Water Authority
of Western Australia

FITZROY VALLEY IRRIGATION CONCEPT PLAN STUDY 232

AN EVALUATION OF DAMS IN THE FITZROY VALLEY

Report No. WP 182
April 1993

1. INTRODUCTION

Some of the earliest interest in dams on the Fitzroy was expressed by Mr C.M. Dimond, then Engineer for the North West, when in 1952 when he initiated a survey of the Margaret River dam site. In 1955 he flew over and selected the dam site on the Fitzroy which now bears his name. The earliest formal documentation of the potential for development of dams on the Fitzroy was the Fitzroy Plan, a preliminary report on the water resource and irrigation potential of the Fitzroy Valley, prepared in January 1964 by Mr John G. Lewis of the Public Works Department.

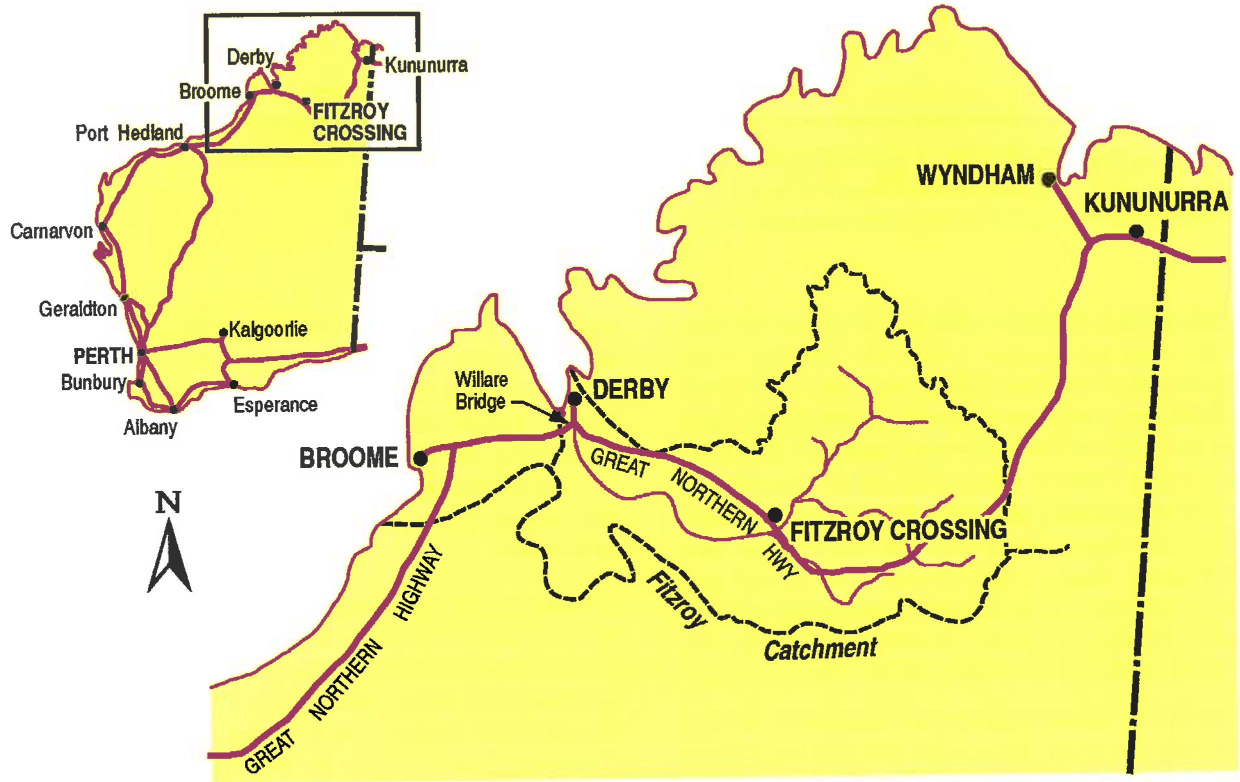
Preliminary reconnaissance evaluation of the potential for dam sites over the Fitzroy Valley continued for some years. Geological reports were prepared on the three main sites which will be further discussed in this report, together with survey work over the dam sites and the reservoir basins and some drilling investigations. However with a waning of interest in the potential for irrigation during the late 1960s investigations by the Public Works Department virtually ceased.

However from time to time a number of interests have reviewed the prospects for development of the resources of the valley, resulting in additional information becoming available on a number of new areas of interest. This has been particularly the case in regard to a number of small dam sites on the upper Fitzroy catchment.

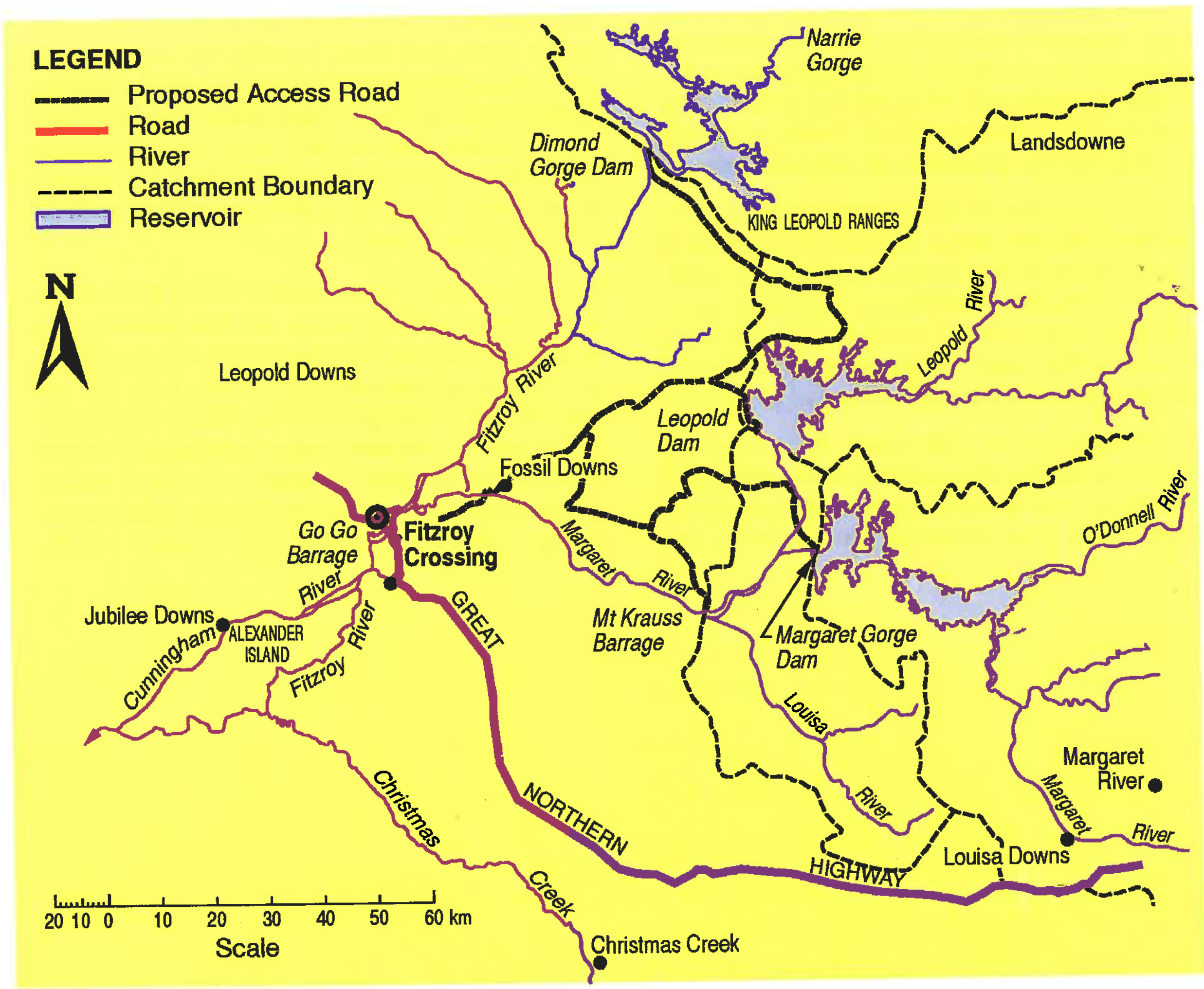
The present review has been a desk study designed to review the existing information and data with a view to assessing the magnitude of the water resource potentially available for development, assessing the approximate cost of development of each of the main sites, the extent of flood mitigation possible on each site, hydro power development potential and the prospects for staged development. The prospects for development of the irrigation diversion structures at Gogo and at Mt Krauss are also evaluated.

The major storage sites which have been evaluated are the Dimond Gorge Site on the Fitzroy River (Fitzroy 423), the Margaret Gorge Site on the Margaret River (Margaret DS 90) and the Barramundi Range site on the Leopold River (Leopold Site DS 22) as shown on Figure 1. Graphs of the reservoir storage characteristics are given in Figures 2 to 4 and tabulations are in the Appendix. The Margaret River storage has had a restriction placed on the full supply level by the need to restrict flooding of the Louisa Downs river frontage land where the Margaret River enters the Mueller Ranges, effectively limiting the storage to a maximum full supply level of 200 m AHD or a storage volume of 2550 million cubic metres.

By the nature of the studies which have been carried out for this review and the limited data which is available, the results figures and costs which are presented herein can only be regarded as a broad guide to the likely magnitude of the specific factors under discussion. Further detailed investigations, both in the field and in office studies, would be required to more accurately define the information presented herein.



Fitzroy Valley: Locality Plan



Fitzroy Valley Damsites: Locations and Catchment Areas

Figure 1: Fitzroy Valley Damsites: Locations and Catchment Areas

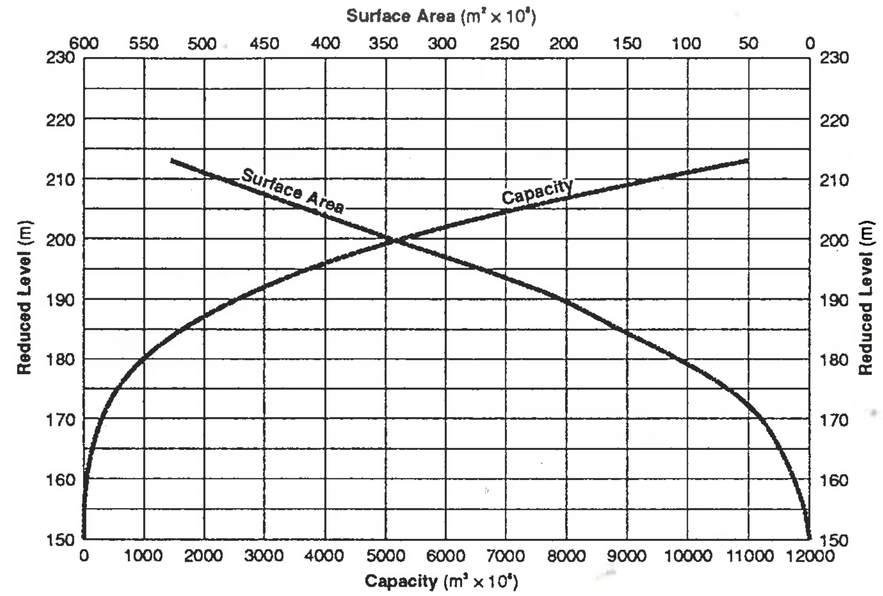


Figure 2: Dimond Gorge Damsite Reservoir Area and Capacity Curve

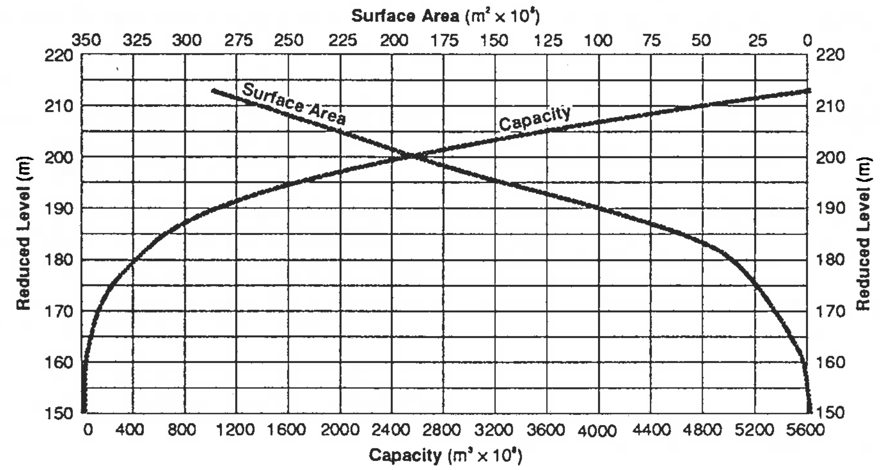


Figure 3: Margaret Gorge Damsite Reservoir Area and Capacity Curve

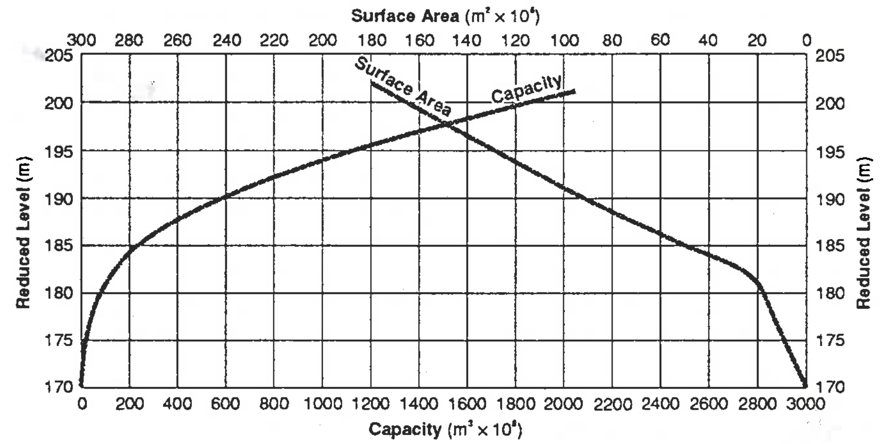


Figure 4: Leopold Damsite Reservoir Area and Capacity Curve

2. RESERVOIR YIELD AND FLOOD FREQUENCY ANALYSES

2.1 Scope of Studies

Reservoir yield and flood frequency analyses were carried out for the Fitzroy Valley irrigation proposal by the Engineering Hydrology section of the Water Authority. The investigations were based on three sites on the Fitzroy, Margaret and Leopold Rivers. The analyses are summarised in the following paragraphs with more detailed explanations of the methodology in the attached Appendices.

2.2 Catchment Characteristics

The Fitzroy Valley lies in the tropical monsoon climate zone with a low to medium summer rainfall. The peak flow months are January to April, with little significant flow occurring outside this period. Pan evaporations range from 2500 mm to 3400 mm over the catchment. The land forms have high to moderate relief, hilly broken terrain with high plateaus and ranges with broad pediplains and mainly shallow skeletal soils over Precambrian metamorphic and igneous rocks.

Table 1
Streamflow characteristics of the three sites

Site	Catchment Area (km²)	Mean Annual Rainfall (mm)	Mean Annual Flow (Mm³)	Mean Annual Flow (mm)	Coeff. of Variation
Fitzroy DS 423	16800	680	2007	119	0.82
Margaret DS 90	12100	450	960	79	0.73
Leopold DS 22	5600	540	594	106	0.64

The vegetation generally consists of Low Tree Savannah on the ranges and hills, Savannah Woodlands on the plains and granite country, Tree steppe on the ridges and on the stony pediplains. The current land use is primarily open range cattle grazing on pastoral leases, with little or no clearing, although significant over grazing is reported to occur on the riverine plains.

The flow characteristics for each site have been derived from gauged flows for the Fitzroy DS 423 for the period from 1964 to 1992 and for the Margaret DS 90 and Leopold Rivers DS 22 for the period 1967 to 1992. A variety of techniques were used to fill out the gauging record to account for missing data in the sequence and these together with the streamflow data for each site are detailed in the Appendices. Table 1 gives the mean annual flow for each site and a measure of the variability.

The average rainfall over the Dimond Gorge catchment is 680 mm compared with 450 mm for the Margaret and 540 mm for the Leopold catchment. The higher average loss rate of 560 mm for the Dimond Gorge catchment when compared to the 370 mm for the Margaret and 430 mm for the Leopold catchment is probably a reflection of the different catchment characteristics. The Fitzroy catchment primarily consists of high plateau and high range country in sandstone terrain with shallow soils. The Margaret and Leopold catchments have a higher proportion of hills, ridges and mesa's of both igneous and metamorphic origins in broader valleys and may be subject to higher grazing pressures along the river frontages.

2.3 Reservoir Yield Analyses

The reservoir simulations to determine yield were carried out for the period for which gauging station flows were available, a period of almost 29 years. A summary of the reservoir yield analyses is shown in Table 2. The initial reservoir-yield analysis was based on one failure per period of stream flow record, resulting in yields which would have a 3 to 4% probability of failure. However a more detailed analysis of the data suggested that the period of record for which the reservoir analysis was carried out is considered an above average rainfall period (see Appendix C). This may have resulted in:

(i) longer-term drought sequences not included in study period;

(ii) an over estimate of the mean annual flow by approximately 5%.

Consequently the available draw is probably over-estimated due to the longer term variability. Based on simulations on the Ord Reservoir for the same short period as for the Fitzroy studies (1965-1990) and for the extended record (1905-1990), there is a reduction in reservoir yield of 13%. Consequently the reservoir yields for the three Fitzroy sites have been revised downwards by 13% to take into account the longer term rainfall record. A more detailed hydrologic study would be required to take account of this longer-term variability.

The total yield available from these three major storages would be of the order of 2000 million cubic metres per year. The restriction on the development of the Margaret Gorge site probably reduces the available yield from that source by about 50 million cubic metres per year. This does not seem to be a significant factor restricting the development of the water resource.

Table 2a
Yield analysis for Fitzroy River DS 423

Storage Mm³	Storage % MAF	Initial Yield Mm³	Initial Yield % MAF	Revised Yield Mm³	Revised Yield % MAF
995	50	450	22	392	20
2563	128	935	47	813	41
5297	264	1295	65	1127	56
9463	471	1400	70	1218	61

Table 2b
Yield analysis for Margaret River DS 90

Storage Mm³	Storage % MAF	Initial Yield Mm³	Initial Yield % MAF	Revised Yield Mm³	Revised Yield % MAF
95	10	59	6	51	5
357	37	180	19	157	16
1080	112	466	49	405	42
2553	266	546	57	475	49

Table 2c
Yield analysis for Leopold River DS 22

Storage Mm³	Storage %MAF	Initial Yield Mm³	Initial Yield %MAF	Revised Yield Mm³	Revised Yield %MAF
85	14	53	9	46	8
243	41	121	20	105	18
598	101	249	42	217	36
1147	193	343	58	298	50
1881	317	360	61	313	53

2.4 Flood Frequency Analyses

A summary of the flood frequency analyses for the three sites is given in Table 3 following. Plots of the flood frequency analyses for the three sites are in Appendix A.

Table 3
Flood frequency analyses for the 3 dam sites

ARI	Fitzroy River (m^3s^{-1})	Margaret River (m^3s^{-1})	Leopold River (m^3s^{-1})
50	10 500	11 000	10 000
100	13 000	13 000	15 000

2.5 Probable Maximum Floods

Based on comparison with the Harding and Fortescue River probable maximum floods (PMFs), the range of estimated values of PMF for Dimond Gorge, Margaret River and Leopold River are given in Table 4a.

Table 4a
Preliminary estimates of PMF

Site	PMF (m^3s^{-1})
Dimond Gorge	80 000 – 100 000
Margaret River	50 000 – 80 000
Leopold River	80 000 – 100 000

The above range of estimates of PMFs is based on the 50 and 100 year flood event for the individual sites. However as the period of record at these sites is not extensive, there is a wide range in the estimated magnitudes of these floods. For the purposes of the feasibility study, a conservative approach has been adopted and the higher value in the range of PMF's has been used.

2.6 Flood Mitigation Effects

One of the critical aspects affecting the development of irrigation in the Fitzroy valley is the question of flooding and flood mitigation. Much of the irrigable land, particularly the Alexander Island area downstream of Fitzroy Crossing is subject to frequent inundation from floods in the Fitzroy River. This study includes an assessment of the likely magnitude of the impact of dams on flooding in the Fitzroy Crossing area.

Dams, and the reservoirs created by them affect floods in two ways;

(i) by the proportion of the catchment controlled at the dam site, and

(ii) by the storage routing effect of the reservoir.

The dams at the three locations indicated would control 34 500 km² or 76% of the catchment at Fitzroy Crossing. The 10 500 km² of catchment between them and Fitzroy Crossing is twice as big as the catchment behind the Leopold Dam and almost as big as the catchment behind the Margaret Gorge Dam. At Willare the dams would only control 38% of the catchment and would be expected to have a much less significant effect on floods at that location.

These storage routing effects have been computed for floods at each of the dam sites and the results are reported in later paragraphs. In general reservoirs have the effect of reducing the magnitude and delaying the time of peak outflow from the storage. This means that at Fitzroy Crossing the first flood rise is likely to come from runoff from the lower catchment and then be followed by the delayed runoff from the spillways. Overall the effect of dams is likely to cause the floods at Fitzroy Crossing to be somewhat reduced but of a longer duration.

The studies have made a preliminary assessment of the combined effect spillway outflows and floods generated from the lower catchment. The approximate flow depths for these floods at Fitzroy Crossing are given in Table 4b. No attempt has been made to estimate the effect of dams on floods at Willare. A much more comprehensive review would be required to be definitive on the issue of floods at either location.

Table 4b
Effects of dams on flood depths at Fitzroy Crossing Gauging Station

ARI	No Dams	Dimond or Margaret Gorge Dam only	Dimond & Margaret Dams only dams	Dimond, Margaret, & Leopold
25 year	13.0 m	12.6 m	12.1 m	11.4 m
50 year	13.3 m	13.0 m	12.4 m	11.9 m
100 year	13.7 m	13.3 m	12.8 m	12.2 m

With all three dams in place, floods at Fitzroy Crossing are largely dominated by flows from the subcatchments between the dams and the town. With only the Dimond Gorge dam and the Margaret Gorge Dams in place, the combined outflow from the Leopold and the Fitzroy Crossing subcatchment dominate the flows, with the outflow from the dams being reduced and delayed.

As can be seen from Table 4b the depth of flooding at Fitzroy Crossing is relatively insensitive to the increased flow rates from the more extreme events. Flow depths are reduced by 0.3 to 0.4 m with one dam in place, by 0.9 m with two dams in place and by about 1.5 m with all three dams constructed.

3. DAM CONSTRUCTION TECHNIQUES

The early feasibility studies for dams on the Fitzroy identified the earth core rockfill dam type as the most cost effective type of dam for all the sites, although some variations were required from site to site. The earth core rockfill type of construction has been widely used over a number of years (Ord, Harding, Wungong and North Dandalup), uses readily available plant and technology and makes the maximum use of locally available materials.

The main disadvantage of this form of construction is that the embankment construction in the main river valley has to be completed in one construction season to avoid the possibility of flood flows damaging a partially completed embankment. This limits the effective size of the main embankment to around three million cubic metres.

Investigations into concrete faced rockfill dams have generally shown them to be not as suited to this climatic environment. The sealing element in this form of construction is a concrete slab on the upstream face, a relatively expensive feature when compared to an earth core constructed from locally available materials. In addition, the time taken to construct a concrete upstream face is considerable, leaving them vulnerable to flood damage during the wet season or requiring extensive use to be made of temporary sealing materials. Homogenous earthfill embankments are generally not cost effective as, in this region, suitable earthfills are not readily available in the quantities required for this form of construction.

Some attention has been given to the possibility of construction of concrete gravity or arch dams. This type of construction was extensively reviewed during the investigations of the late 1960s and found to be a relatively expensive form of construction, although potentially less susceptible to flood damage during construction. A review of the application of the latest forms of rapid construction of concrete dams, such as roller compacted concrete, to a dam on the Fitzroy indicated that the overall cost of construction would be 50% to 100% more expensive than the rockfill alternative.

4. STAGE CONSTRUCTION

Stage construction on the Fitzroy is based on the need to supply increments of water to meet the minimum economic size of irrigation area. This is believed to be about 20 000 ha, requiring a total water supply of around 200 to 300 million cubic metres on the irrigation area. Allowing for losses in delivery down the river and in the distribution system the source works should be capable of producing 500 to 600 million cubic metres minimum in the first instance.

Stage construction of the individual dams on the Fitzroy is not an economical form of construction. The requirements for flood control and security of the dam have shown that full height construction of the dam is often more economical than construction of a smaller dam. This means that at each site each dam should be built to its ultimate capacity, leaving the order of building as the only option for staging construction.

The requirement to make the first stage of construction provide about 500 million cubic metres of water per year means that either the Dimond Gorge (Fitzroy DS423) site or the Margaret site could be the first two sites to be developed followed by the Leopold. Consideration was given to the construction of a smaller scheme on the Narrie Range site on the Fitzroy River, but the smaller storage available at this site (600 million cubic metres) means that the yield which can be developed would only be around 200 million cubic metres per annum, less than half the amount required for the first stage construction.

Following on from the previous paragraph, it was concluded that in the first instance it will be necessary to construct an access road from the Great Northern Highway at Fitzroy Crossing into the Margaret Gorge dam site. As a minimum requirement a single lane sealed access road will be required with an overall length of approximately 125 kilometres.

Access into the Dimond Gorge site would probably be by means of an access road from the Margaret Gorge access road, an additional distance of 105 km, a total of 155 km from Fitzroy Crossing. Access into the Leopold dam site at Barramundi Range would probably be by means of an access road from the Dimond Gorge access road, an additional distance of 15 km, a total of 85 km from Fitzroy Crossing.

5. HYDRO POWER POTENTIAL

An analysis of the power producing potential of each of the sites was undertaken using the storage behaviour data derived from the reservoir simulation studies.

Table 5
Hydro Power Production Potential

Site	Total Energy Production GW.h per annum	Installed Capacity MW
Dimond Gorge	130	30
Margaret Gorge	50	11
Leopold	15	4

The estimated values of total energy production and the required installed capacity are listed in Table 5. While detailed analysis of the hydro power potential has not been undertaken, it is envisaged that either Francis or Kaplan turbines would be used, depending on the head range and electrical load profile.

6. FITZROY RIVER — DIMOND GORGE

6.1 Introduction

The dam has been sited in Dimond Gorge in the King Leopold Ranges, approximately 95 kilometres north east of Fitzroy Crossing as shown on figure 1. A reconnaissance geological survey was carried out in Dimond Gorge in 1962. Three dam site locations were proposed and investigated.

A diamond drilling programme was subsequently carried out on the most likely location of the dam site. Survey control was established on the site and cross sections produced for the dam centre line.

The dam site has been located where the gorge has narrow sides with rock abutments suitable in shape and structure for a rockfill dam. The full supply level of the storage has been selected to maximise the available yield from the Fitzroy River. The top embankment level was set from the maximum reservoir level obtained from routing the PMF through the reservoir. The principal characteristics of the structure are given in Table 6.

Table 6
Dimond Gorge DS 423

Location	Approximately 75 kilometres NE of Fitzroy Crossing Located on Fitzroy River in the King Leopold Range
Catchment Area	16 800 km²
Mean Annual Flow	$2\,007 \times 10^6$ m³
Yield	$1\,218 \times 10^6$ m³

Flood Design

Flood	Inflow	Outflow
PMF	100 000 m³/s	49 510 m³/s
1:100 year	13 000 m³/s	690 m³/s

Dam Type	Rock Fill with clay core Batter slopes 1.6 H : 1 V

Storage Data

	RL	Storage	Reservoir Area
Full Supply Level	210	9.46×10^9 m³	485×10^6 m³
Top Bank Level	240	29.68×10^9 m³	869×10^6 m³

Foundation Level	RL 123
Top Crest Width	8 metres
Top Crest Width	415 metres
Embankment Volume	3.2×10^6 m³
Spillway	Unlined channel cut into a natural saddle NW of the dam Main spillway width = 325 metres Auxiliary spillway width = 20 metres Crest height = RL 210, chute length = 2000 metres
Hydro-Power Potential	130 GW.h per annum 30 MW installed capacity costing $40 million

Estimated Project Costs

Features	Cost $ million
Embankment works	71.4
Spillway works	45.8
Outlet works	6.4
Hydro-power	40.0
Road works and communications	14.5
Overheads	26.5
Contingency	51.1
Total	**255.7**

NB: Costs in 1993 dollars

6.2 Geology

The Diamond Gorge dam site lies in the King Leopold Ranges, a distinctive physiographic unit dividing the comparatively flat area of the Kimberley Plateau from the low rounded hills and ragged but subdued topography of the basement complex. The surface relief in the King Leopold Ranges is rugged, with deeply dissected valleys and strike ridges. These ridges or ranges consist of folded beds of resistant quartzite and sandstone and many of the valleys are floored with volcanic rocks and alluvium. The course of the Fitzroy has followed the geological structure. On its westward course, the river follows the foot of the back slopes of the King Leopold Ranges, the Narrie Ranges and the Sir John Ranges, and again the King Leopold Ranges in the vicinity of the dam site.

The river then cuts obliquely across the bedding of the quartzitic sandstones by following a strong topographic feature, one of three parallel lineaments that run north-eastwards, and appear to be splay faults of a major fracture. Down-cutting has formed a gorge in the sandstone and this is the area of the Dimond Gorge dam sites. About 1.5 kilometres north-west of the dam sites area, the Fitzroy valley is crossed by a prominent northerly trending fracture zone, which has had the effect of directing the river to conform with the strike of bedding, except that it then flows in a southerly, not a northerly direction.

The rocks at the dam site consist of gently dipping and folded quartzite, sandstone and shale of Upper Proterozoic age, with topographically extensive high plateaus, cuestas and escarpments with restricted lower slopes. Softer members in the sandstone succession occur every 10 metres or so, and these give rise to a series of overhangs. The geological features of this valley wall which will have most influence on the construction of a dam may be summarized as:

(i) deep weathering along nearly horizontal joint surfaces, and four or five fissile shaly beds in the section which have been deeply eroded;

(ii) in the upper part of the cliff the combination of joint breakage and surface weathering has reduced a considerable thickness of rock to rubble. This will mean a considerable limitation on the height of the crest.

Two problems common to the site are the effect of weathering on the alternation of friable shaly beds in the sandstone sequence, and the physical division of the rock by strongly developed sets of joints. The joints are a consequence of the rock type — a well bedded, competent sandstone being involved in general folding and faulting movements.

The cutting of the gorge of the Fitzroy River has allowed weathering agents access to the gently dipping and folded strata and the results have been severe on the exposed slopes above the gorge, and in the more shaly bands in the sequence. The flatly dipping bedding planes in conjunction with the vertical joints are favourably disposed to the passage of water, and an extensive grouting programme will be necessary. A considerable amount of rock will have to be removed in order to expose a plane surface necessary for adhesion of either concrete or earth core.

The dam site has an unfavourable geological environment with relatively tight cross river folding and faulting necessitating large scale excavation and dental treatment on either abutment.

6.3 Dam Types

As discussed in the earlier paragraphs, the early investigations showed that a rockfill dam would be the most suitable structure for this site. The dam is a composite rockfill/earthfill embankment comprising of a central earthfill core as the impervious sealing element with filter zones incorporated to control seepage and piping, supported by rockfill shoulders.

Extensive excavation and subsequent foundation clean up will be required. The foundation excavation for the dam footprint would require the earthfill core taken down to fresh to slightly weathered rock, with dental and backfill concrete together with blanket and curtain grouting. The rockfill section could be excavated to slightly weathered to moderately weathered rock to provide a foundation with sufficient strength to support the rockfills.

Materials for embankment construction would be expected to be obtained from local sources.

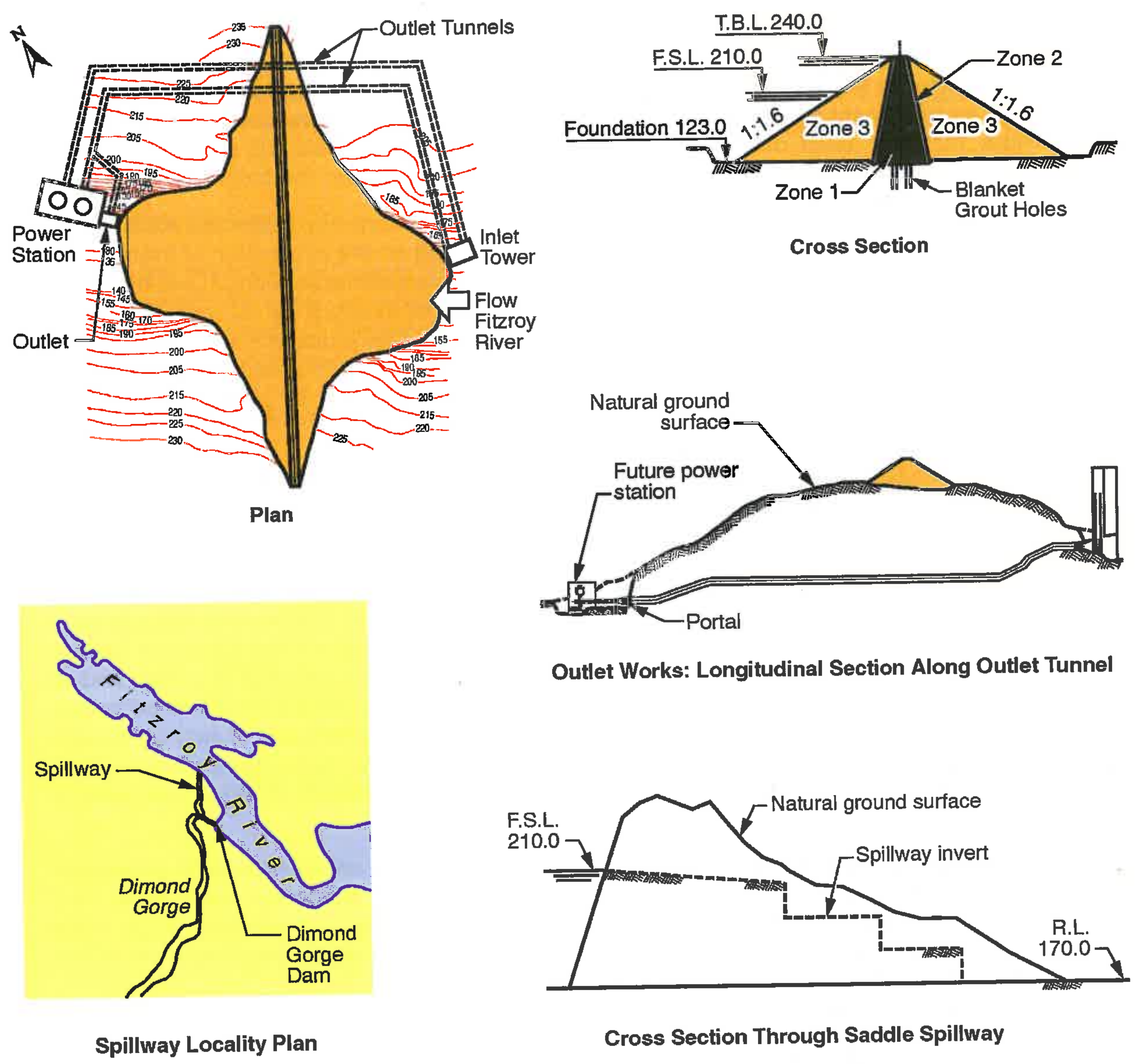


Figure 5: Dimond Gorge Damsite

Earthfill for the core would be expected to be obtained from the river terraces along the main and tributary channels, with the filter elements and concrete aggregates obtained from the river gravels. Rockfill could be partially obtained from the spillway excavation, but the majority would have to come from a quarry established for the purpose.

6.4 Spillway

The earlier investigations for a dam on the Fitzroy located a suitable site for a spillway which would be excavated through a natural saddle located northwest of Dimond Gorge, approximately one kilometre downstream from the main dam site. Survey data was obtained and cross-sections can be prepared from the data.

The proposed spillway would be unlined, with an uncontrolled free overflow concrete crest. The spillway width has been designed to have a slot 20 metres wide to pass the 100 year flood, with the overall width increasing to 325 metres to pass the probable maximum flood. The overall length would be of the order of 2 000 metres, with a total excavation volume of around 3 600 000 cubic metres.

6.5 Outlet System

The outlet system would be designed to provide diversion capacity during construction, provide sufficient capacity for irrigation releases and be suitable for incorporating into the proposed hydro electric power station. Water quality at the outlet is not expected to be an important issue and hence the intake structure has been planned to draw water from below the minimum operating level. Two outlet tunnels, 5 metres in diameter, concrete lined at the upstream end and steel lined at the downstream end have been planned.

Initially it is envisaged that the outlet system will be used for stream diversion during the construction period and later for conduits to serve the normal irrigation release either through cone dispersion valves or turbines in the hydro-electric power station.

6.6 Construction Programme

The construction of a dam on the Fitzroy would probably take three years for the main dam construction. Additional works such as site establishment, road construction and final site restoration would probably add a further six months to the start and the finish dates. The main construction season would span from April to December, with the site shut down through the shoulder periods.

Work in the first year of the main dam construction would consist of construction of the diversion works and lining of the tunnels, together with a start on the foundation preparation. The second year would consist of excavation of the river bed sediments and construction of the embankment back to the river bed level, together with excavation of the spillway. The final year would include completion of the outlet works and main embankment, together with the other outstanding features. The construction of the hydro electric power station need not be carried out with the main dam construction, but could be delayed to suit load requirements.

7. MARGARET GORGE

7.1 Introduction

For the purposes of this study the dam has been sited in Margaret Gorge in the King Leopold Ranges, on the Margaret River approximately 80 kilometres east of Fitzroy Crossing. As was noted in paragraph 1, the full storage of the Margaret Gorge Dam has been restricted by the need to minimise flooding of the river frontage country where the Margaret River enters the Mueller Ranges. The level of 200 m AHD may be somewhat conservative, but in view of the accuracy of the data available on this issue it is the best estimate that can be made. The restriction on the full supply level means that approximately 50 million cubic metres of water cannot be harvested at this site.

A number of other sites possibly exist further upstream on the Margaret River but these have not been investigated in any detail in previous studies. Development of these sites would be limited to the maximum level of 200 m AHD described in the previous paragraph and they would all therefore have smaller storages and not meet the criteria of providing the maximum development of the Margaret River resource. For the purposes of this study an evaluation of these sites has not been made.

A reconnaissance geological survey was carried out in Margaret Gorge in 1966 by Geological Survey of Western Australia. Survey control was established prior to the geological survey, from which a series of cross sections have been produced for the Margaret Gorge dam site.

The dam site has been located where the gorge has narrow sides with rock abutments suitable in shape and structure for a rockfill dam. Water jetting tests were carried out by the Public Works Department on the proposed dam site location.

The top embankment level was selected to maximise the available yield from the Margaret River and the spillway has been arranged to provide some measure of flood mitigation up to the 100 year flood level. The top embankment level was set from the maximum reservoir level obtained from routing the PMF through the reservoir. The principal dam statistics are given in Table 7.

7.2 Geology

The Margaret Gorge has long been regarded as an obvious choice for a dam site because the natural barrier of the King Leopold Range is breached by a narrow steep sided rock gorge and there is a wide flat storage area immediately upstream, known as the Mt Ball Basin. The predominant rock type at the dam site is the King Leopold sandstone, a medium to course grained quartz sandstone and pebble conglomerate.

On the left bank the walls of the gorge rise at an average slope of about 52° to 90 metres above the alluvials in the river bed. The right bank on the survey line is steeper, with an average slope of 60°, and rises immediately to about 75 metres above the river bed. It is noteworthy that on both cliffs there is a 13 metre high section of vertical or overhanging wall at the foot of the slope.

The cliff on the north side of the gorge has been breached by a sawcut gorge (Ratio Gully) up to 75 metres deep, that continues for some miles to the north in the centre of the King Leopold Range. A similar feature, but not so profound, divides the range on the southern side of the gorge.

The Mt Ball Basin opens out immediately upstream of the King Leopold Range, roughly oval in shape with the river forming the shorter axis. To the east, the basin ends where subdued foothills appear on either side of the river. Further to the east the river runs in a gorge through another major quartzite escarpment, which could possibly also be suitable for dam development.

Subdued outcrops of weathered and eroded igneous rocks of the Lamboo Complex appear through the broad composite valley plain of the Margaret and Leopold Rivers to the west of the King Leopold Range. The westerly flowing Margaret River joins the Leopold river 6 kilometres west of the dam site, and the combined flow is known as the Margaret River, and continues in a southwesterly direction.

About 5 kilometres to the north of the gorge, there is another natural break through the King Leopold Range at Jenny's Glen. This is a possible emergency spillway site.

Table 7
Margaret Gorge DS 90

Location	Approximately 80 kilometres East of Fitzroy Crossing Located on Margaret River
Catchment Area	12 100 km^2
Mean Annual Flow	960 × 10^6 m^3
Yield	475 × 10^6 m^3

Flood Design

Flood	Inflow	Outflow
PMF	80 000 m^3/s	39 500 m^3/s
1:100 year	13 000 m^3/s	2 360 m^3/s

Dam Type	Rock Fill with central clay core Batter slopes 1.6 H : 1 V

Storage Data

	RL	Storage	Reservoir Area
Full Supply Level	200	2.55 × 10^9 m^3	183 × 10^6 m^3
Top Bank Level	244	17.38 × 10^9 m^3	506 × 10^6 m^3

Foundation Level	RL 146
Top Crest Width	8 metres
Top Crest Width	450 metres
Embankment Volume	3.2 × 10^6 m^3
Spillway	Unlined channel cut into a natural saddle NW of the dam Main spillway width = 100 metres Auxillary spillway width = 15 metres Crest height = RL 200, chute length = 1500 metres
Hydro-Power Potential	50 GW.h per annum 11 MW installed capacity costing $13 million

Estimated Project Costs

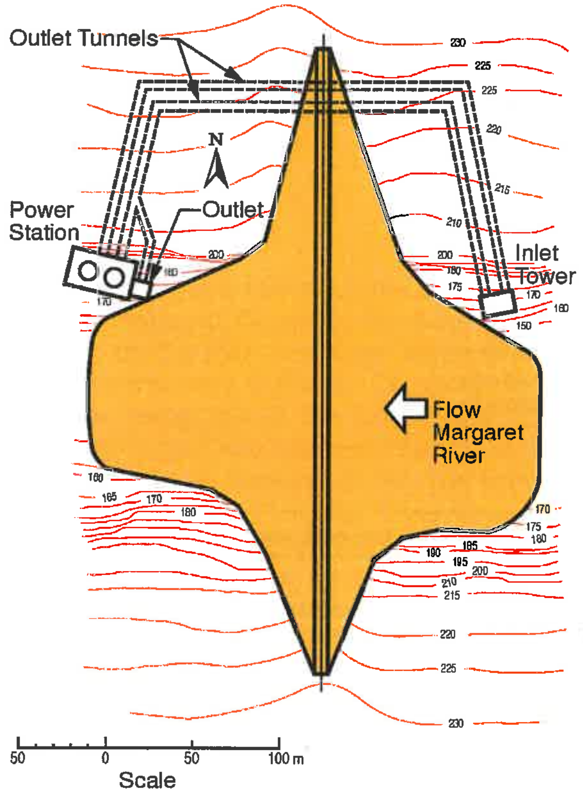
Features	Cost $ million
Embankment works	70.7
Spillway works	44.6
Outlet works	5.6
Hydro-power	13.0
Road works and communications	16.7
Overheads	25.0
Contingency	44.2
Total	**219.8**

NB: Costs in 1993 dollars

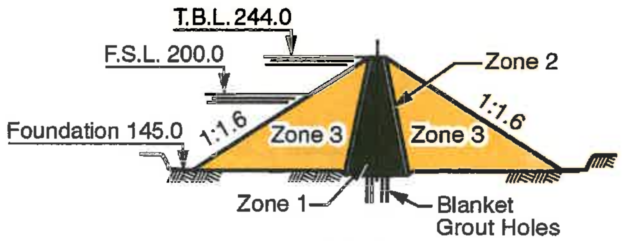
The King Leopold Range in the vicinity of Margaret Gorge has been divided along its length by the Ratio Gully Fault. The resulting blocks on either bank are dissimilar. The downstream block on the south abutment is not topographically as prominent as the upstream block and large scale block gliding and deep weathering mean that this downstream block is not desirable as a foundation area.

On the northern abutment, the downstream block is topographically the stronger, while the upstream block is subdued. Although all the major faulting and folding has been confined to the downstream block, the upstream block is not a suitable foundation area for a dam because of lack of relief and breaching of the reservoir rim to the north.

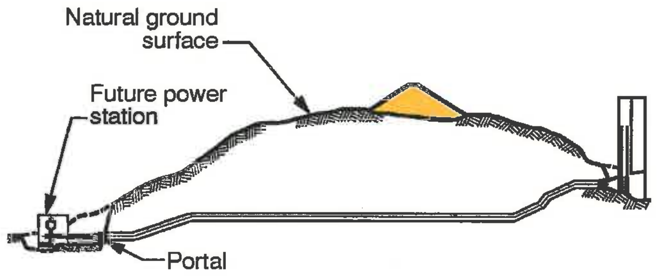
This means that the preferred centre line will cross the Ratio Gully Fault at an acute angle. It also means that many of the folded structures, which appear to trend parallel to the fault, will not cross the centre line. Folded quartzite beds will occur in the foundation area of the dam, and in view of the tightness of the folding and the distance apart of the walls of the gorge, correlations from wall to wall will be almost impossible to make.



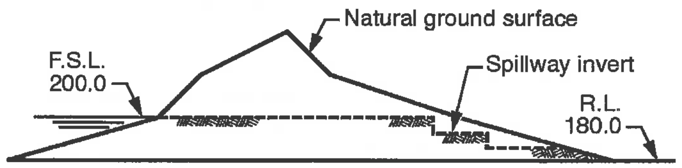
Plan



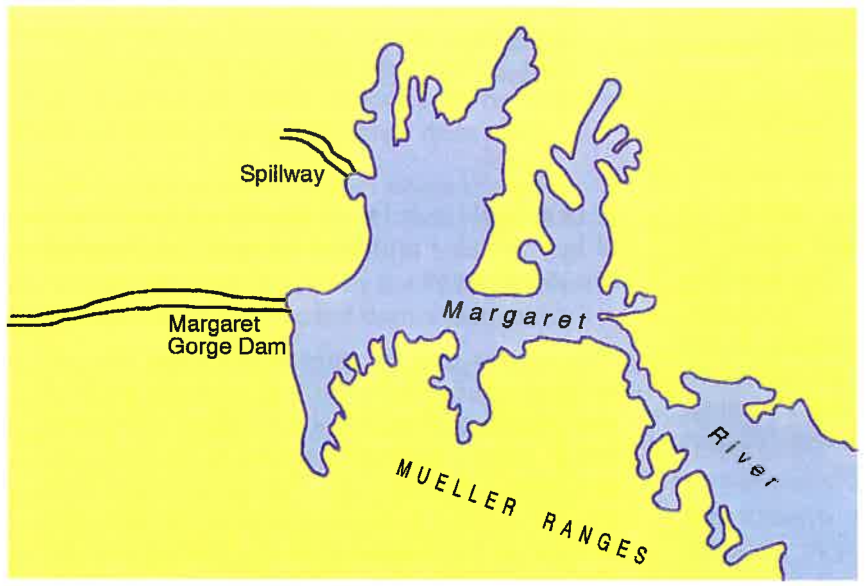
Cross Section



Outlet Works: Longitudinal Section Along Outlet Tunnel



Cross Section Through Saddle Spillway



Spillway Locality Plan

Figure 6: Margaret Gorge Damsite

The structure of the rock in the river bed will have a dominating influence on the topography of the bedrock, and some highly irregular patterns may be expected, requiring the excavation of deep fissures and the large scale use of dental concrete. Filling of the gaps opened in the folds to prevent consolidation of the rock under load and to seal off leakage paths, will need a programme of curtain and blanket grouting. The vertical walls in the lower part of the gorge almost certainly extend below the alluvium in the river bed.

7.3 Dam Types

As discussed for the Dimond Gorge site, a rockfill dam is considered the most suitable form of construction for this site and would have a similar cross section. Particular care has to be taken with slope correction work in the area of the core contact on the steep abutment sections. Most of the comments regarding foundation preparation and grouting would also be applicable.

All the rock necessary to build a rock fill dam is immediately available on the site. Larger dimension rock is readily obtainable from the massive beds of the King Leopold Sandstone. Material for the clay core would be expected to be obtained from the river terrace deposits and weathered scree slope materials. A possible source has been identified on the south side of the Mt Ball Basin.

The gravels of the Margaret River would probably be suitable for the manufacture of the filter zones required for the protection of the clay core. However, as they have a considerable component of chalcedony, derived by alteration of the bedded limestone of the Lawford Beds, they may cause an alkali reaction with cement and not be suitable for use as concrete aggregates. Concrete aggregates would possibly have to be obtained by crushing rock quarried from the massive sandstones present in the region.

7.4 Spillway

The proposed spillway, to be excavated through a natural saddle located to the north of Margaret Gorge know as Jenny's Glen. Aerial reconnaissance is the only investigation carried out on the spillway site to date. From air photo interpretation it appears that erosion after faulting oblique to the range has exposed a tongue of Hart Dolerite through the King Leopold Range.

The proposed spillway would be unlined, with an uncontrolled free overflow concrete crest. The spillway has been designed to have a slot 15 metres wide to pass the 100 year flood, with the overall width increasing to 100 metres to pass the probable maximum flood. The spillway would have a length of 2,000 metres which would necessitate some 4 500,000 cubic metres of excavation.

The spillway will pass the probable maximum flood, but an extremely high depth of water passes through the chute. Further consideration could be given to assessing the suitability of other saddles, in the reservoir basin which could be used as auxiliary spillways to pass a portion of the flood.

7.5 Outlet System

As for the Dimond Gorge dam, the outlet system would be designed to provide diversion capacity during construction, provide sufficient capacity for irrigation releases and be suitable for incorporating into the proposed hydro electric power station. Water quality at the outlet is not expected to be an important issue and hence the intake structure has been planned to draw water from below the minimum operating level. Two outlet tunnels, 3.5 metres in diameter, concrete lined at the upstream end and steel lined at the downstream end have been planned.

Initially it is envisaged that the outlet system will be used for stream diversion during the construction period and later for conduits to serve the normal irrigation release either through cone dispersion valves or turbines in the hydro-electric power station.

7.6 Construction Programme

The construction of a dam on the Margaret would probably take three years for the main dam construction. Additional works such as site establishment, road construction and final site restoration would probably add a further six months to the start and the finish dates. The main construction season would span from April to December, with the site shut down through the shoulder periods.

Work in the first year of the main dam construction would consist of construction of the diversion works and lining of the tunnels, together with a start on the foundation preparation. The second year would consist of excavation of the river bed sediments and construction of the embankment back to the river bed level, together with excavation of the spillway.

The final year would include completion of the outlet works and main embankment, together with the other outstanding features. The construction of the hydro electric power station need not be carried out with the main dam construction, but could be delayed to suit load requirements.

8. LEOPOLD DAM SITE

8.1 Introduction

The Leopold dam site is situated on the Leopold River at an opening in the Barramundi Range approximately 70 kilometres east north east of Fitzroy Crossing. The site was selected by the Public Works Department following aerial reconnaissance of the Fitzroy River system in 1964. The dam is located in a constriction on the Leopold River system but is unusually wide for a major dam. As will be apparent in the subsequent discussion, the width of the valley makes this a very expensive site to develop.

Over the years consideration has been given to other sites further upstream on the Leopold River, including a site around the junction with the Little Gold River and further upstream near Horse Creek. However, there is no data available on which to judge the suitability of these sites and without significant further expenditure on field investigations no meaningful comment can be made at this stage. In the future if a decision is ever made to proceed further with investigations on the Leopold River basin, it will be necessary to examine the prospects for these sites.

Survey control at the Barramundi Range site was established in July 1965 and a drilling programme carried out to establish depth to bedrock across the site. The geological reconnaissance was carried out by Geological Survey of WA, who made a number of recommendations about the dam site.

The top embankment level was selected to maximise the available yield from the Leopold River. The top embankment level was set from the maximum reservoir level obtained from routing the Probable Maximum Flood through the reservoir. The principal statistics for the Leopold Dam are shown on Table 8.

8.2 Geology

The site is located at one of the few constrictions of the Leopold River system. The constriction is formed by the Barramundi Range on the west side of the wide river valley, and by a narrow, steep sided ridge that forms the westernmost edge of the King Leopold Ranges swinging from a direction parallel with the river to impinge on it, south of the Leopold-Saddlers Creek junction. This ridge is faulted off on its northern end, and to the north and east a broad alluvial plain has developed on the left bank of the river.

The river valley is of considerable width in spite of the narrowing on the eastern side, and in the 4 kilometres between the river and the Barramundi Range there are large intermittent outcrops of granitic rocks of subdued topography, rising up to 10 metres above the surrounding sand plain. The eastern margin of the Barramundi Range rises steeply above minor foothills of weathered crystalline rocks.

The site is unusually wide for a major dam. The dam would be over 4.5 kilometres long. The weathered and broken schist of the right abutment would provide a leakage path, but the problem has not been fully defined. No unusual problems are expected from leakage in the foundation area or on the left abutment, except possibly where the Mt Elma Fault transects the site.

The auger drilling appears to show that the present river channel has a small thickness of alluvium above bedrock, but this may be an anomaly caused by the investigation technique.

Foundation conditions on the right abutment will be dependent on the top water level finally adopted. However, the broken mica schist material, if part of the dam foundation, would have to be removed in the core area, to expose mechanically sound rock. The fault zone of Mt Elma Fault may pose a problem if the fault zone is wide and the rock is extensively broken up.

Observations on adjacent outcrops of the fault will be necessary and further definition of the position of the fault and the physical properties of the fault zone. Minor construction problems will arise in placing a clay core in the pinnacled granite areas. A considerable number of minor smoothing operations involving blasting will be necessary. The physical condition of the rock below intervening areas of sand plain should also be investigated by dozer costeans. As already noted, the areas of outcrop are areas of highly jointed and broken rock.

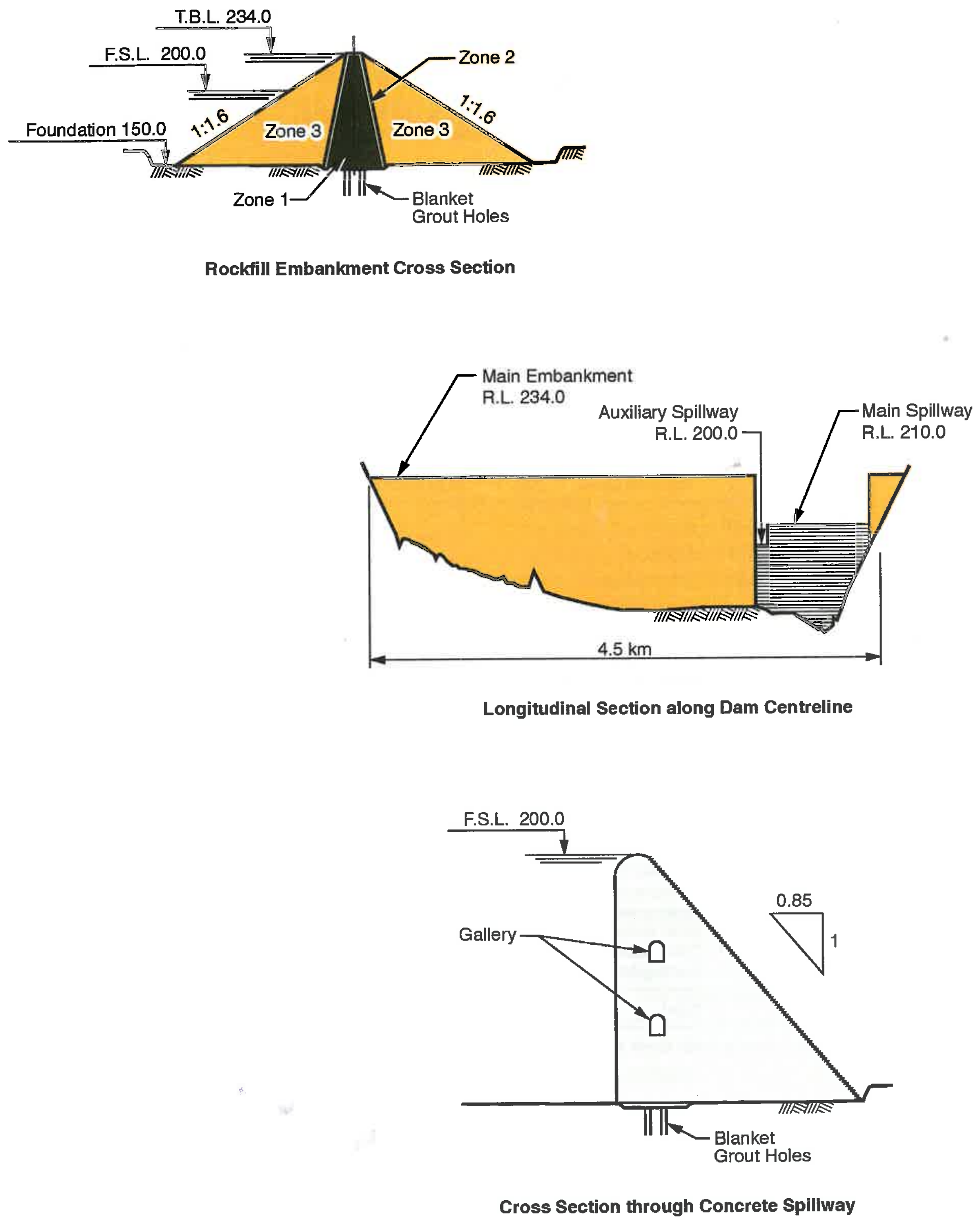


Figure 7: Leopold Gorge Damsite

Table 8
Leopold Dam DS 22

Location	Approximately 70 kilometres ENE of Fitzroy Crossing Located on Leopold River at Baramundi Range
Catchment Area	5 600 km²
Mean Annual Flow	594 × 10⁶ m³
Yield	313 × 10⁶ m³

Flood Design

Flood	Inflow	Outflow
PMF	100 000 m³/s	78 200 m³/s
1:100 year	15 000 m³/s	7 600 m³/s

Dam Type Rock Fill with central clay core
Batter slopes 1.6 H : 1 V

Storage Data

	RL	Storage	Reservoir Area
Full Supply Level	200	1.88 × 10⁹ m³	165.0 × 10⁶ m³
Top Bank Level	244	11.81 × 10⁹ m³	419.2 × 10⁶ m³

Foundation Level	RL 150
Top Crest Width	8 metres
Top Crest Width	4500 metres
Embankment Volume	26.1 × 10⁶ m³
Spillway	Concrete free flow ogee crest on LHS abutment Main spillway width = 325 metres Auxillary spillway width = 100 metres Crest height = RL 200
Hydro-Power Potential	15 GW.h per annum 4 MW installed capacity costing $5 million

Estimated Project Costs

Features	Cost $ million
Embankment works	563.9
Spillway works	107.3
Outlet works	5.7
Hydro-power	5.0
Road works and communications	3.3
Overheads	142.5
Contingency	206.9
Total	**1034.6**

NB: Costs in 1993 dollars

The left abutment rises sharply from the river bed in a strong ridge development of basal quartz sandstones, topped with siltstones both of the O'Donnell group of rocks. These rocks unconformably overlie the Chaney's Granite member of the Lamboo Complex.

8.3 Dam Alternatives

As discussed for the Dimond Gorge site, a rockfill dam is considered the most suitable form of construction for this site and would have a similar cross section. Particular care has to be taken with slope correction work in the area of the core contact on the steep abutment sections. Most of the comments regarding foundation preparation and grouting would also be applicable.

Clay for the impervious core of the dam may be obtained from deeply weathered schist areas that are not exposed on the surface, as is the rock on the right abutment. Sand covered areas at the foot of Barramundi Range to the north of the dam site are likely locations for suitable earthfill materials. It appears that a considerable thickness of clay was encountered in the Gemco holes drilled in the present river channel, and this area could also contain suitable materials

The Barramundi Conglomerate which forms the conspicuous hills immediately to the west of the site would provide an excellent source of rock fill. Larger rock for the rip rap would be available from the granite outcrop south of Barramundi yard and adjacent to the Watery River.

Adequate filter zone material appears to be available in the form of quartz sand in the bed of the Watery River.

8.4 Spillway

The proposed spillway would be a concrete gravity section with an uncontrolled free overflow ogee crest. It has been located on the left abutment in the existing river valley. Concrete abutments and training walls will be required to protect the rockfill dam structure. Following further foundation investigation, a better appreciation of the type and location of the spillway would be possible.

The spillway has been sized to pass the PMF, but extensive work would be required to train the water passing through the spillway.

8.5 Outlet Works

As for the Dimond Gorge dam, the outlet system would be designed to provide diversion capacity during construction, provide sufficient capacity for irrigation releases and be suitable for incorporating into the proposed hydro electric power station. Water quality at the outlet is not expected to be an important issue and hence the intake structure has been planned to draw water from below the minimum operating level. One outlet tunnel, 4 metres in diameter, concrete lined at the upstream end and steel lined at the downstream end have been planned.

Initially it is envisaged that the outlet system will be used for stream diversion during the construction period and later for conduits to serve the normal irrigation release either through cone dispersion valves or turbines in a hydro-electric power station. However the value of the energy produced from this site is quite small and it may not prove worthwhile to develop.

8.6 Construction Programme

The Leopold Dam if constructed on this site would be one of the largest earth and rockfill structures in the Australia and would be large by world standards. The foundation preparation and fill placement would probably take four or five years to complete. Additional works such as site establishment, road construction and final site restoration would probably add a further six months to the start and the finish dates. The main construction season would span from April to December, with the site shut down through the shoulder periods.

Work in the early years of the main dam construction would consist of construction of the fills furthest away from the main river channel and could probably be done with little risk of flood damage. The final year would see the construction of the closing fills and the gravity spillway section. This would require the construction of the diversion works and lining of the tunnels to have been completed prior to starting this work. The final year would also include completion of the outlet works and other outstanding features.

9. DIVERSION STRUCTURES

9.1 Types of Structures

The diversion dams are required for the supply of water onto the irrigation areas, either by gravity command of the main supply channel system or by providing a pond of water for the suction of a pumping station. The size of the storage has to be sufficient to even out any fluctuations in the supply rate and in the variation in demand for water in the irrigation system. Typically these storages would hold 5 to 10 x 10^6 m^3 and would be approximately the size of the Fitzroy Barrage at Camballin.

The impact of the structure on floods is important. They have to be designed and operated so that they cause a minimal increase in river water levels during medium to large floods, in order to limit the flood effects on the associated irrigation offtake works and, in the case of the Gogo Barrage, to limit the increase in flood levels upstream of the diversion structure to avoid increasing flooding in Fitzroy Crossing.

In the past, these structures have typically been constructed similar to the Fitzroy Barrage at Camballin and consist of a low level concrete sill structure supported on sheet pile cutoff walls. The concrete sill provides the base and support for a steel gate structure which is designed to collapse when overtopped by a flood. The Fitzroy Barrage has operated successfully for more than 30 years. However it requires considerable manpower to operate and the steel gates suffer considerable damage from abrasion, corrosion and flood damage.

The current technology which has been used overseas and also extensively in Queensland uses a similar concrete supporting structure, but the gate structure is replaced by an inflatable reinforced rubber dam. Air pressure is generally used to inflate the dams to maintain pool levels under normal conditions. Under flood conditions the dams gradually deflate as the water levels rise and can be rapidly reinflated once the flood has passed. The operating and maintenance costs for this form of structure are generally lower than for the alternative collapsing shutter system.

9.2 Barrage Sites

Two specific sites have been chosen for evaluation in this study, at Gogo and at Mt Krauss. The Gogo site would provide water onto the Alexander Island irrigation area and the Mt Krauss site would deliver water onto the Fossil Downs area. Neither structure would provide full gravity command of the irrigation areas and some pumping would be required. Although this study has reviewed these two main sites, this type of dam could be readily adapted for many of the other possible diversion sites which could be required.

9.3 Gogo Diversion Site

The proposed dam is located in the valley of the Fitzroy River between two outcrops of the Permian Grant Formation. The valley is partially filled with Recent alluvial sediments which overlie the Grant Formation. The Recent alluvial sediments are at least 30 metres thick over a large part of the foundation area.

In the thickest section there is a known maximum of 21 metres of very coarse sands and gravels which are well sorted, permeable and believed to extend for at least a 1.5 kilometres upstream. Elsewhere the oldest alluvials range from silts to medium sands. The youngest alluvials are silts which cover most of the area, and are 3-10 metre thick. The upper 2-3 metres of this sequence is invariably a grey-brown silty soil.

In the channels of the major water courses where the diversion structure would be sited, i.e. Fitzroy River, are medium to coarse sands and gravels. The vertical extent of these sediments has not been tested by drilling, but if the channels have retained the same general position for any period of time these sediments could be quite thick. The thick, permeable, coarse sands and gravels in these channels, must be sealed if the structure is to achieve its intended purpose.

The proposed barrage is shown on figure 8 and has a 2.5 metre concrete sill structure supported on sheet piles surmounted by a 3 metre high rubber dam. The estimated capital cost is of the order of $21 million. The top water level would normally put water 2.5 metres deep over the old crossing in Fitzroy Crossing, but the storage would primarily be retained within the banks of the main stream. This proposed arrangement would not be expected to have any significant impact on flood levels in the town.

9.4 Mt Krauss Diversion Site

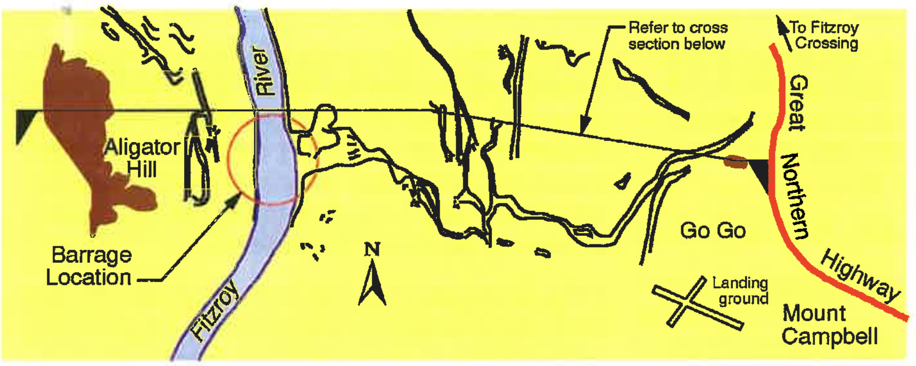
This diversion site located on the Margaret River at Mt Krauss, a prominence on the southern end of the Hull Range, a cuesta like form composed of the Pillara formation, a limestone reef complex of Devonian age. The river bed has little outcrop and is covered in alluvial materials.

The limestones of this formation are composed of friable rubble beds, alternating with massive beds, often dolomitised and very strong and are well bedded and strongly jointed. Where the river has cut through the range it is not known whether this has resulted in the limestone formation being breached, exposing the underlying Halls Creek Group schist. If this has happened there could be a considerable depth of sediments in the main river bed.

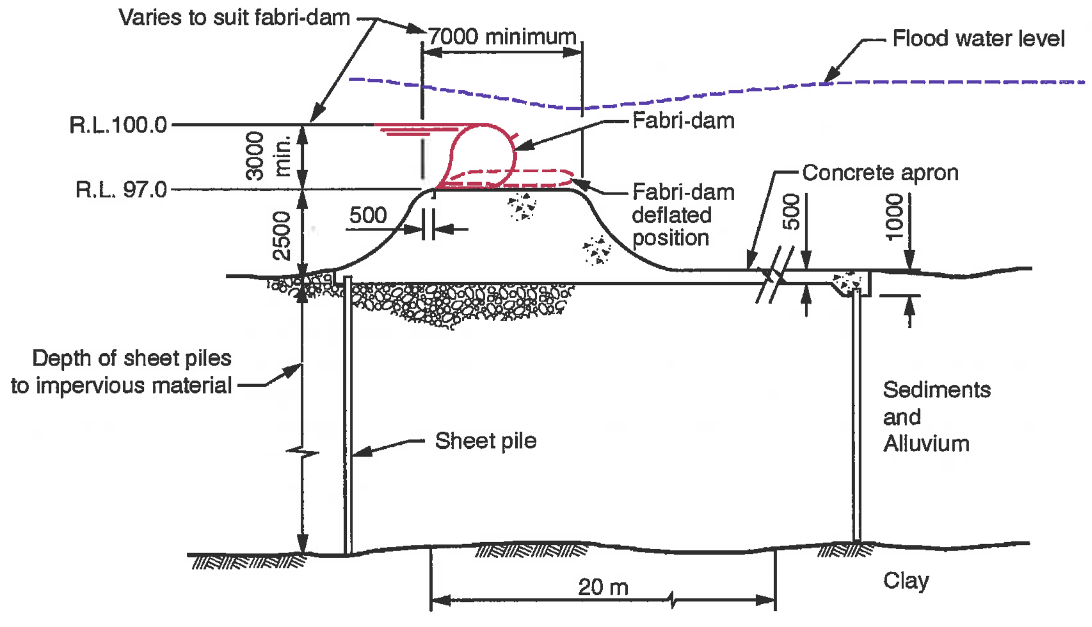
No drilling has been carried out in the river bed, and conditions can only be inferred from the adjacent limestone outcrops, which dip upstream at about 15°. River erosion has probably resulted in a staircase effect, the thick massive layers forming the steps, and the thin bedded limestones forming the vertical faces. Based on the observations of outcrop, it appears that the limestone could be highly permeable. While the possible loss of water may not be significant for this type of structure, the stability of the foundations may be cause for concern.

If the limestone has not been breached by the river, the foundation will probably be stepped, with overhangs and washouts developed adjacent to major steps and large open vertical joints in the massive beds. It is possible, however, that the limestone has been completely eroded in the river bed. If the limestone has been breached, a fairly deep channel cut in Halls Creek Group schist may be anticipated. The area of contact between the two rocks would almost certainly be an area of weakness, due to weathering of the schist.

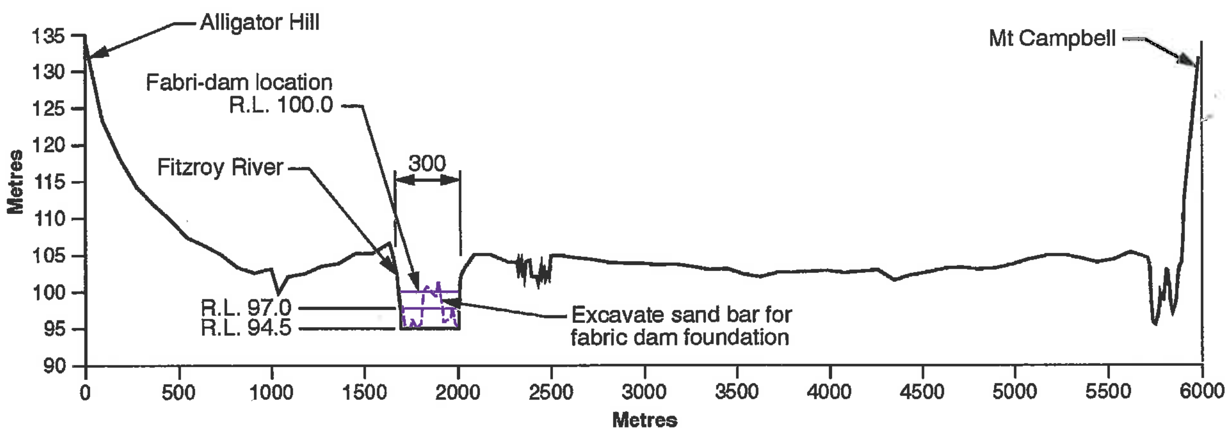
The proposed barrage is shown on figure 9 and has a 2.5 metre concrete sill structure supported on sheet piles surmounted by a 3 metre high rubber dam. The estimated capital cost of the structure is of the order of $22 million. The top water level (RL 150 m AHD) would not be high enough to provide gravity command of all the Fossil Downs irrigation soils, and pumping of at least a portion of the supply will probably be required. The storage would primarily be retained within the banks of the main stream.



Locality Plan of Fabri-Dam

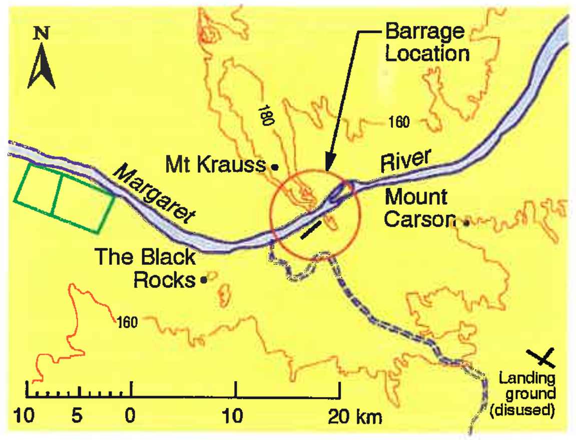


Cross Section through Fabri-Dam Crest Structure

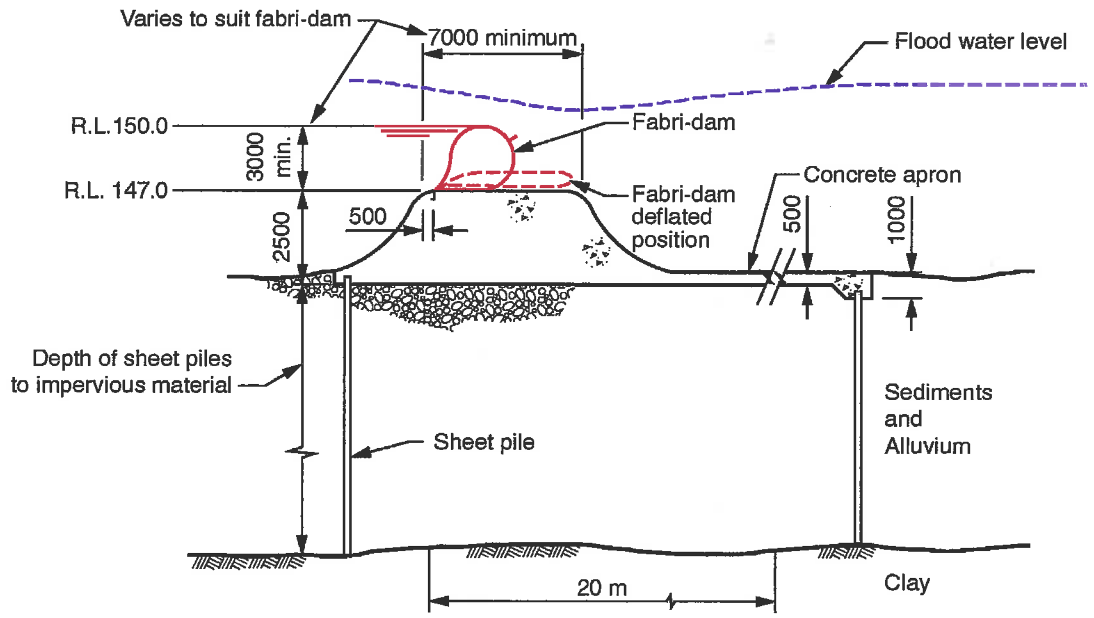


Cross Section Through River Valley

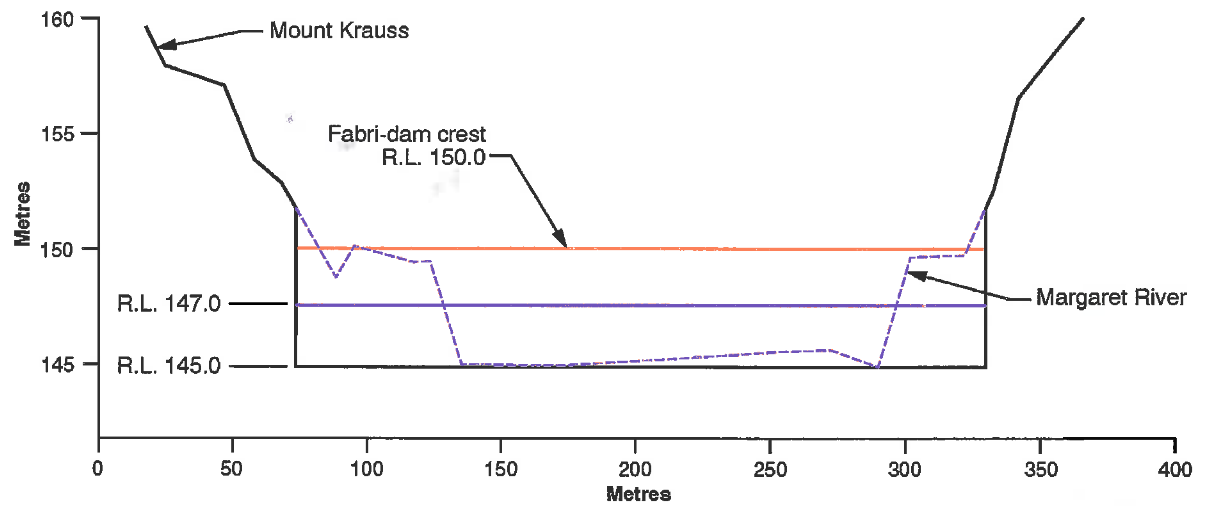
Figure 8: Gogo Barrage



Locality Plan of Fabri-Dam



Cross Section through Fabri-Dam Crest Structure



Cross Section Through River Valley

Figure 9: Mt Krauss Barrage

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APPENDIX A — STORAGE TABLES

Storage Area — Capacity Curves

Preliminary reservoir storage area and storage capacity curves, for the Dimond and Margaret catchments, were generated by the Department of Lands and Survey from 10 feet contour maps during the 1960s. The storage area data was converted to metric format and used to provide data base information for the in house AREAVOL volume analysis program.

The program provides tabulated area and capacity values at one metre intervals for storage reservoirs.

The storage area's for the Margaret reservoir were checked by scaling off 20 metre contour levels from 1:100 000 topography maps produced by the Department of Minerals and Energy. The variance in data was found to be small for this site.

There was no data produced by Lands and Survey for the Leopold reservoir. Data was produced by measuring areas off 20 metre contour levels from 1:100 000 topography maps produced by the Department of Minerals and Energy. This data was analysed using AREAVOL to produce tabulated area and capacity information for the reservoir.

Capacity and surface area capacity and surface area tables for Dimond Gorge Dam

Volume (V) in millions of cubic metres   Surface Area (A) in millions of square metres

R.L. metres		0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
150.0	V	0.0	0.0	0.0	0.2	2.2	5.9	11.4	18.5	27.3	37.7
	A	0.0	0.0	0.0	0.9	2.8	4.6	6.4	8.0	9.6	11.2
160.0	V	49.8	63.7	79.8	98.2	119.0	142.1	167.8	196.1	227.3	261.8
	A	13.0	15.0	17.3	19.6	21.9	24.4	26.9	29.7	32.8	36.2
170.0	V	299.9	341.9	388.5	440.2	497.5	561.2	631.8	710.0	796.3	891.2
	A	40.0	44.3	49.0	54.4	60.4	67.0	74.3	82.2	90.5	99.3
180.0	V	995.0	1108.1	1230.7	1363.1	1505.3	1657.3	1819.2	1990.9	2172.1	2362.8
	A	108.4	117.8	127.5	137.2	147.1	157.0	166.8	176.4	185.9	195.6
190.0	V	2563.4	2774.5	2997.1	3232.2	3481.4	3745.5	4025.2	4320.5	4631.3	4956.9
	A	205.7	216.6	228.6	242.0	256.5	271.8	287.5	303.2	318.3	332.9
200.0	V	5297.0	5651.3	6019.7	6402.1	6798.3	7208.2	7631.8	8069.1	8520.0	8984.6
	A	347.2	361.4	375.4	389.3	403.1	416.8	430.4	444.1	457.8	471.5
210.0	V	9463.0	9955.3	10461.5	10976.6						
	A	485.3	499.2	513.3	527.4						

Capacity and surface area capacity and surface area tables for Margaret Gorge Dam

Volume (V) in millions of cubic metres   Surface Area (A) in millions of square metres

R.L. metres		0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
160.0	V	0.0	0.8	3.6	8.4	15.0	23.6	34.0	46.4	60.6	76.8
	A	0.0	1.9	3.8	5.7	7.6	9.5	11.4	13.3	15.2	17.1
170.0	V	94.8	114.7	136.0	158.5	182.0	206.6	232.3	259.7	289.2	321.5
	A	19.0	20.7	21.9	23.0	24.0	25.1	26.5	28.3	30.7	33.9
180.0	V	357.3	397.8	443.9	496.4	556.0	623.2	698.4	781.7	873.3	972.8
	A	38.0	43.1	49.2	55.9	63.3	71.2	79.3	87.4	95.6	103.5
190.0	V	1080.1	1194.7	1316.6	1445.8	1582.2	1725.8	1876.7	2034.8	2200.2	2372.8
	A	111.0	118.3	125.5	132.8	140.0	147.3	154.5	161.7	169.0	176.2
200.0	V	2552.7	2737.8								
	A	183.5	190.7								

Capacity and surface area capacity and surface area tables for Leopold River Dam

Volume (V) in millions of cubic metres   Surface Area (A) in millions of square metres

R.L. metres		0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
170.0	V	0.0	0.7	3.4	7.9	14.3	22.5	32.2	43.2	55.4	69.0
	A	0.0	1.8	3.6	5.5	7.3	9.0	10.4	11.5	12.8	14.6
180.0	V	85.0	104.6	129.2	159.9	197.7	243.3	297.3	359.8	430.9	510.5
	A	17.6	21.9	27.5	34.1	41.6	49.7	58.2	66.8	75.4	83.6
190.0	V	598.0	693.1	795.5	905.3	1022.5	1147.1	1279.1	1418.4	1565.2	1719.3
	A	91.4	98.7	106.1	113.5	120.9	128.3	135.7	143.0	150.4	157.8
200.0	V	1880.8	2048.0								
	A	165.2	172.5								

APPENDIX B — COST ESTIMATES

FITZROY DAM PROJECTS ESTIMATE QUALIFICATIONS

Overheads

The cost estimates for the project overheads were derived from previous projects designed and constructed by the Water Authority. Typically on past projects, overheads have totalled approximately 13% of the total cost of the project excluding contingencies.

The overheads have been broken down into five main areas:

1. Investigation;
2. Design and Drafting;
3. Supervision
4. Survey
5. Review

which total to 13% of the project costs.

Regional Factors

Wherever possible local rates for various classes of construction work have been allowed. However where rates for the equivalent class of work are not available, rates from other projects in the South West or elsewhere in Australia have been used, with an escalation factor applied. For the transfer of current rates from the south west to Fitzroy Crossing, a multiplier varying from 1.8 to 2.5 has been used.

Services

Communications

A preliminary assessment was made by TELECOM's, Enterprise Projects Section, for establishing a communication system into each of the major dam sites. The estimate allowed for a radio type network system. However further feasibility studies would need to be carried out into the question of connecting the area into the optical fibre network currently being layed throughout Australia.

Roads

The requirements for road for these projects amount to a single lane, sealed road 3.8 metres in width, running from the Great Northern Highway into each of the sites. The routes would follow established routes into existing gauging stations in the area. Costs were based on a kilometre rate which included foundation preparation, base course preparation and sealing.

The kilometre rate of $120 000/km was derived from similar projects.

Diversion Works

A nominal lump sum amount of $200000 was assumed for the construction and replacement of a small coffer dam while the outlet tunnels were excavated and for the diversion of water into the outlet works while embankment construction is under way.

Outlet Works

Tunnels

The outlet tunnels were modelled on the arrangements constructed for the Ord River Dam. Tunnel diameters ranged from 3.5 to 5 metre, to be excavated by conventional tunnelling equipment in a horseshoe shape. The costs have been based on current costs for this class of work.

Concrete Lining

The tunnels were expected to fully operational on impounding, they were assumed to be fully lined to a circular shape with a 300 mm nominal thickness concrete lining. A nominal amount of steel reinforcement was assumed and this cost, together with the cost of steel lining, temporary support and other minor items was included in the overall rates.

The concrete rate of $600/m3 included supply and placement of concrete with re-usable forms. Cement and flyash would have to be shipped in and aggregate obtained from onsite crushing. Hence the criteria used in establishing the concrete rate were, supply of materials, transport costs, mixing and placement of concrete.

Intake Structure and Valving

The intake arrangements consist of a single level offtake located below minimum operating level. Experience at the Ord River has indicated that although the lakes will stratify, the temperature of the lower waters are not all that low and the discharges downstream of the dam have not affected the aquatic life to any noticeable extent.

The intake structure would have a trash rack system designed to minimise energy losses, with a fixed wheel gate on each conduit at the upstream end for emergency closure of the tunnels and cone dispersion valves for irrigation releases not passing through the power station.

The estimated cost of these works was 1.5% of total project costs for the dam construction work.

Dam Construction

Clearing

Full clearing of the reservoir has not been deemed necessary and it is envisaged that clearing will only take place in close proximity to the dam embankments for the works areas, borrow pits and stockpiles.

Drilling, Grouting and Water Testing

A grout programme consisting of Curtain and Blanket grouting was considered necessary for these sites. Curtain grout primary holes were spaced at 12 metre centres with secondary holes at 6 metres and tertiary holes at 3 metre centres. Depth was assumed to be 100 metres for the primary holes with closure holes to 20 metres. The blanket gout holes were spaced on a 6 metre grid pattern with secondary holes at 3 metre centres and depths of 10 metres.

The rates were based on current tender rates. The overall grouting rate of $50/m includes drilling, pressure grouting and handling of materials per lineal metre. The water testing rate of $285/hole includes hook-up and water testing.

Excavate Overburden/Stripping and Weathered Rock

A nominal depth of stripping was assumed over the dam foot print area for excavation of overburden and stripping to expose the foundation rock. An additional allowance for excavation of the river bed deposits has been included in the Margaret Gorge dam estimate to allow for the removal of these materials from this site.

Excavation of weathered rock was assumed to be nominally 10 metres deep over the dam footprint area. This includes the removal of rock unsuitable for inclusion in the dam foundation and the removal of material for foundation shaping. Current tender rates were used for this item.

Slope Correction and Backfill Concrete

Slope correction and backfill concrete would be required over the area where Zone 1 and 2 materials would be placed. The concrete rate used for this item is based on the marginal rate of concrete production with some allowance for formwork.

Embankment Materials

Embankment quantities were calculated from cross sections shown in the sketches. Materials were generally assumed to be sourced locally. Zone 1 material was an impervious core material sloping outwards at 0.5H:1.0V obtained from either local deposits along the river lines or from weathered rock deposits. Surrounding this core material would be a protective layer of Zone 2 material, consisting of fine and coarse filter zones each 2 metres thick. The zone 2 materials were assumed to be screened from local river bed shingle deposits.

The supporting rockfill Zone 3 material, sloping outwards at 1.6H:1.0V, was assumed to come partly from the spillway excavation and partly from quarried rock.

The rates for each Zone material were based on similar rates from current tenders, with the relevant Kimberly factor applied as follows.

Zone 1 — $7.00/m^3
Zone 2 — $30/m^3
Zone 3 — $15/m^3

Some economy resulting from the large volumes of materials being handled has been included in the estimates. The rockfill rate includes a special transition rockfill zone upstream and downstream of the core, together with an allowance for finishing the faces of the rockfill zone.

Spillway

Excavation

Excavation quantities were calculated from cross sections using the available survey data. Some reliable survey information was available for the Dimond Gorge Dam, but the only data available for the other sites was the 20 m contour interval maps at 1:100000. In all locations the quantities are very approximate. Some allowance was made for some of the material to be used as Zone 3 material in the dam embankment.

Also some economy, was assumed, resulting from the large volume of material being handled. Hence the rate used was based on current tender prices with a Kimberly factor applied.

Concrete Crest Structure

A simple ogee type spillway crest was assumed. This would be an unreinforced mass concrete structure utilizing a flyash concrete mix. The concrete rate of $250/m^3 was based on supply of materials into the area, transport costs, mixing and placement of concrete.

Hydro-Power Station

A detailed analysis of the hydro-power potential was not undertaken, it was assumed that either Francis or Kaplan turbines would be used, depending on the head range and electrical load profile. The approximate cost would be of the order of $1200/kW of installed capacity to construct each hydro-power station.

Barrages

Foundation Work

The available data suggests that the diversion barrages will be constructed on alluvial deposits. Under these conditions it will be necessary to consolidate the alluvial material using vibro-compaction techniques. A preliminary estimate was obtained from GFWA for this work. Their estimate indicated that it would cost approximately $496/m^2 to consolidate the material to 5 metres in depth. This rate includes overheads and supply of backfill material.

Sheet Piling

The foundation cutoff would consist of two rows of sheet piles 20 metres apart which will be installed to the first layer of clay or rock. A cost of $738/m^2 has been used to cost this work, it includes a Kimberly factor of 1.8 in the rate.

Concrete Work

The concrete work was estimated similar to the concrete works on the dams. That is the rate includes supply of materials into the area, transport costs, mixing and placement of concrete. It was assumed structures would be unreinforced.

Rubberized Fabri Dam

A budget price was obtained from Maruberi/Bridgestone for the supply of a fabri-dam. They quoted a budget price for the fabrication and supply of the rubber dam for each of the sites, including the supply of control and inflation equipment.

Irrigation Diversion

It was assumed that a diversion structure similar to the Camballin diversion would be required. Consisting of a stilling basin, a series of sluice gates for clearing the stilling basin and channel offtake gate valves for controlling water supply.

Contingency

A contingency value of 25% was placed on the project costs due to the preliminary nature of the design at this point in time.

Estimate for Dimond Gorge

DESCRIPTION	QUANTITY	UNIT	RATE	AMOUNT
OVERHEADS				
Foundation Investigation		Lump Sum		4000000
Design and Drafting		Lump Sum		8000000
Supervision and Testing		Lump Sum		10000000
Survey Control		Lump Sum		3500000
Engineering Review and Reports		Lump Sum		500000
SERVICES				
Communications		Lump Sum		1900000
Establish Roads	105	km	120000	12600000
DIVERSION WORKS				
Coffer dam		Lump Sum		200000
OUTLET WORKS				
Excavate tunnels	15700	m^3	220	3454000
Concrete lining	1944	m^3	600	1166400
Intake Sructure		Lump Sum		1200000
Valving		Lump Sum		550000
DAM CONSTRUCTION				
Clearing		Lump Sum		500000
Drilling and grouting	17855	m	54	964170
Water pressure testing	1383	No	285	394155
Excavate overburden	44200	m^3	5.5	243100
Excavate rock	480000	m^3	20	9600000
Clean off foundations	55000	m^2	15	825000
Correction concrete	13860	m^2	200	2772000
Place Zone 1	532413	m^3	7	3726891
Place Zone 2	190156	m^3	30	5704680
Place Zone 3	3052013	m^3	15	45780195
Place Upstream Blanket	6000	m^3	7	42000
Instrumentation		Lump Sum		150000
SPILLWAY				
Excavate	3600000	m^3	10	36000000
Concrete crest structure	39200	m^3	250	9800000
HYDRO-STATION				
Construct and Commission		Lump Sum		40000000
REHABILITATION WORK				
Hydromulch and Seed		Lump Sum		500000
Topsoiling		Lump Sum		500000
CONTINGENCY (25%)				51143148
			TOTAL	$255715739

NB: Costs in 1993 dollars

Estimate for Margaret Gorge

DESCRIPTION	QUANTITY	UNIT	RATE	AMOUNT
OVERHEADS				
Foundation Investigation		Lump Sum		4000000
Design and Drafting		Lump Sum		8000000
Supervision and Testing		Lump Sum		9000000
Survey Control		Lump Sum		3500000
Engineering Review and Reports		Lump Sum		500000
SERVICES				
Communications		Lump Sum		1700000
Establish Roads	125	km	120000	15000000
DIVERSION WORKS				
Coffer dam		Lump Sum		200000
OUTLET WORKS				
Excavate tunnels	13800	m^3	220	3036000
Concrete lining	1700	m^3	600	1020000
Intake Sructure		Lump Sum		1000000
Valving		Lump Sum		500000
DAM CONSTRUCTION				
Clearing		Lump Sum		500000
Drilling and grouting	21450	m	54	1158300
Water pressure testing	1598	No	285	455430
Strip o'burden and alluvials	690000	m^3	5.5	3795000
Excavate rock	550000	m^3	20	11000000
Clean off foundations	53100	m^2	15	796500
Correction concrete	20000	m^2	200	4000000
Place Zone 1	469205	m^3	7	3284435
Place Zone 2	192952	m^3	30	5788560
Place Zone 3	2613485	m^3	15	39202275
Place Upstream Blanket	5500	m^3	7	38500
Instrumentation		Lump Sum		150000
SPILLWAY				
Excavate	4461000	m^3	10	44610000
Concrete crest structure	150	m^3	250	37500
HYDRO-STATION				
Construct and Commission		Lump Sum		13000000
REHABILITATION WORK				
Hydromulch and Seed		Lump Sum		250000
Topsoiling		Lump Sum		250000
CONTINGENCY (25%)				43943125
			TOTAL	$219715625

NB: Costs in 1993 dollars

Estimate for Leopold Dam

DESCRIPTION	QUANTITY	UNIT	RATE	AMOUNT
OVERHEADS				
Foundation Investigation		Lump Sum		21000000
Design and Drafting		Lump Sum		51000000
Supervision and Testing		Lump Sum		60000000
Survey Control		Lump Sum		10000000
Engineering Review and Reports		Lump Sum		500000
SERVICES				
Communications		Lump Sum		1500000
Establish Roads	15	km	120000	1800000
DIVERSION WORKS				
Coffer dam		Lump Sum		200000
OUTLET WORKS				
Excavate tunnels	13800	m^3	220	3036000
Concrete lining	1700	m^3	600	1020000
Intake Sructure		Lump Sum		1200000
Valving		Lump Sum		550000
DAM CONSTRUCTION				
Clearing		Lump Sum		500000
Drilling and grouting	231920	m	54	12523680
Water pressure testing	22270	No	285	6346950
Excavate overburden (see rock excavation)				
Excavate rock	8125000	m^3	15	121875000
Clean off foundations	1812500	m^2	1	1812500
Correction concrete	290000	m^2	200	58000000
Place Zone 1	5878450	m^3	7	41149150
Place Zone 2	1161890	m^3	30	34856700
Place Zone 3	18843040	m^3	15	282645600
Place Upstream Blanket	250000	m^3	7	1750000
Instrumentation		Lump Sum		150000
SPILLWAY				
Concrete crest structure	429060	m^3	250	107265000
HYDRO-STATION				
Construct and Commission		Lump Sum		5000000
REHABILITATION WORK				
Hydromulch and Seed		Lump Sum		1000000
Topsoiling		Lump Sum		1000000
CONTINGENCY (25%)				206920145
			TOTAL	$1034600725

NB: Costs in 1993 dollars

Estimate for Gogo Barage

DESCRIPTION	QUANTITY	UNIT	RATE	AMOUNT
OVERHEADS				
Foundation Investigation		Lump Sum		500000
Design and Drafting		Lump Sum		750000
Supervision and Testing		Lump Sum		800000
Survey Control		Lump Sum		450000
Engineering Review and Reports		Lump Sum		50000
SERVICES				
Communications		Lump Sum		250000
Establish Roads	2	km	120000	240000
FOUNDATION WORK				
Excavate overburden	16500	m^3	5.5	90750
Sheet Piling	6500	m^2	738	4797000
Vibro-compaction	6000	m^2	496	2976000
CONCRETE WORKS				
Spillway base	2700	m^3	250	675000
Apron	2250	m^3	250	562500
Piers	27	m^3	250	6750
Abutments	90	m^3	250	22500
RUBBERIZED FABRI-DAM				
Dam	3	number	1249340	3748020
Installation		Lump Sum		281102
IRRIGATION DIVERSION				
Concrete	340	m^3	500	170000
Sluice gates	5	No	15000	75000
Gate valves	5	No	20000	100000
CONTINGENCY (25%)				4136155
			TOTAL	$20680777

NB: Costs in 1993 dollars

Estimate for Mt Krauss Barage

DESCRIPTION	QUANTITY	UNIT	RATE	AMOUNT
OVERHEADS				
Foundation Investigation		Lump Sum		500000
Design and Drafting		Lump Sum		750000
Supervision and Testing		Lump Sum		800000
Survey Control		Lump Sum		450000
Engineering Review and Reports		Lump Sum		50000
SERVICES				
Communications		Lump Sum		250000
Establish Roads	10	km	120000	1200000
FOUNDATION WORK				
Excavate overburden	11000	m³	5.5	60500
Sheet Piling	5500	m²	738	4059000
Vibro-compaction	5000	m²	496	2480000
CONCRETE WORKS				
Spillway base	4500	m³	250	1125000
Apron	1875	m³	250	468750
Piers	45	m³	250	11250
Abutments	90	m³	250	22500
RUBBERIZED FABRI-DAM				
Dam	3	number	1658026	4974078
Installation		Lump Sum		373056
IRRIGATION DIVERSION				
Concrete	340	m³	500	170000
Sluice gates	5	No	15000	75000
Gate valves	5	No	20000	100000
CONTINGENCY (25%)				4479783
			TOTAL	$22398917

NB: Costs in 1993 dollars

APPENDIX C
FITZROY YIELD AND FLOOD STUDY

Reservoir Yield and Flood Frequency Analyses

Preliminary reservoir yield and flood frequency analyses were carried out for the Fitzroy Valley irrigation proposal by the Engineering Hydrology section of the Water Authority. The investigations were based on three sites on the Fitzroy, Margaret and Leopold Rivers. Yield analyses were conducted using RESIM, a reservoir simulation program, with a one month time step. Flood frequency analyses were conducted using the in-house AFAP flood frequency analysis program. The analyses are summarised below with more detailed explanations of the methodology in the attached Appendix.

The mean annual flow for each site and a measure of their variability is shown in Table 1.

Table 1:
Streamflow characteristics of the three sites

Site	Catchment Area (km²)	Mean Annual Flow (Mm³)	Mean Annual Flow (mm)	Coefficient of Variation
Fitzroy River	16800	2007	119	0.82
Margaret River	12100	960	79	0.73
Leopold River	5600	594	106	0.64

Reservoir Yield Analyses

A summary of the reservoir yield analyses is shown in Figure 1. The maximum yields for the Fitzroy, Margaret and Leopold were 70%, 57% and 60% of mean annual flow. The reservoir-yield analysis was based on 1 failure per period of record, which was approximately a 3 to 4% probability of failure. A more detailed description of the analysis is given in the attached results.

The period of record for which the reservoir analysis was carried out is considered an above average rainfall period (see Figures 4, 5a and 5b). This may have resulted in:

(i) longer-term drought sequences not included in study period;

(ii) mean annual flow over-estimated by approximately 5%.

Consequently the available draw is probably over-estimated due to the longer term variability. Based on simulations on the Ord Reservoir for the same short period as for the Fitzroy studies (1965-1990) and for the extended record (1905-1990), there is a reduction in reservoir yield of 13%. Consequently the reservoir yields for the three Fitzroy sites were reduced by 13% to take into account the longer term rainfall record. A more detailed hydrologic study would be required to take account of this longer-term variability.

Table 2a:
Yield analysis results for Fitzroy River site

Storage Mm³	Storage %MAF	Initial Yield Mm³	Initial Yield %MAF	Revised Yield Mm³	Revised Yield %MAF
995	50	450	22	392	20
2563	128	935	47	813	41
5297	264	1295	65	1127	56
9463	471	1400	70	1218	61

Table 2b:
Yield analysis results for Margaret River site

Storage Mm³	Storage %MAF	Initial Yield Mm³	Initial Yield %MAF	Revised Yield Mm³	Revised Yield %MAF
95	10	59	6	51	5
357	37	180	19	157	16
1080	112	466	49	405	42
2553	266	546	57	475	49

Table 2c:
Yield analysis results for Leopold River site

Storage Mm³	Storage %MAF	Initial Yield Mm³	Initial Yield %MAF	Revised Yield Mm³	Revised Yield %MAF
85	14	53	9	46	8
243	41	121	20	105	18
598	101	249	42	217	36
1147	193	343	58	298	50
1881	317	360	61	313	53

Flood Frequency Analyses

A summary of the preliminary flood frequency analyses for the three sites is given in Table 3 below, with plots of the flood frequency analysis for the three sites given in Figures 2a-c. The flood peaks for the 50 and 100 ARI have a large range of estimates (defined as confidence limits in Figures 2a-c) from which the flood magnitudes could be found. The large confidence limits are shown in Table 3 and in Figures 2a-c. Some of the specific concerns with the analysis are:

(a) high flow extrapolation of the flow-stage rating curves can only be considered fair;

(b) the maximum flood observed on the Leopold River is based on surveying of flood debris, with the omission of this event having a significant impact on the design floods;

(c) the maximum floods observed at the Margaret River gauging station were based on estimated flows;

(d) the period of record for the flood frequency analysis was only 26 years; and

(e) there has been no flood routing to determine and/or confirm flood events and the relative contribution of the Fitzroy (Dimond Gorge), Leopold and Margaret Rivers to the Fitzroy Crossing flooding.

An hourly hydrograph recorded at the Dimond Gorge gauging station on the Fitzroy River (Figure 3) is included in the flood frequency results.

Table 3:
Flood frequency analyses for the 3 dam sites

ARI (years)	Fitzroy River ($m^3 s^{-1}$)	Margaret River ($m^3 s^{-1}$)	Leopold River ($m^3 s^{-1}$)
50	10 500 (5600 - 20000)	11 000 (6600 - 18000)	10 000 (2900 - 35000)
100	13 000 (5900 - 29000)	13 000 (6900 - 24000)	15 000 (3200 - 67000)

Note 1: 5 and 95% confidence limits are shown in brackets

Note 2: Margaret River flows are factored by $(^{12100}/_{7800})^{0.77}$ from the gauging station 802198

Probable Maximum Floods

Based on comparison with the Harding and Fortescue River probable maximum floods (PMFs), the following range of estimated values of PMF for Dimond Gorge, Margaret River and Leopold River are given:

The estimated PMF for the Ord Reservoir catchment was not included in the comparisons due to the low estimate of PMF compared to the 50 and 100 year flood event.

Table 4:
Preliminary estimates of PMF

Site	PMF ($m^3 s^{-1}$)
Dimond Gorge	80 000 - 100 000
Margaret Gorge	50 000 - 80 000
Leopold River	80 000 - 100 000

The above range of estimates of PMF are based on the 50 and 100 year flood event for the individual sites. However the period of record at these sites is not extensive. The reliability of the estimated PMFs are considered low due to the problems with the flood frequency analysis and the lack of any detailed flood routing included in the study. Consequently the higher value in the range is recommended in any preliminary design and considerably more detailed hydrologic analysis is required to derive reliable estimates of a PMF for the three sites.

Comparison of flood magnitude at Fitzroy Crossing

A qualitative impression of the relative contribution of the Margaret, Leopold and Fitzroy Rivers to the flooding at Fitzroy Crossing can be made by comparing the flood magnitudes at the three upstream sites with the flood magnitude at Fitzroy Crossing. The three sites provide a significant proportion of the flood magnitude at Fitzroy Crossing for most floods (see Table 5 and Figure 6). However in the case of the February 1991 flood event, over 50% of the flow originated downstream of the three proposed damsites. Consequently there is still the potential for significant floods at Fitzroy Crossing even when ignoring the contribution from the three proposed dammed catchment areas. For a more confident evaluation of the flooding mitigation potential of the three proposed damsites, there needs to be:

- a rigorous runoff-routing analysis; and
- an evaluation of the magnitude and probability of flood events originating from the catchment area not regulated by the three proposed damsites.

Year	Fitzroy River at Dimond Gorge (m3s-1)	Margaret River (m3s-1)	Leopold River (m3s-1)	Fitzroy Crossing (m3s-1)
1955	-	-	-	14750
1956	-	-	-	-
1957	-	-	-	2774
1958	-	-	-	10073
1959	-	-	-	3082
1960	-	-	-	3122
1961	-	-	-	13216
1962	4057	-	-	-
1963	260	-	-	296
1964	267	-	-	811
1965	2482	615	-	8983
1966	3000	1823	3064	12207
1967	2402	3007	1414	8807
1968	5137	1596	659	9219
1969	173	198	251	-
1970	1149	1254	612	2379
1971	1116	2298	1017	3258
1972	1163	880	-	1140
1973	3611	2401	1925	9817
1974	110	1567	694	2663
1975	2517	901	1049	4270
1976	180	1810	665	1375
1977	3944	1365	2587 9716	
1978	841	623	489	-
1979	2499	2517	-	10490
1980	-	-	-	14427
1981	1339	2659	-	11218
1982	5310	8978	12000	29892
1983	2942	3639	-	21318
1984	332	1091	-	1340
1985	8043	5537	2811	17821
1986	1136	2193	885	3623
1987	2433	2620	381	6809
1988	1650	1468	777	3247
1989	472	615	194	-
1990	4817	5534	2704	23325
1991	247	239	-	-

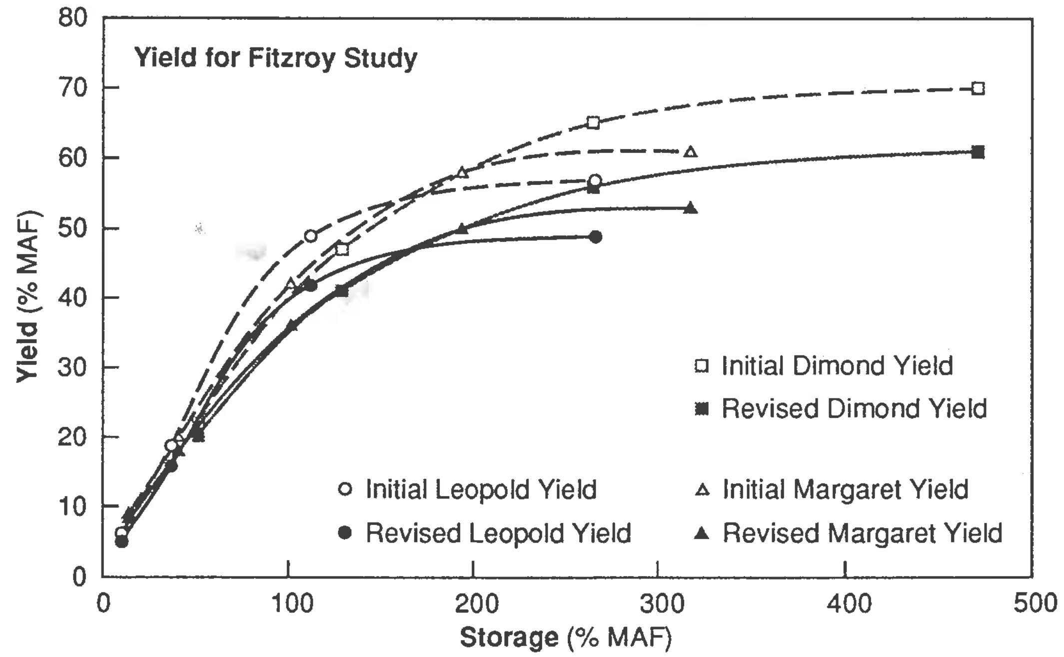


Figure 1: Results of Yield Analyses

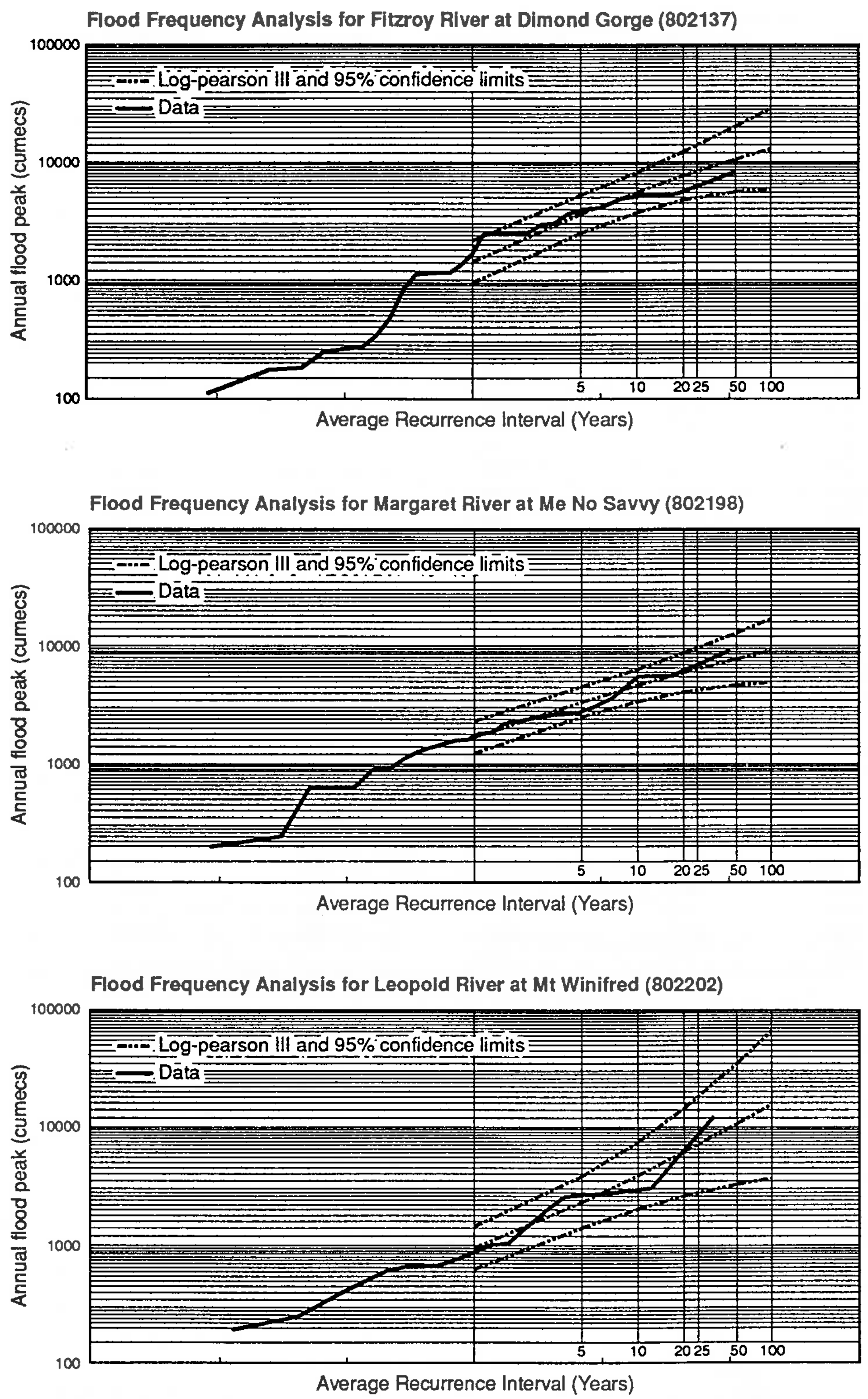


Figure 2: Flood Frequency Analyses

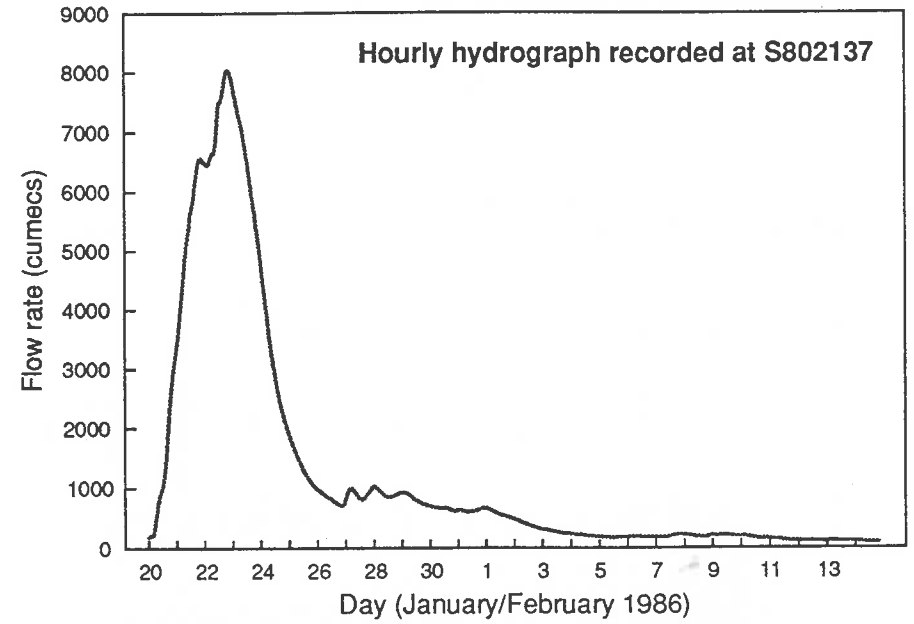


Figure 3: Hourly Hydrograph

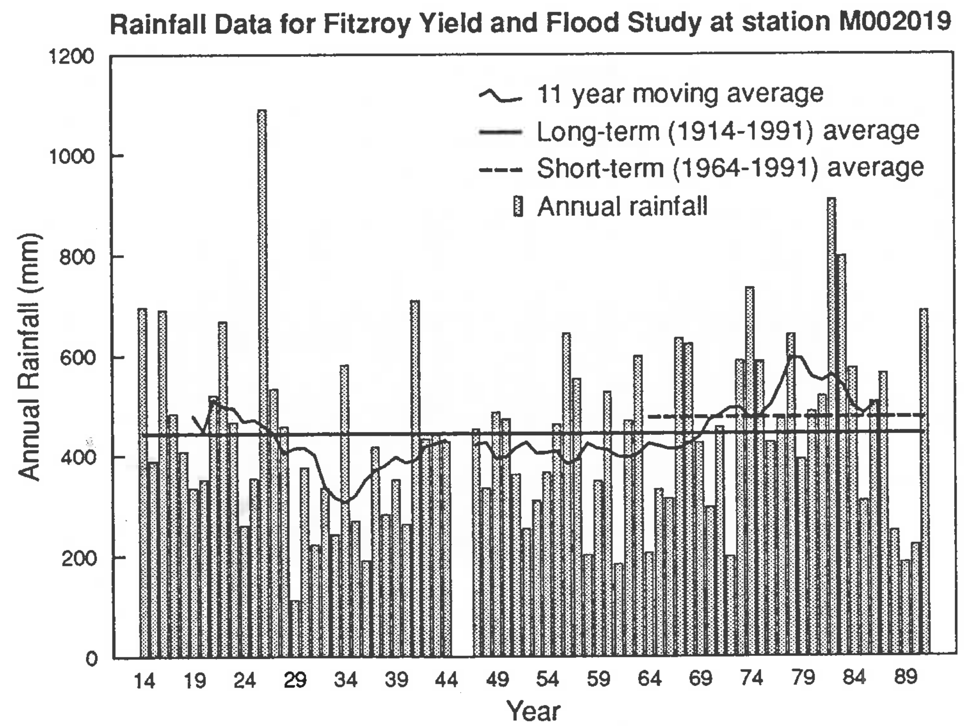
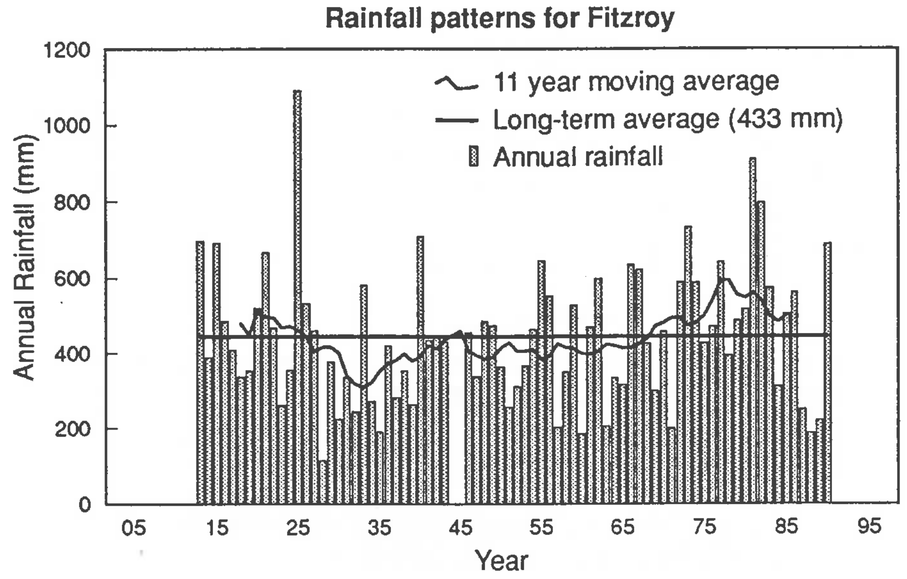


Figure 4: Long-term rainfall at M002019



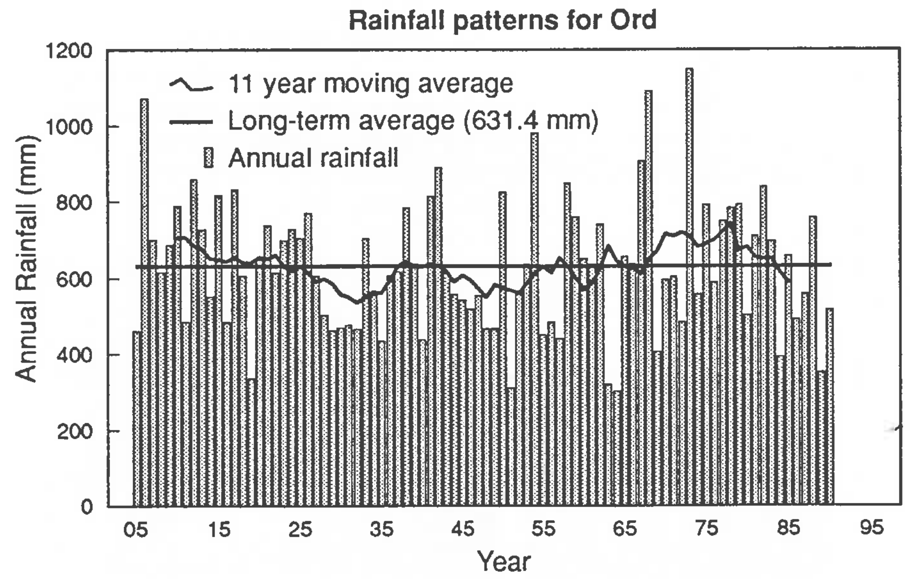
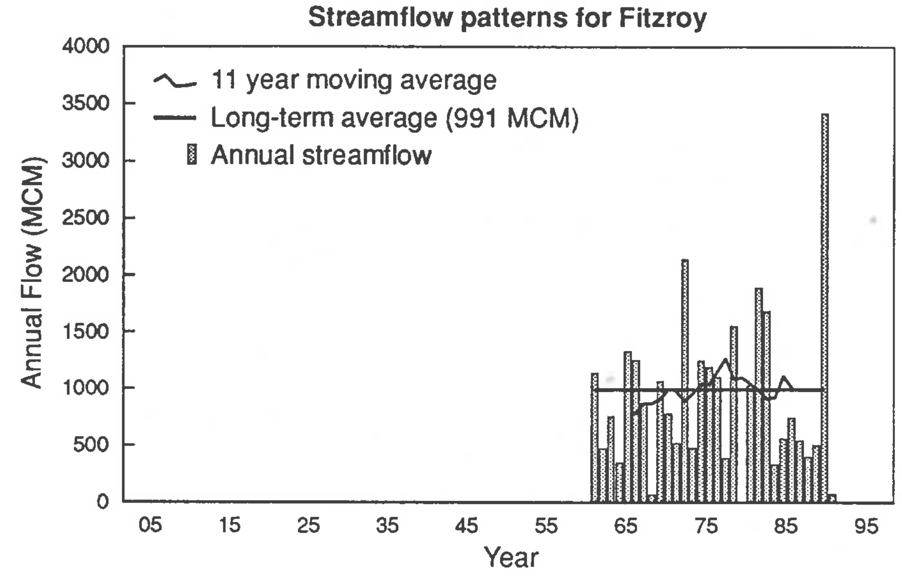


Figure 5a: Rainfall patterns for Fitzroy and Ord



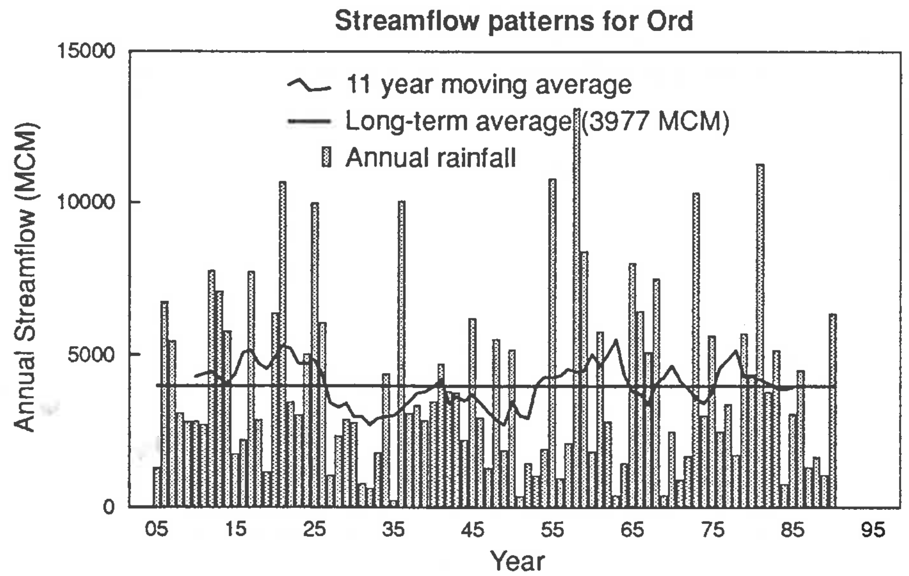
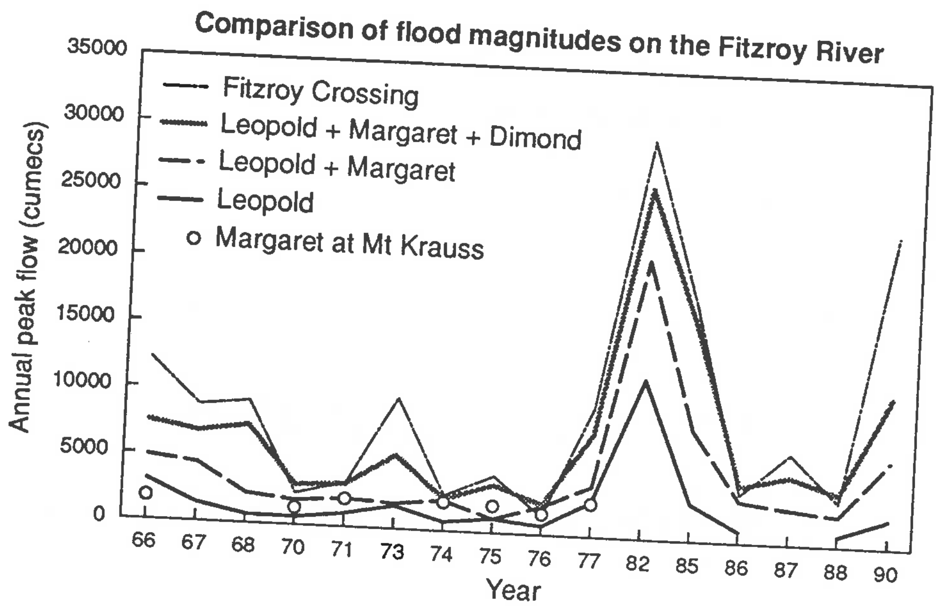


Figure 5b: Streamflow patterns for Fitzroy and Ord



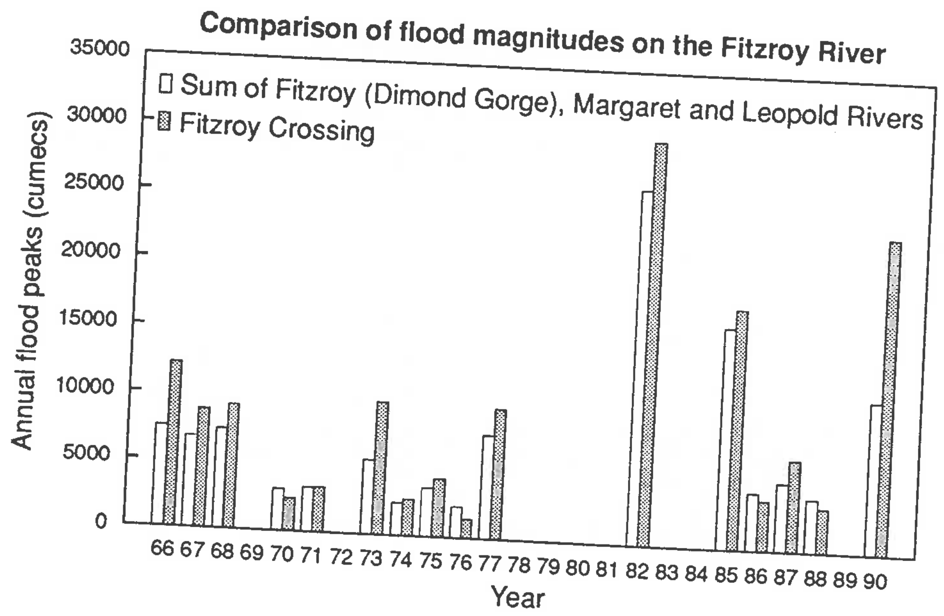


Figure 6: Comparisons of flood magnitudes

DETAILED RESULTS

Fitzroy River DS 423

Catchment Area 16800 km²
Gauging Station S802137 (1964 – 1992)
Catchment Area 16800 km²

Summarised below are the procedures followed during the preparation of streamflow and rainfall data for the Dimond Gorge dam site on the Fitzroy River as well as results of the RESIM runs and flood frequency analyses for that site. Data was prepared using SAS programs and Lotus 1-2-3 spreadsheets to prepare it for input for RESIM. Correlations were determined for streamflow sites where possible based on available information at nearby rainfall and streamflow sites in order to fill missing record. The flood frequency analysis was carried out using the AFAP flood frequency analysis program.

The yields calculated are for one Type 1 failure of 1 month in duration only where a Type 1 failure is defined as 'No water is supplied at all because the water level is below the minimum draw level for the entire period of failure'.

In order to accurately estimate the yield for each of the dam sites, it was necessary to ensure that the water level in the dam at the beginning of a run matched the water level at the end of that same run.

FLOW DATA (S137.DAT): Missing monthly flow data was replaced and/or extended according to the equations:

(a) $STR137 = -641.905 + (6.53084)*(RAIN137) \geq 0$

then

(b) $STR137 = -25.1494 + (4.781626)*(RAIN198) \geq 0$

where STR137 is the unmodified streamflow record for Dimond Gorge

RAIN137 is the rainfall data for Dimond Gorge

RAIN198 is the rainfall data for Margaret River

For data that was still missing after the above correlations, the following rules were applied:

(i) If month is between November and April inclusive, then replace with mean value for that month.

(ii) If month is between May and October inclusive, then replace with zero.

The filling of record resulted in a total of 29 years of flow data as shown in Table A1.

RAIN DATA: Filling of missing daily rainfall data: Use station M002039 data if it exists or else station M502001, if still have missing record, try M502005. Otherwise, fill record with zero value.

Table A1: Corrected monthly flow data for Dimond Gorge (Units: $10^3 m^3$)

Note: Year used is water year (1962 = October 1962 to September 1963)

Dimond Gorge — S802137													
Year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Total**
1962	0	0	46140	584800	2090400	347300	14900	0	0	0	0	0	3083540
1963	0	0	0	446357	73800	6300	9700	2000	200	0	0	0	538357
1964	0	16800	6700	34100	30800	20100	200	0	0	0	0	0	108700
1965	0	15500	11200	580300	553300	75200	6400	3100	1200	0	0	0	1246200
1966	0	0	0	742700	2085500	1332100	22900	2500	200	0	0	0	4185900
1967	0	0	0	340600	1880700	1734600	61800	59700	31800	10700	4000	500	4124400
1968	0	13200	11700	533800	1876400	2675000	78300	12500	4500	1400	100	0	5206900
1969	0	0	16600	15200	24500	44500	3000	100	0	0	0	0	103900
1970	0	0	800	79900	243300	848800	119400	4800	400	0	0	0	1297400
1971	0	15200	32900	13500	70900	559500	2700	0	0	0	0	0	694700
1972	0	0	3400	585700	163700	318200	19400	5900	900	100	0	0	1097300
1973	0	121700	177200	154858	212982	506000	987599	0	0	9200	2500	27300	2199339
1974	0	0	0	98039	547361	19600	0	0	0	0	0	0	665000
1975	24500	269000	75800	588700	2276900	1297000	72100	12000	5000	2300	400	0	4623700
1976	0	0	35300	45000	57400	119600	9200	300	0	0	0	0	266800
1977	0	0	8600	1119900	1229500	323900	36400	7000	31200	134400	7500	600	2899000
1978	0	0	0	55700	280500	675100	46000	105300	32300	3100	300	0	1198300
1979	0	0	10600	126900	1225400	174900	25000	2900	300	0	0	0	1566000
1981	0	4500	77100	446357	1076400	664281	79108	21900	5200	1500	200	0	2376547
1982	0	0	28900	15600	129800	2838700	1104300	66500	13800	5000	1200	100	4203900
1983	0	0	5800	1130800	196700	2255100	0	0	0	0	0	0	3588400
1984	0	0	48200	0	482706	44600	3400	100	0	0	0	0	579006
1985	0	0	14600	2492900	635100	230600	0	2900	200	1900	900	0	3379100
1986	0	0	0	454623	1033400	99900	3800	200	0	0	0	0	1591923
1987	0	0	588100	115300	86300	9300	10500	400	0	0	0	0	809900
1988	0	0	0	0	0	1152900	215100	25300	4400	1000	0	0	1398700
1989	0	0	0	163900	0	0	9400	800	0	0	0	0	174100
1990	0	0	251514	2023984	2349100	192800	15100	1100	0	0	0	0	4833598
1991	0	0	0	8200	96400	34000	9600	0	0	0	0	0	148200

Results:

These results are the output from the RESIM runs and have not been reduced to account for the long term rainfall record.

Dimond Gorge		
Full Supply Level (m)	**Yield** ($10^6 m^3$)	**Starting Water Level** (m)
180	450	165
190	935	175
200	1295	188
210	1400	191

The above values are based on 29 years of rainfall and streamflow data and represent a probability of failure of 3%.

Margaret River

DS 90 Catchment Area 12100 km²
Gauging Station S802198 (1967 – 1992)
Catchment Area 7800 km²

Summarised below are the procedures followed during the preparation of streamflow and rainfall data for the Margaret River dam site as well as results of the RESIM runs and flood frequency analyses. Data was prepared using SAS programs and Lotus 123 spreadsheets to prepare it for input for RESIM. Correlations were determined for streamflow sites where possible based on available information at nearby rainfall and streamflow sites in order to fill missing record. The flood frequency analysis was carried out using the AFAP flood frequency analysis program.

The yields calculated are for one Type 1 failure of 1 month in duration only where a Type 1 failure is defined as 'No water is supplied at all because the water level is below the minimum draw level for the entire period of failure'.

In order to accurately estimate the yield for each of the dam sites, it was necessary to ensure that the water level in the dam at the beginning of a run matched the water level at the end of that same run.

FLOW DATA (S198.DAT): Missing monthly flow data was replaced and/or extended according to the equations:

(a) STR198 = -100.371 + (2.234867)*(RAIN198) ≥ 0

then

(b) STR198 = -213.908 + (2.295938)*(RAIN202) ≥ 0

then

(c) STR198 = 9.988561 + (0.204107)*(STR137) ≥ 0

where STR198 is the streamflow record for Margaret River

STR137 is the unmodified streamflow record for Dimond Gorge

RAIN198 is the rainfall data for Margaret River

RAIN202 is the rainfall data for Leopold River

For data that was still missing after the above correlations, the following rules were applied:

(i) If month is between November and April inclusive, then replace with mean value for that month.

(ii) If month is between May and October inclusive, then replace with zero.

The filling of record resulted in a total of 29 years of flow data as shown in Figure A2.

Finally all flow data was scaled according to the ratio of the catchment area of the proposal to the catchment area of gauging station S802198 (i.e. 12100/7800).

RAIN DATA (R198.DAT): Filling of missing daily rainfall data: Use station M502006 data if it exists or else station M002017. Otherwise, fill record with zero value.

Table A2: Corrected flow data for the Margaret River damsite (*Units: $10^3 m^3$*).

Note: Year shown is water year (1962 = October 1962 to September 1963).

Margaret River — S802198													
Year	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Total**
1962	15495	15495	80452	200655	677358	125457	20213	0	0	0	0	0	1135126
1963	0	15495	15495	287910	38862	17490	18566	16128	15558	15495	15495	15495	471990
1964	15495	20814	0	268645	3773	447538	0	0	0	0	0	0	756265
1965	0	2327	76478	226002	45297	1241	155	0	0	0	0	0	351501
1966	0	0	19391	408608	752626	143649	155	0	0	0	0	0	1324428
1967	0	0	2637	185688	353227	666741	2327	38162	776	0	0	0	1249558
1968	0	15513	0	163195	644713	48090	155	0	0	0	0	0	871665
1969	0	0	26992	155	32267	4033	1241	0	0	0	0	0	64688
1970	0	621	285901	114485	96179	556445	9153	0	0	0	0	0	1062783
1971	0	13651	419932	26992	12721	300794	0	0	0	0	0	0	774090
1972	0	0	310	412951	98817	1241	1086	2792	0	0	310	0	517508
1973	0	0	209708	936372	209014	56312	578587	31956	776	0	0	109861	2132585
1974	0	0	7446	7136	460265	0	0	0	0	0	0	0	474847
1975	163251	52899	153112	224962	321689	326196	776	0	0	0	0	0	1242884
1976	0	0	238136	383322	491756	67791	1706	0	0	0	0	0	1182712
1977	0	0	29940	307154	434514	35524	3103	24355	73686	190497	931	0	1099704
1978	0	0	0	59104	130618	85941	1396	111847	2017	0	0	0	390923
1979	0	0	310	106728	1439124	6360	465	0	0	0	0	0	1552988
1981	0	0	53697	287910	516553	161326	2595	5429	776	0	0	0	1028286
1982	0	17064	95559	0	40176	1449474	263791	17374	4809	1706	310	0	1890264
1983	0	0	1086	531935	5740	1119871	18150	2482	310	155	155	0	1679883
1984	0	2172	28233	2327	276283	23269	155	155	155	155	155	155	333215
1985	0	1086	12410	408453	104867	30250	155	0	0	0	0	310	557531
1986	0	0	0	80977	651694	8377	2172	2017	0	0	0	0	745236
1987	0	9463	447855	0	78495	2327	2792	0	0	0	0	0	540932
1988	0	31026	80822	19701	5119	258288	4188	0	0	0	0	0	399145
1989	0	0	0	323753	96179	76633	3103	0	0	0	0	0	499668
1990	0	0	0	2192272	1167650	53829	4654	310	155	0	0	0	3418871
1991	0	0	1086	23269	46073	2172	0	0	0	0	0	0	72600

Results:

These results are the output from the RESIM runs and have not been reduced to account for the long term rainfall record.

Margaret River		
Full Supply Level (m)	**Yield** ($10^6 m^3$)	**Starting Water Level** (m)
170	59	163
180	180	163
190	466	168
200	546	189

The above values are based on 29 years of rainfall and streamflow data and represent a probability of failure of 3%.

Leopold River DS 37

Catchment Area 5600 km²
Gauging Station S802202 (1967 – 1992)
Catchment Area 5220 km²

Summarised below are the procedures followed during the preparation of streamflow and rainfall data for the Leopold River dam site as well as results of the RESIM runs and flood frequency analyses. Data was prepared using SAS programs and Lotus 123 spreadsheets to prepare it for input for RESIM. Correlations were determined for streamflow sites where possible based on available information at nearby rainfall and streamflow sites in order to fill missing record. The flood frequency analysis was carried out using the AFAP flood frequency analysis program.

The yields calculated are for one Type 1 failure of 1 month in duration only where a Type 1 failure is defined as 'No water is supplied at all because the water level is below the minimum draw level for the entire period of failure'.

In order to accurately estimate the yield for each of the dam sites, it was necessary to ensure that the water level in the dam at the beginning of a run matched the water level at the end of that same run.

FLOW DATA (S202.DAT): Missing monthly flow data was replaced and/or extended according to the equations:

(a) $STR202 = -14.0151 + (1.1153328)*(RAIN202) \geq 0$

then

(b) $STR202 = -21.8863 + (1.386073)*(RAIN198) \geq 0$

then

(c) $STR202 = 1.894379 + (0.185846)*(STR137) \geq 0$

where STR202 is the streamflow record for Leopold River

STR137 is the unmodified streamflow record for Dimond Gorge

RAIN202 is the rainfall data for Leopold River

RAIN198 is the rainfall data for Margaret River

For data that was still missing after the above correlations, the following rules were applied:

(i) If month is between November and April inclusive, then replace with mean value for that month.

(ii) If month is between May and October inclusive, then replace with zero.

The filling of record resulted in a total of 29 years of flow data as shown in Table A3.

Finally, all flow data was scaled according to the ratio of the catchment area of the proposal to the catchment area of gauging station S802202 (i.e. 5600/5220).

RAIN DATA (R202.DAT): Filling of missing daily rainfall data: Use station M502001 data if it exists or else station M502005, if still have missing record, try M002039. Otherwise, fill record with zero value.

Table A3: Corrected flow data for Leopold River damsite (*Units: 10³m³*)

Note: Year shown is water year (1962 = October 1962 to September 1963).

Leopold River — S802202

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total
1962	2033	2033	17894	118628	418807	71276	5004	0	0	0	0	0	635674
1963	0	2033	2033	186598	16747	3289	3967	2432	2073	2033	2033	2033	225269
1964	2033	5382	0	158526	44921	235254	0	0	0	0	0	0	446117
1965	0	8639	94438	140236	47152	0	0	0	0	0	0	0	290465
1966	16669	24847	751	171755	901364	313686	1716	107	0	0	0	0	1430895
1967	0	0	0	71877	165747	327632	2575	8261	0	1502	0	0	577594
1968	0	0	23509	84772	309073	186989	2789	0	0	0	0	0	607132
1969	0	0	3433	0	25962	2789	7295	107	0	0	0	0	39586
1970	0	1609	2038	37762	74130	199218	6544	0	0	0	0	0	321303
1971	0	644	135329	4724	11264	195034	0	0	0	0	0	0	346996
1972	8844	66997	2711	302763	50274	31390	1180	0	19485	0	0	0	483644
1973	0	21670	110284	1074299	72414	31540	336644	8475	429	0	0	90423	1746178
1974	0	4720	22529	39157	157916	9762	16950	0	0	0	0	0	251034
1975	9977	25640	91939	125410	643785	114880	0	0	0	0	0	0	1011631
1976	0	0	3755	63402	9226	7939	1180	0	0	0	0	0	85502
1977	0	0	2038	329054	165856	79493	1609	644	91866	61058	0	0	731618
1978	0	0	0	55366	206191	97310	322	81962	6759	107	0	0	448017
1979	0	0	0	178229	386959	16887	1502	0	0	0	0	0	583576
1981	0	78627	66334	186598	279686	103446	20846	0	0	0	0	0	735538
1982	0	25795	73678	18743	153483	547311	101888	0	0	0	3153	0	924051
1983	0	83824	29878	357883	38415	624889	0	0	0	0	0	0	1134889
1984	0	9834	142100	41509	198025	123541	0	0	0	0	0	0	515009
1985	0	322	4291	450432	111678	34330	215	0	0	0	0	0	601267
1986	0	0	0	41839	357134	11801	215	0	0	0	0	0	410989
1987	0	0	335735	145193	54391	966	2253	0	0	0	0	0	538538
1988	0	84442	107703	41632	77019	158559	10192	0	0	0	0	0	479548
1989	0	11443	141358	247764	122551	43985	1502	0	0	0	0	0	568602
1990	0	0	27034	416889	417211	27464	1395	107	0	0	0	0	890100
1991	0	0	322	10192	56109	47943	37426	0	0	0	0	0	151990

Results:

These results are the output from the RESIM runs and have not been reduced to account for the long term rainfall record.

Leopold River

Full Supply Level (m)	Yield (10^6 m³)	Starting Water Level (m)
185	121	179
190	249	180
195	343	186
200	360	187

The above values are based on 29 years of rainfall and streamflow data and represent a probability of failure of 3%.