ability of specific archaeological data to answer regional research questions (cf. Raab and Klinger, 1977).

Changing priorities occur in the expanding discipline of archaeology. The research approach of scaling sites through quantitative analysis of site attributes such as site variety and clarity (cf. Glassow, 1977) is considered to be unacceptable. On a regional scale, the sites and isolated items located within the Harris reservoir basin would rank low in terms of significance based on site variety, quantity, clarity, integrity and even environmental context (after Glassow, 1977). This material is significant, however, in terms of detailing patterns of exploitation in this hinterland, forest zone. For example, the high density of small sites located in the present survey is at variance with the findings of other jarrah forest surveys closer to the scarp (see Anderson, 1982). These differences are likely to be informative in postulating models for patterns of movement in these more interior regions.

It is argued, here, that individual site protection of this type of material is subsumed by the need to ensure the survival of a representative regional data base. The types of site located at the Harris, though different in their patterning and distribution are replicated in type in the broader region (see Pearce, 1981b).

The stratified sites mentioned in the text (Section 4.0) are likely to be significant in their ability to answer questions relating to:

- Cultural sequences
- Lithic technological sequences
- Length/duration of occupancy in this archaeologically "unknown" area.

More specific questions can only be made within broad problem domains, and await the results of preliminary testing at the three prime locations.

8.0 RECOMMENDATIONS

The 64 sites and 69 isolated finds reported in Section 4.0 of this report will be destroyed and/or loose their integrity in the event of the construction of the dam. The Principal is therefore required to make an application to the Trustees (W.A. Museum) for permission to disturb these sites (as outlined in Section 18 of the Western Australian Aboriginal Heritage Act, 1972-80). In order to mitigate the impact of the proposed development on the cultural material, the following salvage/research recommendations are made:

- A salvage/research programme should be undertaken. By taking into account regional cultural sequences and the results of this survey, an explicit research framework would direct the surveying, sampling and research of the salvage programme. It is recommended that testing/excavation be carried out as part of this programme in the three prime locations identified in Section 4.0 of this report. Detailed in-the-field recording should be carried out at an assemblage and attribute analytical level on all the large sites (i.e. those with more than 100 pieces) and the archaeological material be collected. Collection of surface material is not considered to be warranted, given its replication in the broader region.

- Human interference with Aboriginal sites is an offence (unless authorised under the Act) as outlined in Section 17 of the Aboriginal Heritage Act, 1972-80. All archaeological sites in the 227m contour basin have been pegged and/or flagged. It is recommended that the Water Authority undertake to inform all personnel associated with site investigations or construction of the obligations under the Act.

- One named ethnographic site, relating to the water serpent (Waugal) has been identified within the catchment area. This site, on the northern reaches of the Harris, is detailed in the ethnographic report (see Appendix I). No archaeological material was noted in the vicinity of this swampy depression.

9.0 BIBLIOGRAPHY

Allen, H. (1972). Where the crow flies backwards: Man and Land in the Darling Basin. Unpublished Doctoral Thesis, Australian National University, Canberra.

Anderson, J. (1982). Survey for Aboriginal sites in the South Canning Dam Project Area, W.A. Unpubl. report, Department of Aboriginal Sites.

Bannister, T. (1833). "A Report of Captain Bannister's Journey to King Georges Sound over Land." pp.98-109 In. Cross, J. (ed.) Journals of Several Expeditions ...

Bates, D. (1906). The Marriage Laws and some Customs of the Western Australian Aborigines. Victorian Geographical Journal. 23: 36-60.

Baudin, N. (1800-1803). The Journal of Post Captain Nicolas Baudin, Commander-in-Chief of the corvettes 'Geographe' and 'Naturaliste'. Translated from the French by Christine Cordell, Adelaide Libraries Board of South Australia, 1974.

Berndt, R.M. (1973). Aborigines of South Western Australia: the Past and the Present. In Merrilees, et al., Aboriginal Man in Southwest Australia Journal of the Royal Soc. of W.A. 56: 50-4.

_____ (1980). Aborigines of the Southwest pp. 81-89 In. Berndt, R.M. and C.H. (eds.) Aborigines of the West: Their Past and Their Present. (Nedlands, U.W.A. Press).

Biggs, E.R., Leech, R.E.J. and S.A. Wilde (1980). Geological Survey of Western Australia In. Atlas of Natural Resources Darling System, Western Australia, Explanatory Text. Department of Conservation and Environment, Western Australia.

Bignell, M. (1971). First the Spring: A History of the Shire of Kojonup. W.A. (Nedlands, U.W.A. Press).

Buller-Murphy, D. (n.d.). Meekadarriby: the Aborigines of the Southwest and Northwest of Western Australia. Unpublished MS Doc. No. 1648a, Battye Lib., W.A.

Bunbury, W.H. and W.P. Morrell (1930). Early Days in Western Australia. (Oxford Uni. Press).

Bussell, J.C. (1833a). Report of an excursion to the Northward of Augusta by Mr. J.C. Bussell pp. 178-85 In. Cross, J. (ed.) Journals of Several Expeditions...

_____ (1833b). Mr. Bussell's Journal of an expedition to the River Vasse, from the Blackwood pp. 186-203 In. Cross. J. (ed.) Journals of Several Expeditions...

Clark, W.N. (1840). Letter from William Nairn Clark Perth Gazette 24/10/1840.

Clarke, J. and C.E. Dortch (1977). A 10,000 year B.P. radiocarbon date for archaeological finds within a soil of the Spearwood Dune System, Mosman Park, W.A. Search 8:36-38.

Collie, A. and Lt. Preston (1829). Observations on the Coast, Country etc. from Cockburn Sound to Geographe Bay between the 17th and 30th of November, 1829. pp.35-50 In. Cross, J. (ed.) Journals of Several Expeditions...

Cross, J. (ed.) (1833). Journals of Several Expeditions made in Western Australia during the years 1829, 1830, 1831 and 1832: under the sanction of the Governor Sir James Stirling, containing the latest authentic information relative to that country. (London, J. Cross).

Churchward, H.M. and W.M. McArthur (1980). Landforms and Soils of the Darling System, Western Australia. In. Atlas of Natural Resources, Darling System, Western Australia, Explanatory Text. Department of Conservation and Environment.

Dewar, J. and A. Smith (1833). Account of the country intervening between Augusta and Swan River pp. 110-13 In. Cross, J. (ed.) Journals of Several Expeditions...

Dimmock, G.M., Bettenay, E. and M.J. Mulcahy (1974). Salt content of lateritic profiles in the Darling Range, Western Australia. Aust. J. Soil. Res. 10:1-14.

Dortch, C.E. (1975). Geometric microliths from a dated archaeological deposit near Northcliffe, Western Australia. J. Roy. Soc. W.A. 54: 103-113.

---------- (1977). Early and late stone industrial phases in Western Australia. In. Wright, R.V.S. (ed.) Stone Tools as Cultural Markers. A.I.A.S. Canberra: 104-132.

Ferguson, W.C. (1977). Report on preliminary archaeological investigations at the Quininup Brook Site Complex, Western Australia. Unpubl. Fourth year honours dissertation. Uni. of W.A.

---------- (1981). Archaeological investigations at the Quininup Brook site complex, Western Australia. Rec. W.A. Museum 8 No. 4: 609-637.

Frith, J. (1967). Waterfowl in Australia. (Sydney, A.H. and A.W. Reed).

Gardner, C.A. (1942). The vegetation of Western Australia, with special reference to the climate and soil. J. Roy. Soc. W.A. 28: 11-27.

Glassow, M.A. (1977). Issues in evaluating the significance of archaeological resources. American Antiquity 42(3): 413-420.

Glover, J.E. (1975). The petrology and probable stratigraphic significance of Aboriginal artefacts from part of Southwest Australia. J. Roy. Soc. W.A. Vol. 58, Part 3:75-85.

Goodyear, A.C. (1978). The status of archaeological research designs in cultural resource management. American Antiquity V. 43: 159-173.

Hallam, S.J. (1974). Excavations in the Orchestra Shell Cave, Wanneroo, Western Australia. Part II A.P.A.O.

---------- (1975). Fire and Hearth: A Study of Aboriginal Usage and European Usurpation in South-West Australia. (Canberra, A.I.A.S.).

Hammond, J.E. (1933). Winjan's People: The Story of the Southwest Aborigines. (P. Hasluck, ed.) Perth Imp. Printing Co.

Heddle, E.M., Loneragan, O.W. and J.J. Hewel (1980). Vegetation complexes of the Darling System, W.A. In. Atlas of Natural Resources, Darling System, Western Australia, Explanatory Text. Department of Conservation and the Environment.

Henty, ?. (1835). Excursion by Mr. Henty. Perth Gazette: 29/8/1835.

Jones, R. (1971). Rocky Cape and the problem of the Tasmanians. Unpubl. Doctoral Thesis, University of Sydney.

Kamminga, J. (1978). Journey into the microcosms: A functional study of certain classes of prehistoric Australian stone tools. Unpubl. Doctoral Thesis, University of Sydney.

Meagher, S. (1973). A reconstruction of the traditional way of life of the Aborigines of South West Australia. Unpubl. M.A. Thesis, Uni. of W.A.

Mulcahy, M.T., Churchward, H.M. and G.M. Dimmock (1972). Landforms and soils on an uplifted peneplain in the Darling Range, Western Australia. Aust. J. Soil Res. 10, 1-14.

Novak, V. (1979). A survey of Aboriginal sites, Griffin Coal Mining Leases, Collie Area. Unpubl. report, Department of Aboriginal Sites.

Pearce, R.H. (1978). A dated sequence from Walyunga, Western Australia J. Roy. Soc. W.A. 61: 1-10.

---------- (1981a). Report on a Survey of Aboriginal Sites for Western Colleries Ltd. Unpubl. manuscript, Department of Aboriginal Sites.

---------- (1981b). Worsley Alumina Project, Survey for Aboriginal Sites. Unpubl. report, Department of Aboriginal Sites.

Pearce, R.H. and M. Barbetti (1981). A 38,000 year old archaeological site at Upper Swan, Western Australia. Archaeol. Oceania 16: 173-178.

Peron, F.A. and L. Freycinet (1807). Voyage de decouvertes aux Terres Australes execute sur les corvettes le 'Geographe' le 'Naturaliste', et la goelette le 'Casuarina', pendant les annees 1800, 1801, 1802, 1803 et 1804. (Paris, Imprimerie Imperiale).

Raab, C.M. and T.C. Klinger (1977). A critical approasal of 'significance' in contract archaeology. American Antiquity 42 (4): 629-634.

Radcliffe Brown, A.R. (1930). The social organization of Australian tribes. Oceania 1: 34-63, 207-246.

Roe, J.S. (1830). Government notice relative to Pt. Leschenault, Surveyor General's Office, Perth. pp. 80-8 In. Cross, J. (ed.) Journals of Several Expeditions...

--------- (1848). A Journey by Mr. J.S. Roe, Esq., Surveyor General, from Perth to Cape Riche. Exploration Diaries, Vol. 4, pp. 90-3, Battye Lib., W.A.

Roth, H.L. (1902). Notes of savage life in the early days of West Australian settlement (Based on the reminiscences of F. Robert Austin, Civil Engineer). Roy. Soc. Queensland, Proceedings 17: 45-69.

Schiffer, M.B. and J.H. House (1975). The Cache River archaeological project: an experiment in contract archaeology. Arkansas Archaeological Survey, Record Series 8.

Schiffer, M.B., Sullivan, A.P. and T.C. Klinger (1978). The design of archaeological surveys. World Archaeology Vol. 10 (1): 1-28.

Shenton, W.K. and R. Wells (1837). Excursion to the Collie and Brunswick Rivers in the county of Wellington, Western Australia, by Messrs, Shenton and Wells. Perth Gazette and W.A. Journal 23/12/1837.

Stirling, J. (1837). Journal of His Excellency Sir James Stirling to and from Kojonup, April 1837. Exploration Diaries, Vol. 3 pp. 591-607 Battye Lib., W.A.

Thomson, J. (1974). Fish of the Ocean and Shore. (Sydney, Collins).

Tindale, N. (1974). Aboriginal Tribes of Australia. (Canberra, A.N.U. Press).

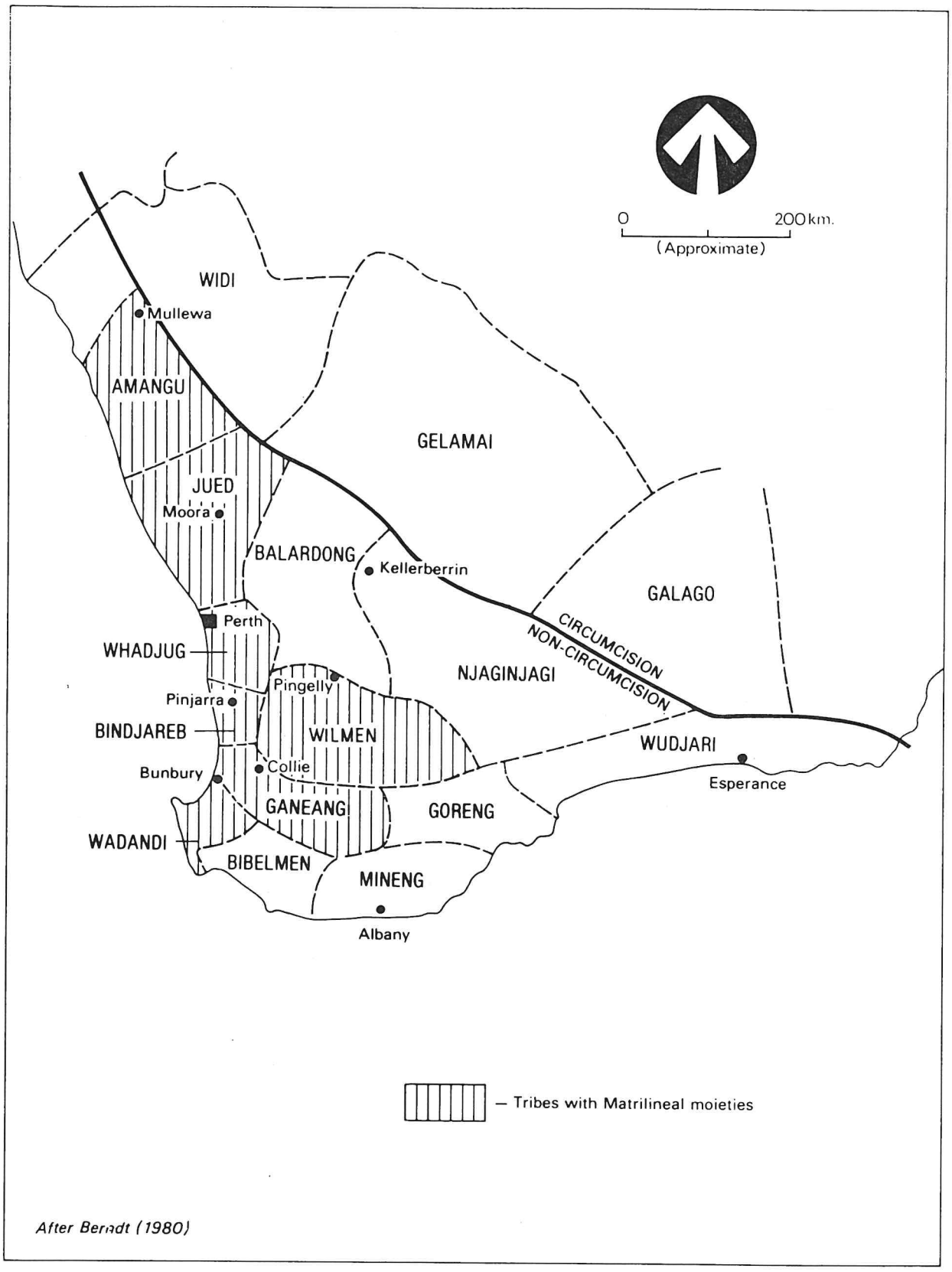
Williams, H.W. (1979). One Day in Collie. (Shire of Collie).

10.0 ACKNOWLEDGEMENTS

Appreciation is extended to Sylvia Hallam, Keith Lindbeck, Battye Library Staff and Forests Department, Collie, for help and advice in various aspects of this project.

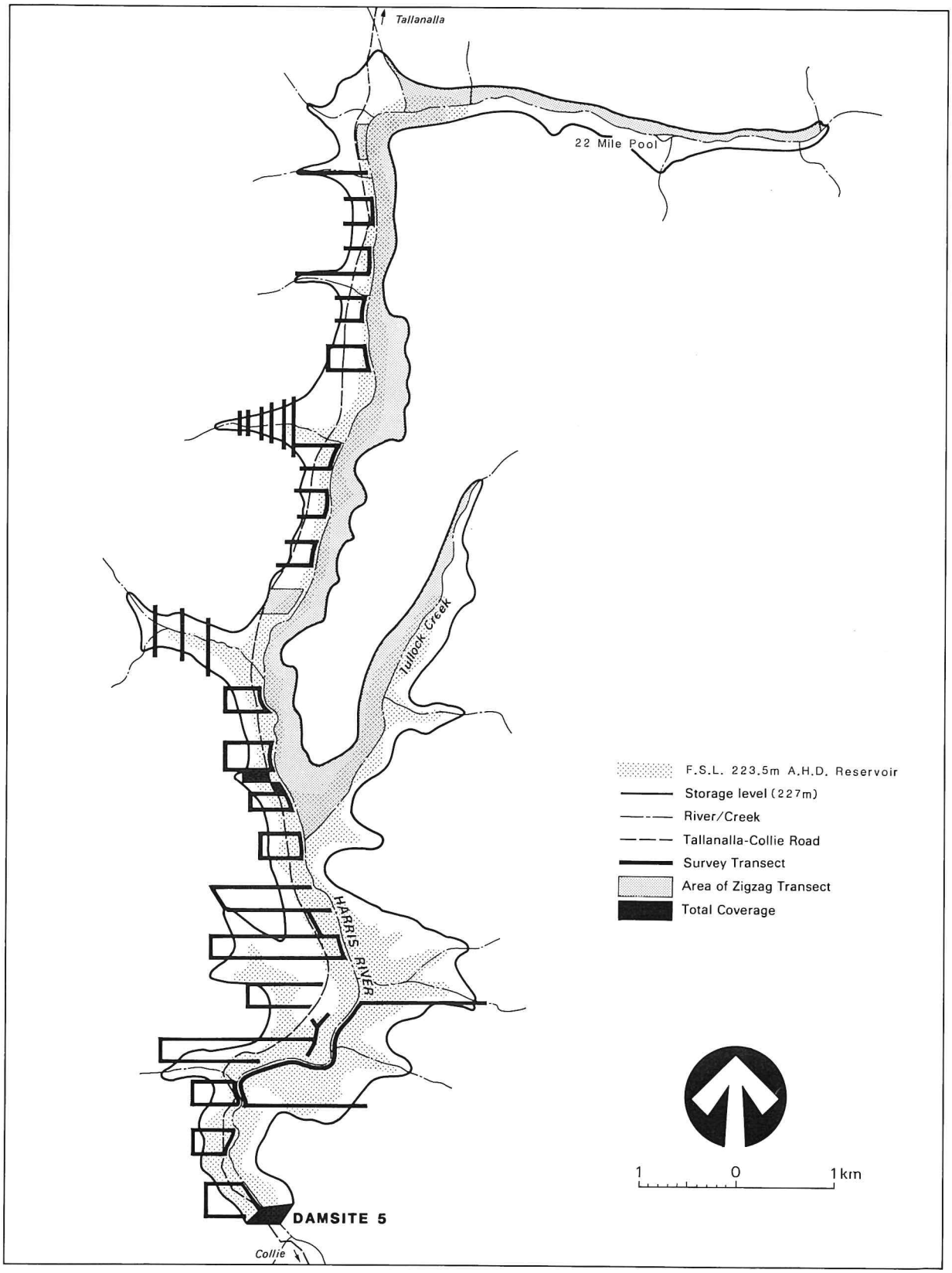
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FIGURES



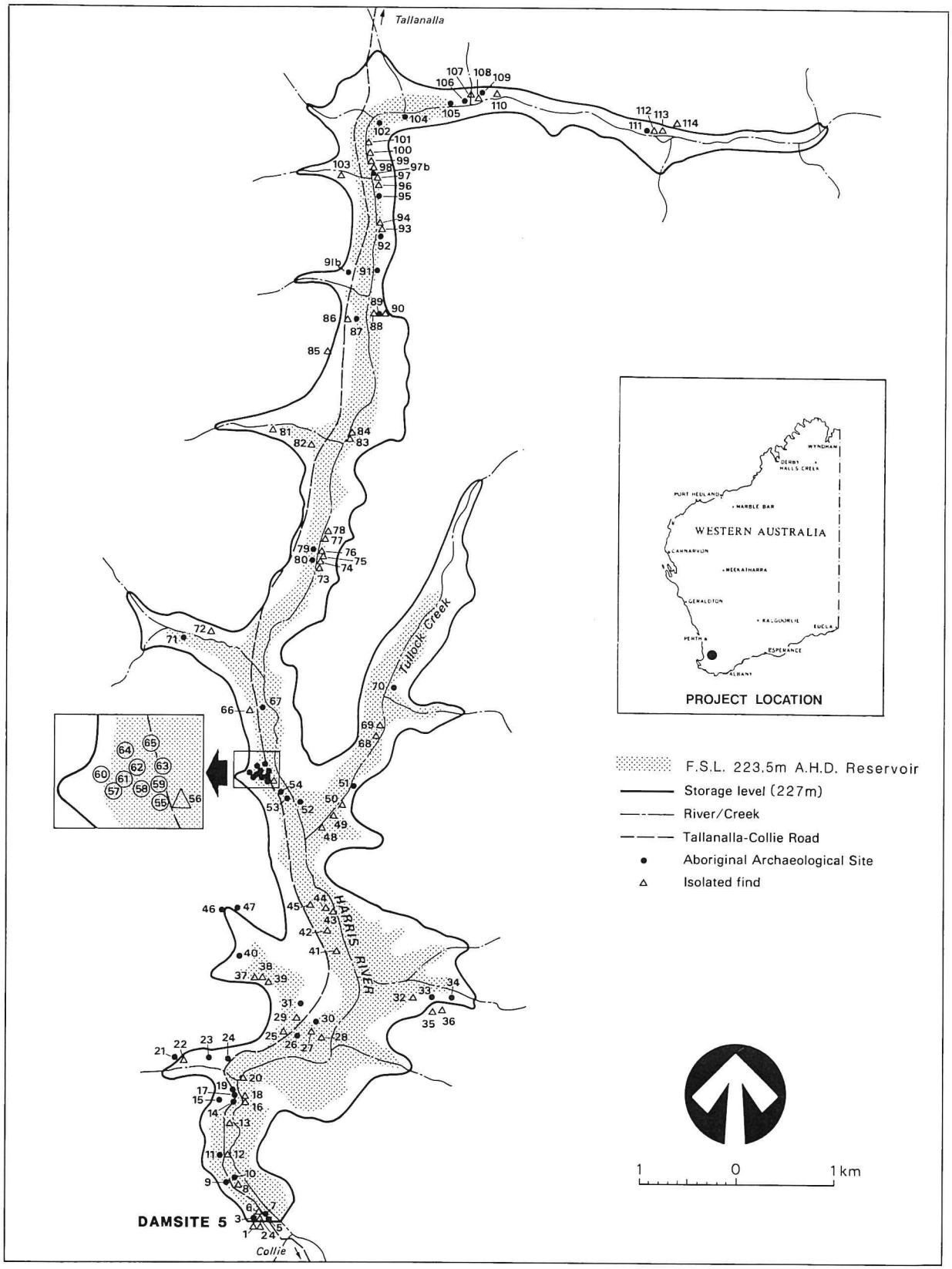
TRIBAL BOUNDARIES OF THE SOUTH WEST

Figure 1
Dames & Moore



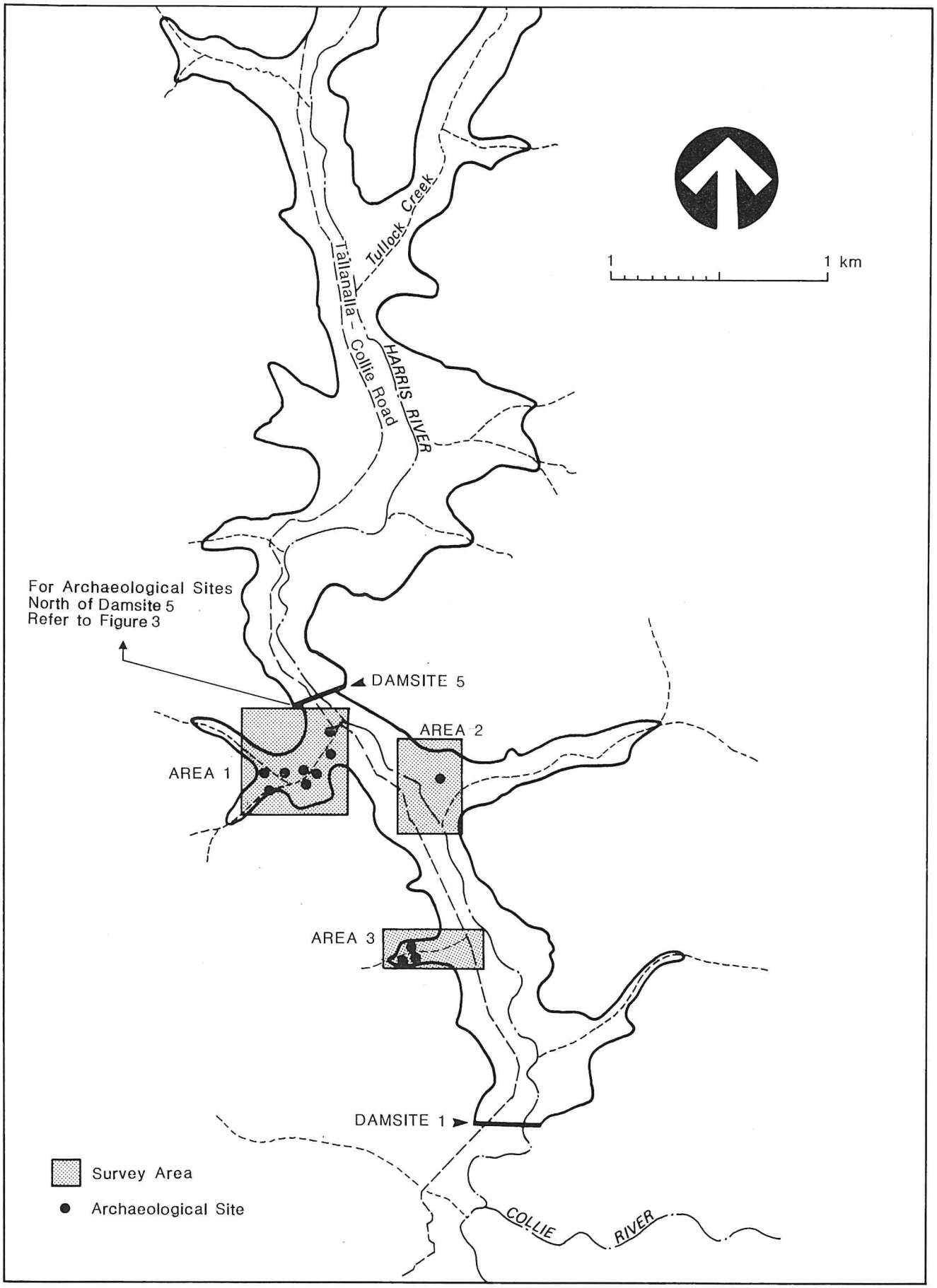
ARCHAEOLOGICAL SURVEY STRATEGY

Figure 2
Dames & Moore



ARCHAEOLOGICAL SITE LOCATIONS

Figure 3
Dames & Moore



LOCATION OF ARCHAEOLOGICAL SITES - DAM EXTENSION SURVEY (DAMSITE 1)

Figure 4
Dames & Moore

PLATES



Plate 1: Valley bottom vegetation, west of Harris River, approximately halfway along 227m contour reservoir area.



Plate 2: Same as above, 2 km north.



Plate 3: Vegetation on low grade valley slope, northern end of the 227m contour reservoir area.

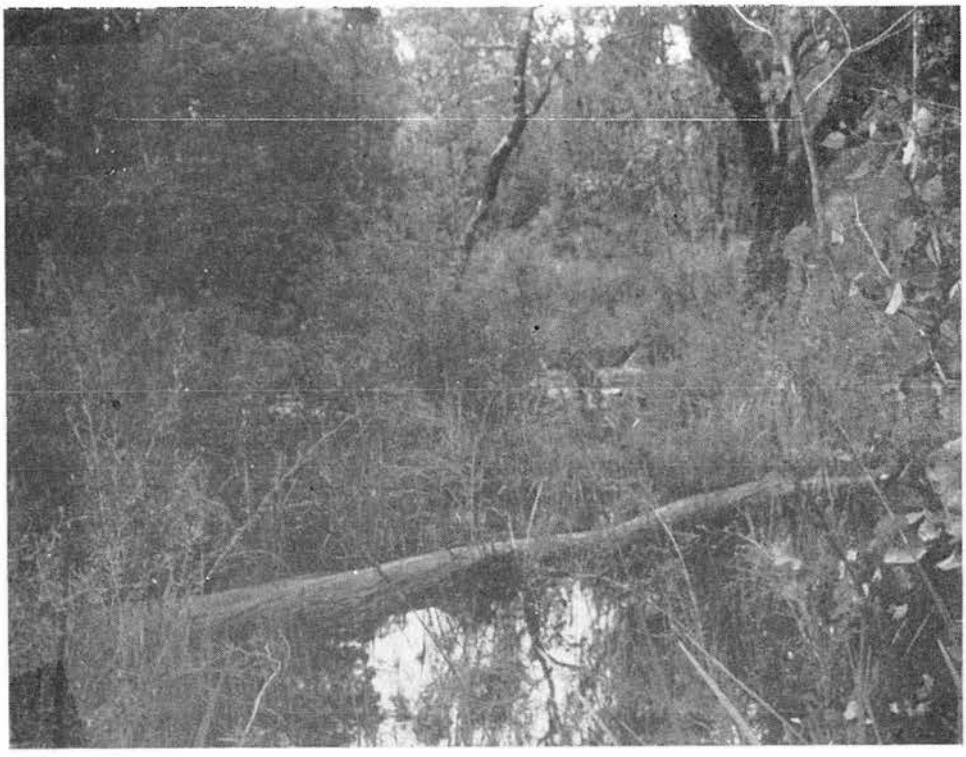


Plate 4: View of the Harris River from the eastern bank, approximately halfway along 227m contour reservoir area.



Plate 5: Blackboy and zamia palm in close association.



Plate 6: View of site S1848 looking NW.



Plate 7: View of site S1862 looking NE.

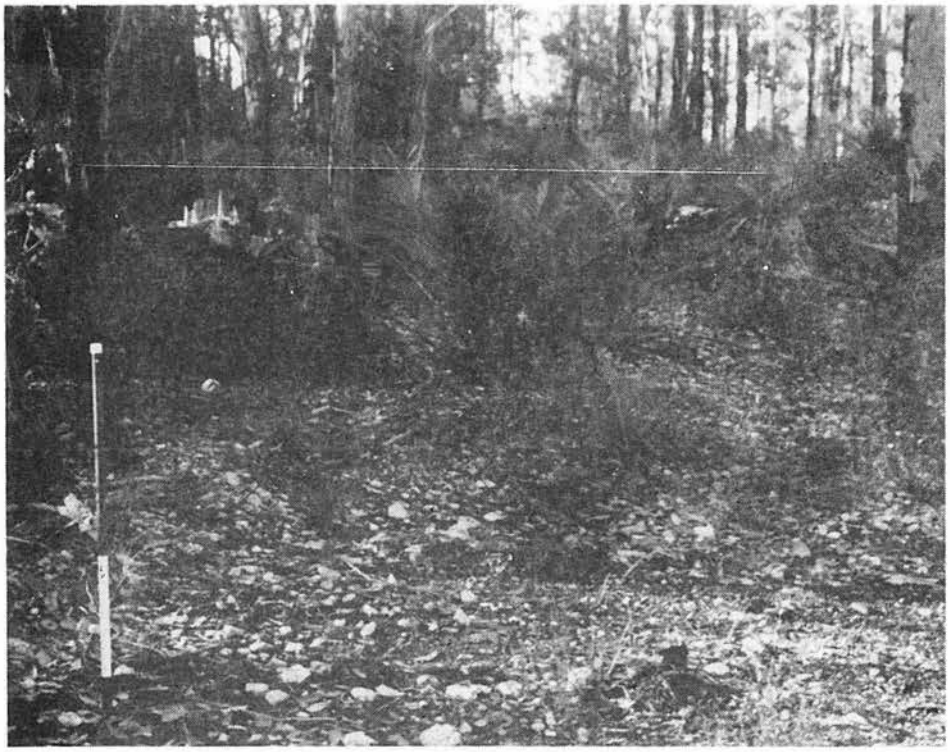


Plate 8: View of site S1867 looking SE.



Plate 9: View of site S1853 looking SW.



Plate 10: View of site S1860. Small horizontal scale placed below one quartz artefact.

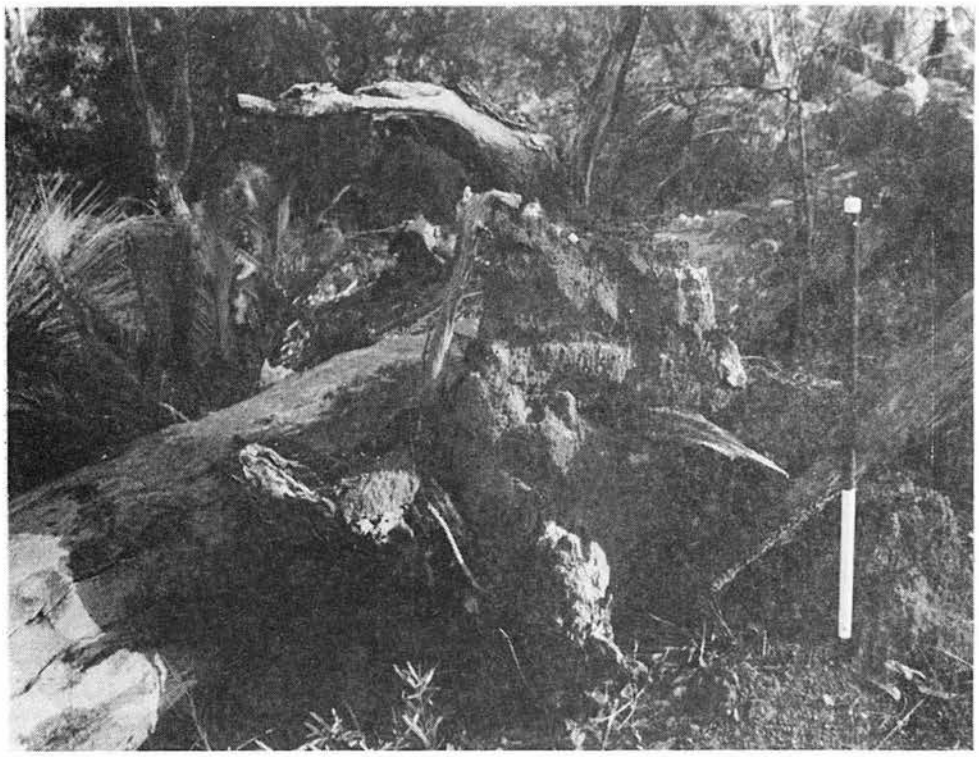


Plate 11: View of Site S1878. Quartz cores, flakes and chips eroding from soil in root matrix of upturned jarrah tree.

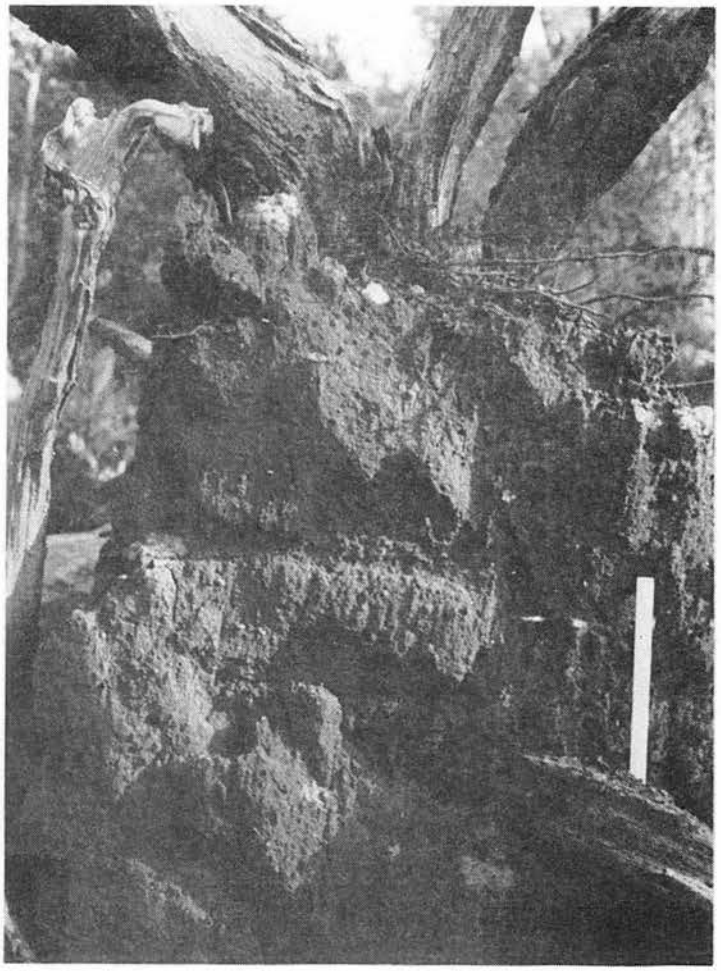


Plate 12: Details of root base of above site.

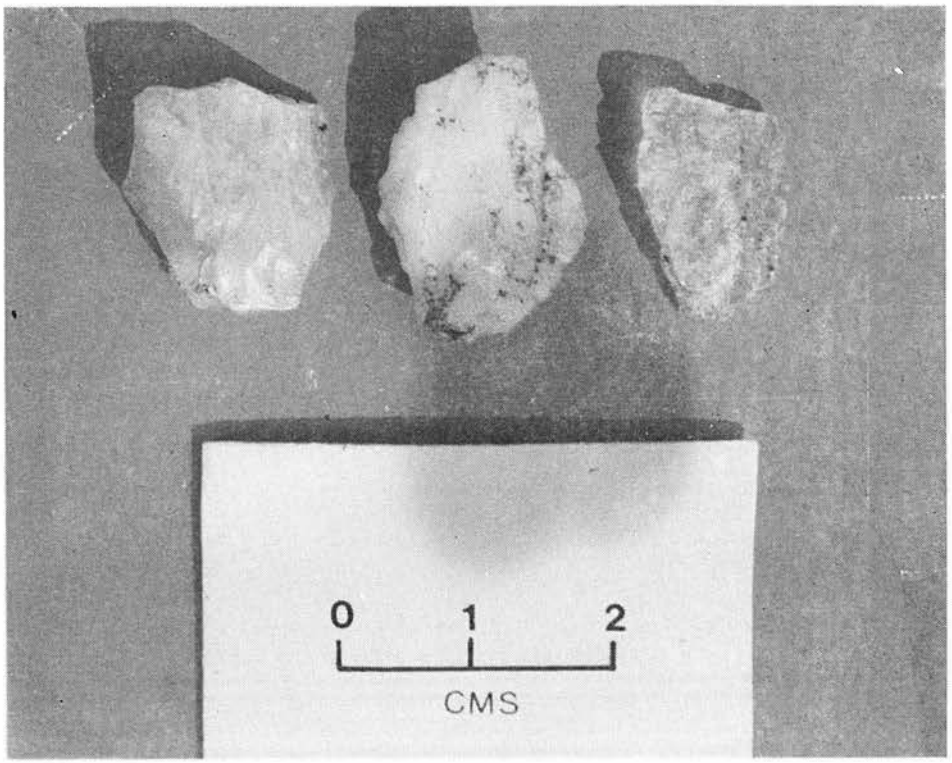


Plate 13: Several quartz artefacts from site S1880. 2 bladelet cores and a flake, L to R.

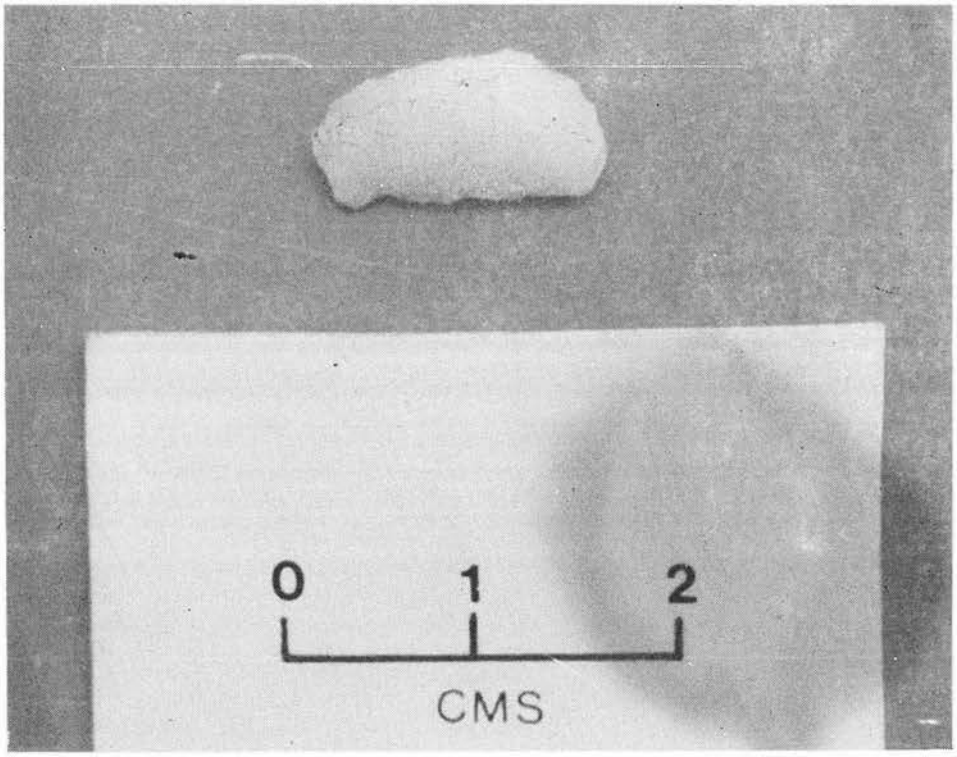


Plate 14: Backed, ovate quartz piece from site S1871.

ADDENDA

ADDENDUM I

Notes on the Recognition of Aboriginal Sites
(Provided by the W.A. Museum)

There are various types of Aboriginal sites, and these notes have been prepared as a guide to the recognition of those types likely to be located in the survey area.

An Aboriginal site is defined in the Aboriginal Heritage Act, 1972-1980 in Section 5 as:

"(a) any place of importance and significance where persons of Aboriginal descent have, or appear to have, left any object, natural or artificial, used for, or made or adapted for use for, any purpose connected with the traditional cultural life of the Aboriginal people, past or present;

(b) any sacred, ritual or ceremonial site, which is of importance and special significance to persons of Aboriginal descent;

(c) any place which, in the opinion of the Trustees, is or was associated with the Aboriginal people and which is of historical, anthropological, archaeological or ethnographical interest and should be preserved because of its importance and significance to the cultural heritage of the State;

(d) any place where objects to which this Act applies are traditionally stored, or to which, under the provisions of this Act, such objects have been taken or removed."

Habitation Sites

These are commonly found throughout Western Australia and usually contain evidence of tool-making, seed grinding and other food processing, cooking, painting, engraving or numerous other activities. The archaeological evidence for some of these activities is discussed in detail under the appropriate heading below.

Habitation sites are usually found near an existing or former water source such as a gnamma hole, rock pool, spring or soak. They are generally in the open, but they sometimes occur in shallow rock shelters or caves. It is particularly important that none of these sites be disturbed as the stratified deposits which may be found at such sites can yield valuable information about the inhabitants when excavated by archaeologists.

Seed Grinding

Polished or smoothed areas are sometimes noticed on/near horizontal rock surfaces. The smooth areas are usually 25cm wide and 40 or 50cm long. They are the result of seed grinding by the Aboriginal women and indicate aspects of the past economy.

Habitation Structures

Aboriginal people sheltered in simple ephemeral structures, generally made of branches and sometimes tussocks of grass. These sites are rarely preserved for more than one occupation period. Occasionally rocks were pushed aside or used to stabilise other building materials. When these rock patterns are located they provide evidence of former habitation sites.

Middens

When a localised source of shellfish and other foods has been exploited from a favoured camping place, the accumulated ashes, hearth stones, shells, bones and other refuse can form mounds at times several metres high and many metres in diameter. Occasionally these refuse mounds or middens contain stone, shell or bone tools. These are most common near the coast but examples on inland lake and river banks are not unknown.

Stone Artefacts Factory Sites

Pieces of rock from which artefacts could be made were often carried to camp sites or other places for final production. Such sites are usually easily recognizable because the manufacturing process produces quantities of flakes and waste material which are clearly out of context when compared with the surrounding rocks. All rocks found on the sandy coastal plain for example, must have been transported by human agencies. These sites are widely distributed throughout the State.

Quarries

When outcrops of rock suitable for the manufacture of stone tools were quarried by Aborigines, evidence of the flaking and chipping of the source material can usually be seen in situ and nearby. Ochre and other mineral pigments used in painting rock surfaces, artefacts and in body decoration are mined from naturally occurring seams, bands and other deposits. This activity can sometimes be recognised by the presence of wooden digging sticks or the marks made by these implements.

Marked Trees

Occasionally trees are located that have designs in the bark which have been incised by Aborigines. Toeholds, to assist the climber, were sometimes cut into the bark and sapwood of trees in the hollow limbs of which possums and other arboreal animals sheltered. Some tree trunks bear scars where sections of bark or wood have been removed and which would have been used to make dishes, shields, spearthrowers and other wooden artefacts. In some parts of the State, platforms were built in trees to accommodate a corpse during complex rituals following death.

Burials

In the north of the State it was formerly the custom to place the bones of the dead on a ledge in a cave after certain rituals were completed. The bones were wrapped in sheets of bark and the skull placed beside this. In other parts of Western Australia the dead were buried, the burial position varying according to the customs of the particular area and time. Natural erosion, or mechanical earthmoving equipment occasionally exposes these burial sites.

Stone Structures

If one or more stones are found partly buried or wedged into a position which is not likely to be the result of natural forces, then it is probably that the place is an Aboriginal site and that possibly there are other important areas nearby. There are several different types of stone arrangements ranging from simple cairns or piles of stone to more elaborate designs. Some were constructed in connection with food

gathering. Low weirs which detain fish when tides fall are found in coastal areas. Some rivers contain similar structures that trap fish against the current. It seems likely that low stone slab structures in the south-west jarrah forests were built to provide suitable environments in which to trap some small animals. Low walls or pits were sometimes made to provide a hide or shelter for a hunter.

Elongated rock fragments are occasionally erected as a sign or warning that a special area is being approached. Heaps of alignments of stones may be naturalistic or symbolic representations of animals, people or mythical figures.

Paintings

These usually occur in rock shelters, caves or other sheltered situations which offer a certain degree of protection from the weather. The best known examples in Western Australia occur in the Kimberley region but paintings are also found through most of the State. One or several coloured ochres as well as other coloured pigments may have been used at a site. Stencilling was a common painting technique used throughout the State. The negative image of an object was created by spraying pigment over the object which was held against the wall.

Engravings

This term describes designs which have been carved, pecked or pounded into a rock surface. They form the predominant art form of the Pilbara region but are known to occur from the Kimberleys in the north to about Toodyay in the south. Most engravings occur in the open, but some are situated in rock shelters.

Caches

It was the custom to hide ceremonial objects in niches and other secluded places. The removal of objects from these places, or photography of the place or objects or any other interference with these places is not permitted.

Ceremonial Grounds

At some sites the ground has been modified in some way by the removal of surface pebbles, or the modelling of the soil, or the digging of pits and trenches. In other places there is no noticeable alteration of the ground surface and Aborigines familiar with the site must be consulted concerning its location.

Mythological Sites

Most sites already described have a place in Aboriginal mythology. In addition there are many Aboriginal sites with no man-made features which enable them to be recognised. They are often natural features in the landscape linked to the Aboriginal account of the formation of the world during the creative 'Dreaming' period in the distant past. Many such sites are located at focal points in the creative journeys of mythical spirit beings of the Dreaming. Such sites can only be identified by the Aboriginal people who are familiar with the associated traditions.

ADDENDUM II

Obligations Relating to Sites Under the Aboriginal Heritage Act, 1972-1980
(Provided by the W.A. Museum)

"Report of Finding

15. Any person who has knowledge of the existence of anything in the nature of Aboriginal burial grounds, symbols or objects of sacred, ritual or ceremonial significance, cave or rock paintings or engravings, stone structures or arranged stones, carved trees, or of any other place or thing to which this Act applied or to which this Act might reasonably be suspected to apply, shall report its existence to the Trustees, or to a police officer, unless he has reasonable cause to believe the existence of the thing or place in question to be already known to the Trustees.

Excavation of Aboriginal Sites

16. (1) Subject to Section 18, the right to excavate or to remove anything from an Aboriginal site is reserved to the Trustees.

(2) The Trustees may authorise the entry upon and excavating of an Aboriginal site and the examination or removal of any thing on or under the site in such manner and subject to such conditions as they may direct.

Offences relating to Aboriginal sites

17. A person who -

(a) excavates, destroys, damages, conceals or in any way alters any Aboriginal site, or

(b) in any way alters, damages, removes, destroys, conceals, or who deals with in a manner not sanctioned by relevant custom, or assumes the possession, custody or control of, any object on or under an Aboriginal site, commits an offence unless he is acting with the authorisation of the Trustees under Section 16 or the consent of the Minister under Section 18.

Consent to certain uses

18. (1) For the purposes of this section, the expression "the owner of any land" includes a lessee from the Crown, and the holder of any mining tenement or mining privilege, or of any right or privilege under the Petroleum Act 1967, in relation to the land.

(2) Where the owner of any land gives to the Trustees notice in writing that he requires to use the land for a purpose which, unless the Minister gives his consent under this section, would be likely to result in a breach of Section 17 in respect of any Aboriginal site that might be on the land, the Trustees shall, as soon as they are reasonably able, form an opinion as to whether there is any Aboriginal site on the land, evaluate the importance and significance of any such site, and submit the notice to the Minister together with their recommendation in writing as to whether or not the Minister should consent to the use of the land for that purpose, and, where applicable, the extent to which and the conditions upon which his consent should be given.

(3) Where the Trustees submit a notice to the Minister under subsection (2) of this section he shall consider their recommendation and having regard to the general interest of the community shall either -

(a) consent to the use of the land the subject of the notice, or a specified part of the land, for the purpose required, subject to such conditions, if any, as he may specify; or

(b) wholly decline the consent to the use of the land, the subject of the notice for the purpose required, and shall forthwith inform the owner in writing of his decision.

(4) Where the owner of any land has given to the Trustees notice pursuant to subsection (2) of this section and the Trustees have not submitted it with their recommendation to the Minister in accordance with that subsection the Minister may require the Trustees to do so within a specified time, or may require the Trustees to take such other action as the Minister considers necessary in order to expedite the matter, and the Trustees shall comply with any such requirement.

(5) Where the owner of any land is aggrieved by a decision of the Minister made under subsection (3) of this section he may, within the time and in the manner prescribed by rules of court, appeal from the decision of the Minister to the Supreme Court which may hear and determine the appeal.

(6) In determining an appeal under subsection (5) of this section the Judge hearing the appeal may confirm or vary the decision of the Minister against which the appeal is made or quash the decision and substitute his own decision which shall have the effect as if it were the decision of the Minister, and may make such order as to the cost of the appeal as he sees fit.

(7) Where the owner of any land gives notice to the Trustees under subsection (2) of this section, the Trustees may, if they are satisified that it is practicable to do so, direct the removal of any object to which this Act applies from the land to a place of safe custody.

(8) Where consent has been given under this section to a person to use any land for a particular purpose nothing done by or on behalf of that person pursuant to, and in accordance with any conditions attached to, the consent constitutes an offence against this Act."

ADDENDUM III

Human Skeletal Material (Provided by the W.A. Museum)

Most old human skeletal material discovered is likely to be of prehistoric (pre-1800) Aboriginal origin. This material may be of profound scientific importance. The extent to which a pathologist or anthropologist can interpret and assess the skeletal material relies largely on the careful recording and handling of specimens when they are first discovered. The officer responsible for the initial investigation must take careful and detailed recordings and ensure that if any disturbance of the burial site has already occurred or is unavoidable, that such disturbance is kept to a minimum.

Ideal recovery of skeletal remains entails not only the careful extraction of all material but also the recording of sufficient information to enable reconstruction of the total picture of the burial. This encompasses the way in which the person was buried, the position in which the body was placed and the nature of any material placed in the grave or associated with it.

Any burial site discovered should be left undisturbed until the Government pathologist, and an archaeologist have had a chance to examine the site. Unfortunately, this is sometimes impractical in terms of both personnel and financial considerations. The best alternative would be to forward photographs, maps, drawings, measurements, and notes, clearly illustrating the nature of the discovery to the Police Department and the Registrar of Aboriginal Sites. Based on an evaluation of such material, the pathologist and the archaeologist will be able to suggest the next steps in handling the material.

ADDENDUM IV

Glossary of Terms

Backed Piece

Piece of stone with bi-directional trimming on the thickest margin. Naturally backed pieces usually have a face at an obtuse angle to the working edge.

Blade Flake

Flake has a length which is equal to, or greater than, twice its width. The length is normal to the striking platform.

Bulb of Percussion

Conchoidal prominance on ventral face of flake resulting from the physical expression of percussion (i.e. Herzian cone).

Burin

Implement that has one, or more, spalls removed from edges parallel to its long axis and/or traversely or obliquely. Product of the burin break is called a burin spall.

Burren Adze

Unifacially retouched scraper with working edges on the lateral margins of a flake.

Core

Stone piece with three or more negative flake scars.

Flake

A piece of stone removed from a parent rock by application of mechanical force. Has evidence of a bulb of percussion and striking platform (usually).

Flake Core

These are generally large flakes which have successive flakes removed from their margins. These have been described as 2^{o} cores.

Flaked Piece

Stone piece with up to three negative flake scars.

Hammerstone

Implement (often pebble) used to strike flakes from a core.

Manuport

A piece of stone humanly transported, usually detected when out of normal geological provenance.

Muller

The upper component of a grinding set - handheld. Moved over basal grindstone (fixed or portable) to process foodstuffs (e.g. seeds, vegetable compounds) and meat (e.g. small lizards). The muller is often a multipurpose implement in that it can be used also as a hammerstone, an anvil or futher worked to form a specific implement, e.g. steep-sided scraper.

Multi-Platform Core

Stone from which successive flakes/blade have been removed from two or more striking platforms.

Nosed-Concave Scraper

Characterised by edges consisting of one to several noses or conves projections flanked by concave edged or notches. These artefacts have evidence of moderate to pronounced edge rounding and a high incidence of shallow step fractures on the unretouched faces.

Notched Scraper

Characterised by relatively small, semi-circular, deeply concave edges. These emplements have similar wear patterns to nosed-concave scrapers.

Pebble Core

(Usually) river pebble from which flakes have been removed. Flakes are generally removed by direct percussion from one direction, although a small number exhibit bi-directional flaking.

Point

Flake/blade that has been trimmed on its distal end to form a point.

Retouch

Modification of the margin of an artefact through fracturing (for shaping, blunting or rejuvenation).

Single Platform Core

Stone from which successive flakes/blades have been removed from the same striking platform.

Steep-Sided Scraper

Characterised by one or more steeply retouched edges. These types range from small utilised chunks and flakes with straight to slightly concave or convex edges to larger core and flake implements with high angled, unifacially retouched or use-damaged edges. These implements have a tendency to be irregular in shape, with evidence of flaking, crushing and edge-undercutting.

Thermal Fracture

Natural fracture induced by temperature differences.

Tula Adze

Unifacially retouched scraper on semi-discoidal flake. Utilised/retouched on distal and/or proximal margin. Typified by both simple and scalar retouch and often exhibiting under cutting. In the advanced state of use this implement is discarded as a narrow slug.

APPENDIX H

HARRIS RIVER COLOUR MODELLING

Prepared by
D. Salim

Report No. W.R.B. 112
December 1984

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1. INTRODUCTION

2. FLOW WEIGHTED COLOUR INTO THE RESERVOIR

3. NATURAL COLOUR REDUCTION

4. SIMULATION

5. RESULTS

6. CONCLUSION

7. REFERENCES

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1. MONTHLY COLOUR REDUCTION FACTOR

2. SUMMARY OF RESERVOIR COLOUR FREQUENCY ANALYSIS

FIGURE

1. PLOT OF COLOUR VS FLOW RATE

APPENDICES

A MONTHLY FLOW WEIGHTED COLOUR CONCENTRATION AND ITS STATISTICS

B MONTHLY RESERVOIR COLOUR CONCENTRATION, STATISTICS AND FREQUENCY ANALYSIS OUTPUTS.

1. INTRODUCTION

Stream which drain swampy areas where peaty soils are present frequently have a high organic colour. This is particular true in the case of Harris River where most of its upper reaches is covered with swamp. Concern has therefore been expressed about the likely colour levels which will occur in the proposed new Harris River storage.

Over the past three years, there has been a considerable increase of stream sampling in the Harris River. This exercise has enabled the relationships between water colour and instantaneous flow rate to be defined more accurately. Consequently the monthly weighted colour concentration were calculated over the historical sequence of 77 years.

Based on the recent study on Wellington reservoir (Loh, 1984), it was found that some natural reduction in colour occured in storage for some of the months. The colour reduction factors obtained by Loh have been used in this study.

A monthly reservoir model has been used to simulate the proposed Harris River storage. The main result required from this study is the ranges of reservoir colour concentration that the system can supply.

The results show that for a town supply draw of 10 million cubic metres per year, the colour concentration of the reservoir has a median value of 12 Hazen. This value is increased to 14 Hazen if the draw is increased to 25 million cubic metres per year.

2. FLOW WEIGHTED COLOUR INTO THE RESERVOIR

Additional frequency sampling has been carried out in recent years so that reliable relationships between colour concentration and instantaneous flow rate can be defined. Based on the data from 1981 to 1983. A total of 266 samples has been collected. Fig. 1 shows the piece wise linear relationships that has been fitted to the colour concentration vs flow rate plot.

The 77 years of daily historical streamflow sequence for Harris River (Salim, 1984a) was first converted into daily flow rate and then into colour concentration using the above piece-wise linear relationships. The monthly flow weighted colour concentration into the reservoir was calculated using the following expression

$$FC = \frac{\Sigma fi*Ci}{\Sigma fi} \qquad (i)$$

where FC = Monthly flow weighted colour concentration in Hazen Unit
fi = Daily flow in cubic metres
Ci = Daily Colour Concentration in Hazen unit

The monthly flow weighted colour concentration listings and its statistics are presented in Appendix A.

3. NATURAL COLOUR REDUCTION

Based on the recent study on Wellington Reservoir (Loh, 1984), the water colour concentration has been observed to 'decay' for certain months while in storage. This reduction in colour appears to be a function of temperature regimes and hydrodynamic conditions of the reservoir.

Assuming that the proposed Harris reservoir experiences the same temperature stratifications as that of Wellington reservoir, it was decided to adopt the colour reduction values of Wellington reservoir for this study. They are tabulated in Table 1.

TABLE 1
MONTHLY COLOUR REDUCTION FACTOR

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
values	1.0	1.0	0.94	0.87	0.62	1.0	1.0	1.0	0.9	0.9	0.9	0.89

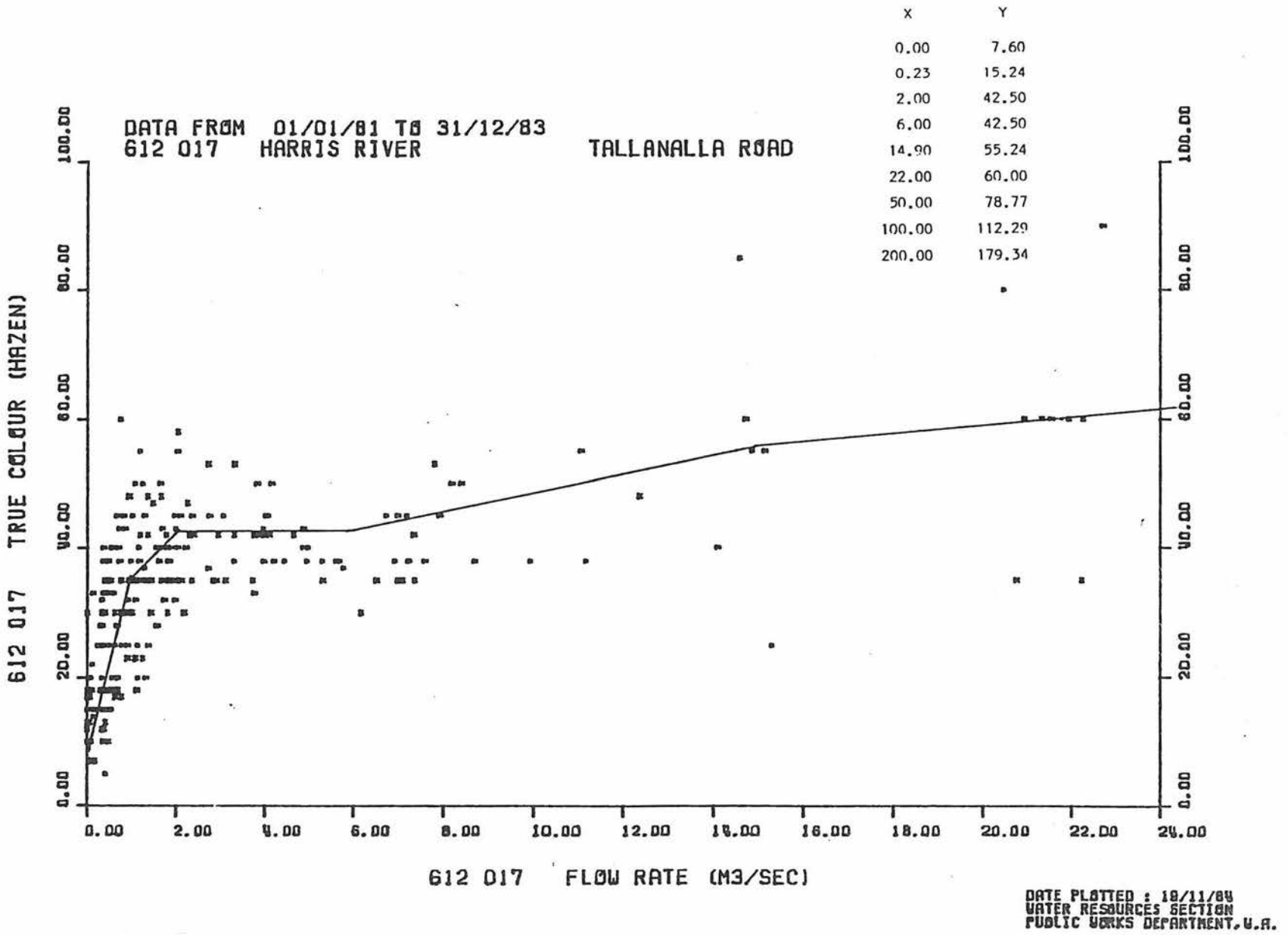

DATA FROM 01/01/81 TO 31/12/83
612 017 HARRIS RIVER
TALLANALLA ROAD
X Y
0.00 7.60
0.23 15.24
2.00 42.50
6.00 42.50
14.90 55.24
22.00 60.00
50.00 78.77
100.00 112.29
200.00 179.34
612 017 TRUE COLOUR (HAZEN)
612 017 FLOW RATE (M3/SEC)
0.00
20.00
40.00
60.00
80.00
100.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
22.00
24.00
DATE PLOTTED : 18/11/84
WATER RESOURCES SECTION
PUBLIC WORKS DEPARTMENT, N.A.

FIGURE 1

4. SIMULATION

The proposed reservoir was simulated on a monthly basis using 77 years of historical sequence. Besides the colour concentration and the reduction factors described previously, the basic input data into the model was adopted from a recent study by Salim (1984b).

Two simulation runs were carried out with the following additional input data into the model:

(i) Dam Site : Number 1 (situated at gauging site)
(ii) Reservoir storage : 120 million cubic metres
(iii) Initial water colour of the reservoir : 17 Hazen
(iv) Town Supply draw : 10 million cubic metres per year and
25 million cubic metres per year

5. RESULTS

Listings of the monthly reservoir colour concentration, statistics, and frequency analysis outputs can be found in Appendix B. Table 2 summarises the results in term of percentiles.

TABLE 2
SUMMARY OF RESERVOIR COLOUR FREQUENCY ANALYSIS

	Town Supply Draw (m^3/yr)	
Percentile	$10x10^6$	$25x10^6$
10	6.3	7.4
20	8.0	9.34
50	12.4	13.8
90	24.0	28.4
92.2	24.9	30.0
95	27.0	32.8
97	30.0	34.8
99	33.4	41.2

The above table shows that if the Town Supply Draw is 10 million cubic metres per year, 97% of the time the system will be supplying water with a colour concentration of less than 30 Hazen. If the draw is to be increased to 25 million cubic metres per year, the same colour concentration will be supplied at 92.2% of the time. Corollary to this, with a relatively larger storage and smaller draw, the system can be expected to have a higher probability of supplying better quality water.

6. CONCLUSION

The modelling of water colour concentration in the proposed Harris reservoir has been presented. The monthly flow weighted colour concentration required by the model has been derived from a total of 266 water sampling from 1981 to 1983 and then extended to the historical sequence of 77 years. The natural colour reduction factors have been adopted from Loh (1984) which are based on Wellington reservoir study.

The results show that with a relatively large storage and small draw the system is able to supply a better quality water. i.e. the water is kept in the storage for a relatively longer period for the colour to decay naturally.

Although this study constitutes a much broader yield study of the proposed Wellington-Harris two dam system, the modelling exercise has been on a single Harris reservoir. No attempt has been made to compensate for the possible effect of the present of a second reservoir.

7. REFERENCES

LOH, I. (1984) - Colour Changes In Wellington Reservoir Over The 1983/84 Summer. Unpublished Report. Water Resources Assessment and Management, Public Works Department WA.

SALIM, D. (1984a) - Harris River Historical Streamflow. Internal Publication No. WRB75. Water Resources Branch, Public Works Department, W.A.

SALIM, D. (1984b) - Harris River Yield Study. Internal Publication No. WRB 111. Water Resources Branch, Public Works Department W.A.

APPENDIX A

MONTHLY FLOW WEIGHTED COLOUR CONCENTRATION AND ITS STATISTICS

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

HARRIS RIVER
N 6316200 E 421250

TALLANALLA ROAD

STATION NO. 612 017
COPY NUMBER ( )

CATCHMENT AREA 382.0 Sq.KM

MONTHLY TOTAL

TRUE COLOUR (FILTERED) PLAT-COBALT IN HAZEN

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1907	8.*E	8.*E	9.*E	10.*E	10.*E	20.*E	40.*E	43.*E	42.*E	24.*E	16.*E	9.*E
1908	8.*E	9.*E	8.*E	9.*E	9.*E	35.*E	44.*E	36.*E	19.*E	17.*E	12.*E	8.*E
1909	8.*E	8.*E	10.*E	11.*E	11.*E	38.*E	24.*E	43.*E	34.*E	37.*E	16.*E	10.*E
1910	9.*E	8.*E	8.*E	9.*E	31.*E	48.*E	55.*E	50.*E	52.*E	28.*E	14.*E	9.*E
1911	8.*E	8.*E	8.*E	14.*E	10.*E	11.*E	43.*E	43.*E	32.*E	17.*E	10.*E	8.*E
1912	8.*E	8.*E	8.*E	8.*E	13.*E	9.*E	41.*E	42.*E	44.*E	37.*E	16.*E	10.*E
1913	8.*E	8.*E	10.*E	10.*E	10.*E	10.*E	44.*E	52.*E	39.*E	19.*E	11.*E	10.*E
1914	8.*E	11.*E	8.*E	10.*E	10.*E	10.*E	41.*E	28.*E	13.*E	9.*E	9.*E	8.*E
1915	9.*E	11.*E	9.*E	9.*E	10.*E	37.*E	45.*E	43.*E	45.*E	38.*E	19.*E	10.*E
1916	10.*E	9.*E	8.*E	9.*E	9.*E	27.*E	42.*E	44.*E	38.*E	17.*E	11.*E	8.*E
1917	8.*E	10.*E	9.*E	13.*E	10.*E	42.*E	57.*E	53.*E	55.*E	61.*E	33.*E	15.*E
1918	10.*E	10.*E	9.*E	9.*E	37.*E	48.*E	44.*E	36.*E	47.*E	23.*E	12.*E	9.*E
1919	8.*E	8.*E	8.*E	9.*E	11.*E	34.*E	43.*E	47.*E	34.*E	15.*E	10.*E	8.*E
1920	8.*E	8.*E	9.*E	8.*E	12.*E	44.*E	45.*E	54.*E	47.*E	20.*E	11.*E	8.*E
1921	8.*E	9.*E	9.*E	8.*E	11.*E	40.*E	43.*E	42.*E	32.*E	19.*E	25.*E	10.*E
1922	8.*E	8.*E	9.*E	8.*E	10.*E	9.*E	37.*E	43.*E	34.*E	21.*E	11.*E	10.*E
1923	9.*E	8.*E	11.*E	11.*E	24.*E	48.*E	50.*E	52.*E	59.*E	43.*E	24.*E	13.*E
1924	9.*E	8.*E	8.*E	8.*E	11.*E	42.*E	43.*E	46.*E	40.*E	47.*E	22.*E	11.*E
1925	9.*E	8.*E	9.*E	8.*E	10.*E	15.*E	42.*E	38.*E	28.*E	15.*E	9.*E	8.*E
1926	8.*E	8.*E	8.*E	11.*E	26.*E	43.*E	55.*E	51.*E	48.*E	60.*E	40.*E	20.*E
1927	11.*E	8.*E	11.*E	10.*E	12.*E	42.*E	46.*E	45.*E	46.*E	22.*E	12.*E	8.*E
1928	12.*E	8.*E	8.*E	13.*E	10.*E	13.*E	46.*E	48.*E	45.*E	48.*E	17.*E	10.*E
1929	8.*E	12.*E	8.*E	9.*E	11.*E	41.*E	41.*E	41.*E	26.*E	13.*E	9.*E	8.*E
1930	8.*E	8.*E	8.*E	9.*E	11.*E	45.*E	55.*E	43.*E	44.*E	42.*E	19.*E	10.*E
1931	8.*E	8.*E	9.*E	11.*E	13.*E	32.*E	44.*E	44.*E	45.*E	34.*E	15.*E	9.*E
1932	8.*E	8.*E	9.*E	9.*E	32.*E	42.*E	53.*E	42.*E	43.*E	17.*E	10.*E	8.*E
1933	10.*E	8.*E	9.*E	10.*E	10.*E	42.*E	43.*E	35.*E	45.*E	28.*E	15.*E	9.*E
1934	8.*E	8.*E	10.*E	8.*E	10.*E	27.*E	43.*E	42.*E	41.*E	33.*E	14.*E	10.*E
1935	8.*E	8.*E	8.*E	10.*E	9.*E	10.*E	47.*E	44.*E	41.*E	24.*E	12.*E	9.*E
1936	9.*E	8.*E	8.*E	8.*E	11.*E	26.*E	41.*E	48.*E	38.*E	24.*E	12.*E	9.*E
1937	8.*E	8.*E	9.*E	12.*E	41.*E	40.*E	40.*E	38.*E	38.*E	17.*E	10.*E	8.*E
1938	8.*E	8.*E	9.*E	10.*E	11.*E	9.*E	44.*E	42.*E	42.*E	21.*E	12.*E	9.*E
1939	12.*E	10.*E	8.*E	8.*E	10.*E	41.*E	49.*E	64.*E	48.*E	36.*E	15.*E	9.*E
1940	8.*E	8.*E	8.*E	8.*E	9.*E	10.*E	19.*E	32.*E	30.*E	15.*E	9.*E	9.*E
1941	8.*E	8.*E	8.*E	10.*E	12.*E	43.*E	44.*E	44.*E	51.*E	36.*E	16.*E	9.*E
1942	8.*E	8.*E	10.*E	10.*E	11.*E	42.*E	46.*E	60.*E	64.*E	44.*E	24.*E	13.*E
1943	9.*E	11.*E	10.*E	9.*E	9.*E	40.*E	43.*E	44.*E	47.*E	32.*E	14.*E	9.*E
1944	8.*E	8.*E	8.*E	8.*E	10.*E	11.*E	43.*E	43.*E	34.*E	15.*E	10.*E	9.*E
1945	8.*E	8.*E	10.*E	9.*E	23.*E	56.*E	55.*E	63.*E	48.*E	36.*E	16.*E	10.*E
1946	8.*E	8.*E	9.*E	9.*E	39.*E	42.*E	60.*E	58.*E	37.*E	17.*E	12.*E	9.*E

KEY

NA	RECORD NOT AVAILABLE
NR	NOT RECORDED
*	FAULTY - VERY CONFIDENT IN CORRECTED TRACE
**	FAULTY - SOME DOUBT IN CORRECTED TRACE
*E	ESTIMATED TRACE
"	DERIVED FROM INCOMPLETE RECORD

PROGRAM MDLIST
PROCESSED ON 15.43 03 JAN 1985

COLLECTING AUTHORITY WATER RES(03)

YEARS 1907 - 1946
STATION NO. 612 017

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

HARRIS RIVER
N 6316200 E 421250

TALLANALLA ROAD

STATION NO. 612 017
COPY NUMBER ( )

CATCHMENT AREA 382.0 SQ.KM

MONTHLY TOTAL

TRUE COLOUR (FILTERED) PLAT-COBALT IN HAZEN

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1947	8.*E	8.*E	8.*E	9.*E	24.*E	50.*E	48.*E	45.*E	20.*E	12.*E	8.*E	8.*E
1948	8.*E	8.*E	9.*E	9.*E	9.*E	10.*E	41.*E	43.*E	40.*E	36.*E	16.*E	10.*E
1949	8.*E	8.*E	9.*E	10.*E	12.*E	10.*E	43.*E	50.*E	39.*E	18.*E	11.*E	8.*E
1950	8.*E	8.*E	8.*E	8.*E	11.*E	28.*E	40.*E	41.*E	40.*E	24.*E	13.*E	9.*E
1951	8.*E	9.*E	8.*E	9.*E	10.*E	43.*E	42.*E	42.*E	28.*E	14.*E	9.*E	10.*E
1952	8.*E	8.*E	10.*E	9.*E	12.*E	44.*E	43.*E	43.	45.	40.	33.	25.*E
1953	8.*E	9.*E	8.*E	8.*E	20.*E	40.*	46.	41.	38.	42.*E	31.*E	25.*E
1954	8.*E	8.*E	8.*E	9.*E	11.*E	21.*E	41.*E	39.*	33.*	17.*	13.	9.*E
1955	8.*E	17.*E	8.*E	8.*E	24.*E	38.	46.*	55.*E	49.	43.	29.	15.
1956	10.	8.*E	15.*E	9.*E	35.*E	45.	46.	47.	36.	24.	16.	15.
1957	10.	8.*E	10.*E	12.*E	15.*E	51.	44.*	42.	40.	26.	15.	10.
1958	8.*E	8.*E	8.*E	9.*E	13.*E	26.	50.*E	43.*E	34.	24.	16.*E	11.*E
1959	8.	8.*E	8.*E	9.*E	10.*E	26.	16.	40.*	17.	27.*	13.	8.
1960	12.*E	8.*E	12.*E	10.*E	21.	25.*E	48.*	41.	30.	21.*E	11.	8.
1961	10.*E	8.*E	10.*E	10.*E	9.*E	44.*E	42.	42.	41.	31.	16.	11.
1962	9.*E	8.*E	8.*E	8.*E	11.*E	33.	33.	41.	38.	33.	23.	14.*E
1963	8.	8.*E	8.*E	9.*E	12.*E	42.	50.	60.	46.	29.	17.*E	10.
1964	8.	8.*E	8.*E	9.*E	8.	49.*	58.	65.	42.	40.	20.	16.
1965	9.	8.	8.	8.	36.	38.	44.	40.	42.	42.	36.	19.
1966	10.	8.	8.	8.	9.*E	31.	44.*	40.	43.	32.	17.*	11.*
1967	10.	8.	8.	8.	26.	45.	48.*	43.	40.*	24.*	16.*	16.*
1968	13.	10.	9.	13.	13.	40.	42.	43.	45.	39.	20.	11.
1969	8.	8.	8.	11.	14.	39.	39.	42.*	22.	15.	10.	8.
1970	8.	8.	8.	8.	9.	47.	44.	42.	39.	45.	19.	11.
1971	8.*	8.*	10.	8.	17.	27.	30.	40.	42.	45.	38.*	19.
1972	13.	8.	8.	8.	8.	16.	27.	40.	35.	20.	13.	8.
1973	8.	8.	8.	8.*E	12.	38.	45.	45.	43.	34.	24.	10.
1974	8.	8.	8.	8.	36.	47.	52.	53.	40.	35.*	22.	13.
1975	9.	8.	8.	8.	13.	31.	40.	41.	33.	23.	15.*	10.*
1976	10.*E	8.	8.	8.	9.	12.	16.	34.	23.	16.	15.	10.
1977	8.**	8.	8.*	8.*	8.*	10.	27.	43.	24.	35.	17.	9.
1978	8.	8.	8.	8.	8.*	28.**	46.**	33.	36.	37.	11.	8.
1979	8.*	8.	8.*	8.*	8.**	8.	30.	19.	16.	16.	13.	8.
1980	8.	8.	8.	8.	8.	19.	29.	41.	35.	25.	15.	9.
1981	8.*	8.	8.	8.	8.	24.	40.	44.**	38.	33.	17.	14.
1982	53.	18.	8.	8.	8.**	16.**	33.	37.	35.	30.	13.	9.
1983	8.	8.	8.	8.*	8.	35.	43.*	47.	50.	29.	0.NA	0.NA

KEY

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**	FAULTY - SOME DOUBT IN CORRECTED TRACE
*E	ESTIMATED TRACE
"	DERIVED FROM INCOMPLETE RECORD

PROGRAM MDLIST
PROCESSED ON 15.43 03 JAN 1985

COLLECTING AUTHORITY WATER RES(03)

YEARS 1947 - 1983
STATION NO. 612 017

.1121

WATER RESOURCES SECTION PROGRAM MUSTAT2 RUN ON 84/11/26 AT 12.57

STATISTICS OF MONTHLY DATA FOR STATION 612 017 PARAMETER 012203 TRANS S END TIME 09 COPY YEARS 77

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MEAN	9.190	8.460	8.626	9.170	14.467	31.707	42.493	44.046	38.571	28.537	16.192	10.548
MEDIAN	8.112	7.835	8.214	8.854	10.698	36.551	43.012	42.709	39.953	26.645	15.063	9.478
STD. DEV.	5.235	1.750	1.223	1.372	8.621	13.706	8.595	7.616	9.537	11.387	7.339	3.748
SKEW	8.062	4.024	2.168	1.420	1.782	-.443	-1.030	.382	-.417	.582	1.417	1.802
MAXIMUM	53.256	18.058	14.541	13.662	40.904	55.928	59.959	65.343	64.003	61.001	40.344	24.845
MINIMUM	7.641	7.600	7.600	7.600	7.600	8.407	15.669	18.703	12.933	9.273	0.000	0.000
S. CORR.	.170	.623	-.071	.317	.091	.454	.519	.575	.591	.624	.763	.860
C. VAR.	.570	.207	.142	.150	.596	.431	.202	.173	.247	.399	.453	.355

STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)

MEAN (%)	3.615	3.330	3.388	3.608	5.417	11.767	16.349	17.030	14.685	10.696	6.085	4.030
S.E.E.	.232	.098	.078	.093	.300	.482	.329	.286	.293	.359	.233	.124

APPENDIX B

MONTHLY RESERVOIR COLOUR CONCENTRATION, STATISTICS AND FREQUENCY ANALYSIS OUTPUTS

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

STATION NUMBER NOT REGISTERED

STATION NO. 000 013
COPY NUMBER (5)

MONTHLY TOTAL

TRUE COLOUR (FILTERED) PLAT-COBALT IN HAZEN

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1907	17.	18.	17.	15.	9.	9.	10.	14.	14.	13.	12.	10.
1908	10.	10.	10.	8.	5.	5.	10.	10.	9.	9.	8.	6.
1909	7.	7.	6.	6.	3.	4.	4.	7.	7.	8.	7.	6.
1910	6.	6.	6.	5.	3.	8.	18.	23.	24.	22.	20.	16.
1911	17.	17.	16.	14.	9.	9.	11.	13.	12.	11.	10.	8.
1912	8.	9.	8.	7.	4.	4.	6.	8.	11.	11.	10.	8.
1913	8.	8.	8.	7.	4.	4.	8.	17.	16.	14.	13.	11.
1914	11.	11.	10.	9.	6.	6.	6.	7.	6.	6.	5.	4.
1915	4.	4.	4.	4.	2.	3.	8.	11.	13.	12.	11.	9.
1916	9.	9.	9.	8.	5.	5.	8.	11.	11.	10.	9.	8.
1917	8.	8.	7.	7.	4.	7.	20.	26.	29.	33.	30.	24.
1918	25.	25.	24.	21.	13.	18.	20.	20.	20.	18.	17.	14.
1919	14.	14.	13.	12.	7.	8.	11.	15.	14.	12.	11.	9.
1920	9.	10.	9.	8.	5.	7.	12.	18.	19.	17.	15.	13.
1921	13.	13.	13.	11.	7.	8.	11.	13.	12.	11.	10.	8.
1922	8.	8.	8.	7.	4.	4.	5.	9.	8.	8.	7.	6.
1923	6.	6.	6.	5.	3.	10.	15.	21.	27.	26.	23.	19.
1924	19.	20.	19.	17.	10.	12.	14.	17.	17.	17.	16.	13.
1925	13.	13.	13.	11.	7.	7.	10.	11.	10.	9.	8.	7.
1926	7.	7.	7.	6.	4.	7.	16.	21.	22.	29.	27.	22.
1927	22.	23.	22.	19.	12.	13.	17.	19.	19.	18.	16.	13.
1928	13.	14.	13.	11.	7.	7.	12.	17.	17.	17.	16.	13.
1929	13.	13.	13.	11.	7.	8.	11.	12.	11.	10.	9.	7.
1930	8.	8.	7.	7.	4.	6.	18.	19.	19.	18.	17.	14.
1931	14.	14.	14.	12.	7.	7.	11.	14.	15.	14.	13.	11.
1932	11.	11.	10.	9.	6.	8.	18.	19.	18.	17.	15.	12.
1933	13.	13.	12.	11.	7.	9.	12.	13.	14.	12.	11.	9.
1934	9.	10.	9.	8.	5.	5.	9.	11.	11.	11.	10.	8.
1935	8.	8.	8.	7.	4.	4.	9.	12.	12.	11.	10.	8.
1936	9.	9.	8.	7.	5.	5.	7.	12.	11.	11.	10.	8.
1937	8.	8.	8.	7.	5.	7.	8.	9.	9.	8.	8.	6.
1938	6.	6.	6.	5.	3.	3.	6.	9.	9.	9.	8.	6.
1939	7.	7.	6.	6.	3.	4.	11.	26.	26.	24.	21.	17.
1940	18.	18.	17.	15.	9.	9.	9.	10.	9.	8.	8.	6.
1941	6.	7.	6.	5.	3.	5.	10.	13.	16.	15.	14.	11.
1942	11.	12.	11.	10.	6.	8.	12.	25.	33.	31.	28.	23.
1943	23.	24.	23.	20.	12.	13.	15.	17.	18.	17.	15.	12.
1944	13.	13.	12.	11.	7.	7.	10.	12.	12.	10.	10.	8.
1945	8.	8.	8.	7.	4.	14.	22.	34.	32.	29.	26.	22.
1946	22.	23.	21.	19.	12.	14.	27.	33.	30.	27.	25.	20.

Draw : 10×10^6 m^3 /year

KEY

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PROGRAM MDLIST
PROCESSED ON 10.33 23 NOV 1984

COLLECTING AUTHORITY WATER RES(03)

YEARS 1907 - 1946
STATION NO. 000 013

31655

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

STATION NUMBER NOT REGISTERED

STATION NO. 000 013
COPY NUMBER (S)

MONTHLY TOTAL

TRUE COLOUR (FILTERED) PLAT-COBALT IN HAZEN

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1947	21.	21.	20.	18.	11.	16.	20.	22.	20.	18.	16.	13.
1948	14.	14.	13.	12.	7.	7.	8.	12.	12.	11.	10.	8.
1949	9.	9.	8.	7.	5.	5.	8.	15.	14.	13.	12.	10.
1950	10.	10.	10.	9.	5.	5.	7.	9.	10.	9.	8.	7.
1951	7.	7.	7.	6.	4.	6.	9.	11.	10.	9.	9.	7.
1952	7.	7.	7.	6.	4.	7.	10.	13.	15.	14.	14.	11.
1953	12.	12.	11.	10.	6.	8.	12.	13.	13.	13.	13.	10.
1954	11.	11.	10.	9.	6.	6.	7.	9.	9.	8.	7.	6.
1955	6.	6.	6.	5.	3.	5.	8.	19.	20.	20.	18.	15.
1956	15.	16.	15.	13.	8.	11.	15.	18.	17.	15.	14.	12.
1957	12.	12.	11.	10.	6.	14.	16.	17.	17.	15.	14.	11.
1958	12.	12.	11.	10.	6.	6.	13.	15.	14.	13.	12.	10.
1959	10.	10.	10.	9.	5.	5.	5.	7.	7.	6.	6.	5.
1960	5.	5.	5.	4.	2.	3.	8.	9.	9.	8.	8.	6.
1961	6.	6.	6.	5.	3.	6.	8.	10.	11.	10.	9.	8.
1962	8.	8.	7.	7.	4.	5.	5.	7.	8.	7.	7.	6.
1963	6.	6.	6.	5.	3.	6.	13.	22.	22.	20.	19.	15.
1964	15.	16.	15.	13.	8.	12.	24.	35.	32.	29.	26.	21.
1965	22.	22.	21.	19.	12.	12.	15.	17.	16.	16.	15.	12.
1966	13.	13.	12.	11.	7.	7.	10.	11.	12.	12.	11.	9.
1967	9.	9.	9.	8.	5.	9.	15.	17.	17.	15.	14.	11.
1968	12.	12.	11.	10.	6.	8.	10.	13.	14.	13.	12.	10.
1969	10.	10.	10.	9.	5.	6.	8.	10.	9.	9.	8.	6.
1970	7.	7.	6.	6.	3.	7.	11.	13.	12.	13.	12.	10.
1971	10.	10.	10.	9.	5.	6.	6.	8.	9.	12.	11.	9.
1972	10.	10.	9.	8.	5.	5.	5.	8.	8.	7.	6.	5.
1973	5.	5.	5.	5.	3.	4.	9.	13.	14.	13.	12.	10.
1974	10.	10.	10.	8.	5.	10.	18.	25.	23.	21.	19.	16.
1975	16.	16.	16.	14.	8.	9.	10.	12.	11.	10.	9.	8.
1976	8.	8.	8.	7.	4.	4.	4.	5.	5.	4.	4.	3.
1977	3.	3.	3.	3.	2.	2.	2.	6.	5.	6.	5.	4.
1978	4.	4.	4.	4.	2.	2.	7.	7.	7.	8.	7.	6.
1979	6.	6.	6.	5.	3.	3.	4.	4.	3.	3.	3.	2.
1980	2.	2.	2.	2.	1.	1.	2.	5.	6.	5.	5.	4.
1981	4.	4.	4.	3.	2.	2.	5.	10.	10.	10.	9.	7.
1982	10.	11.	10.	9.	5.	6.	6.	7.	7.	7.	6.	5.
1983	5.	5.	5.	5.	3.	3.	7.	12.	16.	14.	13.	11.

Draw : 10×10^6 m^3/year

KEY

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"	DERIVED FROM INCOMPLETE RECORD

PROGRAM MDLIST
PROCESSED ON 10.33 23 NOV 1984

COLLECTING AUTHORITY WATER RES(03)

YEARS 1947 - 1983
STATION NO. 000 013

WATER RESOURCES SECTION PROGRAM MOSTAT2 RUN ON 84/11/23 AT 10.35

STATISTICS OF MONTHLY DATA FOR STATION 000 013 PARAMETER Q12203 TRANS 5 END TIME 24 COPY 5 YEARS 77

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MEAN	10.542	10.750	10.263	8.980	5.556	7.048	10.717	14.236	14.373	13.639	12.505	10.208
MEDIAN	9.569	9.770	9.345	8.188	5.078	6.520	9.820	12.604	12.553	12.391	11.364	9.296
STD. DEV.	5.003	5.103	4.860	4.254	2.616	3.364	5.070	6.600	6.715	6.523	5.902	4.857
SKEW	1.034	1.028	1.019	1.019	1.008	.978	.917	1.133	1.041	1.124	1.116	1.106
MAXIMUM	24.776	25.110	23.964	20.974	12.904	17.713	26.956	34.721	33.403	32.654	29.923	24.323
MINIMUM	2.436	2.477	2.372	2.060	1.270	1.336	2.094	3.702	3.415	3.172	2.910	2.380
S. CORR.	.998	1.000	1.000	1.000	1.000	.805	.812	.903	.969	.980	1.000	1.000
C. VAR.	.475	.475	.474	.474	.471	.477	.473	.464	.467	.478	.477	.476

STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)

MEAN (%)	8.322	8.486	8.105	7.092	4.390	5.390	8.128	10.944	11.080	10.524	9.656	7.884
S.E.E.	.283	.288	.275	.241	.149	.138	.179	.243	.284	.289	.266	.217

Draw : 10×10^6 m^3 /year

31657

LINEAR FREQUENCY ANALYSIS
WITH FIRST VALUE : 0.
CLASS INTERVAL : 1.00000

RANGE	NUMBER	PROBAB. %	ACCUM	ACCUM %	MEAN	SUM IN-RANGE	% TOTAL	ACCUM SUM	ACCUM % SUM
0.	0	0.	0	0.	0.	0.	0.	0.	0.
1.0000	0	0.	0	0.	0.	0.	0.	0.	0.
2.0000	4	.43290	4	.43290	1.5412	6.1646	.62151E-01	6.1646	.62151E-01
3.0000	19	2.0563	23	2.4892	2.4781	47.084	.47469	53.248	.53684
4.0000	31	3.3550	54	5.8442	3.4337	106.44	1.0732	159.69	1.6100
5.0000	55	5.9524	109	11.797	4.4580	245.19	2.4720	404.88	4.0820
6.0000	79	8.5498	188	20.346	5.5172	435.86	4.3943	840.74	8.4763
7.0000	79	8.5498	267	28.896	6.5558	517.91	5.2214	1358.6	13.698
8.0000	81	8.7662	348	37.662	7.5403	610.76	6.1576	1969.4	19.855
9.0000	72	7.7922	420	45.455	8.4461	608.12	6.1310	2577.5	25.986
10.000	80	8.6580	500	54.113	9.5325	762.60	7.6884	3340.1	33.675
11.000	65	7.0346	565	61.147	10.490	681.82	6.8740	4022.0	40.549
12.000	58	6.2771	623	67.424	11.496	666.80	6.7225	4688.8	47.271
13.000	55	5.9524	678	73.377	12.488	686.85	6.9247	5375.6	54.196
14.000	43	4.6537	721	78.030	13.411	576.68	5.8140	5952.3	60.010
15.000	23	2.4892	744	80.519	14.417	331.58	3.3429	6283.9	63.353
16.000	31	3.3550	775	83.874	15.440	478.62	4.8254	6762.5	68.178
17.000	24	2.5974	799	86.472	16.524	396.57	3.9982	7159.1	72.177
18.000	22	2.3810	821	88.853	17.508	385.17	3.8832	7544.2	76.060
19.000	14	1.5152	835	90.368	18.497	258.96	2.6108	7803.2	78.671
20.000	13	1.4069	848	91.775	19.442	252.74	2.5481	8055.9	81.219
21.000	12	1.2987	860	93.074	20.321	243.85	2.4584	8299.8	83.677
22.000	13	1.4069	873	94.481	21.536	279.97	2.8226	8579.7	86.500
23.000	12	1.2987	885	95.779	22.443	269.32	2.7152	8849.1	89.215
24.000	7	.75758	892	96.537	23.583	165.08	1.6643	9014.1	90.879
25.000	6	.64935	898	97.186	24.623	147.74	1.4895	9161.9	92.369
26.000	3	.32468	901	97.511	25.500	76.501	.77127	9238.4	93.140
27.000	7	.75758	908	98.268	26.573	186.01	1.8753	9424.4	95.015
28.000	1	.10823	909	98.377	27.466	27.466	.27691	9451.9	95.292
29.000	2	.21645	911	98.593	28.592	57.184	.57652	9509.0	95.869
30.000	4	.43290	915	99.026	29.323	117.29	1.1825	9626.3	97.051
31.000	2	.21645	917	99.242	30.616	61.232	.61733	9687.6	97.669
32.000	2	.21645	919	99.459	31.741	63.481	.64001	9751.0	98.309
33.000	1	.10823	920	99.567	32.654	32.654	.32921	9783.7	98.638
34.000	3	.32468	923	99.892	33.466	100.40	1.0122	9884.1	99.650
35.000	1	.10823	924	100.00	34.721	34.721	.35005	9918.8	100.00

NUMBER OF VALUES : 924
NUMBER OF ZEROES : 0
NON ZEROES : 924
MEAN VALUE : 10.7346
STD DEV : 5.80434

Draw : 10×10^6 m^3/year

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

STATION NUMBER NOT REGISTERED

STATION NO. 000 013
COPY NUMBER (5)

MONTHLY TOTAL

TRUE COLOUR (FILTERED) PLAT-COBALT IN HAZEN

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1907	17.	18.	17.	15.	9.	9.	11.	15.	14.	13.	12.	10.
1908	10.	10.	10.	9.	5.	6.	10.	11.	10.	9.	8.	7.
1909	7.	7.	7.	6.	4.	4.	5.	9.	8.	9.	8.	7.
1910	7.	7.	7.	6.	4.	10.	22.	26.	27.	24.	22.	18.
1911	19.	19.	18.	16.	10.	10.	12.	14.	13.	12.	11.	9.
1912	9.	9.	9.	8.	5.	5.	7.	9.	13.	13.	11.	9.
1913	10.	10.	9.	8.	5.	5.	9.	19.	16.	16.	15.	12.
1914	12.	13.	12.	11.	7.	7.	7.	8.	7.	6.	6.	5.
1915	5.	5.	5.	4.	3.	3.	10.	14.	16.	15.	14.	11.
1916	11.	11.	11.	10.	6.	6.	9.	14.	13.	12.	11.	9.
1917	9.	9.	9.	8.	5.	9.	24.	29.	31.	34.	31.	25.
1918	26.	26.	25.	22.	13.	19.	20.	21.	21.	19.	17.	14.
1919	14.	15.	14.	12.	8.	8.	12.	16.	15.	13.	12.	10.
1920	10.	10.	10.	9.	5.	8.	12.	19.	20.	18.	16.	13.
1921	13.	14.	13.	12.	7.	9.	12.	14.	13.	12.	11.	9.
1922	9.	9.	9.	8.	5.	5.	6.	10.	9.	9.	8.	6.
1923	6.	7.	6.	5.	3.	12.	18.	23.	28.	27.	25.	20.
1924	20.	21.	20.	18.	11.	13.	15.	18.	17.	18.	16.	13.
1925	14.	14.	13.	12.	7.	7.	10.	11.	10.	9.	9.	7.
1926	7.	7.	7.	6.	4.	8.	18.	24.	24.	30.	28.	23.
1927	23.	24.	22.	20.	12.	13.	17.	20.	20.	18.	17.	14.
1928	14.	14.	13.	12.	7.	7.	13.	18.	18.	18.	16.	13.
1929	14.	14.	13.	11.	7.	9.	11.	13.	12.	11.	10.	8.
1930	8.	8.	8.	7.	4.	7.	20.	21.	21.	20.	18.	15.
1931	15.	15.	15.	13.	8.	8.	12.	15.	16.	15.	14.	11.
1932	11.	12.	11.	10.	6.	9.	19.	20.	19.	17.	16.	13.
1933	13.	13.	13.	11.	7.	10.	13.	14.	14.	13.	12.	10.
1934	10.	10.	10.	9.	5.	6.	9.	12.	12.	11.	10.	9.
1935	9.	9.	8.	7.	5.	5.	10.	13.	13.	12.	11.	9.
1936	9.	9.	9.	8.	5.	5.	7.	13.	12.	11.	10.	8.
1937	9.	9.	8.	7.	5.	7.	9.	10.	10.	9.	8.	7.
1938	7.	7.	7.	6.	4.	4.	6.	10.	11.	10.	9.	7.
1939	8.	8.	7.	6.	4.	5.	13.	29.	28.	26.	23.	19.
1940	19.	20.	19.	17.	10.	10.	10.	11.	10.	9.	8.	7.
1941	7.	7.	7.	6.	4.	6.	12.	16.	19.	18.	16.	13.
1942	13.	14.	13.	11.	7.	10.	14.	27.	34.	32.	29.	24.
1943	24.	25.	23.	20.	13.	13.	15.	18.	19.	17.	16.	13.
1944	13.	13.	13.	11.	7.	7.	11.	13.	12.	11.	10.	8.
1945	8.	9.	8.	7.	4.	16.	24.	35.	33.	30.	27.	22.
1946	23.	23.	22.	19.	12.	14.	26.	35.	31.	28.	26.	21.

Draw : 25×10^6 m^3 /year

KEY

NA	RECORD NOT AVAILABLE
NR	NOT RECORDED
*	FAULTY - VERY CONFIDENT IN CORRECTED TRACE
**	FAULTY - SOME DOUBT IN CORRECTED TRACE
*E	ESTIMATED TRACE
"	DERIVED FROM INCOMPLETE RECORD

PROGRAM MDLIST
PROCESSED ON 15.55 29 NOV 1984

COLLECTING AUTHORITY WATER RES(03)

YEARS 1907 - 1946
STATION NO. 000 013

39527

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

STATION NUMBER NOT REGISTERED

STATION NO. 000 013
COPY NUMBER (5)

MONTHLY TOTAL

TRUE COLOUR (FILTERED) PLAT-COBALT IN HAZEN

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1947	21.	22.	21.	18.	11.	17.	21.	23.	20.	18.	17.	14.
1948	14.	14.	14.	12.	7.	7.	6.	13.	13.	12.	11.	9.
1949	9.	9.	9.	8.	5.	5.	9.	17.	16.	15.	13.	11.
1950	11.	11.	11.	9.	6.	6.	8.	10.	11.	10.	9.	7.
1951	8.	8.	7.	6.	4.	7.	11.	13.	12.	11.	10.	8.
1952	8.	8.	8.	7.	4.	8.	12.	16.	17.	16.	15.	12.
1953	13.	13.	12.	11.	7.	9.	13.	14.	14.	14.	13.	11.
1954	11.	11.	11.	10.	6.	6.	8.	10.	9.	8.	8.	6.
1955	6.	6.	6.	5.	3.	5.	10.	22.	23.	22.	20.	16.
1956	17.	17.	16.	14.	9.	12.	16.	19.	18.	16.	15.	12.
1957	12.	13.	12.	11.	6.	15.	17.	18.	17.	16.	15.	12.
1958	12.	12.	12.	10.	6.	7.	14.	16.	15.	14.	13.	10.
1959	11.	11.	10.	9.	6.	6.	6.	8.	7.	7.	6.	5.
1960	5.	5.	5.	4.	3.	3.	9.	12.	11.	10.	9.	8.
1961	8.	8.	7.	7.	4.	7.	11.	14.	14.	13.	12.	10.
1962	10.	10.	10.	9.	5.	6.	7.	10.	10.	10.	9.	8.
1963	8.	8.	8.	7.	4.	9.	19.	28.	27.	25.	22.	18.
1964	19.	19.	18.	16.	10.	14.	26.	36.	33.	30.	27.	22.
1965	23.	23.	22.	19.	12.	13.	16.	17.	17.	17.	16.	13.
1966	13.	13.	13.	11.	7.	7.	10.	12.	13.	12.	11.	9.
1967	9.	10.	9.	8.	5.	10.	16.	18.	18.	16.	15.	12.
1968	12.	12.	12.	10.	6.	8.	11.	13.	14.	14.	13.	10.
1969	11.	11.	10.	9.	6.	7.	9.	11.	10.	9.	8.	7.
1970	7.	7.	7.	6.	4.	9.	13.	15.	14.	15.	14.	11.
1971	11.	12.	11.	10.	6.	6.	7.	9.	10.	13.	12.	10.
1972	10.	10.	10.	9.	5.	5.	6.	8.	8.	8.	7.	6.
1973	6.	6.	6.	5.	3.	5.	11.	15.	16.	15.	13.	11.
1974	11.	11.	11.	10.	6.	11.	19.	26.	24.	22.	20.	16.
1975	17.	17.	16.	14.	9.	9.	11.	13.	12.	11.	10.	8.
1976	8.	8.	8.	7.	4.	4.	4.	6.	5.	5.	4.	4.
1977	4.	4.	4.	3.	2.	2.	3.	8.	8.	8.	7.	6.
1978	6.	6.	6.	5.	3.	4.	11.	12.	12.	13.	12.	9.
1979	10.	10.	10.	8.	5.	5.	6.	7.	6.	6.	5.	4.
1980	5.	5.	5.	4.	2.	3.	8.	19.	19.	18.	16.	13.
1981	14.	14.	14.	12.	7.	15.	34.	40.	36.	32.	29.	24.
1982	32.	33.	31.	28.	17.	17.	20.	23.	23.	21.	20.	16.
1983	17.	17.	17.	15.	9.	34.	41.	44.	42.	38.	35.	29.

Draw : 25×10^6 m^3 /year

KEY

NA	RECORD NOT AVAILABLE
NR	NOT RECORDED
*	FAULTY - VERY CONFIDENT IN CORRECTED TRACE
**	FAULTY - SOME DOUBT IN CORRECTED TRACE
*E	ESTIMATED TRACE
"	DERIVED FROM INCOMPLETE RECORD

PROGRAM MDLIST
PROCESSED ON 15.55 29 NOV 1984

COLLECTING AUTHORITY WATER RES(03)

YEARS 1947 - 1983
STATION NO. 000 013

WATER RESOURCES SECTION PROGRAM MOSTAT2 RUN ON 84/11/29 AT 15.56

STATISTICS OF MONTHLY DATA FOR STATION 000 013 PARAMETER 012203 TRANS 5 END TIME 24 COPY 5. YEARS 77

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MEAN	11.984	12.226	11.685	10.231	6.326	8.500	13.040	15.895	16.726	15.754	14.431	11.786
MEDIAN	10.679	10.902	10.411	9.057	5.608	7.416	11.222	14.564	14.497	13.936	12.799	10.451
STD. DEV.	5.474	5.582	5.335	4.686	2.886	4.698	6.741	7.916	7.665	7.242	6.608	5.397
SKEW	1.263	1.259	1.273	1.291	1.306	2.468	1.678	1.360	1.165	1.135	1.133	1.138
MAXIMUM	31.974	32.637	31.484	27.637	17.282	34.019	41.461	44.294	41.895	38.140	35.110	28.891
MINIMUM	3.751	3.834	3.678	3.238	1.996	1.993	2.505	5.539	5.275	4.867	4.477	3.668
S. CORR.	.987	1.000	1.000	1.000	1.000	.648	.836	.920	.978	.984	1.000	1.000
C. VAR.	.457	.457	.457	.458	.456	.553	.517	.469	.458	.460	.458	.458

STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)

MEAN (%)	117.502	119.858	114.544	100.273	62.043	76.485	111.854	144.280	142.268	133.579	122.427	100.000
S.E.E.	6.753	6.884	6.578	5.760	3.563	3.346	2.942	1.843	1.047	.174	.045	0.000

Draw : 25×10^6 m^3 /year

39529

LINEAR FREQUENCY ANALYSIS
WITH FIRST VALUE : 0.
CLASS INTERVAL : 1.00000

RANGE	NUMBER	PROBAB. %	ACCUM	ACCUM %	MEAN	SUM IN RANGE	% TOTAL	ACCUM SUM	ACCUM % SUM
0.	0	0.	0	0.	0.	0.	0.	0.	0.
1.0000	0	0.	0	0.	0.	0.	0.	0.	0.
2.0000	2	.21645	2	.21645	1.9942	3.9884	.34628E-01	3.9884	.34628E-01
3.0000	5	.54113	7	.75758	2.6063	13.032	.11314	17.020	.14777
4.0000	22	2.3810	29	3.1385	3.5907	78.996	.68585	96.016	.83362
5.0000	38	4.1126	67	7.2511	4.6322	176.02	1.5283	272.04	2.3619
6.0000	48	5.1948	115	12.446	5.5707	267.39	2.3215	539.43	4.6834
7.0000	60	6.4935	175	18.939	6.5604	393.62	3.4175	933.06	8.1009
8.0000	73	7.9004	248	26.840	7.4803	546.06	4.7410	1479.1	12.842
9.0000	65	7.0346	313	33.874	8.5046	552.80	4.7994	2031.9	17.641
10.000	84	9.0909	397	42.965	9.4780	796.16	6.9123	2828.1	24.554
11.000	68	7.3593	465	50.325	10.491	713.38	6.1937	3541.5	30.747
12.000	59	6.3853	524	56.710	11.450	675.54	5.8651	4217.0	36.612
13.000	62	6.7100	586	63.420	12.460	772.52	6.7071	4989.5	43.319
14.000	68	7.3593	654	70.779	13.461	915.36	7.9472	5904.9	51.267
15.000	32	3.4632	686	74.242	14.517	464.55	4.0333	6369.4	55.300
16.000	21	2.2727	707	76.515	15.482	325.12	2.8227	6694.5	58.123
17.000	36	3.8961	743	80.411	16.450	592.21	5.1416	7286.8	63.264
18.000	22	2.3810	765	82.792	17.483	384.63	3.3394	7671.4	66.604
19.000	24	2.5974	789	85.390	18.402	441.64	3.8343	8113.0	70.438
20.000	23	2.4892	812	87.879	19.455	447.47	3.8850	8560.5	74.323
21.000	15	1.6234	827	89.502	20.474	307.11	2.6663	8867.6	76.989
22.000	9	.97403	836	90.476	21.552	193.97	1.6841	9061.6	78.673
23.000	14	1.5152	850	91.991	22.474	314.64	2.7317	9376.2	81.405
24.000	14	1.5152	864	93.506	23.509	329.13	2.8575	9705.3	84.263
25.000	7	.75758	871	94.264	24.466	171.26	1.4869	9876.6	85.750
26.000	5	.54113	876	94.805	25.682	128.41	1.1149	10005.	86.864
27.000	6	.64935	882	95.455	26.456	158.74	1.3782	10164.	88.243
28.000	4	.43290	886	95.887	27.440	109.76	.95295	10274.	89.196
29.000	8	.86580	894	96.753	28.463	227.71	1.9770	10501.	91.173
30.000	4	.43290	898	97.186	29.386	117.54	1.0205	10619.	92.193
31.000	2	.21645	900	97.403	30.172	60.343	.52390	10679.	92.717
32.000	6	.64935	906	98.052	31.507	189.04	1.6413	10868.	94.358
33.000	3	.32468	909	98.377	32.520	97.559	.84702	10966.	95.205
34.000	1	.10823	910	98.485	33.008	33.008	.28658	10999.	95.492
35.000	6	.64935	916	99.134	34.365	206.19	1.7902	11205.	97.282
36.000	2	.21645	918	99.351	35.400	70.799	.61468	11276.	97.897
37.000	1	.10823	919	99.459	36.347	36.347	.31557	11312.	98.212
38.000	0	0.	919	99.459	0.	0.	0.	11312.	98.212
39.000	1	.10823	920	99.567	38.140	38.140	.33113	11350.	98.543
40.000	0	0.	920	99.567	0.	0.	0.	11350.	98.543
41.000	1	.10823	921	99.675	40.122	40.122	.34834	11390.	98.892
42.000	2	.21645	923	99.892	41.678	83.356	.72370	11474.	99.615
43.000	0	0.	923	99.892	0.	0.	0.	11474.	99.615
44.000	0	0.	923	99.892	0.	0.	0.	11474.	99.615
45.000	1	.10823	924	100.00	44.294	44.294	.38456	11518.	100.00

NUMBER OF VALUES : 924
NUMBER OF ZEROES : 0
NON ZEROES : 924
MEAN VALUE : 12.4653
STD DEV : 6.71705

Draw : 25×10^6 m^3 /year

APPENDIX I

REPORT ON THE ETHNOGRAPHIC SURVEY HARRIS DAM PROJECT

Prepared by
R. O'Connor
Consulting to Dames & Moore

26th April 1984

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1.0 INTRODUCTION

1.1 BACKGROUND

This report is based on a period of field research which was carried out in March and April, 1984. It was commissioned by Dames & Moore, Lyall Street, South Perth, on behalf of the Water Authority of Western Australia (Water Authority) with the specific aim of interviewing relevant Aboriginal persons to ensure that proposed development of the Harris Dam at Collie, did not interfere with any Aboriginal sites of mythological or ritual significance. In the course of the survey, serendipitous information was obtained on Aboriginal population movements in the Collie area and also on Aboriginal employment in the early decades of this century. All of this material, which is relevant to the central theme, is included in this report.

1.2 ACKNOWLEDGEMENTS

In accordance with normal practice, the privacy of major informants is protected and their names are not revealed in this report. They will, however, be listed in the Aboriginal Sites Department at the Western Australian Museum, together with a description and map of the sites revealed by them.

The author gratefully acknowledges the co-operation of the following Aboriginal people, who willingly gave their assistance to ensure that all persons with relevant knowledge of the Collie area should be identified and interviewed:

Mrs G. Abraham, Collie.
Mr D. Cockey, Collie.
Mrs L. Cockey, Collie.
Mr G. Colbung, Albany.
Mr K. Colbung, Perth.
Mr L. Eades, Wagin.
Mr C. Hart, Collie.
Mrs J. Kelly, Medina.
Mr O. Little, Pinjarra.
Mrs C. Northover, Collie.
Mr J. Northover, Collie.
Mrs P. Thorne, Medina.
Mr R. Woods, Medina.
Mrs S. Wynne, Collie.

1.3 FORMAT OF REPORT

A consideration of the rights and responsibilities of Australian Aborigines vis-a-vis specific significant sites in the Collie area, should be based on an understanding of traditional concepts of land ownership, and how these were based on religion. Section Two therefore discusses these concepts, and also addresses the question of the importance of mythological sites to present-day Aborigines and the resulting need for protection of such areas. Section Three discusses recent Aboriginal history in the Collie region and the formulation of a survey methodology suited to the area. Section Four describes the sole mythological site identified in the vicinity of the Harris Dam Project, and discusses this site within a regional mythological framework. Finally, Section Five offers for consideration a series of recommendations based on the results of the research.

2.0 LAND AND RELIGION IN ABORIGINAL AUSTRALIA

2.1 ALL LAND SACRED

There is a sense in which it can be said that all land is sacred to Aboriginal Australians. By examining the implications of this statement, we can gain an understanding of mythological beliefs and land ownership in pre-contact South-Western Australia, and thus an understanding of the importance of mythological sites to present-day Aborigines.

Throughout Aboriginal Australia there was, and is, a belief in a formative or creative era, which is generally rendered in English as the 'Dreaming' or 'Dreamtime'.[1] In this era, mythological ancestors, many of whom were part-animal and part-human or had shape-changing characteristics, roamed the earth and transformed it from a featureless plain into its present shape, by creating or forming the various physical features which we now know. In some cases, these ancestors were also responsible for the creation of

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1. The reader is directed to Berndt & Berndt (1977) and Tonkinson (1974) for a detailed analysis of this concept. The brief statement above is based on these works and on my own fieldnotes.

animal and plant species and of human beings. Their wanderings crossed and recrossed the countryside. At sites on these journeys they camped, ate, killed, made love, gave birth and performed magical and ritual acts. In places they are metamorphosed in stone, water or other natural features. In places such as deep, still waterholes, they may still lurk; ready to accost the unwary passer-by. In other places, they have left behind a spiritual essence, which can be drawn upon by those with the knowledge and the right to do so. Thus, they have not left the earth, but remain behind in a spiritual manner.

Aboriginal Australians, engaged in their quotidian food-gathering labours, were actually following in the tracks of these ancestors. On all sides, topographic features, food resources and even living beings were a constant physical reminder of their passing. Geographical information was expressed in terms of the ancestor's travels, and when newcomers arrived in an area, as happened often in the unsettled years following contact with Europeans, they also learned the geography of their new domicile in terms of its mythic associations.

The ritual, social and economic life of the Aborigines was based on the land and largely imitated the behaviour of the mythological ancestors. It is in this sense that all land is sacred, and the sites on the tracks where the ancestors were metamorphosed, performed specific actions or left a physical sign of their presence, are the foci from which this sacred presence radiates.

2.2 LAND OWNERSHIP

In relation to land, the concepts of ownership among traditionally-orientated Aborigines and among Euro-Australians differ widely. To the latter, ownership is generally expressed in terms of individual and exclusive rights to use of and/or residence on land. Landlessness is not an irremediable state; land may be acquired by purchase or other means and may then be given by way of bequest, or sold or otherwise disposed of for profit-making or other reasons. In such a viewpoint, land is seen either as a resource for individual use, or as a commodity which can be dealt with or dealt over in much the same way as any other material possession. In the history of inter-ethnic affairs in Australia much misunderstanding has occurred because such considerations regarding land, which are largely taken for granted by Euro-Australians, are at odds with Aboriginal concepts of land ownership.

To the Aboriginal Australian, ownership was expressed in terms of collective responsibility to a given tract of land, and particularly to a mythologically important site or group of sites within that tract, and in terms of rights over mythological and ritual sequences associated with it, and in certain areas over symbolic patterns, designs and objects relating to it (Berndt & Berndt, 1978: 17; Bardon, 1979:22). Ownership also implied rights to hunt and gather food over a given area, although it is important to realise that these rights were not necessarily exclusive. This collective ownership was vested in a group which has been variously termed a 'clan' (Elkin, 1938: 77) or a 'local descent group' (Berndt & Berndt, 1977: 40) and whose members were generally related through patrilineal descent. These groups were exogamous: female members marrying male members of other groups, while male members sought wives outside the group (Berndt & Berndt, 1952: 37). The tract of land over which the group excercised this ownership was termed an 'estate' by Stanner (1965), and this term is encountered in the literature, although it has the unfortunate English connotation of an area of land which is designated in relation to its boundaries; whereas, as stated above, the local descent group's land was designated in relation to the mythological sites within it, and the clear delineation of external boundaries was not always an issue.

In Aboriginal Australia, therefore, a clearly defined and acknowledged form of land ownership existed. It was vested in an identifiable group, whose relationship with the land was expressed in mythological terms and actively demonstrated in religious rituals. These rituals were based on the activities of the mythological ancestors of the Dreaming in the course of their travels across the land, and alluded to or were centered on the specific sites in the estate which were relevant to those ancestors. The male members of the particular local descent group maintained these sites and had sole rights to 'speak for' them or to reveal their presence to outsiders. Traditionally, these rights were inalienable. Ownership was received from the previous generation and the land was held in trust, to be passed to the succeeding generation. Such notions as conquest of another group's land, or sale of one's own land for profit were not applicable to this situation.

2.3 OTHER CLAIMS TO LAND

Other claims to land, not centrally relevant to this report, but nonetheless necessary for an understanding of the importance of protection of Aboriginal mythological and ritual sites, may arise from conception or birth in a particular area.

Secondary rights (Berndt, 1982: 5) may also exist over 'mother's country'; that is, the estate of the mother's local descent group.

In areas where contact with Europeans brought disease or violent conflict, it is often the case that traditional owners, or even those with secondary rights, have died out. Their places may have been taken by other Aboriginal people who moved into the area. These newcomers may have received the sacred knowledge pertaining to the area from the traditional owners prior to their death, and thus exercise a broad custodianship over the land and sites therein.

In areas of intensive European contact, where populations of mixed ethnic background exist and where all tribal or traditionally-orientated people have died out, it should not be taken for granted that knowledge of traditional religion has also died out and that protection of mythological sites is unnecessary (see Colbung, 1980 and Bropho, 1980). It has been shown that these sites were at the core of traditional Aboriginal religious life. In the present decade, which has witnessed a resurgence of pride in Aboriginality, they are a guarantee of continuity with the past and are thus as important to urbanised Aborigines as they are to their counterparts in the remote regions of the country (c.f. Liberman, 1976: 34).

In the South-West of Australia, the arrival at the one time of relatively large numbers of land-seeking Europeans meant that the shock of contact was sudden and total. The armed conflict which erupted in places was brief, and was followed for the Aborigines by dispossession, pauperisation and the creation of a situation where the remnants of the original land-owners became dependent on hand-outs for survival (see Elkin, 1951). Thus, the pattern for the impoverished fringe-dwelling communities was set in the early years of contact. However, in areas where continuity with the past has been maintained, knowledge of Aboriginal mythology and sites will still be held by these communities.

3.0 ABORIGINES OF SOUTH-WESTERN AUSTRALIA

3.1 POPULATION MOVEMENTS

The Aboriginal inhabitants of the South-Western corner of this State appear to have been a distinct socio-cultural group in pre-contact times (Howard, 1980: 90). Linguistic variation occurred, and was used by them to delimit and identify separate sub-groups within this larger collectivity. These labels probably identified different dialectal units of a common South-West language, although they were taken by early settlers to signify separate 'tribal' groups (Berndt, 1980: 81-82). Figure 1 shows a reconstruction of these pre-contact Aboriginal 'tribal' boundaries, which suggests that the area under survey falls in the North-central sector of the lands of the group identified as Ganeang.

Brown (1983: 3-4), quoting from early settlers' accounts, points out that a strong sense of territorial ownership of land existed, and that each group had its own distinct ground. These early accounts appear to refer, however, not to the larger dialectal units, but to the estates of local descent groups. Salvado wrote in 1846 that:

> "....an individual risks his life whenever he leaves the district where he was born, or where his friends assure his safety... nothing would convince them (to accompany him from New Norcia to Perth)...fear, amounting to panic, of being killed by other natives forced them to turn back."
> (trans. Stormon, 1977: 57).

Also, Nairn (1976: 8) quotes records from the W.A. Historical Society as revealing that:

> "....the local natives were annoyed by the Murray River tribesmen for the 'trespassing' on Swan River territory. The raiders had also stolen flour which could well have been taken by the Swan River natives, so as a reprisal, local native trackers speedily identified several of the raiders by footprints left in spilt flour."

It would appear, therefore that apart from the separateness of estates, the groups referred to as dialectal units also maintained a degree of territorial separation.

These divisions disappeared soon after contact. Thus Salvado noted in 1848 that:

> "....the enmity between natives from widely separated parts disappeared, so that they could be trusted to take letters for distances of more than a hundred miles."
> (op. cit.: 85)

Berndt (1980: 81) points out that the merging of social units occurred when people of different dialectal units were forced to live in mixed-membership settlements. Thus settlements such as those at Carrolup or at Moore River have been instrumental in forging a South-Western Aboriginal identity; a widely-scattered population of mixed ethnic background who live in the South-West of this State, see themselves as sharing a common identity and refer to themselves as Nyungars. For example, Colbung (op. cit.: 100) writes that:

> "....my particular land is the territory of the Nyungars located in the South West of Western Australia."

The findings of the ethnohistorical component of this report suggest a pre-contact pattern of movement between the coastal plains and the hills by the Ganeang, as supplies of the various resources changed with the seasons and as the weather conditions improved or worsened. Aboriginal informants, however, stated that to the best of their knowledge the "old people" (i.e. pre-contact Aborigines) visited the upper reaches of the Harris River only during the winter months, but that a permanent population resided in the vicinity of the present township of Collie, where a year round supply of freshwater was guaranteed. This would seem more consistent with patterns of Aboriginal land use encountered elsewhere in Australia. These informants also suggested closer links with Aborigines in the vicinity of present-day Darkan than with residents of the coastal plain. It is, however, conceivable that land-owners from the hills would have rights of access to coastal resources at certain seasons of the year, and would offer reciprocal hospitality at other times (see Doolan, 1979 for a discussion of the concept of permeable boundaries). O'Connor and Veth (1983) have identified a similar pattern of shared land use in the Pilbara. Such reciprocity, however, would not obscure the fact that identifiable groups owned sites in the Collie region and others in the coastal plain.

The ethnohistorical component also notes a second phase of Aboriginal settlement in the 1920's and 1930's, arising from the need for labour in the expanding wood industry. As most of these newcomers were males, those who settled in the region married Aboriginal women from the South-West, including some from the Collie region. It is generally the children of such unions that the researcher encounters nowadays, and traditional knowledge, where it exists, is to be found among the senior members of this generation. An example of this is the history of one woman who contributed to the

present survey. She was born in the early 1930's in the Aboriginal camp near the junction of Mistley and Old Sandalwood Roads in the upper reaches of the Harris River. Her father came from the vicinity of Port Hedland: her mother was a South-Western woman.

It appears that Patrick Mingo ("Old Collie Paddy"), who was born in the vicinity of 8 Mile Pool and who died approximately ten years ago was the last surviving member of the previous generation.

Prior to this migration, numbers of local Aborigines and residents of the coastal plains had been employed as shepherds by settlers to the west of Collie. Their value to the settlers lay in their knowledge of water supplies and other resources in the jarrah forests, which could be tapped during dry seasons. While Australia was affected by the economic slump of the early 1930's; this avenue of employment closed and some of the Aboriginal shepherds (including the father of one of the informants to this survey) grouped together to trap and sell brumbies in the upper Harris River area. Their womenfolk contributed to the families' upkeep by collecting Boronia during its flowering season. These flowers, one woman reminisced, "were bought by hawkers from Perth for thirty bob a crate". Live brumbies were sold for one pound each by the trappers.

Many of these families supported themselves in part by hunting and gathering during this period. The women collected yams, emu eggs, turtles and freshwater mussels (Plate 1e) from the swampy areas in the upper reaches of the Harris River. The men occasionally hunted kangaroo and wallaby and feral pigs which, according to local tradition, spread from the Murray River region.[2] One informant reminisced about "djidji water"; a beverage produced by infusing Banksia flowers in fresh water -- "that was our beer in those days".

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2. An interesting example of the mythologization of a historical personage occurred here. In reply to a question regarding the identity of these Murray River settlers, one informant replied: "the only one we really know much about was Daisy Bates -- she settled there in the early days".

Thus, although the area had been subjected to large-scale (by Aboriginal standards) population movements and to the effects of intermarriage with outsiders, a pivotal generation of people, who had known and associated with the original inhabitants, still maintained contact with the country in the 1930's and 1940's.

3.2 METHODOLOGY

As it becomes obvious in the early part of this survey that no single person would be seen by all South-Western Aborigines as sole spokesperson for the area, the researcher concentrated on interviewing a wide cross-section of the Aboriginal population to establish the identity of persons who had associated with the country in the vicinity of the Harris River in the 1930's and 1940's. In this way, a group of informants was selected. These were driven through the target area, and the extent of impact of the proposed development discussed with them, to establish whether a threat was posed to any known Aboriginal sites in the vicinity.

4.0 SURVEY RESULTS

4.1 REGIONAL FRAMEWORK: Waugal (also Wagal or Uocol), the Mythological Serpent.

Berndt (1980: 85) quotes George Fletcher Moore as speaking of Waugal as "a huge winged serpent", who lived in deep dark waters and who was feared as a carrier of sickness. In the Perth area, this serpent "emerged at Mount Eliza and, crawling its way to the sea, created the Swan River".

Salvado (op. cit.: 128-129) wrote of Uocol as follows:

> "....they dread even more going near large pools of water, in which they believe there lurks a great serpent called Uocol, who kills them if they dare to drink there or draw water during the night. A large number of natives came to me one evening asking for water. The first ones took all I had and drank it, and the others, about fifteen of them, asked me to go to a pool nearby to get some for them. I showed them the bucket and told them to go themselves. They all fell silent, and no-one dared to take the bucket, or tell me what they were afraid of, until, about an hour later, one of them said respectfully:
> n-alla cape uoto, chetchet cuaragn; nunda uoto quaragn inad (if we go and take water, very soon we will be killed, but if you go you will be alright).....however much the natives of both sexes like to swim 'dog-paddle' style in summer, they will never go into water that is dark and deep, because they say that the serpent Uocol is there, and they are afraid of him even during the daytime."

Although the existence of a mythological serpent ancestor is in keeping with Aboriginal religious belief elsewhere in Australia; the 'bogey-man' image portrayed by Salvado and Moore seems dubious. It is more likely the case that a Waugal cult existed in pre-contact South-Western Australia, and that the object of this cult was a creative being similar to the Wati Kutjarra or the Wonarmbi serpents in the arid regions in the interior of the country. Even today it is possible (particularly for female researchers, who will not be made privy to secret/sacred material) to gain a similar incorrect impression of the nature of the mythological ancestors of the desert regions. This is especially so in Central Australia where the sagas of the ancestors are being reduced to the level of European fairy tales by insensitive researchers.

4.2 PILING AND WAUGAL

The swamp in the upper reaches of the Harris River, which stretches from the junction of Mistley and Old Sandalwood Roads (also referred to as Trees Road) to Treesville was known to local Aborigines as Piling Swamp (see Figure 2 and Plate 1d). Although the swamp itself did not have mythological significance, it was believed that Waugal had lived among the rocks in the hills on its northern side. At a point 100 metres east of the old wooden bridge across the swamp's western limit, a claypan, which forms a deep pool during the rainy season is encountered. This was known to local Aborigines as Wuridjong Pool; a winnaitch site where Waugal, the mythic serpent was believed to reside (Plates 1a, 1b, 1c). Children who grew up in the Aboriginal camp a short distance to the West were forbidden to stray into the vicinity of Wuridjong Pool, and one woman to this day remembers her fear of Waugal and the consequences which might befall her if she were to approach his abode too closely. These children knew the pool as "Woggy Pool" or "One Eyed Pool". In the 1930's, there was a beehive in one of the trees close to this pool, but the Aborigines did not collect its honey; as it was believed that Wurdaatji, spirits who live in the jarrah forests and can be harmful to humans if aroused, collected and ate this honey.

Approximately two kilometres to the west of Wuridjong Pool is 22 Mile Pool. One old Aboriginal woman claimed that "children weren't allowed to go there because it was a corroborree ground". However, as this was not corroborated by other informants, and as that person had not grown up in the area, it seems likely that she was confusing it with Wuridjong Pool.

No other mythic associations were reported for the Harris River to the north of Damsite 1.

Well to the south of the area of impact, where the Collie River flows over Road Number 2017 (Lintott Road) and under the water pipeline, is another potentially sensitive area. This area, known nowadays as 8 Mile Pool and originally as Woggary Pool, appears to have ancient Aboriginal associations (Plates 2f, 2g, 2h). Informants stated that Aborigines had camped here in pre-contact times and had held corroborrees on the high ground to the north-east of the pool. This habitation/ritual pattern was replicated in later years by immigrant Aborigines, although an Aboriginal hostel was later built on the high ground. In later years, Aborigines have used the area as a picnic and recreation ground. Informants also pointed out another old corroborree ground to the south of Collie, but it was sufficiently far from the area of impact to be irrelevant to the present survey.

At the present time, much Aboriginal interest in the Collie region is centered on the activities of the Aboriginal Lands Enquiry. Due to this, from the viewpoint of a possible land claim (as opposed to the issue of protection of a mythological or ritual site) another potentially sensitive area exists to the west of the Tallanalla-Collie Road, stretching from the existing boundary of the Coates Hire Service yard to the point where the water pipeline crosses the roadway. This takes in the old Aboriginal Reserve and the creek where the Reserve dwellers dug for soakage water (Plates 2i, 2j). Although this is a long distance from the impact area, it is preferable that its existence be made known at an early stage to developers in the region.

No other sites of a mythological or ritual nature; nor areas of potential sensitivity in the Collie region were known to the Aboriginal informants consulted during this survey.

5.0 RECOMMENDATIONS

As Wuridjong Pool is outside the area which will be inundated following the damming of the Harris River, no specific recommendations for its protection are required at this stage (Plates 1b, 1c). It is, however, likely that recreational or picnic facilities may be constructed in the vicinity of the reservoir which will result from the dam construction. In such an event, it would be necessary, under the terms of the Western Australian Aboriginal Heritage Act, (1972-80) to protect this site from damage.

Accordingly, it is recommended that the Collie and Harvey Offices of the Department of Conservation and Land Management (CALM) be notified of the existence of this site and of their obligations under the above Act. Further, a request should be made to CALM to monitor any future logging or recreational activities that may occur in the area, with a view to avoiding accidental damage to the site.

As 8 Mile Pool would appear to be outside the area which could be reasonably seen as the responsibility of the Principal, it will be registered as an Aboriginal Site at the Department of Aboriginal Sites at the W.A. Museum (Plates 2f, 2g, 2h). In this way it will be afforded the protection of the Aboriginal Heritage Act, (1972-80).

6.0 REFERENCES

Bardon, G. (1979). Aboriginal Art of the Western Desert, Melbourne: Rigby.

Berndt, R. (1980). 'Aborigines of the South West', in R. Berndt and C. Berndt (eds.), Aborigines of the West, The University of Western Australia Press.

Berndt, R. (1982). 'Traditional Concepts of Aboriginal Land', in R. Berndt (ed.), Aboriginal Sites, Rights and Resource Development, The University of Western Australia Press.

Berndt, R. and C. Berndt (1952). The First Australians, Sydney: Ure Smith.

Berndt, R. and C. Berndt (1977). The World of the First Australians, Sydney: Ure Smith.

Berndt, R. and C. Berndt (1978). Pioneers and Settlers, Victoria: Pitman.

Bropho, R. (1980). Fringedweller. Sydney: Alternative Publishing.

Brown, S. (1983). A Survey for Aboriginal Sites in the Perth Metropolitan Area, Unpublished Report Commissioned by the Main Roads Dept.

Colbung, K. (1980). 'On Being an Aboriginal: A Personal Statement', in R. Berndt and C. Berndt (eds.), Aborigines of the West, The University of Western Australia Press.

Doolan, J. (1979). 'Aboriginal Concept of Boundary. How do Aboriginals Conceive "Easements" -- How do They Grant Them?', Oceania, XLIX (3).

Elkin, A. (1938). The Australian Aborigines, Sydney: Angus and Robertson.

Elkin, A. (1951). 'Reaction and Interaction: A Food-Gathering People and European Settlement in Australia', American Anthropologist, 53 (2).

Howard, M. (1980). 'Aboriginal Society in South-Western Australia', in R. Berndt and C. Berndt (eds.), Aborigines of the West, The University of Western Australia Press.

Liberman, K. (1976). A Survey for Aboriginal Sites: Yeelirrie Uranium Project, Unpublished Report W.A. Museum.

Nairn, J. (1976). Western Australia's Tempestuous History, Perth: Independent Newspapers.

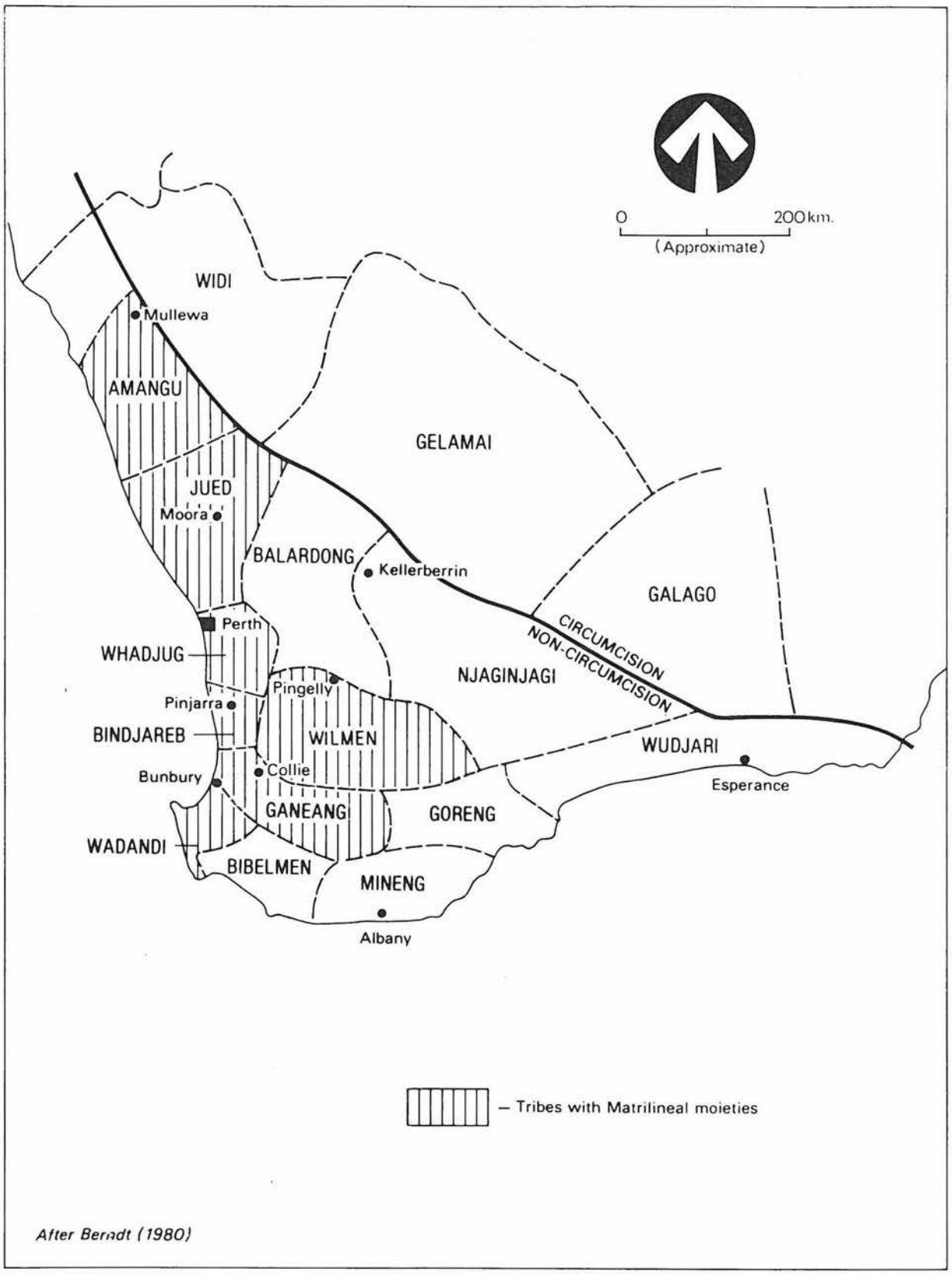
O'Connor, R. and P. Veth (1983). A Survey for Aboriginal Sites in the Vicinity of The Proposed 220kV Overhead Powerline Between West Roebourne and Port Hedland. Unpublished Report, W.A. Museum.

Stanner, W. (1965). 'Aboriginal Territorial Organization: Estate, Range, Domain and Regime', Oceania, 35 (1).

Stormon, E. (1977 trans.). Historical Memoirs of Australia, by Rosendo Salvado. The University of Western Australia Press.

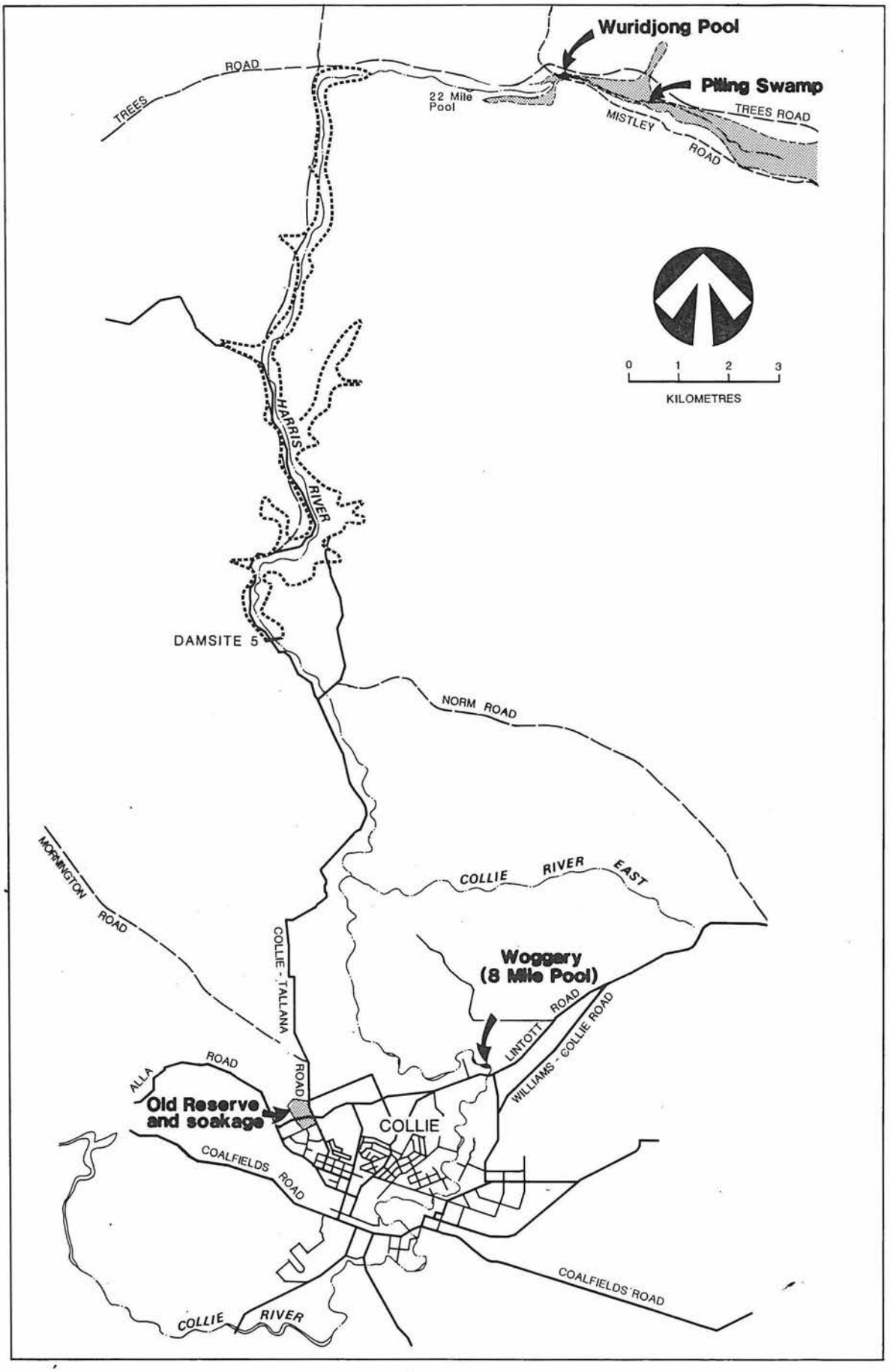
Tonkinson, R. (1974). The Jigalong Mob, California: Cummings.

FIGURES



TRIBAL BOUNDARIES OF THE SOUTH WEST

Figure 1
Dames & Moore



LOCATION OF SITES IDENTIFIED DURING THE ETHNOGRAPHIC SURVEY

Figure 2
Dames & Moore

PLATES

CAPTIONS - PLATE 1

a. Wuridjong Pool, viewed across Piling Swamp

b. Wuridjong Pool

c. Wuridjong Pool

d. Piling Swamp viewed from Mistley Road

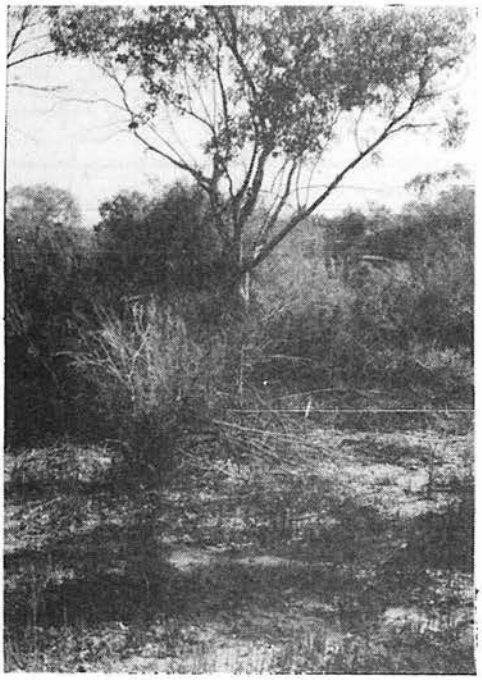
e. Freshwater mussels in 22 Mile Pool



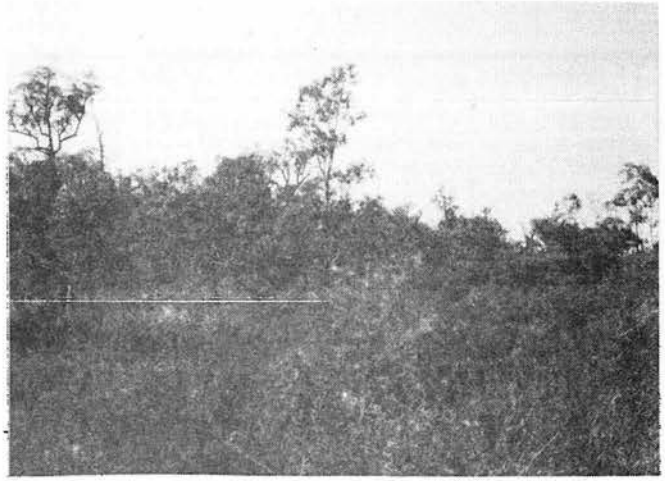
a.



b.



c.



d.



e.

Plate 1

CAPTIONS - PLATE 2

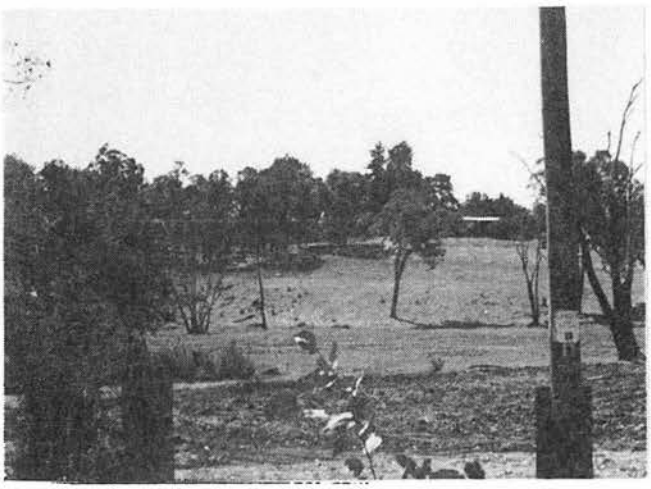
f. Corroborree ground on hill above 8 Mile Pool

g. 8 Mile Pool

h. 8 Mile Pool

i. Old Aboriginal Reserve, Collie - Tallanalla Road

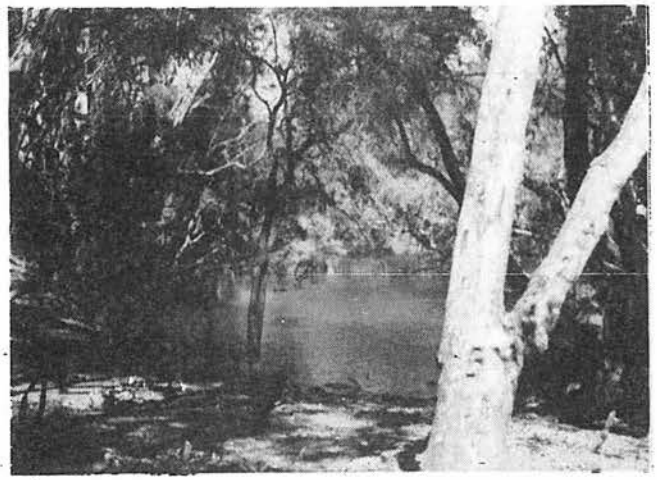
j. Soakage near old Aboriginal Reserve



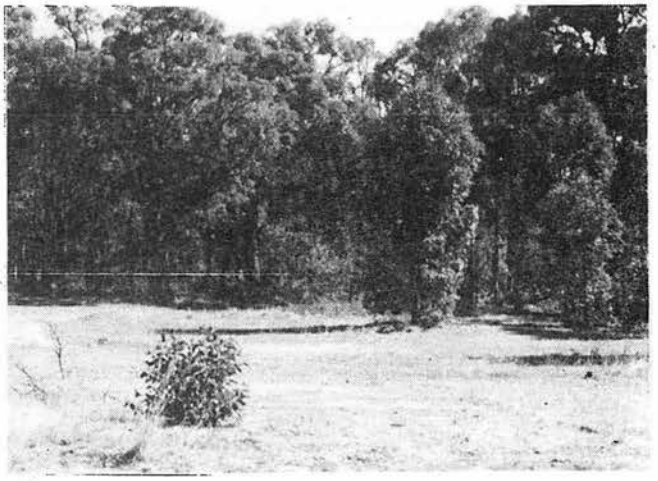
f.



g.



h.



i.





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Plate 2

APPENDIX J

WELLINGTON RESERVOIR AND HARRIS RIVER WATER QUALITY REPORT

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WELLINGTON RESERVOIR AND HARRIS RIVER
WATER QUALITY REPORT

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1.0 BACKGROUND

Water quality in the Collie River and Wellington Reservoir has been monitored by the PWD for more than forty years. The principal concern in the past has been salinity (total disolved solids, TDS). The impact of salinity in Wellington Reservoir can be reduced by the supplementation of water from Wellington with lower salinity water from another source. Investigations of alternative sources for supplementation have centred on the Harris River, which is a tributary of the Collie River.

Detailed water quality investigations of a range of parameters including TDS, have been conducted by the PWD. Profile data on water stored in Wellington Reservoir has revealed stratification and cyclic variations of colour as measured by colour Hazen Units (HU). Colour in Wellington Reservoir and in the Harris River is typical for rivers in pluvial areas of Australia and it is frequently referred to as peat stain. Colour of water drawn from Wellington Reservoir over the past 22 years, has averaged 20 HU and a range of 5 to 50 HU. Over a recent period, (1981-84) the colour of water drawn from Wellington Reservoir averaged 22 HU.

Flows into the Reservoir, over the period 1980-1984, have a flow weighted average colour of 39 HU. The range of colour at sampling point GS 612017 (Harris River) is 5 to 90 HU with a flow weighted average of 41.5 HU for the period 1981 to 1984.

The following report investigates the possible impacts of colour from both sources. Other parameters (excluding salinity) are considered where they may influence conclusions relative to colour.

2.0 DEFINITION OF PROBLEM

2.1 Overall

The problems relative to colour in Wellington Reservoir and the Harris River include:

a) What colour criteria or standard should be established for water delivered from either source?

b) Should established criteria include an "initial" criteria and a "long term" goal?

c) If such criteria are proposed, what would be the impact of such criteria relative to the level of treatment required from each source?

d) What would be the capital and operating costs of required treatment processes?

It may be noted from the above questions that the first question, relating to establishment of criteria, is the dominant question. If the criteria for colour is established at 50 HU*, it is possible that such a limit could be met from either source without any treatement other than disinfection.

* The current desirable colour criteria for drinking water in Australia is 50 HU.

2.2 Question of Proposed Criteria

Colour, in itself, is not a health risk. The rationale to establish a limit on colour is aesthetic. Colour may be responsible for minor consumer inconvenience and only limited complaints and problems are evident in the area currently served from Wellington Reservoir.

The NHMRC long term objective for colour is 5 HU. This is felt to be too low and the basis for the adoption of a lower limit is discussed in detail in subsequent sections.

2.3 Timing

The second question then becomes; "if it is accepted that there are aesthetic reasons to establish a colour criteria of less than 50 HU, when should such a limit be applied?" The answer depends on the cost of implementation of a lower limit, budget realities and policy. It

should be noted that it may be economically more feasible, on a unit cost basis, to introduce colour limitations for large communities (rather than rural areas) because the capital costs of treatment plants (and operating costs) are not directly related to size but are related on an exponential basis similar to the form $Y = fX\ 0.7$;

where Y = capital cost,
f = is a common factor,
and X = capacity of plant in ML/d

Thus the unit costs of a plant (and the cost of benefits of low colour) for 10,000 people may be twice the unit costs of a plant for 100,000 people.

If, however, authorities adopt a policy of identical standards for metropolitan and country water supplies, then the economic adversity of small supplies may be overridden, except in respect to probable deferment.

When water quality parameters do not meet criteria, but are not critical, implementation of corrective facilities tend to be deferred. It is difficult to forecast timing of future policy in respect to adoption of colour limits for rural communities in W.A. Even if a stringent criteria for colour were adopted, application of the criteria could be deferred indefinitely.

2.4 Level of Treatment

Once a limit or criteria is adopted, it will be possible to establish the level of treatment or process required to conform to such a standard. The solution to the question of required process is a technical response and is outlined in subsequent sections.

2.5 Costs

The cost of treatment alternatives are relatively easy to establish. Unlike predictions of policies and forecasts of timing, cost estimates are a more reliable guide, if adjustments are made for changes in construction and supply cost indices. All estimates, construction costs and chemical costs listed hereinafter are based on June 1984 prices.

2.6 Basic Hydraulic Data

The existing Wellington Dam has a capacity of 186,000 ML. The proposed Harris River impoundment (which will be located within the catchment of Wellington Dam) will have a capacity of 100,000 to 150,000 ML. The mean flow, upstream of the proposed Harris River impoundment will normally be intercepted when the impoundment is constructed and the future mean (uncontrolled) inflow to Wellington Dam will be reduced accordingly.

Hydraulic criteria for the two impoundments are as follows:

Storage Capacity, Wellington Dam (ML)	186,000
Estimated Capacity, Harris River Dam (ML)	125,000
Historical estimated mean inflow, Wellington (ML/y)	250,000
Projected mean inflow, Harris River Dam (ML/y)	45,000
Mean projected inflow, Wellington (Post Harris (ML/y)	205,000
Typical detention time, Wellington (Post Harris) (years)	0.9*
Typical detention time, Harris River Dam (years)	2.8*

* Detention times are based on full impoundments. Typical detention times will be less and will be influenced by reservoir management options.

From the above data, it should be noted that the estimated detention time in the proposed Harris River Dam may be two or three times longer than Wellington Dam. In 1983, the estimated inflow to Wellington Dam was 925,000 ML, which would have been equivalent to 0.2 years detention. (Detention times are theoretical and density differences due to temperature and salinity factors can cause inflow to be (1) discharged (short circuited), (2) blended or (3) stored at depth and existing contents displaced).

3.0 PREVIOUS INVESTIGATIONS

3.1 General

Three previous reports on the subject of colour in Wellington Reservoir and/or the Harris River were reviewed. During the course of the investigations, a fourth report was prepared by the PWD which was partially influenced by the preliminary conclusions of this (the MHS) report. Other information relative to water quality and bench tests conducted by the Government Chemical Labs was also reviewed. The significant conclusions of previous reports are summarised as follows:

3.2 R. Murton, PWD

A study by R. Murton entitled "Harris River Colour Study" was prepared and dated December, 1981. The report analyses data from Harris River gauging stations. It notes flow weighted data but does not conclude any relationship between flow and colour.

The report notes colour reductions in Wellington Reservoir due to storage but also notes that storage of a single Harris River sample did not indicate similar colour reductions.

The report appears to conclude that a limit of 30 HU would be appropriate for PWD supplies.

The study includes the qualified statement that ..."We must rely on colour dissipation in the reservoir to reduce the supply colour to an acceptable level", and also that "...it seems the weight of evidence and opinion is that colour of the water supplied from a dam on the Harris would be within the limit." (Presumably 30 HU). The last conclusion is qualified by a statement on the need for an additional year of sampling and investigation.

3.3 Dames & Moore

An 8-page report entitled "Harris River Colour Issue" by Dames & Moore was submitted to the PWD in February, 1983.

The report is pessimistic relative to the possibility of using an impounded supply from the Harris River in a similar manner to the Wellington Reservoir supply.

It raises the issue of higher colour due to increased pH in pipelines and is not optimistic about decreases in colour due to storage.

The report suggests a "level of 15 - 20 Hazens, occasionally rising to 30 Hazens" as acceptable criteria.

The report suggests "partial treatment" but such an option, as subsequently explained in the report, would involve capital expenditure for a plant that may only be used on a part time basis when colour from the source exceeded 15 or 20 or 30 HU.

The report indicates that the only alternative to "full treatment" with alum could be the Sirofloc process. The report assumes, without explanation, that "full treatment" (including filtration) would require pumping and that Sirofloc treatment would not.

The report is silent on other potential processes such as ozonation, super chlorination, direct filtration or in-reservoir treatment. No cost data was included.

3.4 I. Loh, PWD

a) An 8-page report plus tables and graphs and entitled "The Harris River Colour Issue Summary of Knowledge to Feb. 1983" was reviewed.

The report restricts discussion to an analysis of available data, comparisons with Wellington Reservoir and estimates of in-storage deterioration and projections of future colour of raw water.

Discussions of treatment methods were not included.

The report concludes that "supply figures of over 30 APHA units (HU) and frequently approaching 50 units could be expected.....".

It is the above conclusion that has flagged the need for additional investigations relative to the possible treatment of Harris River water.

b) An eight-page draft report entitled "Colour Changes in Wellington Reservoir Over the 1983/84 Summer" was reviewed. The report included computer data on salinity/colour relationships and graphs on flow/colour relationships.

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The report was prepared to supplement information to this, (the MHS report) and included additional sampling flow data and reservoir profile information collected during the period January to June, 1984.

The report concluded that there was a 60 percent reduction of colour in Wellington Dam during a 7-month period, Nov. 83 to 8 June, 1984. It also noted that there was an initial 20 percent reduction in colour during a 6-week period in early summer. There was a qualified conclusion that similar reductions in the proposed Harris storage were likely.

3.5 Govt. Chemical Labs

A letter and three memoranda to the Public Works Department on the subject of Harris River Water Colour, all dated 20 October, 1981 were reviewed.

The letter summarises colour data from the Harris River and noted that the Harris River samples "are more coloured than seasonally normal". The letter also notes that, in relation to colour decrease during storage, "a conservative estimate might be 50 percent per annum."

Two of the memoranda refer to the nature of the colour and one is optimistic that colour in an impoundment on the Harris River would not exceed 30 HU.

One memorandum Lab. No. 81 W4809 outlines jar tests and in-line filtration tests which were conducted on one sample of water from the Harris River Dam Site 5, taken Aug 20 '81. The tests were conducted on an above-average coloured sample (65 HU). The tests indicated that in excess of 30 mg/L of Alum was required to coagulate colour. The tests also indicated that coagulated water could be filtered. The depth of the filter utilized in tests was 300mm which is approximately 30% of what would be utilized in a full scale application. The filtration rate utilized in filtration tests was low (1mm/sec.) (Typical full scale plant criteria would be 4mm/sec.). The memo recommends that in-line treatment would be a suitable option for colour removal. (No economic evaluation was made and the data developed indicated that conventional treatment would be necessary).

3.6 Summary of Previous Investigations

The conclusions of previous investigations have in respect to Harris River varied from possible colour dissipation to less than 30 HU by natural means during impoundment to the need for complete treatment or Sirofloc treatment. Loh initially concluded that, without treatment, colour of a supply from an impoundment on the Harris could frequently be expected to be in the range of 30 to 50 HU. Subsequent data, in a 1984 report by Loh, tended to modify the initial conclusion.

4.0 RELATED QUALITY PARAMETERS

4.1 General

Apart from salinity, there are several other parameters that may influence the relative value or ranking of coloured water from the two sources. If it was desirable to treat water, to correct other parameters, reduction of colour may be incidently achieved during such a treatment process. Those parameters that could require treatment, or would be significantly influenced if a treatment process was installed, are, therefore, linked.

The following four parameters are linked and are investigated in detail in subsequent sections. They are:

Colour
Turbidity
Microorganisms
THMs

4.2 Non-Critical Parameters

In addition to the parameters listed in 4.1, there are three other parameters that are not critical, but should be discussed. The following factors are not linked to colour, they could, when considered in combination, influence the relative value or utility of the water from each source. The three parameters are:

pH and Corrositivity
Hardness
Sodium

pH (and corrositivity) could be adjusted without the need for physical treatment and, therefore, without significant capital investment and with minor costs for chemicals. Adjustments of pH and the feeding of corrosion adjusting additives (including zinc) are relatively simple. Comments on the need for adoption of corrosion indices are contentious and beyond the scope of this report. It should be noted, though, that both sources are corrosive but the Harris source is less buffered and would require less adjusting additives than the Wellington source.

Hardness is a complex characteristic and, if it were considered to be a critical parameter, a very signifi-

cant investment would be required to make adjustments. (A softening process using lime and soda ash would result in a significant incidental reduction in colour and organics. Ion exchange processes do not necessarily result in colour reduction and may not be feasible with coloured waters due to organic fouling of the exchange media). Clearly the Harris River is a much softer water than combined flows into the Wellington Reservoir. (In 1982 the flow-weighted hardness average in the Collie River at Mungalup Tower was 127 mg/L as $CaCO_3$ compared to a corresponding figure of 21 mg/L on the Harris River at Tallanalla Road). Over the past forty years hardness in Wellington Reservoir has increased.

There are published reports that indicate that the incidence of cardio-vascular (CV) disease is inverseley related to hardness in drinking water. It can be argued from a health basis that moderately hard water is preferable to soft water. Modern detergents are effective with moderately hard waters. Consumers are marginally economically affected by hard waters. There can be complaints if water hardness is variable from one day to another. Gradual changes on a seasonal basis should not cause consumer problems. Thus the higher hardness of Wellington Reservoir is not, in itself, an adverse factor and does not make the source less valuable.

Sodium in drinking water is of concern. Although there are no mandatory limits for sodium, the effect on persons with hypertension is well documented. Sodium is also adverse for almost all irrigation applications - especially on clay soils. It is clear that Harris River water is significantly lower in sodium than the Wellington Reservoir supply. The sodium content of the Wellington supply is closely related to the overall salinity issue. Additional discussion on sodium (or salinity) is not included hereinafter, but it should be noted that the lower sodium levels in the Harris source makes it a more valuable source.

4.3 Colour

During the period 1980-84, the flow weighted average for colour on the Harris River was 41.5 HU (Station No. 612017). During the same period, the average colour of water entering Wellington Dam was 39.0 HU.

It may be confidently assumed that the natural colour in both the Harris River and Wellington Reservoir is due principally to humic matter and fulvic acid.

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Humic matter is derived from breakdown of organic (vegative) material under submerged or wet conditions. Humic matter and/or humic acid is present in water in a coloidal form. The coloids of humic acid have molecular weights of 10,000 to 150,000. They are strongly negatively charged and will pass through a 0.45 micron filter.

Fulvic acid may be regarded as a more oxidised form of humic acid. Molecular weights of fulvic acid are generally in the range of 2,000 to 10,000. Fulvic acid exists in water in a coloidal state and will pass through 0.45 micron filters. The coloids are strongly negatively charged and contribute more to colour than humic material. The breakdown from humic to fulvic acid is slow and is normally considered to be a biological process. Fulvic acid molecules are not easily defined and probably no two are identical. The molecules tend to be absorbed on clays but pass easily through sands.

Tannic acid is a known constituent of Australian vegetation but is seldom identified in water analyses, although probably present. In contrast to fulvic acid, tannic acids have defined molecular forms. Although several molecular compositions are published, one accepted form is $C_{76}H_{52}O_{46}$ (MW 1700). When disolved in water, tannic acid has a yellow colour. The presence of certain metal ions can result in a broad range of colours. Tannic acid is used as a dye fixer. It is stable and resists biological breakdown. Where its yellow colour characteristic is not an adversity (in the cases of beer and wine) it is used as a coagulant.

It may be assumed that tannic acid is present in both Harris River and Wellington Reservoir water. Its presence is of academic interest only and there are no economical methods of removing it from water. Methods of colour removal are normally limited to oxidation of fulvic acid and/or destabilization of humic and fulvic colloids with metal iron coagulants.

4.4 Turbidity

Turbidity is strongly linked to colour because it is the most common reason to treat water and the processes required to remove turbidity normally incidently remove colour.

The current Australian criteria for turbidity is 25 turbidity units (TU).

The long term objective for turbidity in Australia is 5 TU. The long term objective could normally be met from Wellington Reservoir, and it is probable that an impoundment in the Harris would also control turbidity within 5 TU.

In the US, there is much more concern relative to turbidity than in Australia. The limits in the US are generally in the range of 0.5 to 1.5 TU. The US EPA standard for turbidity is one (interpreted as 1.5 maximum) TU. The concern for turbidity in the US is not aesthetic but is related to the efficiency of disinfection of water containing turbidity in the form of suspended particulates.

In Europe and the US, turbidity is a dominant measure of potability of water and is the principal parameter for establishing the need for treatment.

Measurements of turbidity, expressed in turbidity units (TU), generally do not appear on analysis or examination sheets prepared by Govt Chem. Labs., and the omission considerably detracts from the value of such examinations and past records. Turbidity, expressed in Standard Turbidity Units (TU), is included in analyses prepared by the PWD Water Resources Branch (Turbidity data indicated in PWD analyses are shown as "APHA" units which are Standard Turbidity Units (TU) as measured by nephlometric or surface scatter type turbidity meters).

By international standards, the current Australian criteria of 25 TU is liberal. The principal purpose of adopting more rigid standards in Europe and the US is to ensure that disinfection is efficient.

Turbidity is a measure of the effect of light scattering by suspended particles in water. The particles are normally 100 micro metres and smaller, usually clay particles but also organic materials, microorganisms, including algae, and mineral particulates such as asbestos, silica, ferric oxide, manganese compounds and titanium. Individually, and in moderate amounts, most of the suspended particulates in water are relatively inert and of minimal health consequences. The principal concern is that particulates tend to protect pathogenic microorganisms from disinfectants. There is also an aesthetic factor. Humans tend to naturally reject tur-

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bid water and above 10 TU turbidity in a glass becomes visible and hence less acceptable.

Under Australian conditions, the risk of potential pathogenic organisms in water sources is much lower than other countries. The need, therefore, to lower turbidities to ensure more efficient disinfection is less and in Australia we tend to consider higher turbidities as acceptable.

Virtually all particles responsible for turbidity are negatively charged and can be neutralized (destabilized) and removed by settling (clarification) and/or filtration.

Turbidities of less than 20 TU can often be treated by the direct filtration process (which eliminates the need for clarification prior to filtration).

Normally the process of removing turbidity also removes colour and effects a significant reduction in micro-organisms.

Data on samples from the Harris River (at Station 6121102) over a 30-month period (1981-83) indicated that less than 10 percent of the samples exceeded 5TU. Impoundment would improve (reduce) turbidity. It is difficult to forecast turbidity after detention but it could be assumed that the frequency of turbidity exceeding 5 TU would be less than 5% of time and possibly less than 1% of time. (In-reservoir treatment and management could control turbidity to less than 5 TU).

In respect to Wellington Reservoir, there is insufficient data on turbidity to comment on the frequency of turbidity exceeding 5TU, or on the effects of impoundment. From the limited data available, it appears that turbidity at the Wellington offtake is normally less than 5 TU but reached 8.3 TU during the flood of January 1982. Upstream from the Reservoir, at Mungalup Tower (Station 612002), samples analysed by the Water Resources Branch indicate that the turbidity exceeds 5 TU more than 20% of the time. Thus it appears that the turbidity in the Harris would be significantly less than the Collie and the chance of Harris impoundment turbidity exceeding the figures for Wellington are unlikely.

If there was need to effect a reduction in turbidity, for either Harris or Wellington Reservoir Water, such a

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need could influence the establishment of other quality criteria, especially colour. Based on the above discussion, however, it appears that projected turbidities from the Wellington Reservoir and any impoundment on the Harris would not require filtration, even if a limit of 5 TU were adopted. It is therefore, not possible for reasons of turbidity to justify treatment of either source which would provide incidental colour removal.

4.5 Microorganisms

The level of pathogenic organisms in either Wellington Reservoir or Harris Reservoir impoundment would be low. In general, it would be possible to meet coliform standards in chlorinated (or chloraminated) water from both sources 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. 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 (chloramination).

The justification of the need for filtration on the basis of combined colour and microbiological control cannot, therefore, be supported.

4.6 THM

Trihalomethanes (THM) are chlorinated organic compounds which are created by the addition of free chlorine to water containing certain natural organic materials (precursors). The term THM covers four or five compounds including chloroform and bromoforms. In the US, there is maximum containment level of 0.10 mg/L for total THMs. The World Health Organization recommended maximum level is 0.03 mg/L, for chloroform only.

Under certain conditions, total trihalomethanes in chlorinated Wellington Reservoir water exceeds the US EPA level of 0.10 mg/L for THM but the WHO standard for chloroform is not exceeded. The cause of high THM in

Wellington Reservoir water is due to the presence of bromide in the water during periods of high salinity. It is doubtful, therefore, that such conditions could occur with chlorinated water from the Harris River. These react with the oxidising agents to form bromoforms.

THMs and chloroform can be controlled by:

a) Reduction of precursors by coagulation, clarification and filtration.

b) Air stripping.

c) Activated carbon treatment.

d) Alternative disinfectants.

Within the past two years, most control practices have centred on alternative disinfectants (monochloramine). Such control involves minimal additional capital and operating costs and is discussed in subsequent sections.

If alternative disinfectants are adopted by the PWD, there would be no problem due to THMs or chloroform from either source.

4.7 Summary of Quality Parameters

The relative range of certain quality parameters is shown on Table 4.1. In general, the quality of water in the harris and Collie Rivers (as indicated by colour and turbidity) is similar. Harris River water is lower in hardness than Collie River, but hardness is not critical and may not be an adverse factor at the levels indicated.

Sodium, on the other hand, is higher in the Collie River and is an adverse parameter. Sodium is closely related to the salinity issue. It cannot be incidently or economically removed by a treatment process and, therefore, does not influence the possibility of a process that may incidently remove colour.

The average flow-weighted colour for the Harris River and the Collie River are shown in Table 4.2. Data for the Collie River was adjusted downward so as to reflect the estimated colour of inflow from other sources into Wellington Dam. Based on the indicated data there is no significant statistical difference in flow-weighted colour for the two sources. The four-year period shown in the table

is for a pluvial period and average colour levels for both sources would have been above average. It should also be noted that the probable detention times (when an impoundment is built on the Harris) may be two or three times greater for the Harris impoundment than for the existing Wellington Dam. (See Section 6.8).

The principal conclusion of investigation of linked quality parameters is that, there is no critical constituent of either the Collie or Harris River which would justify the need for a treatment process that would incidentally reduce colour

TABLE 4.1
SELECTED QUALITY PARAMETERS
WELLINGTON RESERVOIR, COLLIE RIVER AND HARRIS RIVER

PARAMETER	UNIT	WELLINGTON	COLLIE	HARRIS	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)	See Text
Hardness($CaCO_3$)	mg/L	127	127	21	1983-1984
Sodium(Average)	mg/L	-	172	47	1982-1983
pH (Average)	pH		7.1	6.9	1982-1983

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

TABLE 4.2
FLOW-WEIGHTED COLOUR
COLLIE RIVER AND HARRIS RIVER 1980-1983

STREAM	PERIOD	NO. SAMPLES	AVERAGE COLOUR (HU)(1)
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 (2)	1980	24	28
(STN 612002)	1981	59	38
(Mungalup Tower)	1982	197	45
Adjusted see note below	1983	269	45
	Mean	-	39.0

(1) Flow-weighted
(2) Estimated colour inflow to Wellington Dam equals actual Collie River flow-weighted data adjusted by equation: HU=0.75 A + 3, where A=actual flow-weighted colour.

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5.0 SUPPLEMENTAL TESTS

5.1 Bench Tests on Representative Sample

40 litres of water was sampled from the outlet of Wellington Reservoir and delivered to the Government Chemical Labs on April 6, 1984. A series of colour reduction tests were conducted on the samples to determine:

1. Minimum alum feed rate for colour reduction.
2. Effect of superchlorimation
3. Effect of monochloramines

5.2 Alum Tests

Jar tests were conducted on one litre samples to determine the minimum practical dose of alum required to produce a settable floc and to reduce colour.

The tests determined that 20 mg/l of alum could produce a settable floc and would reduce colour by approximately 75% (from 37 HU to 9HU).

5.3 Superchlorination Tests

One litre samples were dosed with:

1. 5 mg/L
2. 10 mg/L
3. 15 mg/L
4. 20 mg/L

of free chlorine.

All samples (above 5 mg/L Cl) showed signs that the initial colour was oxidised. The colour changed from a brown (tea-like) colouration to a hazy yellow colour. There was no settling of residual colour after 20 hours but after 5 days most of the residual (apparent) colour had settled. After filtration through 0.45 micron filter paper, the following true (residual) colours remained.

	Chlorine Feed Rate	Initial Colour (HU)	True colour (HU after 5 days)
1.	5 mg/L	37	30
2.	10 mg/L	37	10
3.	15 mg/L	37	10
4.	20 mg/L	37	10

The tests indicated that the colour could be oxidized at free chlorine dose rates of 10 mg/L. The residual oxidized material remained in suspension for more than 20 hours. It is probable that certain chlorinated organic materials were produced and remained in solution.

No tests for residual disolved chlorinated organics (chloroform or THMs) were, however, conducted. (Previous tests for chlorinated organics in chlorinated Wellington Reservoir water indicated that the formation of such material was significantly influenced by the presence of salinity associated compounds during periods when the salinity was higher than during the April 1984 tests).

5.4 Monochloramine Tests

Tests to establish the effect of combined chlorine (monochloramine) were conducted. The contact time for tests was 24 hours. No reduction in colour was evident at the following concentrations:

2.5 mg/L Chlorine and 1 mg/L NH_4
5.0 mg/L Chlorine and 2 mg/L NH_4
10.0mg/L Chlorine and 4 mg/l NH_4

No reduction in colour was evident after 8 days.

5.5 Evaluation, Supplemental Tests

The supplemental tests on a sample of Wellington Reservoir water established:

a) Colour could be reduced 75% by the addition of 20 mg/L of alum.

b) Colour could be reduced approximately 73% (from 37 to 10 HU) by superchlorination, 10mg/L of free chlorine.

c) Both alum and superchlorination treatment would require additional processing (clarification or direct filtration to remove residual particulate material).

d) Monochloramination is not effective in reducing (oxidizing) colour.

e) The data developed from supplemental tests shows that the colour is 75% oxidizable and can also be removed by nominal doses of alum.

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6. NATURAL PROCESSES

6.1 General

Natural processes which reduce colour during storage in Wellington Reservoir (and in a reservoir on the Harris River) include:

Destabilization due to blending
Bleaching due to ultra violet light
Microbiological degradation of humic and fulvic acid.
Settling
Oxidation

It is difficult to separate the impact of each of the above processes but it is evident that they each play a part in the natural degradation process.

6.2 Destabilization Due to Blending

There are two aspects of blending. The first and most obvious is the averaging process that occurs when two waters are mixed. Normally such a process results in an intermediate colour between the two waters. In a reservoir, mixing or blending may be initially slowed due to density differences during storage but ultimately seasonal turnover affects a blend.

Another factor (other than averaging) is the destabilization of colour colloids due to higher ionic potentials in water with high levels of disolved solids. During periods when salinity is high, colour is low. The average annual colour at the outlet of Wellington Reservoir in 1980, when salinity was at its highest, was 5 HU, whereas, in 1983, a low salinity year, mean colour was 25. If all samples are grouped into two classifications (a) above 500 mg/L tds and (b) less than 500 mg/L tds, the mean colours for the groups are 16 HU and 37 HU respectively. (Subsequent work by Loh, PWD, indicated a more scattered and gradual transition from low to higher salinities, but generally confirmed the inverse relationship).

No practical application can be gleaned from the inverse relationship between tds and colour.

6.3 Bleaching Due to Ultra Violet Light

When UV light is absorbed in water, hydrogen peroxide is formed. The potential of HO_3, causes accellerated

oxidation of disolved or colloidal material. The process contributes to sunlight bleaching and storage purification.

Although the rate of oxidation by HO_3 may be more rapid than O_2, the overall bleaching process is slow. (In 1983, MHS tried to simulate the process in bench tests for EWS Dept, South Australia, on River Murray water, using commercial hydrogen peroxide. The affects, at nominal dosages of HO_3, were minimal.)

Bleaching near the surface occurs in the Wellington Reservoir. Reductions of colour of 50 percent may require several months. (Under favourable conditions, total reductions in colour of 60 percent are possible over a 7 month summer period - See Fig. 6.1). There does not appear to be any way that the process can be significantly accelerated. Water near the surface is mixed to a depth of approximately 10 metres by wind. Aeration of a reservoir, so as to effect destratification, may provide a favourable improvement in the overall reduction due to bleaching but the improvement is judged to be less than 10 percent over a period of several months.

6.4 Microbiological Degradation of Colour

Humic and fulvic acids are stable and do not appear to be subject to natural degradation by biological processes. MHS was unable to find references to such processes in technical publications. If it occurs, it may add to the bleaching process discussed in the previous Section. Tannins are particularly stable constituents of certain wastewaters and are not significantly reduced by biological treatment processes. (Tests conducted by PWD indicated that the bleaching process was not adversely affected by the presence of a biological inhibitor, copper sulphate).

Thus, even if biological degradation does not occur under current conditions, it is limited and there are no known methods of enhancing the process.

6.5 Settling

Humic and fulvic acids are classic colloids. They appear to stay in suspension indefinitely. Only if destabilization by salinity, metal ion coagulants or polyelectolytes occurs, will there be settling. Thus, non-natural means (destabilizing with alum, or another

coagulant), appear to be the only way of accelerating the settling process.

6.6 Oxidation

It was demonstrated that super chlorination will oxidize colour. (See Section 5). On the other hand, the oxidation potential of monochloramines did not influence colour over an 8-day period.

The contribution of oxidation, due to natural dissolved oxygen, is difficult to estimate. It is generally accepted that stratification in reservoirs (that results in an anaerobic strata to be formed below the wind-mixed zone) is adverse. Most reservoir management plans include provision for aeration and mixing which raise dissolved oxygen levels. Such a process in Wellington could reduce colour at the lower levels but the effect may only be incremental and it would be difficult to assess the impacts even if full scale tests were undertaken.

In summary, oxidation of colour by natural affects of dissolved oxygen in the upper 10 metres of water stored in Wellington Reservoir, is incremental and slow. The effect cannot be separated from UV light, temperature and other possible natural affects. There are, however, favourable long term effects and it is recommended that provision for forced air aeration of both Wellington and the proposed Harris River Reservoir be investigated as a management tool. (See Section 6.9 (d)).

6.7 Temperature

It is possible that colour reduction is correlated to temperature. In practice it is difficult to separate temperature factors from light absorbance (and bleaching). Controlled bench testing would be necessary to confirm a possible correlation.

6.8 Cumulative Affects

The long term effect of bleaching in particular, but with contributions from initial mixing, oxidation, settling and other affects can be gauged from Figure 6.1. it should be noted that detention times, particularly detention during a summer season, are positively related to colour reduction. The effect is compounded if average detention times exceed more than one year, because storage volume/inflow ratios lower the blended

colour significantly before the effect of bleaching commences.

The forecast levels of colour from the proposed Harris River impoundment will depend significantly on management policies. It is difficult to estimate the frequency that the impoundment may be less than say half full at the end of each summer. During drought cycles such an occurance may be common. It is, however, speculative to try to assess the risk of above-average colour and high inflows occurring when reservoir capacity is low. Inflows similar to the 1983 inflow may occur infrequently - say once every 20 years. The effect on a half full dam could be to raise the colour to above 30 HU. The duration of such an effect, however, may last for say several weeks and thus the risk for exceeding 30 HU from Harris may be less than 0.5 percent. In-reservoir treatment and/or other water quality management options could further reduce the risk.

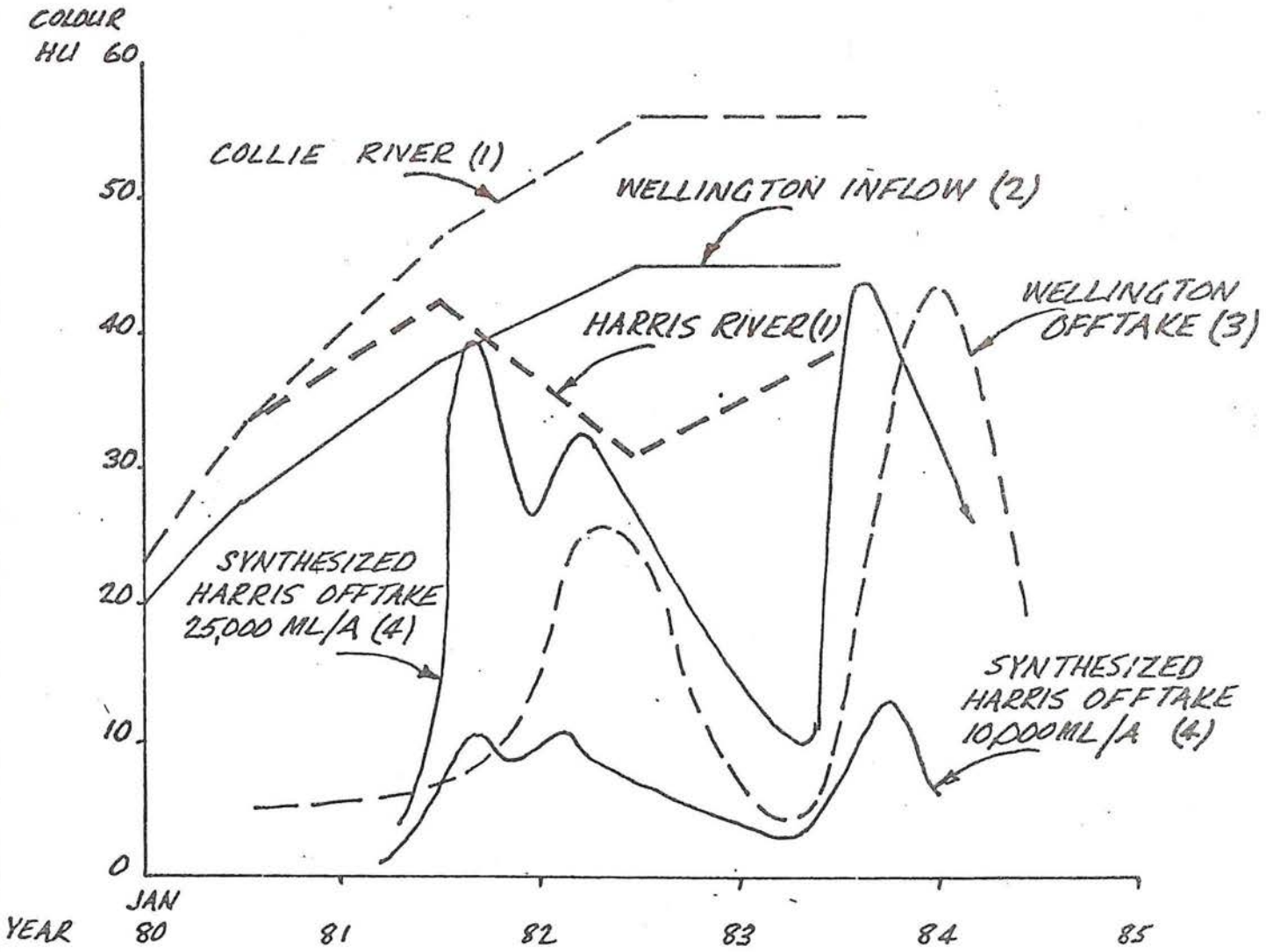
6.9 Summary of Natural Process Effects

a) Natural bleaching of colour in the upper levels of Wellington Reservoir occurs under existing natural conditions. The process is slow. Natural reductions of colour of 60% can take place by Autumn.

b) There is evidence that the ionic effects of waters with salinities in excess of 500 mg/L TDS has a significant effect on reducing colour. However, there appears to be little practical application of the phenomenon. The economic and practical reasons for maintaining salinities at the lowest practical level is much greater than any benefits that may result from reduced colour.

c) Microbiological effects (or biological degredation) and settling appear to make negligable contributions to colour reductions.

d) Oxidation, due to the presence of natural dissolved oxygen, may contribute to the colour reduction in the upper levels of storage. The process is slow and may be overshadowed by other factors. Adequate dissolved oxygen levels in stored water are, however, important for reasons apart from possible colour reduction. Adequate DO reduces chlorine demands, reduces microbiological counts, prevents taste and odour problems and reduces dissolved metals and organic complexes.



COLOUR TRENDS 1980-84

NOTES :

(1) WEIGHTED ANNUAL MEAN

(2) ADJUSTED TO REFLECT LOW-COLOUR FLOWS FROM LOCAL STREAMS

(3) TREND BASED ON ACTUAL DATA

(4) TRENDS BASED ON COMPUTED DATA BY PWD BASED ON WEIGHTED FLOWS, STORAGE DILLUTION AND ASSUMED NATURAL EFFECTS AT INDICATED ANNUAL DRAWS.

Revised 25/2/85

FIG. 6.1

7.0 RESERVOIR MANAGEMENT

7.1 Discussion

There are several different aspects of reservoir management for Wellington Reservoir. Normally, destratification is a favoured practice but in the case of Wellington, the controlling more dense saline waters in the lower levels is a strategy that may take precedence.

From a strictly colour aspect, mixing of water in the reservoir above a certain level (due to salinity constraints), but within a band more than 10 metres in depth, may have a limited effect on colour. Nevertheless, for the reasons outlined in Section 6.9(d), it has merit.

Other management tools, including algae prevention (by chemicals such as copper sulphate) and vegetation control would not influence colour. (Initially, in the case of a Harris River impoundment, it would be prudent to burn off all vegetation in the area to be inundated).

The most appropriate colour management strategies, in addition to natural bleaching, appear to be:

1. treatment of contributing tributaries and
2. in-reservoir treatment.

7.2 Tributary Treatment

In the case of the Harris River, there are several contributing sources to the river that are much higher in colour than the main flow. It would be possible to identify such tributaries and treat the base flows with alum. (One source that was inspected near Treeville in the Harris catchment had a colour of 500 HU). Tributary treatment may only be required on a seasonal basis so as to effect a weighted reduction of colour inflow.

7.3 In-Reservoir Treatment

In-reservoir treatment with alum to reduce colour has been effectively practiced by the Sydney Water Board and the E & WS Department, South Australia. (The E & WS treatment of an Adelaide Hills reservoir was designed to reduce turbidity, but colour reduction was also accomplished).

Based on the supplemental tests outlined in Section 5, a minimum of 20 mg/L of alum may be required to effect significant colour control. Alum could be added to the reservoir(s) from a boat or fed at the same location as an air mixing input.

The efficiency of adding alum at a single location would need to be checked by full scale tests. It is probable that such a practice may reduce colour only over a limited areal extent of a reservoir.

7.4 Summary of Reservoir Management Options

Colour control or reduction by reservoir management techniques includes three basic approaches:

a) Destabilization of contributing inflows.

b) In-reservoir treatment with a coagulant fed from a boat or at fixed mixing points.

c) Destratification with air.

The impact of destabilization of contributing inflows (addition of alum to selected tributaries) would require further investigation. The investigations would need to identify those tributaries that contribute significant colour. Estimates of flow and colour inputs against time would need to be tabulated. Jar tests of typical water samples would need to be conducted to establish coagulant feed rates and estimates of capital costs, chemical costs and operation costs. It could be an effective method of management but there are no known precedents operating on a permanent basis.

In-reservoir feeding of a coagulant, such as alum, is a more common practice. In Australia it has been utilized by the E & WS Department in South Australia and the Sydney Water Board. It could be tested on a full scale basis at Wellington Reservoir. Two basic methods of feeding would be:

1) Addition from a boat
2) Feeding at an air mix location

It would appear that the second method would be the most cost effective in respect to operational costs. The areal extent of the effect of the air mix process could only be estimated by full scale tests.

Air mixing (without coagulant addition) may have limited effects on colour. It is a valuable and practical reservoir management tool.

8.0 RECOMMENDED COLOUR CRITERIA

8.1 Existing Criteria

Unlike the US and certain European countries, Australia does not have mandatory drinking water standards. Existing guides utilized by authorities in Australia may be generally referred to as desirable criteria (or goals) rather than standards. A list of Australian and international criteria in respect to colour is outlined in the following table.

TABLE 8
COLOUR CRITERIA AND STANDARDS

Reference	Colour Units (Maximum)
1. Australia, Dept. of Health. Desirable Criteria (1980)	50
2. WHO International Standards for Drinking Water (1)	5
3. USA Environmental Protection Agency Secondary Drinking Water Regulations (1981)	15
4. California Dept. of Health Regulations (1974)	15
5. USA National Academy of Sciences Water Quality Criteria (Raw Surface Waters)	75 (2)
6. European Economic Community, Drinking Water Standards (1980)	1 Guide 20 Max.
7. South Australia E & WS Dept. Treated Water Goals	10 90% 15 100%

(1) Also Australia Dept of Health, Long Term Objectives

(2) Surface water to be treated.

8.2 Comments on Existing Criteria

a) General

As noted in Section 2.2 herein, colour, in itself, is not a health risk. The reason for adopting a limit for colour is mainly aesthetic. In normally uncoloured waters, however, a significant change in colour could be an indication of contamination.

Where waters are naturally coloured, the origin is normally humic and fulvic materials and perhaps tannins. In Australia, highly coloured waters are common in pluvial regions. Swamp waters may have colour readings in the range of 100 to 750 HU. Such waters may be of good mineral quality.

Considering that in many instances in Australia, there may not be a choice of water sources, coloured water has been more acceptable than in other countries.

b) Current Desirable Criteria (Reference 1)

The existing criteria in Australia of 50 HU, reflects attitude and realities. There is no dominant reason in many regions of Australia to adopt more stringent goals except where treatment may be required for other purposes and colour can be incidently and economically reduced. If more stringent criteria for colour is adopted in Australia, it is probable that capital expenditure for treatment plants required solely to reduce colour would be subject to indefinite deferments.

c) WHO Standards (Reference 2)

The 1982 WHO Standard of 5 HU represents a very stringent limit for colour. It is not a practical limit because it is not technically or economically feasible to reduce many peat stained waters to less than 10 HU by conventional treatment processes. Experience in treatment of River Murray and local reservoir waters in South Australia has shown that it is not possible, on a continuous basis, to produce water of 5 HU or less even with massive doses of alum.

d) US EPA Regulations (Reference 3)

The US Environmental Protection Agency Secondary Regulations are voluntary and not enforceable standards. The adoption of a "Maximum Contaminant Level" of 15 HU recognises the realities of treatment processes. It is a reasonable and easily attainable level when treatment of highly coloured waters is practiced. The limit also permits many lightly coloured waters (especially groundwaters) to be supplied without the need for treatment. It also allows for possible blending of two or more sources.

e) California Department of Health (Reference 4)

The California Regulations reflect the acceptance in the US of 15 HU as an attainable limit for colour. (The Regulations were based on the (1962) US Public Health Service Standards).

f) USA National Academy of Sciences (Reference 5)

The US NAS Quality Criteria is a relatively obscure guide that indicates acceptable quality of sources of supply (raw water). The NAS recommendations are intended to characterize raw surface waters that can be treated to produce "a safe, clear, aesthetically pleasing and acceptable public water supply". The criteria assumes that raw water will be treated by coagulation, sedimentation, filtration and disinfection.

g) EEC (1980) Drinking Water Standards (Reference 6)

The EEC Standards include an optimum guide and a practical limit. They cover a range of colour similar to US Regulations.

h) South Australian Goals (Reference 7)

The South Australian Goals were adopted by the E & WS Department based on recommendations made to them by MHS. The goals were based on extensive tests conducted by E & WS on a wide range of water samples from the River Murray and reservoirs in the Mount Lofty Ranges in South Australia. The goals also reflect experience in operations of several water treatment plants in the Adelaide region. (Similar goals were recommended to Sydney

Water Board by MHS in 1982. The recommendation was based on results of pilot plant reatment tests on three water sources in the Blue Mountains, NSW).

8.3 Recommended Criteria

For the purposes of planning and evaluation of water resources, the PWD will need to make a decision on an appropriate long term quality goal for colour. Colour standards are generally imposed for purely aesthetic reasons, there is no compelling health reason for a lower standard at present. Where colour is being reduced as part of the water treatment process, experience in other States suggests that NHMRC long term standard is far too low. As the problem is essentially one of consumer reaction to the product, the PWD should further investigate this aspect before making a decision on the long term objective. Present indications are that water from the Harris Reservoir will meet the NHMRC current criteria and with appropriate reservoir management colour can be kept to levels which will not cause any adverse consumer reaction.

9.0 WATER TREATMENT OPTIONS

9.1 Current Criteria

The existing supplies from Wellington reservoir and the proposed supply from Harris Reservoir both meet current NHMRC colour standards. However, the colour levels in both sources can be enhanced by a number of reservoir management options. These include:

(i) retention of reserve storage in the reservoir for dilution.

(ii) forced air aeration of the reservoir at variable depths.

(iii) dosing with allum, either by spreading, injecting with air at aeration points or by treatment of tributaries.

The present water quality operations on Wellington reservoir utilise salinity stratification to optimise the levels of total soluble salts in the water supply. Forced air aeration is designed to break up this stratification and would not be compatible with salinity management for most of the year. Experience with the reservoir management options described could possibly show that colour levels in the Harris dam can be maintained at levels below 15 HU on a continuous basis, although this is unlikely. During floods and periods of high inflow to impoundments there would be limited impact on colour and during such periods it may be necessary to discontinue in reservoir or tributary treatment.

9.2 Long Term Objectives

In the long run, if a colour standard similar to the South Australian goals was adopted, the only economical method of treatment will be a process which incorporates filtration. Experience overseas indicates there is a case for the filtration of all drinking water supplies so as to remove particulates, including micro-organisms, filtration etc.

Filtration would effectively remove all gross particulates including organic matter derived from vegetation and residuals from any previous treatment process, such as oxidation or coagulation.

The Dames and Moore report (See Section 3.3 herein) assumed that the Sirofloc, without filtration process would be an appropriate process. No cost comparisons were included. The Sirofloc process may be cost effective if the filtration phase of a treatment process was not included. Such a process may be inferior to direct filtration.

The assumption herein that filtration would be a more favourable process is based on judgement. It would be possible to evaluate Sirofloc and other alternative processes during a future pilot treatment plant study. (See Table 10).

It should also be noted that ozone could remove colour. Ozonation of naturally coloured water results in a floc formed from oxidized organics. The floc (or ash) can be easily removed by filtration. (The City of Los Angeles is currently building a treatment plant that incorporates preozonation and direct filtration but the process is not common). Preozonation and filtration of Wellington Reservoir or Harris River water is judged to be equal or more expensive than the direct filtration process. Also ozone does not leave a residual disinfectant in water and subsequent conventional chlorination or monochlorination would be required. A process which incorporated ozonation could be evaluated in the future. (See Table 10).

All available data indicates that colour reduction by oxidation or coagulation would require filtration as part of the overall process.

It is probable that the most economical process would be direct filtration. Other potential processes include in-line filtration, conventional treatment and Sirofloc.

In-line filtration is a process of coagulant addition, mixing, disinfection and filtration.

Direct filtration may be described as in-line filtration plus intentional flocculation after mixing.

Conventional treatment includes coagulant addition, mixing, flocculation, sedimentation, disinfection and filtration.

There would be a significant capital cost saving if direct filtration is feasible. (Deletion of the sedimentation (or clarification) process saves an addition-

al investment equivalent to approximately 30 percent of the total cost of a conventional water treatment plant). Operation of a direct filtration plant is, however, more difficult and careful attention has to be given to the selection of coagulants, flocculation, filter media and monitoring. It is, therefore, prudent to precede the design of direct filtration plant with a pilot plant testing program designed to test coagulant combinations, mixing energy and filter media design.

Normally filtration plants are designed as gravity flow plants (open basins and filters) but in certain cases (and especially with direct filtration applications) pressure filters may be more economical.

In summary, the long run appropriate treatment would appear to be direct filtration. In the case of the existing Wellington Reservoir system, it would be more economical for the plant to be a pressure plant, if a plant were ever required. For the future Harris River system, it is possible to design off-take piping so that a gravity treatment plant could be located at a suitable hydraulic grade line elevation.

10.0 COST ESTIMATES

10.1 Basis of Estimates

a) The following capital cost and operating cost estimates are based on current (mid 1984) prices.

b) The cost of investigations by PWD are not included.

c) The cost of engineering associated with design and construction of permanent facilities is based on an allowance of 15% for design, inspection, construction supervision and start up.

d) A contingency provision of 10% of estimated construction costs is included, as shown.

e) Water treatment plant capital costs were estimated using the formula

$$Y = 0.28\ X^{0.7}$$

where Y = cost in A\$ $\times 10^6$

X = nominal capacity in ML/day

f) Reservoir management facilities were estimated on the basis of an installed compressor and other facilities with a total load of 25 KW. Construction costs for all equipment and controls was estimated at A$5,000 per kW.

10.2 Construction Costs

Estimated construction costs for reservoir management and water treatment plant costs are outlined in Table 11.

TABLE 10

Construction Costs, Water Quality Control Facilities

Item	Description	Cost
1.	Air mixing and alum feed system Reservoir management, Wellington	$125,000.00
2.	Air mixing and alum feed system Harris impoundment	125,000.00
3.	Tributary control systems (3)	75,000.00
4.	Harris Reservoir treatment plant (100 ML/d nominal capacity)	7,050,000.00
	Sub total	7,375,000.00
	Contingencies 10%	740,000.00
	Engineering 15%	1,100,000.00
	TOTAL	$9,215,000.00

10.3 Annual and Unit Costs

Based on a mean flow (production) of 68.5 ML/d, (25,000 ML/yr), for a Harris River source, the estimated annual and unit cost (based on 1984 costs) are as follows:

Chemicals and supplies	$150,000.00
Power and lighting (1)	70,000.00
Wages and salaries (2)	140,000.00
Maintenance and replacement	70,000.00
Total annual operating costs	$430,000.00
Operating cost/ML	$17.20
Interest and ammortization (3)	$1,465,000.00
Total annual costs	$1,895,000.00
Total cost/ML	$75.80
Total cost/kL	7.6 c

(1) Excludes pumping costs
(2) Assumes total staff of 8 full time plus 2 part time
(3) Interest 12%, Amort. 4%

SUMMARY AND CONCLUSIONS

1. The PWD of WA is considering an impoundment on the Harris River as a low-salinity source of water to supplement the supply from the existing Wellington Dam. Prior to the commencement of this report, by Montgomery Hosking and Stone Pty Ltd (MHS), it had appeared that water from the Harris River source would be more coloured than the existing source from Wellington Dam. There was concern that water from the Harris source would require treatment to reduce colour and that treatment could adversely affect the economics of the Harris River source.

2. The purpose of the report by MHS was essentially to investigate and forecast natural colour of water from both sources, establish candidate colour criteria for potable water, outline methods of colour reduction, treatment and disinfection and provide cost estimates.

3. The conclusions of several previous investigations of Harris River water had varied from possible natural colour dissipation resulting in less than 30 HU (Hazen Colour Units) to the need for Sirofloc or complete treatment of water drawn from the proposed Harris impoundment. Investigations by Loh, PWD, initially concluded that outflow from the Harris impoundment may exceed 30 HU at times.

4. An investigation of water quality parameters that could be linked to colour was undertaken. In general, the water quality of both sources are similar and there is no critical constituent of either source which would justify the need for a treatment process, that would incidently reduce colour.

   It was noted that there were minor risks associated with THMs or chloroform from Wellington Dam and no similar problems with Harris River water. It was also noted that there would be no risks of formation of chlorinated organics from either source, if the PWD adopted chloramination (instead of chlorination) for disinfection.

5. Supplemental tests conducted by Government Chemical Laboratories indicated that colour could be reduced by approximately 75 percent by alum treatment or super-

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chlorination. Both processes would require filtration to remove residual particulate material.

6. Natural bleaching of colour in reservoirs can result in a 60 percent reduction over a 7-month summer period. Other natural processes contribute only incremental colour reductions.

7. The most widely accepted method of reservoir quality management is destratification and mixing with air. It is recommended that the use of air mixing facilities be investigated for both Wellington and Harris Reservoirs.

8. It is recommended that the PWD investigate and adopt a long term quality goal for colour. In the interim period, a goal of less than 30HU could be adopted. It is estimated that such a goal could be achieved more than 95 percent of the time from Wellington Dam and 99 percent of the time from the proposed Harris River impoundment. No capital investment (except for reservoir aeration) is required to conform with the interim goal.

9. Ih the longer term if a higher colour standard is adopted the appropriate treatment process appears to be direct filtration. The estimated capital cost of possible water quality control facilities is outlined in Table 11. The estimated cost of aeration facilities for Wellington Dam and the proposed Harris River Impoundment, is $158,000 for each site. If a treatment plant is required for the Harris River Impoundment, the estimated capital cost is $8,900,000. (The above estimated capital costs are based on June 1984 costs and include contingencies and engineering). The total cost for treating water is estimated to be 7.6 cents per kilolitre.

APPENDIX K

SIMULATION OF WELLINGTON RESERVOIR SUPPLY SALINITIES FOR SELECTED HARRIS STORAGE SIZES

An Internal Report by the
Water Authority of Western Australia

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

1. INTRODUCTION

Construction of a storage on the Harris River, a fresh tributary of the Collie River, upstream of Wellington Reservoir will enable the salinity of supply to the Great Southern Towns Water Supply (GSTWS) Scheme to be reduced to approximately 200 to 250 mg/L TSS. However the impact of the reservoir on salinity stratification in Wellington Reservoir and hence the supply to the irrigation district is uncertain. The adopted operating procedures for the two reservoirs therefore need to be formulated to ensure irrigation salinities are maintained at the lowest possible level at any one time.

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

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

2. APPROACH

The Centre for Water Research at the University of Western Australia has developed a complex dynamic reservoir simulation

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

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

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

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

3. SIMULATIONS UNDERTAKEN

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

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

The construction of a Harris storage would:

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

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

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

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

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

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

and documents fine tuning of the policy to minimise supply salinities at the end of a drought sequence.

4. RESULTS AND DISCUSSION

4.1 Operating Strategy

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

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

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

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

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

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

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

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

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

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

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

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

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

(ii) NA - Not Applicable

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

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

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

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

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

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

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

Notes : (i) NA - Not Applicable

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

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

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

4.2 Dam Sizes and Dam Sites

Varying the size of the Harris Reservoir clearly impacts on the levels of irrigation supply salinity from Wellington Reservoir. Increased storage allows larger volumes of fresh water to be stored on the Harris Reservoir for subsequent release to the Wellington Reservoir, thus releases could be of greater volume and

also be sustained for lengthier periods than would be the case with a smaller storage.

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

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

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

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

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

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

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

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

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

4.3 Preliminary Optimisation of Operational Strategy

There is a trend under the adopted strategies to therefore improve salinity levels in the early stages of the low inflow sequence

when historic salinities are at acceptable levels, but possibly produce disbenefits (depending on storage size) when they approach unacceptably high levels in the latter periods.

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

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

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

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

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

Year	Run C Salinity (mg/L)	HARRIS D/S 1 Difference (mg/L) With Run C for Volume (10^6m^3): 80	HARRIS D/S 1 Difference (mg/L) With Run C for Volume (10^6m^3): 100	HARRIS D/S 5 Difference (mg/L) With Run C for Volume (10^6m^3): 71 (TWS=$10\times10^6m^3$)	HARRIS D/S 5 Difference (mg/L) With Run C for Volume (10^6m^3): 71 (TWS=$15\times10^6m^3$)
1974/75	319.5	9	6	6	6
1975/76	551.6	89	86	57	55
1976/77	645.0	40	40	34	45
1977/78	902.4	82	71	84	71
1978/79	861.3	129	162	59	54
1979/80	953.5	154	202	123	-118
1980/81	962.9	-63	51	-89	-90
1981/82	672.3	-29	-36	-3	-5
Annual	733.4	51	73	33	4

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

4.4 Effect of Increasing TWS

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

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

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

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

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

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

4.5 Summary

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

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

5. FUTURE SUPPLY SALINITIES FROM THE TWO DAM SYSTEM

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

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

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

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

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

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

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

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

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

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

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

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

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

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

REFERENCES

HOOKEY, G.R. and LOH, I.C. (1985). Hydrodynamic Simulation of the Mixing Processes and Supply Salinities of the Harris-Wellington System. Water Authority of Western Australia, Report No WH01.

IMBERGER, J., PATTERSON, J., HEBBERT. R. and LOH, I. (1978). Dynamics of Reservoirs of Medium Size. Journal of the Hydraulics Division, ASCE, Vol. 104, No HY5, Proc. paper 13773 pp 725-743.

MEARES, I.G., JOKELA, J.B. and PATTERSON, J.C. (1985). Harris-Wellington Two-Dam Modelling Project. Report to Public Works Department, W.A. by Centre for Water Research, University of W.A. Working Paper No WP-84-023.

APPENDIX L

HARRIS RIVER - HYDROLOGY

Prepared by
D. Salim

Report No. W.R.B. 114
December 1984

This study constitues a chapter in the Environmental Review and Management Program (ER & MP) report which is being prepared by Dames and Moore Consulting Engineers.

The major part of this Study (section 1 to 6.1) has been extracted from three publications (Salim 1984 a,b,c). Additional studies to obtain the effect of storage yield with pumpback and to analyse the flood frequency have been included in the last part of this study.

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1. CATCHMENT DESCRIPTION

The Harris River Catchment is located between latitude 33°5' to 33°17'S and longitude 116°5' to 116°25'E in the South Western Australia. It lies within the boundary of Wellington Reservoir Catchment.

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.

The vegetation consists mainly of Jarrah forests with little clearing.

The catchment lies in the high to medium winter rainfall climatic zone and has a mean annual rainfall of 969 mm. The historical mean annual streamflow to the gauging site is 45.1 million cubic metres.

2. AVAILABLE INFORMATION

2.1 Dam Sites Data

The proposed Dam Site 1 is situated near the mainstream gauging station sites and encompasses an area of 383 square kilometres. The proposed Dam Site 5 is about 5 kilometres upstream of the previous site and the catchment has an area of 321 square kilometres. The intervening catchment, defined as the region between the two dam sites has a total area of 62 square kilometres. Three temporary gauging stations were installed in this region and they occupied a total area of 44.1 square kilometres. These stations were installed so that the streamflow at Dam Site 5 can be estimated by calculating the difference between streamflow at Dam Site 1 and streamflow from the intervening catchment. The mean annual streamflow to Dam Site 1 and Dam Site 5 were calculated to be 45.1 and 35.5 million cubic metres respectively.

2.2 Streamflow Data

There are two long term gauging stations on the Harris River and three temporary stations installed in its tributaries as tabulated in Table 1 (Fig 1).

TABLE 1
AVAILABLE STREAMFLOW DATA

Station			Period of Record	
Name	AWRC No	Area(km^2)	From	To
Harris River Stubbs Farm	612036	383.	Jan 1952	Mar 1976
Harris River Tallanalla Rd	612017	382.	Apr 1976	Date
Hanson Bk River Bend	612027	8.19	Jun 1983	Date
Harris River Trib. Scar Rd	612028	15.25	Jun 1983	Date
Harris River Trib. Norm Rd	612029	20.84	Jun 1983	Date

The first twelve years of record from Stubbs Farm were of relatively poor quality with most of the missing data occurring in the first five months and last two months of the 12 year period.

Although the Tallanalla Road gauging station is about 1 kilometre upstream of the Stubbs Farm station, their difference in areas has been ignored and the two sets of data collected at these stations have been considered to be recording the same catchment area.

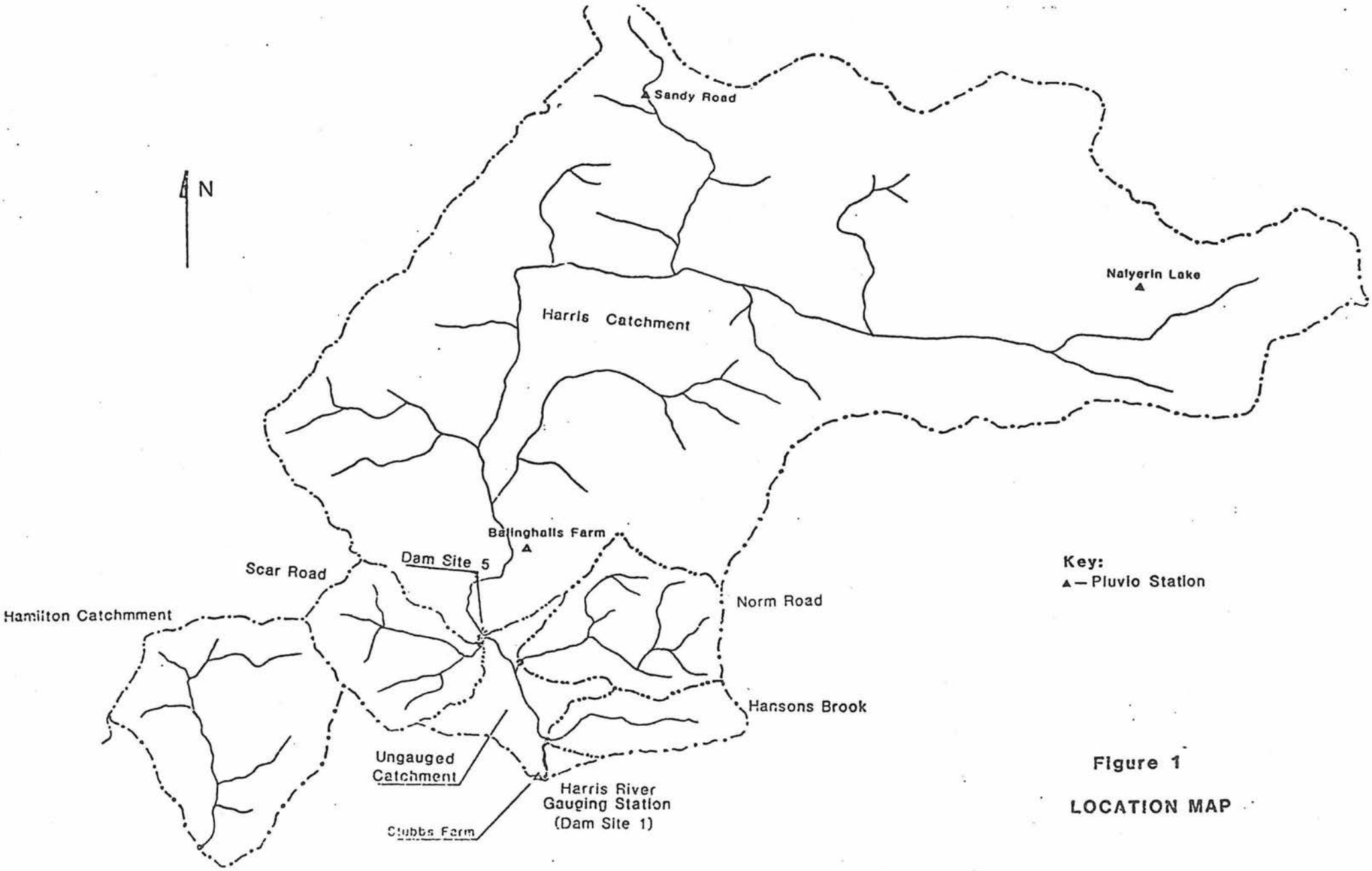


Figure 1

LOCATION MAP

Streamflow records for the three newly installed stations were of good quality.

2.3 Rainfall Data

Table 2 lists the four pluviograph stations that were used in this study. They are distributed uniformly over the Harris River Catchment as shown in Figure 1 and most of the data are of good quality.

TABLE 2
AVAILABLE RAINFALL DATA

Station		Period of Record	
Name	AWRC No.	From	To
Nalyerin Lake	509079	May 1972	Date
Balinghalls Farm	509081	Apr 1972	Date
Sandy Road	509082	May 1972	Date
Stubbs Farm	509110	May 1972	Dec 1980

The mean catchment rainfall was determined from the above data by applying the appropriate Thiessen Weights and isohyetal corrections. Where any of the stations had missing record, the Thiessen Weights appropriate to the active stations only were applied. The mean annual rainfall for period 1972 to 1983 being 863 mm.

3. METHODOLOGY

The Sacramento rainfall-runoff model was fitted to the catchment using the observed streamflows and the Thiessen weighted catchment rainfalls. A total of 12 years from 1972 to 1983 was used to calibrate the catchment. To establish an historical stream flow sequence for the Harris Catchment, it was necessary to produce a corresponding historical daily rainfall sequence. This was done by developing a relationship between the short period of Harris Catchment rainfall and the longer period of Collie Post Office rainfall data during the common period of 1972 to 1983.

The extended historical catchment rainfall and the optimised parameters were used as inputs to the catchment model to establish an historical daily streamflow sequence.

The sequence when combined with the observed streamflow gave a total record of 77 years from 1907 to 1983. The mean annual streamflow at the gauging station which is the proposed site for Dam Site 1 is calculated to be 45.1 million cubic metres.

A piece-wise linear transformation was used to estimate the historical streamflow for the intervening catchment from the streamflow sequence at Dam Site 1. The corresponding streamflow for Dam Site 5 was obtained by calculating the difference between the two streamflow sequences. The mean annual streamflow was estimated to be 35.5 million cubic metres.

For each dam site, the Matalas transformation alogrithms were used on the statistics of the historical streamflow sequence to generate 500 years of synthetic records. They were then used in conjunction with the relationships between annual historical streamflows and rainfalls, to establish the corresponding 500 years of synthetic rainfall records.

A reservoir simulation program 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.

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

TABLE 3

HARRIS RIVER N 6316200 E 421250

TALLANALLA ROAD

STATION NO. 612 017
COPY NUMBER (1)

HISTORICAL MONTHLY STREAMFLOW (10^3 M^3) FOR HARRIS RIVER DAM SITE 1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1907	3.*E	0.*E	23.*E	16.*E	86.*E	601.*E	5553.*E	15461.*E	6966.*E	1912.*E	588.*E	111.*E	31322.*E
1908	29.*E	19.*E	8.*E	15.*E	87.*E	1111.*E	13450.*E	4000.*E	1061.*E	747.*E	287.*E	50.*E	20863.*E
1909	13.*E	3.*E	35.*E	55.*E	119.*E	1896.*E	2003.*E	9507.*E	3504.*E	4533.*E	682.*E	127.*E	22475.*E
1910	45.*E	13.*E	4.*E	35.*E	959.*E	12526.*E	34119.*E	21538.*E	20532.*E	2202.*E	423.*E	89.*E	92486.*E
1911	18.*E	5.*E	13.*E	63.*E	84.*E	68.*E	6069.*E	5610.*E	3121.*E	715.*E	139.*E	44.*E	19967.*E
1912	8.*E	2.*E	5.*E	6.*E	107.*E	40.*E	4459.*E	7133.*E	15234.*E	4423.*E	664.*E	146.*E	32225.*E
1913	34.*E	6.*E	26.*E	41.*E	49.*E	106.*E	9907.*E	29567.*E	5488.*E	1080.*E	217.*E	106.*E	46626.*E
1914	10.*E	37.*E	3.*E	50.*E	45.*E	91.*E	2402.*E	2139.*E	352.*E	107.*E	84.*E	12.*E	5331.*E
1915	10.*E	39.*E	52.*E	23.*E	37.*E	1435.*E	12732.*E	11491.*E	12311.*E	4447.*E	992.*E	189.*E	43759.*E
1916	65.*E	39.*E	12.*E	21.*E	79.*E	640.*E	8535.*E	13556.*E	4657.*E	801.*E	214.*E	37.*E	28657.*E
1917	9.*E	22.*E	37.*E	74.*E	89.*E	9275.*E	42071.*E	29222.*E	36763.*E	33830.*E	3073.*E	578.*E	155040.*E
1918	135.*E	75.*E	26.*E	36.*E	1267.*E	19220.*E	9413.*E	4306.*E	11358.*E	1577.*E	276.*E	62.*E	47751.*E
1919	20.*E	8.*E	9.*E	42.*E	77.*E	2795.*E	10531.*E	14965.*E	3050.*E	601.*E	138.*E	27.*E	32263.*E
1920	7.*E	10.*E	12.*E	8.*E	108.*E	6458.*E	14997.*E	23165.*E	12097.*E	1228.*E	236.*E	53.*E	58379.*E
1921	16.*E	16.*E	21.*E	20.*E	147.*E	5283.*E	9057.*E	8604.*E	2887.*E	1015.*E	1214.*E	177.*E	28457.*E
1922	33.*E	15.*E	18.*E	8.*E	80.*E	68.*E	2888.*E	11300.*E	3365.*E	1218.*E	235.*E	91.*E	19319.*E
1923	35.*E	3.*E	39.*E	50.*E	961.*E	19056.*E	20312.*E	23058.*E	37133.*E	11572.*E	1718.*E	329.*E	114270.*E
1924	69.*E	14.*E	4.*E	9.*E	164.*E	6826.*E	9473.*E	13914.*E	6314.*E	11395.*E	1364.*E	248.*E	49793.*E
1925	61.*E	11.*E	27.*E	16.*E	85.*E	145.*E	9370.*E	4737.*E	2072.*E	528.*E	96.*E	31.*E	17178.*E
1926	4.*E	17.*E	17.*E	115.*E	337.*E	8661.*E	27748.*E	23053.*E	14622.*E	46579.*E	6580.*E	1135.*E	128870.*E
1927	225.*E	47.*E	84.*E	38.*E	83.*E	3743.*E	16840.*E	13880.*E	11465.*E	1388.*E	272.*E	58.*E	48122.*E
1928	69.*E	6.*E	1.*E	71.*E	59.*E	353.*E	16181.*E	20779.*E	7566.*E	8690.*E	747.*E	152.*E	54673.*E
1929	28.*E	59.*E	5.*E	38.*E	145.*E	5999.*E	7766.*E	6356.*E	1888.*E	370.*E	107.*E	22.*E	22784.*E
1930	3.*E	2.*E	4.*E	34.*E	72.*E	5336.*E	35292.*E	9048.*E	11081.*E	7360.*E	951.*E	189.*E	69372.*E
1931	36.*E	9.*E	26.*E	59.*E	119.*E	376.*E	11148.*E	12988.*E	12463.*E	3729.*E	489.*E	115.*E	41556.*E
1932	30.*E	10.*E	19.*E	36.*E	305.*E	7901.*E	31131.*E	8061.*E	6841.*E	744.*E	144.*E	35.*E	55256.*E
1933	57.*E	9.*E	23.*E	27.*E	73.*E	7730.*E	11761.*E	3752.*E	9722.*E	2234.*E	553.*E	105.*E	36047.*E
1934	28.*E	11.*E	28.*E	12.*E	98.*E	1554.*E	11109.*E	8403.*E	7347.*E	2921.*E	456.*E	113.*E	32080.*E
1935	31.*E	20.*E	3.*E	46.*E	56.*E	104.*E	15121.*E	10694.*E	7068.*E	1496.*E	305.*E	68.*E	35212.*E
1936	47.*E	4.*E	7.*E	18.*E	84.*E	1583.*E	6557.*E	15393.*E	4937.*E	1699.*E	287.*E	71.*E	30687.*E
1937	12.*E	12.*E	46.*E	63.*E	2659.*E	6385.*E	5650.*E	4189.*E	4534.*E	747.*E	150.*E	35.*E	24483.*E
1938	6.*E	2.*E	59.*E	25.*E	94.*E	64.*E	6602.*E	9555.*E	7879.*E	1283.*E	254.*E	59.*E	25881.*E
1939	60.*E	32.*E	2.*E	16.*E	104.*E	2234.*E	19567.*E	50586.*E	15439.*E	4053.*E	589.*E	119.*E	92800.*E
1940	40.*E	8.*E	7.*E	11.*E	47.*E	73.*E	325.*E	2416.*E	2637.*E	535.*E	100.*E	45.*E	6243.*E
1941	6.*E	7.*E	17.*E	72.*E	73.*E	4412.*E	14837.*E	11363.*E	17809.*E	3736.*E	600.*E	126.*E	53057.*E
1942	24.*E	5.*E	67.*E	40.*E	143.*E	7966.*E	13642.*E	44602.*E	57796.*E	11382.*E	1713.*E	337.*E	137720.*E
1943	68.*E	56.*E	73.*E	56.*E	65.*E	3261.*E	7680.*E	11627.*E	12385.*E	2758.*E	428.*E	100.*E	38557.*E
1944	18.*E	3.*E	6.*E	7.*E	102.*E	116.*E	10943.*E	9181.*E	3074.*E	567.*E	127.*E	70.*E	24215.*E
1945	11.*E	5.*E	29.*E	23.*E	282.*E	26512.*E	30421.*E	47928.*E	20476.*E	3714.*E	622.*E	142.*E	130170.*E
1946	32.*E	6.*E	22.*E	30.*E	998.*E	8764.*E	49069.*E	33670.*E	4123.*E	778.*E	213.*E	61.*E	97766.*E

KEY

*E DERIVED FROM RAINFALL DATA AND SACRAMENTO MODEL

PROGRAM MDLIST

COLLECTING AUTHORITY WATER RES(03)

YEARS 1907 - 1946

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

TABLE 3 . HARRIS RIVER TALLANALLA ROAD

N 6316200 E 421250

STATION NO. 612 017
COPY NUMBER (1)

HISTORICAL MONTHLY STREAMFLOW (10^3 M^3) FOR HARRIS RIVER DAM SITE 1

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1947	13.*E	3.*E	2.*E	34.*E	1247.*E	16714.*E	19069.*E	10225.*E	1182.*E	306.*E	56.*E	21.*E	48873.*E
1948	3.*E	0.*E	11.*E	33.*E	23.*E	91.*E	2998.*E	13441.*E	5763.*E	4042.*E	587.*E	139.*E	27131.*E
1949	26.*E	5.*E	23.*E	34.*E	53.*E	96.*E	10546.*E	23877.*E	5482.*E	885.*E	194.*E	37.*E	41257.*E
1950	13.*E	3.*E	0.*E	4.*E	86.*E	275.*E	6192.*E	7643.*E	6305.*E	1814.*E	357.*E	80.*E	22772.*E
1951	18.*E	25.*E	3.*E	50.*E	48.*E	8370.*E	9107.*E	8803.*E	2125.*E	427.*E	87.*E	71.*E	29134.*E
1952	5.*E	3.*E	21.*E	16.*E	120.*E	9180.*E	10183.*E	14373.	13050.	5960.	3498.	1628.*E	58038.*E
1953	5.*E	20.*E	1.*E	19.*E	325.*E	6162.*	13464.	7062.	4374.	9556.*E	2550.*E	1224.*E	44761.*E
1954	33.*E	6.*E	4.*E	25.*E	75.*E	613.*E	6236.*E	5636.*	2834.*	743.*	362.	47.*E	16612.*E
1955	6.*E	137.*E	0.*E	26.*E	317.*E	4917.	10174.*	36502.*E	18190.	11421.	2240.	618.	84548.*E
1956	123.	15.*E	77.*E	70.*E	2377.*E	11203.	15930.	12272.	3952.	1927.	733.	502.	49180.*E
1957	99.	1.*E	19.*E	64.*E	252.*E	22994.	9478.*	6525.	5825.	2156.	568.	165.	48146.*E
1958	31.*E	4.*E	1.*E	18.*E	157.*E	1203.	19645.*E	10594.*E	3540.	1871.	622.*E	119.*E	37804.*E
1959	23.	0.*E	12.*E	43.*E	50.*E	817.	590.	6159.*	854.	1569.*	329.	34.	10480.*E
1960	138.*E	3.*E	66.*E	13.*E	381.	1651.*E	11928.*	6886.	2862.	1064.*E	229.	25.	25246.*E
1961	27.*E	5.*E	22.*E	94.*E	40.*E	6257.*E	7874.	8463.	6939.	2747.	737.	265.	33469.*E
1962	55.*E	10.*E	2.*E	8.*E	89.*E	1811.	3175.	6622.	4677.	3255.	1597.	331.*E	21631.*E
1963	28.	3.*E	7.*E	33.*E	143.*E	9298.	23937.	29940.	13842.	2835.	791.*E	158.	81014.*E
1964	3.	6.*E	6.*E	33.*E	0.	12873.*	41244.	45014.	7010.	6042.	1049.	590.	113870.*E
1965	96.	16.	7.	20.	944.	4695.	11367.	7435.	6885.	7875.	3948.	917.	44206.
1966	111.	12.	8.	12.	82.*E	2253.	8925.*	7214.	9875.	3188.	806.*	236.*	32722.*E
1967	148.	38.	6.	23.	765.	13652.	22588.*	11029.	6491.*	1753.*	709.*	690.*	57893.*
1968	339.	114.	49.	297.	406.	5629.	8274.	10231.	11332.	4774.	1167.	253.	42865.
1969	53.	5.	15.	147.	371.	3613.	5711.	8095.*	1520.	515.	176.	41.	20261.*
1970	4.	0.	0.	0.	53.	10661.	12034.	7687.	5076.	10195.	1049.	193.	46953.
1971	39.*	13.	24.	33.	412.	2048.	3022.	6842.	8838.	12739.	4229.*	1170.	39410.*
1972	294.	9.	9.	11.	14.	213.	2405.	7556.	3545.	1179.	293.	38.	15566.
1973	17.	3.	0.	2.*E	59.	4364.	14565.	16096.	9487.	3637.	1445.	126.	49801.*E
1974	20.	9.	12.	32.	1640.	13138.	29794.	29834.	5220.	3771.*	1603.	364.	85438.*
1975	95.	39.	36.	57.	179.	1442.	5816.	6923.	3331.	1708.	643.*	188.*	20456.*
1976	143.*E	52.	35.	53.	78.	273.	651.	3281.	1529.	723.	448.	147.	7414.*E
1977	7.**	3.	1.*	3.*	20.*	82.	1236.	9031.	1859.	3393.	620.	52.	16308.**
1978	7.	4.	0.	2.	28.*	727.**	10155.**	2825.	3308.	3971.	211.	28.	21265.**
1979	9.*	4.	8.*	10.*	15.**	35.	1796.	1104.	699.	682.	276.	21.	4658.**
1980	2.	1.	0.	10.	18.	372.	2559.	6632.	3935.	1954.	485.	67.	16033.
1981	12.*	5.	5.	11.	25.	1400.	6364.	14036.**	4663.	2744.	782.	266.	30352.**
1982	7628.	517.	49.	31.	60.**	602.**	2943.	4245.	3359.	2238.	302.	82.	22056.**
1983	16.	25.	13.	15.*	28.	1773.	10297.*	17466.	21287.	402."	0.NA	0.NA	51322."

KEY

NA	RECORD NOT AVAILABLE
NR	NOT RECORDED
*	FAULTY - VERY CONFIDENT IN CORRECTED TRACE
**	FAULTY - SOME DOUBT IN CORRECTED TRACE
*E	ESTIMATED TRACE OR DERIVED FROM MODEL
"	DERIVED FROM INCOMPLETE RECORD

PROGRAM MDLIST
PROCESSED ON 12.25 27 JAN 1984

COLLECTING AUTHORITY WATER RES(03)

YEARS 1947 - 1983
STATION NO. 612 017

WATER RESOURCES SECTION TABLE 3 PROGRAM MDSTAT2 RUN ON 94/01/27 AT 12.26

HISTORICAL MONTHLY STREAMFLOW STATISTICS (10^6 M^3) FOR HARRIS RIVER DAM SITE 1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MEAN	.145	.023	.019	.037	.281	4.835	12.455	13.667	8.447	4.117	.833	.216	45.073
MEDIAN	.028	.009	.012	.030	.087	2.234	10.155	9.610	5.763	1.954	.489	.111	36.047
STD. DEV.	.866	.062	.020	.040	.492	5.774	10.238	11.003	8.997	6.786	1.088	.308	32.433
SKEW	8.708	7.042	1.482	4.142	3.158	1.681	1.592	1.750	3.125	4.511	3.055	2.740	1.553
MAXIMUM	7.628	.517	.084	.297	2.659	26.512	49.069	50.586	57.796	46.579	6.580	1.628	155.040
MINIMUM	.002	0.000	0.000	0.000	.000	.035	.325	1.104	.352	.107	0.056	0.012	4.658
S. CORR.	.065	.933	.230	.305	.165	.466	.541	.600	.572	.464	.829	.861	.010
C. VAR.	5.988	2.663	1.051	1.093	1.754	1.194	.822	.805	1.065	1.648	1.306	1.429	.720
STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)													
MEAN (%)	.621	.090	.062	.123	.696	9.445	27.583	32.028	18.285	8.543	2.020	.502	
S.E.E.	.448	.033	.009	.020	.158	1.116	1.459	1.472	1.068	.825	.229	.069	

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

TABLE 4

HARRIS RIVER N 6316200 TALLANALLA ROAD E 421250

STATION NO. 612 017
COPY NUMBER (1)

HISTORICAL MONTHLY STREAMFLOW (10^3 M^3) FOR HARRIS RIVER DAM SITE 5

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1907	2.*E	0.*E	18.*E	13.*E	67.*E	468.*E	4325.*E	12040.*E	5425.*E	1489.*E	458.*E	87.*E	24391.*E
1908	21.*E	14.*E	6.*E	11.*E	65.*E	832.*E	10074.*E	2996.*E	794.*E	559.*E	215.*E	38.*E	15626.*E
1909	10.*E	2.*E	26.*E	42.*E	90.*E	1432.*E	1513.*E	7181.*E	2646.*E	3424.*E	515.*E	96.*E	16977.*E
1910	36.*E	11.*E	3.*E	27.*E	763.*E	9971.*E	27161.*E	17145.*E	16345.*E	1753.*E	337.*E	71.*E	73624.*E
1911	13.*E	4.*E	9.*E	47.*E	63.*E	51.*E	4521.*E	7159.*E	2325.*E	548.*E	104.*E	33.*E	14875.*E
1912	6.*E	1.*E	4.*E	5.*E	83.*E	31.*E	3480.*E	5567.*E	11888.*E	3451.*E	518.*E	114.*E	25148.*E
1913	27.*E	5.*E	21.*E	33.*E	39.*E	84.*E	7888.*E	23541.*E	4370.*E	860.*E	172.*E	84.*E	37124.*E
1914	6.*E	22.*E	2.*E	30.*E	27.*E	54.*E	1430.*E	1273.*E	209.*E	64.*E	50.*E	7.*E	3174.*E
1915	8.*E	31.*E	42.*E	18.*E	29.*E	1141.*E	10130.*E	9143.*E	9795.*E	3538.*E	790.*E	150.*E	34816.*E
1916	50.*E	30.*E	10.*E	16.*E	61.*E	495.*E	6599.*E	10481.*E	3601.*E	620.*E	165.*E	29.*E	22157.*E
1917	8.*E	18.*E	31.*E	61.*E	74.*E	7641.*E	34660.*E	24075.*E	30287.*E	27871.*E	2531.*E	476.*E	127730.*E
1918	107.*E	59.*E	21.*E	29.*E	1006.*E	15258.*E	7473.*E	2419.*E	9017.*E	1252.*E	219.*E	49.*E	37908.*E
1919	16.*E	6.*E	7.*E	33.*E	60.*E	2181.*E	8219.*E	11679.*E	2381.*E	469.*E	108.*E	21.*E	25180.*E
1920	5.*E	8.*E	9.*E	6.*E	84.*E	5012.*E	11640.*E	17979.*E	9389.*E	953.*E	183.*E	41.*E	45310.*E
1921	12.*E	12.*E	17.*E	15.*E	114.*E	4082.*E	6999.*E	6648.*E	2231.*E	784.*E	938.*E	137.*E	21990.*E
1922	24.*E	11.*E	13.*E	6.*E	60.*E	50.*E	2143.*E	8383.*E	2496.*E	903.*E	174.*E	68.*E	14332.*E
1923	28.*E	2.*E	31.*E	40.*E	774.*E	15339.*E	16350.*E	18560.*E	29889.*E	9315.*E	1383.*E	264.*E	91975.*E
1924	55.*E	11.*E	3.*E	7.*E	130.*E	5391.*E	7482.*E	10990.*E	4987.*E	9000.*E	1078.*E	196.*E	39330.*E
1925	44.*E	8.*E	20.*E	12.*E	62.*E	106.*E	6839.*E	3457.*E	1512.*E	385.*E	70.*E	22.*E	12537.*E
1926	3.*E	13.*E	14.*E	93.*E	272.*E	7009.*E	22454.*E	18655.*E	11832.*E	37692.*E	5324.*E	918.*E	104280.*E
1927	178.*E	37.*E	67.*E	30.*E	66.*E	2969.*E	13356.*E	11008.*E	9093.*E	1101.*E	216.*E	46.*E	38166.*E
1928	54.*E	5.*E	1.*E	55.*E	46.*E	276.*E	12646.*E	14240.*E	5913.*E	6791.*E	584.*E	118.*E	42729.*E
1929	21.*E	45.*E	4.*E	29.*E	110.*E	4538.*E	5875.*E	4808.*E	1428.*E	280.*E	81.*E	17.*E	17236.*E
1930	3.*E	1.*E	3.*E	27.*E	56.*E	4165.*E	27547.*E	7062.*E	8650.*E	5745.*E	742.*E	147.*E	54148.*E
1931	28.*E	7.*E	21.*E	47.*E	95.*E	298.*E	8844.*E	10304.*E	9888.*E	2958.*E	388.*E	91.*E	32969.*E
1932	23.*E	7.*E	15.*E	28.*E	238.*E	6168.*E	24302.*E	6293.*E	5340.*E	581.*E	112.*E	27.*E	43135.*E
1933	45.*E	7.*E	18.*E	21.*E	57.*E	6080.*E	9251.*E	2951.*E	7647.*E	1757.*E	435.*E	82.*E	28352.*E
1934	22.*E	9.*E	22.*E	9.*E	76.*E	1212.*E	8666.*E	6556.*E	5732.*E	2278.*E	356.*E	88.*E	25026.*E
1935	24.*E	15.*E	3.*E	26.*E	44.*E	82.*E	11874.*E	8398.*E	5550.*E	1332.*E	240.*E	54.*E	27652.*E
1936	37.*E	3.*E	5.*E	14.*E	66.*E	1231.*E	5098.*E	11968.*E	3838.*E	1321.*E	223.*E	55.*E	23859.*E
1937	9.*E	9.*E	35.*E	48.*E	2027.*E	4867.*E	4306.*E	3193.*E	3456.*E	569.*E	115.*E	27.*E	18660.*E
1938	4.*E	2.*E	45.*E	19.*E	72.*E	49.*E	5059.*E	7321.*E	6037.*E	983.*E	195.*E	45.*E	19831.*E
1939	48.*E	25.*E	2.*E	12.*E	83.*E	1778.*E	15580.*E	40277.*E	12293.*E	3227.*E	469.*E	95.*E	73889.*E
1940	24.*E	5.*E	4.*E	7.*E	28.*E	43.*E	193.*E	1438.*E	1570.*E	319.*E	60.*E	27.*E	3717.*E
1941	4.*E	5.*E	13.*E	56.*E	57.*E	3459.*E	11634.*E	9910.*E	13964.*E	2929.*E	470.*E	99.*E	41602.*E
1942	20.*E	4.*E	55.*E	33.*E	117.*E	6488.*E	11110.*E	24325.*E	47070.*E	9270.*E	1395.*E	275.*E	112160.*E
1943	54.*E	44.*E	58.*E	44.*E	51.*E	2575.*E	6067.*E	6184.*E	9783.*E	2179.*E	338.*E	79.*E	30456.*E
1944	14.*E	3.*E	5.*E	6.*E	78.*E	88.*E	8331.*E	6990.*E	2341.*E	432.*E	97.*E	54.*E	18435.*E
1945	9.*E	4.*E	23.*E	19.*E	229.*E	21463.*E	24627.*E	38799.*E	16576.*E	3007.*E	504.*E	115.*E	105370.*E
1946	26.*E	5.*E	18.*E	24.*E	797.*E	6999.*E	39185.*E	26888.*E	3292.*E	621.*E	170.*E	49.*E	78073.*E

KEY

NA	RECORD NOT AVAILABLE
NR	NOT RECORDED
*	FAULTY - VERY CONFIDENT IN CORRECTED TRACE
**	FAULTY - SOME DOUBT IN CORRECTED TRACE
*E	ESTIMATED TRACE
"	DERIVED FROM INCOMPLETE RECORD

PROGRAM MDLIST
PROCESSED ON 11.58 27 JAN 1984

COLLECTING AUTHORITY WATER RES(03)

YEARS 1907 - 1946
STATION NO. 612 017

PUBLIC WORKS DEPARTMENT
WATER RESOURCES SECTION

TABLE 4

HARRIS RIVER N 6316200 E 421250 TALLANALLA ROAD

STATION NO. 612 017
COPY NUMBER (1)

HISTORICAL MONTHLY STREAMFLOW (10^3 M^3) FOR HARRIS RIVER DAM SITE 5

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1947	10.*E	3.*E	2.*E	27.*E	987.*E	13231.*E	15095.*E	8094.*E	936.*E	243.*E	45.*E	17.*E	38688.*E
1948	2.*E	0.*E	8.*E	25.*E	18.*E	70.*E	2307.*E	10343.*E	4435.*E	3110.*E	452.*E	107.*E	20878.*E
1949	20.*E	4.*E	18.*E	27.*E	42.*E	76.*E	8363.*E	18935.*E	4347.*E	702.*E	154.*E	30.*E	32718.*E
1950	10.*E	2.*E	0.*E	3.*E	65.*E	208.*E	4684.*E	5781.*E	4769.*E	1372.*E	270.*E	61.*E	17226.*E
1951	14.*E	19.*E	2.*E	39.*E	37.*E	6481.*E	7052.*E	6816.*E	1645.*E	331.*E	68.*E	55.*E	22558.*E
1952	4.*E	3.*E	16.*E	13.*E	94.*E	7129.*E	7908.*E	11162.*E	10135.*E	4628.*E	2716.*E	1265.*E	45072.*E
1953	4.*E	16.*E	1.*E	15.*E	259.*E	4909.*E	10725.*E	5625.*E	3484.*E	7412.*E	2031.*E	975.*E	35655.*E
1954	24.*E	4.*E	3.*E	18.*E	55.*E	445.*E	4528.*E	4093.*E	2058.*E	539.*E	263.*E	34.*E	12063.*E
1955	5.*E	108.*E	0.*E	20.*E	251.*E	3892.*E	8055.*E	28899.*E	14401.*E	9042.*E	1774.*E	489.*E	66937.*E
1956	97.*E	12.*E	61.*E	56.*E	1881.*E	8862.*E	12601.*E	9708.*E	3126.*E	1524.*E	579.*E	397.*E	38903.*E
1957	78.*E	1.*E	15.*E	51.*E	200.*E	18235.*E	7517.*E	5175.*E	4620.*E	1710.*E	450.*E	131.*E	38182.*E
1958	24.*E	3.*E	1.*E	14.*E	124.*E	949.*E	15498.*E	8358.*E	2793.*E	1476.*E	491.*E	94.*E	29824.*E
1959	15.*E	0.*E	8.*E	28.*E	33.*E	539.*E	390.*E	4069.*E	564.*E	1036.*E	217.*E	23.*E	6924.*E
1960	105.*E	2.*E	50.*E	10.*E	291.*E	1262.*E	9118.*E	5264.*E	2188.*E	813.*E	175.*E	19.*E	19299.*E
1961	21.*E	4.*E	17.*E	74.*E	31.*E	4897.*E	6162.*E	6623.*E	5430.*E	2149.*E	577.*E	207.*E	26191.*E
1962	41.*E	7.*E	2.*E	6.*E	67.*E	1362.*E	2388.*E	4980.*E	3518.*E	2448.*E	1202.*E	249.*E	16269.*E
1963	22.*E	3.*E	5.*E	26.*E	113.*E	7340.*E	18898.*E	23637.*E	10928.*E	2238.*E	624.*E	125.*E	63959.*E
1964	3.*E	5.*E	5.*E	26.*E	0.*E	10360.*E	33194.*E	36227.*E	5641.*E	4863.*E	844.*E	475.*E	91643.*E
1965	76.*E	13.*E	5.*E	16.*E	752.*E	3738.*E	9049.*E	5918.*E	5481.*E	6269.*E	3143.*E	730.*E	35190.*E
1966	87.*E	10.*E	6.*E	9.*E	64.*E	1760.*E	6973.*E	5636.*E	7715.*E	2491.*E	630.*E	184.*E	25565.*E
1967	115.*E	30.*E	5.*E	18.*E	594.*E	10605.*E	17546.*E	8568.*E	5042.*E	1362.*E	551.*E	536.*E	44971.*E
1968	269.*E	90.*E	39.*E	836.*E	323.*E	4474.*E	6576.*E	8131.*E	9006.*E	3794.*E	927.*E	201.*E	34066.*E
1969	39.*E	4.*E	12.*E	110.*E	277.*E	2696.*E	4262.*E	6041.*E	1134.*E	384.*E	132.*E	30.*E	15121.*E
1970	3.*E	0.*E	0.*E	0.*E	42.*E	8481.*E	9574.*E	6115.*E	4038.*E	8110.*E	834.*E	154.*E	37352.*E
1971	31.*E	10.*E	19.*E	26.*E	326.*E	1620.*E	2390.*E	5411.*E	6990.*E	10076.*E	3345.*E	925.*E	31171.*E
1972	211.*E	6.*E	7.*E	8.*E	10.*E	153.*E	1729.*E	5430.*E	2548.*E	847.*E	211.*E	28.*E	11187.*E
1973	14.*E	2.*E	0.*E	2.*E	47.*E	3447.*E	11504.*E	12713.*E	7494.*E	2872.*E	1141.*E	100.*E	39334.*E
1974	16.*E	7.*E	9.*E	26.*E	1300.*E	10409.*E	23603.*E	23635.*E	4136.*E	2988.*E	1270.*E	289.*E	67686.*E
1975	71.*E	29.*E	27.*E	43.*E	134.*E	1077.*E	4345.*E	5173.*E	2489.*E	1276.*E	480.*E	140.*E	15284.*E
1976	85.*E	31.*E	21.*E	31.*E	47.*E	163.*E	388.*E	1953.*E	910.*E	431.*E	267.*E	87.*E	4413.*E
1977	5.*E	2.*E	1.*E	2.*E	15.*E	59.*E	895.*E	6539.*E	1346.*E	2457.*E	449.*E	38.*E	11808.*E
1978	5.*E	3.*E	0.*E	2.*E	21.*E	546.*E	7623.*E	2121.*E	2483.*E	2981.*E	158.*E	21.*E	15962.*E
1979	5.*E	2.*E	5.*E	6.*E	9.*E	21.*E	1069.*E	657.*E	416.*E	406.*E	164.*E	12.*E	2773.*E
1980	1.*E	1.*E	0.*E	7.*E	13.*E	269.*E	1848.*E	4789.*E	2841.*E	1411.*E	358.*E	48.*E	11578.*E
1981	9.*E	4.*E	4.*E	8.*E	19.*E	1087.*E	4944.*E	10903.*E	3622.*E	2147.*E	607.*E	222.*E	23578.*E
1982	5750.*E	390.*E	37.*E	23.*E	45.*E	453.*E	2219.*E	3200.*E	2532.*E	1497.*E	228.*E	61.*E	14626.*E
1983	13.*E	20.*E	10.*E	12.*E	22.*E	1395.*E	8105.*E	12747.*E	16754.*E	316.*E	0.*E	0.*E	40394.*E

KEY

NA	RECORD NOT AVAILABLE
NR	NOT RECORDED
*	FAULTY - VERY CONFIDENT IN CORRECTED TRACE
**	FAULTY - SOME DOUBT IN CORRECTED TRACE
*E	ESTIMATED TRACE
"	DERIVED FROM INCOMPLETE RECORD

PROGRAM MDLIST
PROCESSED ON 11.59 27 JAN 1984

COLLECTING AUTHORITY WATER RES(03)

YEARS 1947 - 1983
STATION NO. 612 017

WATER RESOURCES SECTION TABLE 4 PROGRAM MOSTAT2 RUN ON 84/01/27 AT 12.00

HISTORICAL MONTHLY STREAMFLOW STATISTICS (10^6 M^3) FOR HARRIS RIVER DAM SITE 5

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MEAN	.110	.018	.015	.028	.220	3.820	9.793	10.724	6.661	3.257	.654	.169	35.467
MEDIAN	.021	.006	.009	.023	.067	1.760	7.888	7.321	4.435	1.524	.388	.087	28.352
STD. DEV.	.653	.047	.016	.031	.386	4.614	8.252	8.927	7.325	5.518	.874	.245	26.568
SKEW	8.706	6.953	1.531	4.253	3.089	1.715	1.618	1.758	3.183	4.546	3.095	2.699	1.591
MAXIMUM	5.750	.390	.067	.236	2.027	21.463	39.185	40.277	47.070	37.692	5.324	1.265	127.730
MINIMUM	.001	0.000	0.000	0.000	.000	.021	.193	.657	.209	.064	0.045	0.007	2.773
S. CORR.	.065	.929	.224	.316	.172	.470	.561	.618	.586	.475	.835	.863	.011
C. VAR.	5.961	2.640	1.068	1.116	1.756	1.208	.843	.832	1.100	1.694	1.337	1.443	.749
STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)													
MEAN (%)	.621	.090	.062	.123	.696	9.445	27.583	32.028	18.285	8.543	2.020	.502	
S.E.E.	.448	.033	.009	.020	.158	1.116	1.459	1.472	1.068	.825	.229	.069	

WATER RESOURCES SECTION TABLE 5 PROGRAM MDSTAT2 RUN ON 84/05/24 AT 08.56

MONTHLY SYNTHESISED STREAMFLOW STATISTICS (10^6 M^3) FOR HARRIS DAM SITE 1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MEAN	.167	.030	.029	.055	.302	4.913	12.729	14.190	8.217	3.814	.881	.247	45.574
MEDIAN	.025	.008	.013	.025	.155	3.436	10.609	11.187	5.894	2.096	.529	.131	39.275
STD. DEV.	.551	.074	.051	.087	.474	4.972	10.170	11.217	8.003	5.010	1.135	.361	31.023
SKEW	6.585	5.521	4.868	4.425	4.805	2.569	2.006	1.881	2.408	3.434	4.010	3.367	1.356
MAXIMUM	5.374	.642	.460	.925	3.263	46.042	76.456	85.546	58.258	42.993	11.184	2.671	185.390
MINIMUM	.000	.000	.000	.000	.001	.054	.049	.051	.035	.015	.004	.001	.255
S. CORR.	.020	.967	.494	.610	.295	.432	.565	.583	.645	.526	.815	.859	-.006
C. VAR.	3.294	2.490	1.760	1.593	1.569	1.012	.799	.798	.974	1.314	1.288	1.461	.681

STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)

MEAN (%)	.442	.074	.064	.121	.668	11.178	28.385	30.771	17.638	8.216	1.910	.534
S.E.E.	.068	.008	.004	.007	.036	.349	.494	.454	.402	.319	.077	.028

WATER RESOURCES SECTION TABLE 6 PROGRAM MDSTAT2 RUN ON 84/05/24 AT 08.50

MONTHLY SYNTHESISED STREAMFLOW STATISTICS (10^6 M^3) FOR HARRIS DAM SITE 5

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
MEAN	.179	.031	.024	.045	.234	3.799	10.287	11.283	6.303	3.139	.707	.188	36.218
MEDIAN	.019	.006	.010	.021	.104	2.546	7.961	8.375	4.733	1.729	.396	.100	30.082
STD. DEV.	.695	.086	.044	.085	.343	3.999	8.801	9.448	5.416	4.230	.932	.258	24.765
SKEW	12.315	8.660	5.508	8.667	3.433	2.722	2.301	1.904	1.943	3.683	3.774	3.101	1.215
MAXIMUM	12.540	1.339	.480	1.345	2.697	34.336	71.833	61.326	38.295	42.240	9.342	1.747	148.880
MINIMUM	.000	.000	.000	.000	.002	.037	.340	.412	.175	.027	.006	.002	1.846
S. CORR.	.048	.973	.368	.681	.297	.449	.614	.576	.585	.434	.895	.874	.010
C. VAR.	3.880	2.758	1.811	1.905	1.462	1.053	.856	.837	.859	1.348	1.317	1.376	.684

STATISTICS OF MONTHLY DATA (EXPRESSED AS PERCENT OF ANNUAL TOTAL)

MEAN (%)	.452	.080	.066	.124	.679	10.562	28.440	30.744	17.756	8.632	1.943	.520	
S.E.E.	.059	.007	.004	.007	.039	.316	.492	.457	.391	.366	.077	.024	

4. DAM SITES STREAMFLOWS

The daily streamflows at Dam Site 1 were estimated for the period 1907 to 1964 using the Sacramento model. The monthly streamflows and their statistics are given in Table 3. The observed streamflows from 1952 are also tabulated in the same Table. Where there are missing records between the overlapping period of 1952 to 1964, the estimated records have been used to fill them in.

The monthly streamflows at Dam Site 5 for the period 1907 to 1983 and their statistics are presented in Table 4.

For the purpose of yield estimation the 77 years of historical data was considered inadequate and longer sequences of 500 years were generated preserving the monthly and annual statistics of the 77 years data. Usually the 2 parameter log normal distribution adequately describes the distribution of annual river flows in South Western Australia. On the Harris River the drier years are particularly severe causing the bottom of the distribution to become non-linear and to drop away.

During the synthetic data generation process, therefore the monthly streamflow was assumed to follow 2 parameter log normal distribution, while the annual streamflow was assumed to follow 3 parameter log normal distribution. The statistics of the generated records are presented in Table 5 for Dam Site 1 and Table 6 for Dam Site 5.

5. PHYSICAL DESCRIPTION OF THE DAMS

Storage and surface area curves for Dam Site 1 and Dam Site 5 were extracted from Department's Plans No. 38461-5-12 and 38461-5-8 respectively. The values are tabulated as shown in Table 7.

TABLE 7
STORAGE AREA CURVES FOR DAM SITE 1 AND DAM SITE 5

Dam Site 1			Dam Site 5		
R.L. m(AHD)	Storage ($10^6 m^3$)	Area (km^2)	R.L. m(AHD)	Storage ($10^6 m^3$)	Area (km^2)
190.00	0.00	0.00	200.00	0.00	0.00
195.00	1.40	0.50	203.00	0.60	0.33
197.50	2.60	0.85	205.00	1.60	0.64
200.00	5.00	1.29	208.00	4.50	1.30
203.00	10.00	2.00	210.00	7.70	1.80
205.00	14.80	2.68	212.50	13.00	2.48
208.00	24.10	3.90	215.00	19.80	3.26
210.00	33.00	4.81	217.50	29.50	4.18
211.00	38.00	5.30	220.00	42.30	5.62
213.10	50.00	6.30	221.00	48.00	6.37
215.00	63.00	7.42	222.50	58.30	7.63
216.00	71.00	8.04	224.80	80.00	9.72
217.10	80.00	8.80	225.00	81.06	9.77
217.20	81.00	8.90	226.76	100.00	11.34
218.00	88.00	9.48	228.85	101.00	11.45
219.00	100.00	10.30	227.50	108.00	11.97
219.10	101.00	10.26	228.50	120.00	12.85
220.00	108.50	11.16	228.60	121.10	12.92
221.00	120.00	12.16	230.00	140.00	14.25
221.05	121.00	12.20	230.50	147.00	14.60
222.00	133.70	13.22	232.50	175.50	16.00
223.00	148.00	14.38	234.30	200.00	17.25
225.00	179.50	16.76			

6. YIELD ESTIMATION

6.1 Yield From Single Storage

A number of simulation runs were made using the synthetic data in order to determine the yield under different dam sites, storage volumes and draw rates. The results for the 2% and 5% probability of failure are presented in Table 8 for Dam Site 1 and Table 9 for Dam Site 5.

TABLE 8
SUMMARY OF THE YIELD FOR DAM SITE 1

Catchment Area: 383 Square Kilometres
Mean Annual Streamflow: 45.6 million cubic metres

Storage		Annual Draw			
	% Mean Annual Flow	2% Prob. of Failure (1:50 yrs)		5% Prob. of Failure (1:20 yrs)	
($10^6 m^3$)		($10^6 m^3$)	% Mean Annual Flow	($10^6 m^3$)	% Mean Annual flow
23	50	13.80	30	15.60	34
46	100	20.40	45	24.20	53
69	150	26.00	57	29.00	64
80	176	29.00	61	30.00	66
100	219	29.85	66	33.00	72
120	263	31.65	70	34.35	75
137	300	33.00	72	35.00	77

TABLE 9
SUMMARY OF THE YIELD FOR DAM SITE 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 yrs)		5% Prob. of Failure (1:20 yrs)	
($10^6 m^3$)		($10^6 m^3$)	% 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

6.2 Yield From Storage With Pumpback

This section investigates the effect of the storage yield at Dam Site 5 with an addition streamflow from the intervening catchment being pumped back into the reservoir. Unlike the previous simulation runs. These runs only employed a total of 77 years of historical data.

6.2.1 Yield From Intervening Catchment Alone

A total of 77 years of daily historical sequence has been used to estimate the amount of streamflow that can be diverted given a small pipehead with a certain diversion capacity. The percentages of the mean annual flow diverted were calculated for different diversion capacities. The results are tabulated in Table 10 and plotted as shown in Figure 2. Included in the plot is the year 1979 which experiences minimum flow.

TABLE 10
YIELD FROM INTERVENING CATCHMENT
Catchment Area : 62.0 square kilometres
Mean Annual Streamflow : 9.6 million cubic metres

Diversion Capacity ($\times 10^3$ m^3/day)	Mean Value Diverted ($\times 10^6$ m^3/a)	Minimum Volume Diverted (1979) ($\times 10^6$ m^3/a)
2.6	0.5	0.5
5.3	0.9	0.8
13.1	1.9	1.3
18.4	2.5	1.5
26.3	3.3	1.6
39.4	4.3	1.7
52.6	5.1	1.8
65.7	4.8	1.8
78.9	6.3	1.9
92.0	6.7	1.9
105.1	7.1	1.9

6.2.2 Yield From Storage With Pumpback

Simulation with a major reservoir at site 5, supplemented by a pumpback scheme from site 1, have been carried out with pumpback capacities of 25, 50 and 80 thousands of cubic metres per day. They represent about 100%, 200% and 300% respectively of the mean annual flow from the intervening catchment. The streamflow from the intervening catchment is diverted on a daily basis and only up to the specified capacity. The results are tabulated in Table 11.

TABLE 11
RESULTS FROM DIVERSION RUNS

Diversion Capacity		Diversion Achieved
Daily	Annually	Annually
($10^3 m^3$)	($10^6 m^3$)	($10^6 m^3$)
25	9.1	3.1
50	18.3	5.0
80	29.2	6.3

The diverted streamflow was added to the inflow into the reservoir at Site 5. The reservoir was then simulated first with its natural inflow and secondly with the added inflows.

The same reservoir simulation program has been used to simulate the yield for a variety of total inflows. However, only 77 years of historical data has been considered and the reservoir is assumed to have a capacity of 100 million cubic metres. The draw from the reservoir that can just supply the demand with zero failure in 77 years has been used as a criteria to determine the effect of pumpback from the intervening catchment. The results are tabulated in Table 12.

TABLE 12
INCREASE IN YIELD FROM PUMPBACK

Diversion Capacity 10^3 m^3/day	Increase in Yield (10^6 m^3)
25	2.4
50	3.1
80	3.4

7. FLOOD ESTIMATION

7.1 Flood Frequency

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 a total of 32 years of data set from 1952 to 1983. The annual flood series were ranked as shown in Table 13. Two probability distributions, log Normal and log Pearson type III Distributions, were fitted to this data set and the results are given in Table 14. On nearly all streams in South Western Australia, the Log-Normal Distribution is accepted as the distribution most appropriate for use. In this case, the difference between the two sets is insignificant.

TABLE 13
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
Jan 1982	4	33.70
Jul 1958	5	31.80
Jun 1957	6	21.50
Aug 1955	7	21.40
Sep 1983	8	19.80
Jul 1960	9	19.80
Jul 1967	10	19.00
Jul 1953	11	18.80
Jul 1970	12	17.90
Jul 1956	13	17.40
Nov 1971	14	17.20
Jul 1978	15	15.80
Jun 1961	16	14.40
Sep 1968	17	13.70
Aug 1973	18	12.40
Sep 1952	19	12.20
Jul 1966	20	12.10
Aug 1977	21	11.70
Aug 1969	22	11.60
Aug 1981	23	11.20
Aug 1962	24	10.80
Oct 1965	25	10.40
Jul 1975	26	9.57
Aug 1959	27	6.89
Aug 1972	28	6.83
Jul 1954	29	5.55
Aug 1980	30	5.30
Aug 1976	31	4.32
Jul 1979	32	2.19

TABLE 14
FLOOD FREQUENCY DISTRIBUTION

Recurrence Interval (Yrs)	Peak based on Log-Normal Distribution (Adopted) (m^3/s)	Peak based on Log-Pearson Type III Distribution (m^3/s)
2	14.21	14.20
10	36.32	36.33
50	63.50	63.00
100	78.00	78.15
200*	93.67	93.89
1000*	138.47	136.96

* Estimated from considerable extension of the probability distribution and should not be accepted without further consideration.

7.2 Flood Peaks

7.2.1 Probable Maximum Rainfall

The Bureau of Meteorology has provided the Department with the estimates of probable maximum rainfall based on the method of adjusted U.S. rainfalls. A summary of the results is given in Table 15.

TABLE 15
PROBABLE MAXIMUM PRECIPITATION

	Duration (hr) 1	6
Extreme rainfall (mm) with a dewpoint of 28°C (modified US Adjusted Data)	280	635

Monthly Probable Maximum Precipitation Estimates
(mm)

	Duration (hr) 12	24	36	48	72	120
Dec	460	600	660	675	700	700
Jan	500	645	710	725	755	755
May	390	510	560	570	595	715
Jun	330	430	470	480	500	620
Jul	300	385	425	430	450	570
Aug	270	350	385	395	410	530
Sep	305	395	435	445	460	580
Oct	360	465	510	520	540	660

7.2.2 Probable Maximum Floods (PMF)

Flood studies have been based on unitgraph method calibrated on August 1964 storm. The ordinates for the two hour unitgraph are listed in Table 16. Based on the September winter storm where the catchment is considered saturated with zero rainfall losses. The PMF was calculated for different storm durations and the results are summarised in Table 17.

TABLE 16
2 HOUR UNITGRAPH ORDINATES FOR HARRIS CATCHMENT

Time (Hr)	Unitgraph ordinate (m^3/sec)	Time	Unitgraph ordinate m^3/s
0	0.00	62	0.63
2	0.15	64	0.60
4	0.40	66	0.57
6	0.59	68	0.52
8	0.71	70	0.46
10	0.84	72	0.44
12	0.97	74	0.45
14	1.30	76	0.46
16	1.83	78	0.42
18	2.19	80	0.39
20	2.41	82	0.35
22	2.76	84	0.29
24	3.06	86	0.25
26	2.98	88	0.27
28	2.73	90	0.27
30	2.68	92	0.26
32	2.50	94	0.24
34	2.29	96	0.19
36	1.99	98	0.15
38	1.63	100	0.13
40	1.37	102	0.11
42	1.23	104	0.11
44	1.19	106	0.11
46	1.15	108	0.10
48	1.14	110	0.09
50	1.08	112	0.06
52	0.98	114	0.04
54	0.88	116	0.03
56	0.76	118	0.03
58	0.68	120	0.03
60	0.65	122	0.02

TABLE 17
PROBABLE MAXIMUM FLOODS

Duration (hr)	PMP (mm)	Peak Flow (m^3/s)
6	222	659
12	305	857
24	395	991
48	445	830

The results show that the 24 hour storm of 395 mm produces the highest flood peak of 991 m^3/s.

The PMF was derived from one catchment model that based on a single storm and incorporate no loss model. This approach is considered preliminary and the derived PMF should be treated with caution until more comprehensive flood studies are carried out.

8. REFERENCES

McMAHON, T.A. & MEIN, R.B. (1978) - Reservoir Capacity and yield. Developments in Water Science, 9., Elsevier Scientific Publishing Company.

SALIM, D. (1984a) Harris River - Historical Streamflow. Internal Publication No WRB 75, Water Resources Branch, Public Works Department, W.A.

SALIM, D. (1984b) Harris River Dam Site 5 - Historical Streamflow. Internal Publication No WRB 84, Water Resources Branch, Public Works Department, W.A.

SALIM, D. (1984c) Harris River Yield Study Internal Publication No. WRB 111, Water Resources Branch, Public Works Department, W.A.

APPENDIX M

WATER QUALITY DETERIORATION

An Internal Report by
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APPENDIX M

WATER QUALITY DETERIORATION

1. EFFECT OF CATCHMENT CLEARING ON INFLOW SALINITIES

The impact of agricultural development on the inflow salinity to Wellington Reservoir is clearly depicted in Figures 1 and 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 be about 280 mg/L TSS. By 1984 the salinity of a year of median inflow had deteriorated to 850 mg/L TSS and is continuing to deteriorate at a current rate of 30 mg/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 in which the annual inflow is exceeded in 90% of years) is 1370 mg/L.

The distribution of inflow salinities within years is extremely complex (Loh and Stokes, 1981) and can give rise to very high daily inflow salinities (often in excess of 2500 mg/L TSS). These variations have important implications for reservoir operations and water supply salinities and are discussed in Section 2.4 below.

2. CAUSES OF THE INCREASE IN SALINITY

Removal of deep rooted forest vegetation and its replacement with shallow rooted crops and pastures has resulted in additional water passing the root zone of the vegetation and thereby recharging the groundwater system. As groundwaters rise, some of the salts stored in the soil profile are mobilised, and eventually additional salts and groundwater discharge to the surface stream

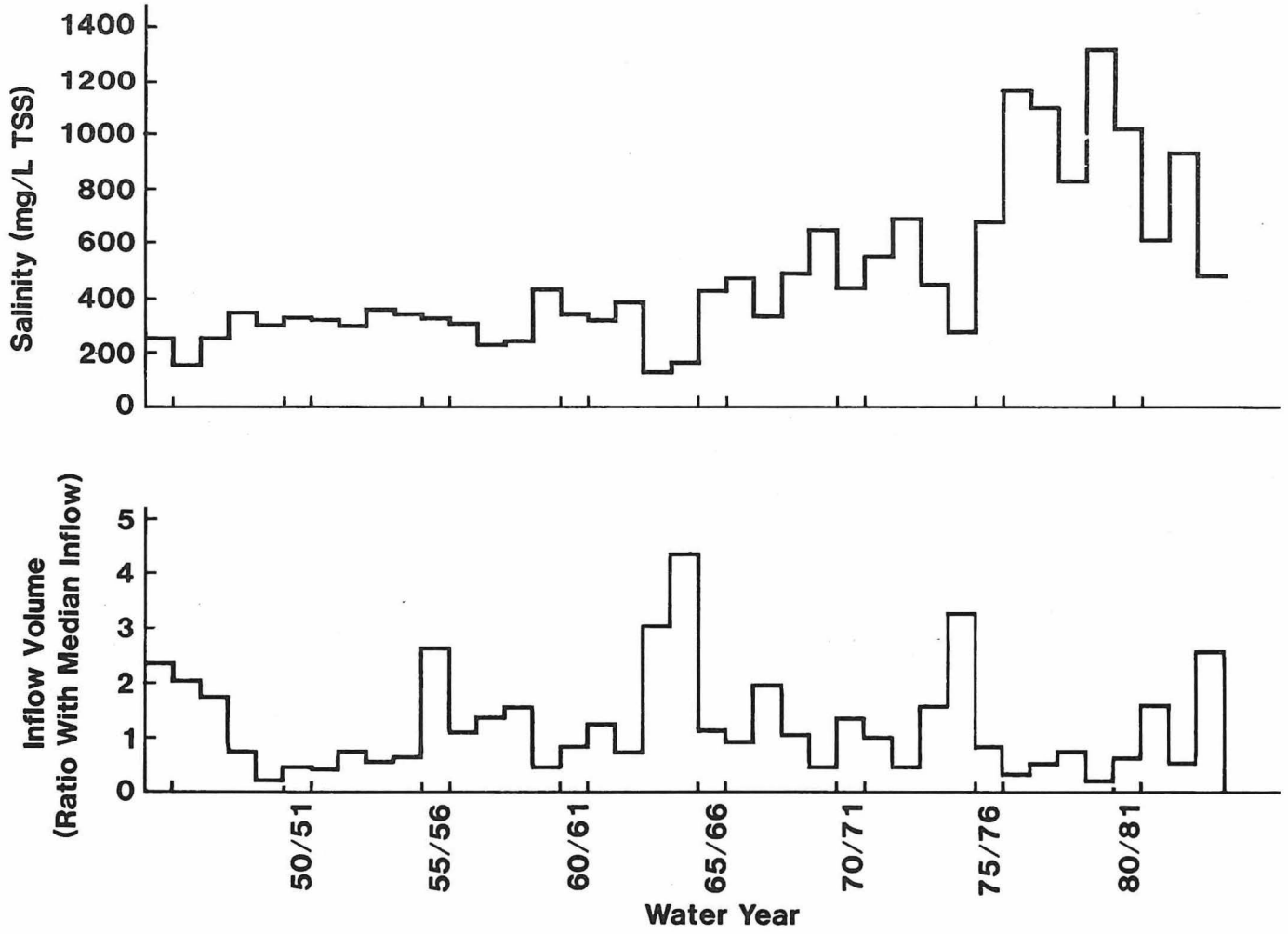
system. Major increases in stream salinities result in areas where there is a large store of salts in the landscape. This generally occurs where annual rainfall is less than 900 mm per annum. Streams draining agricultural land in these regions commonly have average salinities in excess of 3000 mg/L. In higher rainfall areas, particularly over 1000 mm per annum, where salt storage is much lower, and where clearing results in additional fresh surface and shallow subsurface water, increases in streamflow salinity are much smaller and can often be difficult to detect (Loh et al, 1983).

The distribution of rainfall, salt storage and agricultural clearing results in a highly variable spatial distribution of stream salinities across the Wellington Reservoir catchment. Over 80% of the salts inflowing to the reservoir come from the eastern and southern subcatchments where rainfalls are less than 900 mm per annum and most of the agricultural development has occurred. In contrast only 20% of salts and over 50% of streamflow comes from the remaining higher rainfall and predominantly forested northern and western portions of the catchment (Barrett and Loh, 1982). The catchment of the proposed Harris River storage is located in this region of fresh streamflow.

The quantities of additional water recharging the groundwater following clearing are relatively small (less than 10% of annual rainfall) and the groundwater system transports water extremely slowly. Consequently, there is a long delay between initial clearing and the time when the additional groundwater discharge reaches its maximum. In the more saline sections of the catchment this delay is invariably in excess of 20 years.

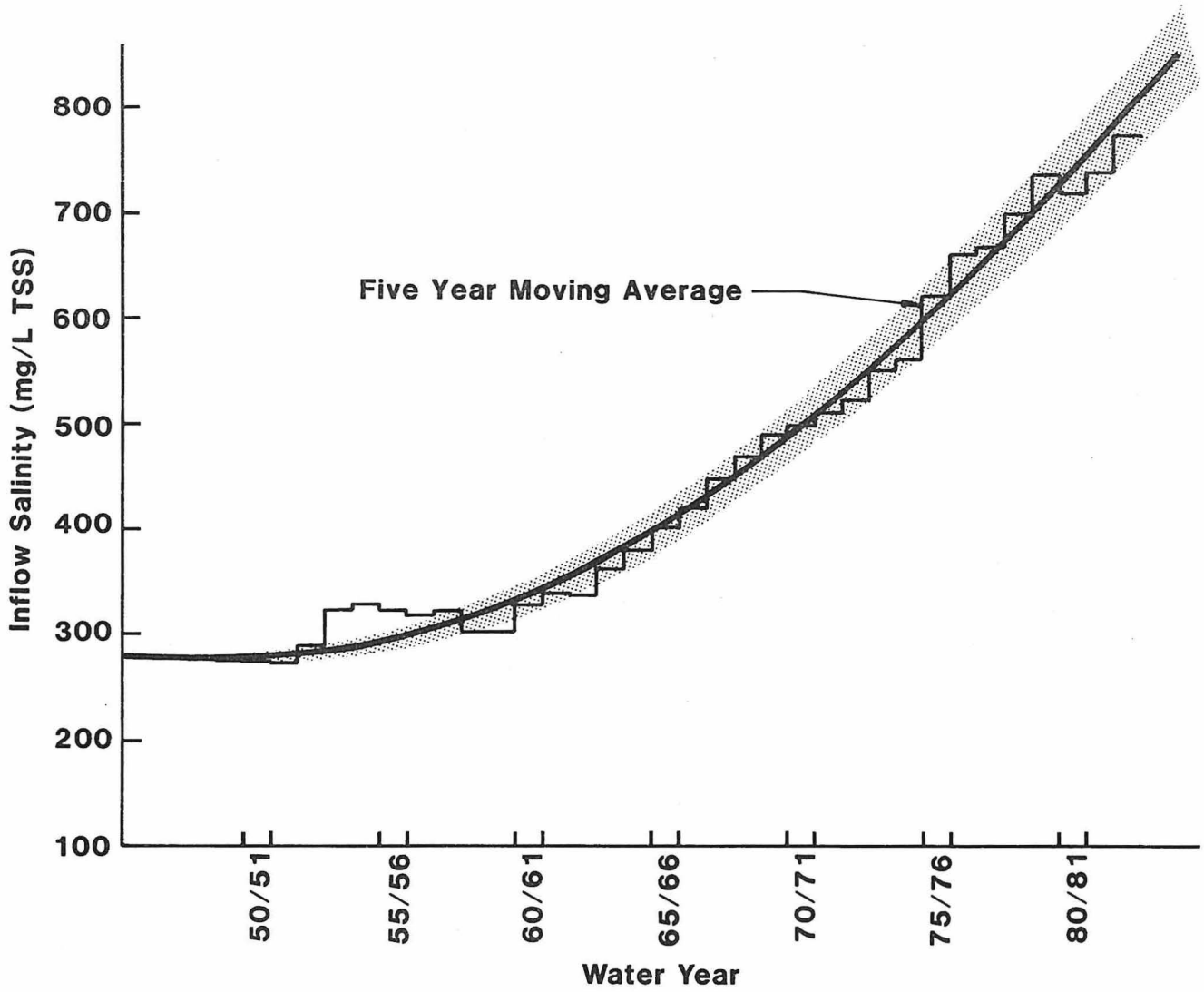
3. CLEARING CONTROLS AND THE EFFECT OF PAST CLEARING

Realising the seriousness of the then current salinity levels and recognising that the full effect of past clearing was not yet reflected in the inflow salinity at that time, the State



Inflow Salinities And Flow Volumes To Wellington Reservoir

Figure 1



Average Inflow Salinity To Wellington Reservoir

Figure 2

Government introduced legislation to control further agricultural development in November, 1976. The Country Areas Water Supply Act was amended to prohibit unlicenced clearing on the catchment. While small scale essential clearing is licenced, large scale agricultural development is not permitted. Farmers affected can claim compensation for their inability to further develop their farm enterprise.

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

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

The estimated future inflow salinities resulting from past clearing are shown in Figure 3 for years of median inflow.

Most importantly, however, are the likely salinity levels in dry years. While dry year estimates are subject to considerable uncertainty, it has been estimated that for an annual inflow

volume likely to be exceeded in 90% of years the inflow salinity in 2010 would be approximately 1800 mg/L, approaching 1880 mg/L TSS by 2040.

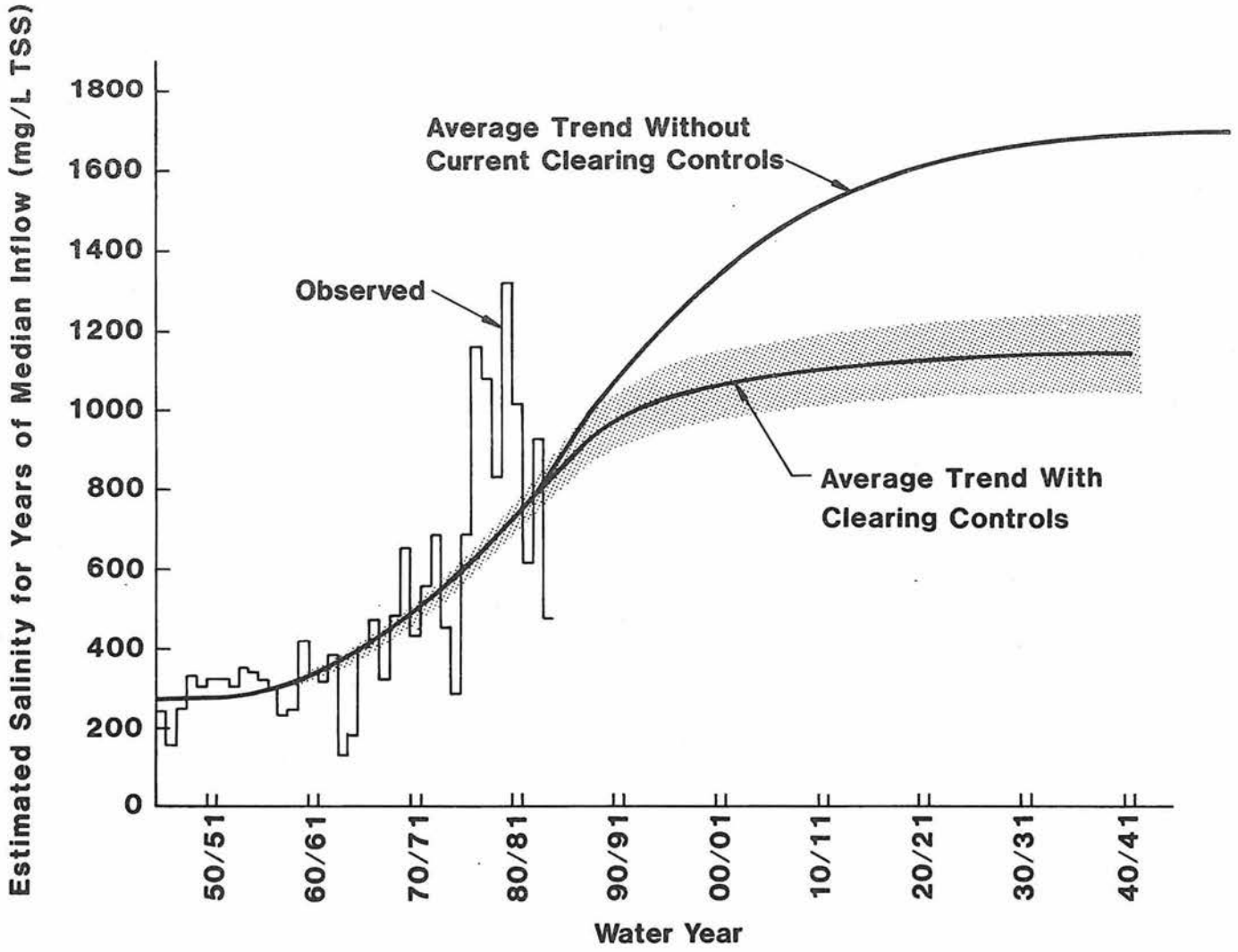
Figure 3 also shows the trend in salinities of median inflow years if the clearing control legislation had not been imposed and clearing had continued to its potential of 100 000 ha by 1990. Ultimate salinity in a year of median flow would have reached 1700 mg/L TSS, while in a dry year (90% probability of exceedance) salinity would have approached 3000 mg/L TSS.

4. REFORESTATION

While the clearing control legislation has had a major effect in minimising further deterioration in reservoir salinity levels, estimates of the full effect of clearing current at the time of the legislation indicated the quality of both town water and irrigation supplies would eventually become unacceptable, particularly in dry years. In addition the deterioration would limit the future utility of the presently uncommitted yield from Wellington Reservoir. Consequently reforestation of cleared farmland in the drier, high salt-yielding parts of the catchment was commenced in 1979.

The reforestation programme was initially proposed to run for six to ten years with an annual replanting target of 2000 ha. The actual planting rate achieved has varied between 700 and 800 ha per year, with a total of 3 370 ha having now been reforested. The reforestation strategy involved planting along the valley bottoms and lower side-slopes, the remaining mid- and upper slopes providing viable strips of cleared farmland which could then be exchanged for lower slope land areas on adjacent farmland to further extend the area of reforestation.

By September 1984 sufficient land had been purchased to enable approximately 8000 ha to be planted. When planting of this area



Observed And Projected Inflow Salinities To Wellington Reservoir

Figure 3

is complete, the total costs of reforestation are expected to be $13 million. This reforestation, which will take several years to complete, will in the longer term exert some control of salt discharges from 18 500 ha of the 51 000 ha of cleared farmland in the highly salt susceptible zones of the catchment. There is however, considerable uncertainty in assessing the magnitude of the salinity reductions which will be achieved by the present reforestation programme.

Despite the difficulties in reliably estimating the effects of reforestation, calculations can be made using knowledge of the distribution of water and salt discharge across the catchment and by assuming various levels of effectiveness of the reforestation in controlling saline groundwater discharge. Estimates of the time scale for reforestation to reduce groundwater levels has been based on the groundwater simulation studies noted above. Assuming the current replanting programme is moderately effective (reducing groundwater discharges by 70%) then long-term salinities of inflow will ultimately reach about 950 mg/L TSS in a median year. The current reforestation programme should therefore reduce the expected level in 2010 (1100 mg/L TSS) by about 150 mg/L, equivalent to a long-term deterioration of about 100 mg/L TSS over current levels.

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

While the reforestation programme will limit the rate of rise of inflow salinity during the 1980's present knowledge suggests that trees will not significantly reduce inflow salinities until the

mid- to late-1990's. Peak inflow salinities can therefore be expected in the early to mid-1990's.

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

Table 1 summarises the estimated inflow salinities for different land use conditions discussed above. It should be remembered that the values are sensitive to the assumptions of the effectiveness of reforestation. If the current reforestation programme were 100% effective, median year inflow salinities would reach about 970 mg/L in the mid-1990's and reduce to about 850 mg/L by the year 2010. Therefore the programme would in the longer term roughly maintain the current inflow salinity levels. If reforestation was only 50% effective median inflow salinities would reach about 1020 mg/L in the mid-1990's and reduce to only 1000 mg/L in 2010.

Figure 4 shows the estimated effect of the current reforestation programme on inflow salinities in a median year.

TABLE 1
BEST ESTIMATES OF INFLOW
SALINITIES TO WELLINGTON RESERVOIR

LAND USE CONDITION	YEAR	INFLOW SALINITY FOR AVERAGE (1) CONDITIONS	INFLOW SALINITY FOR DRY (2) CONDITIONS
Current Situation	1984	850	1330
If all private land had been cleared by 1990	2020	1620	2830
	2050	1700	3000
Clearing Controlled to 1976 Level by Legislation	2010	1100	1800
	2040	1150	1880
Completion of the Current Reforestation by the Early 1990's (70% effective)	mid-1990's	1005	1610
	2010	950	1510
	2040	950	1510

(1) Average Conditions - A year of median inflow volume
(2) Dry Conditions - A year with an inflow volume exceeded in 90% of years

5. RESERVOIR OPERATION AND WATER SUPPLY QUALITY

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

Results from a research project on the water mixing processes in Wellington Reservoir (Imberger and Hebbert, 1980) first identified strong seasonal layering of salinity in the reservoir in 1975. Initial flows from the eastern portion of the catchment at the start of each winter are cold and highly saline, often over 3000 mg/L TSS. As this inflow is more dense than the stored water, it underflows the waterbody and lodges at the base of the reservoir. By selectively releasing this saline water during early winter and also by supplying summer irrigation water from the base of the

reservoir, improvements in the town water supply quality are possible. A new operating policy based on these concepts was introduced in 1976 and has been working effectively since.

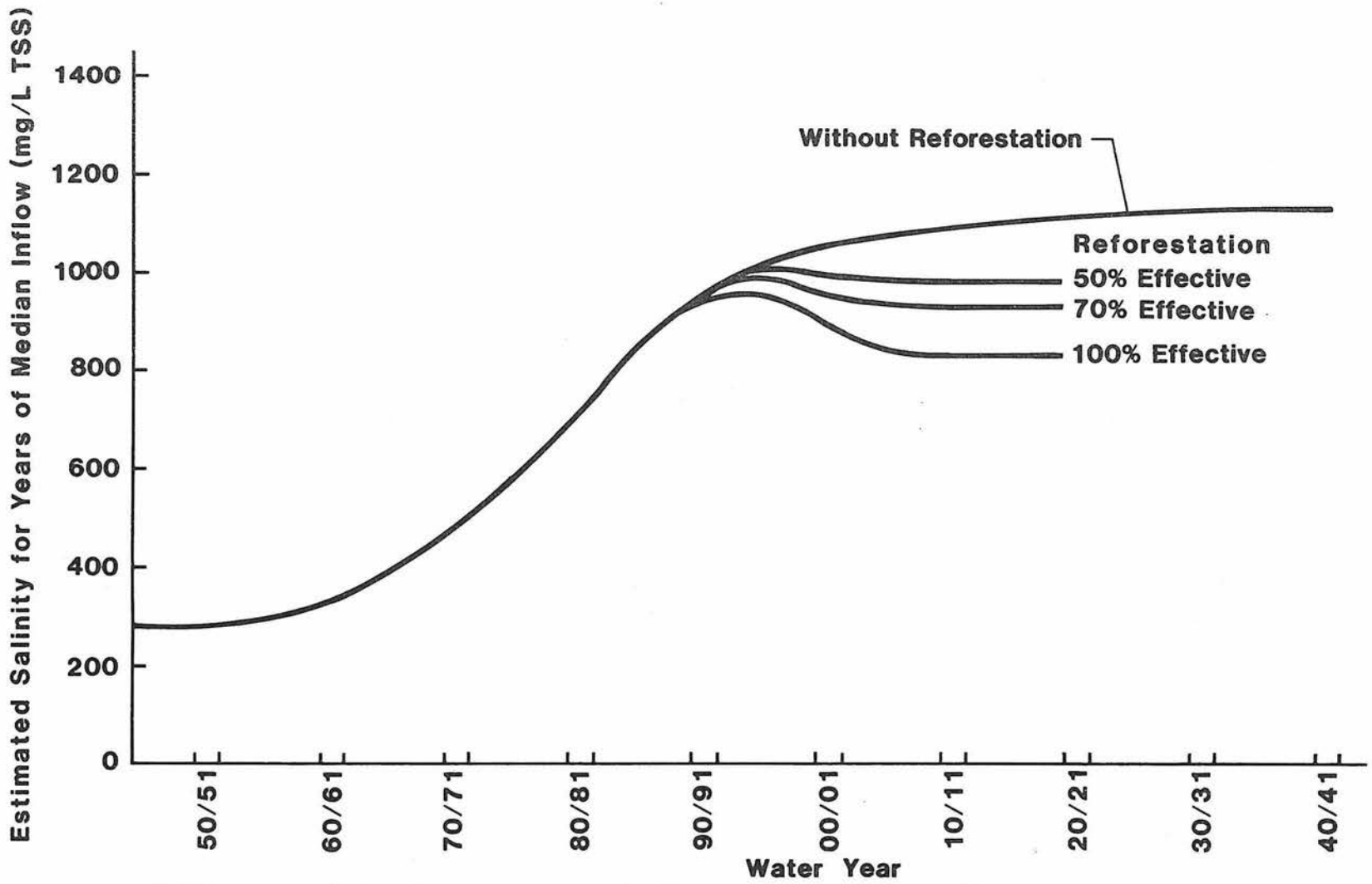
The benefits obtained have been studied in detail using the most recent version of a complex reservoir simulation programme which takes into account all the main mixing processes in Wellington Reservoir (Meares, Jokela and Patterson, 1985). Daily simulations of the salinity and temperature structure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

Table 2 presents the results of the average, 50th (median) and 95th percentiles of supply salinities for both the previous and current operational procedures over the eight year study period.

TABLE 2
SUPPLY SALINITIES OVER EIGHT YEAR SIMULATION PERIOD

	OPERATIONAL PROCEDURES	
	Previous Method (1)	Current Method (2)
INFLOW SALINITY		
Total Salt/Total Water (4)	619	619
Equivalent Median Year Salinity	741	741
MEAN SUPPLY SALINITY		
Town Water	768	693 (10%)
Irrigation Water	764	733 (4%)
MEDIAN SUPPLY SALINITY		
Town Water	860	770 (10%)
Irrigation Water	830	790 (5%)
95TH PERCENTILE SUPPLY SALINITY		
Town Water	1045	980 (6%)
Irrigation Water	1060	1040 (2%)

Notes : (1) Previous method - No winter scour, irrigate through hydroelectric station offtake at mid-level of the dam wall.



Effect Of Current Reforestation Programme On Average Inflow Salinities

Figure 4

(2) Current method - Early winter scour, irrigate from base of the reservoir.
(3) Values in brackets are the percent improvements due to the new operational procedures over the previous method.
(4) Total salt load divided by the total volume of streamflow over the eight year study period.

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

On the basis of the salinities of inflow in a median year results of the current operation simulations over the eight year period have been scaled up to estimate the supply salinities for the range of land use conditions discussed in sections 3 and 4. The results are presented in Table 3. These form the base set of supply salinities from which to compare the effect of various options for improving the supply to the Great Southern.

The results indicate that with a moderately effective (70%) reforestation programme and the application of suitable reservoir operating procedures, the mean town water supply salinity will ultimately approach 890 mg/L TSS but could still approach 1250 mg/L TSS in a run of dry years similar to the late 1970's. Irrigation supply salinities will average approximately 940 mg/L but could exceed 1330 mg/L in a run of dry years. However before the full effects of reforestation become apparent mean town water and irrigation supply salinities could reach 940 mg/L and 990 mg/L in the mid-1990's respectively.

If a run of dry years similar to those experienced in the late 1970's again occurred in the mid-1990's, supply salinities in excess of 1330 and 1410 mg/L for town water and irrigation supplies could be expected.

While the long term salinities would be similar to the current levels if reforestation were 100% effective, mean levels of 910 and 960 mg/L would still be reached in the mid-1990's. These could exceed 1280 mg/L and 1360 mg/L if dry conditions were experienced at that time.

In view of the estimates in Table 3, coupled with the current chloride limits on drinking water of 1100 mg/L TSS, and the likelihood of more stringent standards being set for sodium levels in the near future, it is clear that a satisfactory supply to the Great Southern Towns Water Supply scheme cannot be guaranteed in the future even with the current reforestation programme operating effectively and application of the recently improved reservoir operational procedures.

TABLE 3
PREDICTED FUTURE WATER SUPPLY SALINITIES FROM WELLINGTON RESERVOIR

Land Use Condition	Current Condition	Without any Reforestation	If All Private Land Had Been Cleared	Completion of Current Reforestation by early 1990's 70% effective		Completion of Current Reforestation by early 1990's 100% effective	
Date	1984	2040		Mid 1990's	2010	Mid 1990's	2010
INFLOW SALINITY							
Total Salt/Total Flow	710	960	1420	839	793	810	710
Median Year Salinity	850	1150	1700	1005	950	970	850
MEAN SUPPLY SALINITY							
Town Water	795	1076	1590	940	888	907	795
Irrigation Water	841	1138	1682	994	940	960	841
MEDIAN SUPPLY SALINITY							
Town Water	883	1196	1766	1044	987	1008	883
Irrigation Water	906	1226	1812	1071	1013	1034	906
95TH PERCENTILE SUPPLY SALINITY							
Town Water	1124	1521	2248	1329	1256	1283	1124
Irrigation Water	1193	1614	2386	1410	1333	1361	1193
YEARLY AVERAGE SUPPLY SALINITY AT END OF DROUGHT SEQUENCE (1980/81)							
Town Water	1109	1534	2218	1311	1240	1266	1109
Irrigation Water	1105	1527	2209	1306	1235	1261	1105

REFERENCES

BARRETT, K.L. and LOH, I.C. (1982). Assessing the Quality of Surface Water Resources. Proceedings of a Symposium on Prediction in Water Quality, Edited by E.M. O'Loughlin and P Cullen, Australian Academy of Science, pp 327 to 345.

HOOKEY, G.R. and LOH, I.C. (1985). Hydrodynamic Simulation of the Mixing Processes and Supply Salinities of the Harris-Wellington Two-Dam System. Water Authority of Western Australia, Report No WH01.

IMBERGER, J. and HEBBERT, R.H.B. (1980). Management of Water Quality in Reservoirs. Australian Water Resources Council, Tech. Paper No. 49. Research project 74/70, 194 pp.

LOH, I.C., VENTRISS, H.B. and COLLINS, P.D.K. (1983). Water resources quality in Western Australia. In "Water Quality : Its significance in Western Australia." Water Research Foundation Seminar Perth, October 1983.

LOH, I.C. and STOKES, R.A. (1981). Predicting Stream Salinity Changes in South-Western Australia. In "Land and Stream Salinity". Ed J.W. Holmes and T. Taslma, Elsevier, 1981, pp 227 to 254.

MEARES, I.G., JOKELA, J.B. and PATTERSON, J.C. (1985). Harris-Wellington Two-Dam Modelling Project. Report to Public Works Department, W.A. by Centre for Water Research, University of W.A. Working Paper No WP-84-023.

APPENDIX N

DEMAND AND ECONOMICS OF SUPPLY

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1.0 DEMAND PROJECTIONS

1.1 CONSUMPTION TRENDS

The Great Southern Towns Water Supply (GSTWS) provides water to 32 towns within an area of 600,000ha of farmland. Over the last 10 to 15 years the scheme has undergone some limited expansion: to Lake Grace in 1974/75, to Tambellup in 1977/78 and to Boddington in 1982/83. Data from the period 1975 to 1985 is shown in Table 1. The largest town is Collie with 3,029 services in 1985. The growth of Collie is related fairly closely to the development of the coal fields for power generation. However towns such as Narrogin, Katanning and Wagin, which have a third of all services, are primarily based on the rural industry. Over the last five years the growth rate in the total number of services on the GSTWS has been 2.4%. The projected overall growth rate for the total number of services in the period to the year 2000 is 1.6%. This increase in the total number of services, together with a marginal increase in the consumption per service results in the projected demands shown in Table 2.

The number of farmland services are expected to grow very slowly. There are wide fluctuations in demand, depending on seasonal conditions. Industrial consumption is not expected to vary significantly from existing levels, particularly as the State Energy Commission are meeting all their water requirements from bores and mine dewatering.

1.2 WATER DELIVERED VERSUS CONSUMPTION

The water consumption figures quoted in Table 1 are based on consumer meter readings. The total of these do not match the water delivered due to meter inaccuracies, losses due to burst mains, scouring, tank overflows and unmetered consumption. Total water deliveries in Table 2 have been estimated by assuming that 85% of the water delivered will be recorded on consumers meters. This is close to the average figure that has been estimated from the data over the last few years.

TABLE 1

GSTWS WATER CONSUMPTION, 1975-1985

YEAR ENDED JUNE 30	NUMBER OF SERVICES		WATER CONSUMPTION $x10^6m^3$	WATER DELIVERED $x10^6m^3$	
	DOMESTIC	TOTAL		ALL SOURCES	EX WELLINGTON DAM
1975	6,866	10,907	4.993	5.949	5.146
1976	7,277	11,191	4.778	5.362	5.446
1977	7,456	11,384	5.816	6.066	5.965
1978	7,548	11,477	4.910	5.891	5.340
1979	7,682	11,630	4.710	6.475	5.625
1980	8,004	12,167	5.206	5.160	6.487
1981	8,236	12,824	5.130	5.302	6.101
1982	8,380	12,993	4.930	6.191	5.877
1983	8,471	13,106	6.640	7.864	6.723
1984	8,717	13,256	5.129	6.412	5.715
1985	8,822	13,670	5.720	7.155	6.869

TABLE 2

GSTWS PROJECTED DEMANDS

YEAR ENDED JUNE 30	NUMBER OF SERVICES		WATER CONSUMPTION $x10^6m^3$	WATER DELIVERED $x10^6m^3$	
	DOMESTIC	TOTAL		ALL SOURCES	EX WELLINGTON DAM
1990	11,035	14,027	7.055	8.819	8.172
1995	12,397	15,596	8.285	9.747	9.107
2000	13,936	17,279	9.110	10.717	10.077

1.3 LOCAL HEADWORKS

The major proportion of the total water delivered to the services in the GSTWS is pumped from Wellington Dam. However, a proportion is derived from local headworks. In 1982 heavy summer rains from Cyclone Ingrid filled most of these storages and they contributed 1,262,000m^3 to the supply. The normal mode of operation for these storages is to provide a summer peaking capacity, with filling taking place from the GSTWS main in late winter. On average the expected contribution from the local headworks amounts to 640,000m^3/annum. This figure has to be deducted from the total demand estimated for all sources to provide the estimated demand from Wellington Dam.

2.0 SALINITY DAMAGE FUNCTION

2.1 SALINITY PROJECTIONS

The salinity projections used for calculating the salinity damage function have been based on the estimates of mean daily salinities for average years, assuming that reforestation is 70% effective and that current reservoir management actions continue. These values are shown in Table 3.

TABLE 3

SALINITY PROJECTIONS

PERIOD	SALINITY OF GSTWS *TDS (mg/l)
Present	800
Mid 1990's	940
2010	890

* Total Dissolved Solids

For the new sources the salinities for Harris, Upper Brunswick and Stirling have been assumed to be equivalent at about 200 to 220mg/l on average. Data suggests that the salinity of the flows at the Brunswick 26 site are slightly higher and would run at around 250mg/l.

2.2 SALINITY DAMAGE

Studies by the Australian Mineral Development Laboratories (AMDEL) for the Engineering and Water Supply Department in South Australia (1982) have produced the most definitive data available for salinity damage for Australian conditions. The AMDEL data has indicated that the major components of the damage function are:

- o Corrosion damage to domestic plumbing fittings, hot water systems and appliances
- o Consumption of soaps and detergents.

The former effect is largely related to the salinity of the water, the latter to the hardness. Table 4 shows the values obtained from the AMDEL report, together with transpositions to the GSTWS, accounting for the change in hardness of the water and the lower utilisation of water softeners.

TABLE 4

DOMESTIC SALINITY DAMAGE VALUES
($/mg/l/household/year)

	AMDEL	GSTWS	
	1980	1980	1985*
Pipework	0.115	0.115	
Hot Water Heaters	0.046	0.046	
Domestic Appliances	0.007	0.007	
Water Softeners	0.014	-	
Detergents & Soaps	0.142	0.144	
Clothing	-	-	
Motor Vehicles	0.022	0.022	
Gardens	0.023	0.023	
Pot Plants	0.004	0.004	
Air Conditioning	0.001	0.001	
TOTAL	0.374	0.362	0.570

* 1980 total value inflated to 1985 dollars.

The damage function reported by AMDEL has a linear relationship with salinity. While AMDEL did not investigate this point, linear relationships have been reported from studies in the United States. Peck, et. al., (1982) have commented on the AMDEL study noting that they agree with a linear salinity damage function for increases in salinity above 200mg/l. They have pointed out that the United States data does not include values for the increased use of soaps and detergents which have been highlighted in the AMDEL study. Peck et. al., have concluded that a minimum value for the salinity damage function could be as low as $0.25/mg/l/household/year at current prices.

2.3 SERVICES AFFECTED BY SALINITY

The salinity damage data reported by AMDEL was for household services. Apart from domestic services GSTWS includes farmland, commercial and other services. Farmland services make up about half of the non-domestic services. For the purposes of this calculation the assumption has been made that the salinity damage for the other services (i.e. farmland, commercial etc.) is half the value for a domestic service.

2.4 IMPACT OF SUPPLIES FROM LOCAL HEADWORKS

As was noted in Section 1.3 local headworks contribute water into the GSTWS system. Over the next 10 or 15 years the contribution from these sources will range from 6% to 10% of the total supply. While much of this water would be of a lower salinity than water from Wellington Reservoir, the effect would be largely compensated by the increases in salinity which occur up the pipeline due to evaporation from the open storages. The benefit data is therefore based on water quality from Wellington Reservoir, ignoring increases in salinity up the pipeline and contributions from local headworks.

2.5 CAPITALISED BENEFITS OF REDUCING SALINITY DAMAGE

The benefits of providing supplies of water at various target mean salinities are shown in Table 5. The figures have been capitalised using real discount rates of 7% and 10%.

TABLE 5

BENEFITS FROM REDUCED SALINITY DAMAGE

TARGET MEAN SUPPLY SALINITY (mg/l)	PRESENT WORTHS ($million) DISCOUNT RATE 10%	DISCOUNT RATE 7%
200	48	72
400	34	53
600	22	33
800	14	23

3.0 HYDRO POWER GENERATION

The alternatives which remove Wellington Dam as the source of water for irrigation will permit the use of the existing hydro power station to generate electricity from the summer irrigation releases. Under the existing operating rules, irrigation water is released from the low level scour outlet in summer to maximise the release of salt from the storage and ensure that the best quality of water is available for the GSTWS. Releases from the lower outlet cannot activate the hydro plant. Under the revised operating rules, with no supplies having to be drawn for the GSTWS, the irrigation water is drawn from the higher level offtake to optimise the salinity of the water for irrigation. Release from this higher offtake permits operation of the hydro plant. The additional power generated would amount to about 8 Gwh per annum. On the basis of the saving in fuel costs this represents a capitalised benefit of $2.18m at a discount rate of 7% or $1.36m at a discount rate of 10%.

4.0 BENEFIT-COST ANALYSIS

The capital costs of the various schemes, the capitalised values of the present worth of the operating costs, the benefits and expected water supply salinities are shown in Table 6. The definition of benefit - cost ratio used has been the present value of the nett benefits divided by the present value of the capital and operating costs, less the present value of the capital and operating costs which would have been incurred had the project not proceeded.

While the benefit-cost ratio would vary directly as the value of the benefits varies, the overall ordering of the projects from most economic to least would not change. If for instance the lower bound value of the benefits for salinity damage was used, the benefit-cost ratio for the Harris Dam would drop from 4.50 to 2.06.

5.0 BIBLIOGRAPHY

AMDEL (1982). Summary of Effects of Salinity in 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.

Peck, A.J., Thomas, J.F., Williamson, D.R. (1983). Water 2000: Consultant's Report No. 8 Salinity Issues, Effects of man on salinity in Australia. Department of Resources and Energy. Aust. Govt. Publishing Service. Canberra 1983.

TABLE 6

CAPITAL, OPERATING AND PRESENT WORTH OF COSTS AND BENEFITS

SCHEME		AVERAGE LONG TERM SALINITY		PROJECT COSTS ($m)			TOTAL PRESENT WORTH ($m)	BENEFITS		NETT BENEFIT/ COST
		GSTWS	IRRIG.	CAPITAL	PRESENT WORTH	PRESENT WORTH OPERATING COSTS		GSTWS	IRRIG.	
					10%	10%	10%			
					7%	7%	7%			
1.0	NO ACTION	900	960	10.5	5.33	5.51	10.54	-	-	-
					6.40	8.14	14.54	-	-	-
4.0	SALINE (A&B) DIVERSIONS	700	700	38.0	27.4	14.3	41.7	14.4	-	0.51
					30.0	21.8	51.8	22.5	-	0.66
5.0	COAL BASIN	720	960	17.7	10.9	9.8	19.7	13.0	-	1.46
		720			12.4	14.8	27.2	21.0	-	1.65
6.1	STIRLING DAM									
	100% GSTWS 10%	200	950	28.2	20.3	6.3	26.6	49.0	-	3.10
	7%	200	950	-	22.2	9.4	31.6	75.0	-	4.39
6.2	50% SUPPLY									
	GSTWS 10%	550	955	23.5	16.8	6.0	22.8	24.5	-	2.04
	7%	550	955	-	18.4	8.9	27.3	38.5	-	3.01
7.1	BRUNSWICK 26									
	100% GSTWS 10%	250	600	53.5	40.4	7.8	48.2	46.0	-	1.23
	7%	250	600	-	43.7	11.8	55.5	70.0	-	1.71
7.2	BRUNSWICK 37									
	100% GSTWS 10%	200	950	32.7	21.1	6.0	27.1	49.0	-	3.01
	7%	200	950	-	21.7	9.0	30.7	75.0	-	4.63
7.3	BRUNSWICK 37									
	50% GSTWS 10%	550	955	29.5	18.5	6.0	24.5	24.5	-	1.79
	7%	550	955	-	18.2	8.9	27.5	38.5	-	2.96
8.1	HARRIS 5									
	100% GSTWS 10%	200	860	38.0	18.1	3.6	21.7	49.0	-	4.50
	7%	200	860	-	18.2	5.2	23.4	75.0	-	8.46
8.2	HARRIS 5									
	50% GSTWS 10%	550	860	28.2	16.9	4.5	20.4	24.5	-	2.55
	7%	550	860	-	16.0	6.5	22.5	38.5	-	4.81