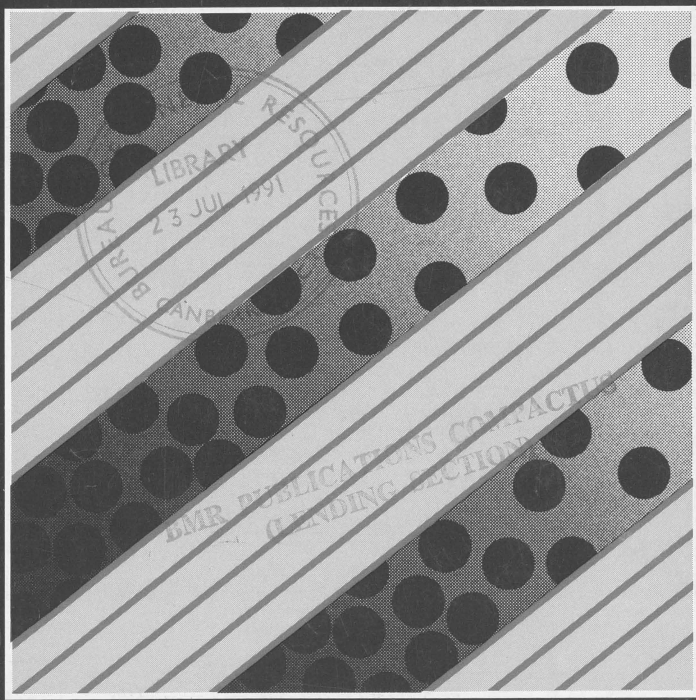
GROUNDWATER 21

HYDROGEOLOGY OF THE KAKADU CONSERVATION ZONE, NEAR CORONATION HILL, NORTHERN TERRITORY

G. JACOBSON



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CONTENTS

ABSTRACT

Groundwater extraction is proposed to fulfil the partial water supply requirements for the proposed gold-platinum-palladium mine at Coronation Hill, Northern Territory. The aquifers in the Conservation Zone surrounding the mine are fractured Proterozoic dolomite and volcanic rocks. These aquifers are recharged partly by direct infiltration of rainfall, and partly by inflow from upstream reaches of the South Alligator River. The aquifers discharge to downstream reaches of the river. The environmental impact review of the mine proposal has raised two hydrogeological issues: whether seepage of cyanide-bearing process water will pollute the aquifer and river; and whether aquifer drawdown will affect the flow and ecology of the river. Available information indicates that some cyanide-bearing process water will seep into the aquifer, but that the pollution plume will be attenuated to some extent by chemical reaction and degradation. Available river stage data have been used to estimate the effects of drawdown due to proposed extraction of groundwater for mine water supply, and also mine pit groundwater inflow. The long term groundwater extraction and pit inflow is probably about 25 L/s. River flow at Coronation Hill has fallen below 250 L/s on 84 days in 8 out of a documented 51 months, and the long term groundwater extraction and pit inflow is equivalent to about 10 % of river flow in these low flow months. The wellfield should be designed for minimal drawdown, and management criteria should be developed to avoid ecological damage in low flow conditions. Remaining doubts about the river/aquifer interaction need to be resolved by further investigations.

INTRODUCTION

Coronation Hill is the site of a proposed gold-platinum-palladium mine in the Northern Territory (Fig.1). It was formerly a uranium mine, and together with several other former uranium mines is located in a Conservation Zone which forms an enclave of about 50 km^2 surrounded by the Kakadu National Park. Whether mining should proceed in the Conservation Zone is presently the subject of inquiry by the Resources Assessment Commission.

At the request of the Resource Assessment Commission a review of hydrogeological data for the Kakadu Conservation Zone was conducted from July to October 1990. The Terms of Reference were to provide additional information on the hydrogeology of the Conservation Zone and to establish whether the proposed Coronation Hill mining project could have significant impacts on groundwater and river water. The scope of the study was defined as gathering baseline hydrogeological information for the Conservation Zone, including the distribution and nature of aquifers and water chemistry. The brief included provision of hydrogeological information for a numerical model to be developed by Mackie, Martin and Associates, in order to assess two important groundwater issues. These are, firstly, methods proposed for preventing and monitoring leakage of toxic waters from storage and residue dams (Fig. 2) into aquifers; and, secondly, the potential for aquifer drawdown to affect the water flow or quality in the South Alligator River.

The available documentation comprises several reports prepared on behalf of the Coronation Hill Joint Venturers : the draft Environmental Impact Statement (Dames & Moore,1988); the final Environmental Impact Statement (Dames & Moore, 1989); and hydrological reports on which these statements were partly based (AGC,1987a; BHP Engineering,1988).

Field investigations were carried out by the author in July 1990 to supplement those of the Joint Venturers. These investigations comprised: levelling the existing water bores to assist in determining the potentiometry and river-aquifer relationship; collection of additional groundwater samples for chemical analyses , to confirm and supplement the company analyses, and to provide additional baseline data if the mine goes ahead; and collection of samples from several ponds and seepages in the area to assist in ascertaining whether there is existing pollution.

GEOLOGY

The Conservation Zone has been mapped geologically in a series of BMR investigations at regional scales (Needham & Stuart-Smith, 1984; Stuart-Smith & others, 1987; Needham, 1988). The rocks are within the Pine Creek Geosyncline sequence, and are traversed by several major faults. Figure 3 shows the generalised site geology. Cainozoic alluvium and colluvium cover about 50 % of the area. To the southwest is Middle Proterozoic platform cover, the Kombolgie Formation, forming the prominent escarpment. The geosynclinal rocks are Early Proterozoic in age (1800 - 1900 million years) and comprise 10 mapped formations.

SURFACE HYDROLOGY

The South Alligator River flows from southeast to northwest through the study area, between the north and south sections of the Conservation Zone (Fig.1). A tributary , Back Valley Creek, flows out of Back Valley, the proposed site of the tailings dam and water storage dam.

The mean monthly discharge of the South Alligator River at Gimbat Crossing near Coronation Hill, is shown in Figure 4. This diagram is based on discharges estimated from a catchment rainfall/runoff relationship (Table C-11, Dames & Moore,1988). River flow is strongly seasonal, with most occurring in the wet season from December to April, and with minimal flow in the dry season, from May to October. Information on river stage heights supplied by the Northern Territory Power and Water Authority suggests that low season flows are in fact an order of magnitude greater than indicated by Dames & Moore. At El Sherana (Fig. 5), 20 km downstream, the seasonal pattern is similar but the wet season discharge is several times greater because of increased catchment area.

Maximum and minimum daily stages over the last 4 years at the Gimbat Crossing gauging station are shown in Figure 6. River stage heights in the wet season are commonly 1 - 2 m above river bed level, which is at an elevation of about 83 m A.H.D. Downstream at El Sherana, stage heights are commonly 8 - 10 m above river bed level, which is about 50 m A.H.D., in the wet season.

The long term record of annual discharge of the South Alligator River at the El Sherana gauging station is shown in Figure 7. It exhibits considerable variability from year to year, the highest recorded annual discharge being about 1270 million m^3 in 1973/4, and the lowest being about 160 million m^3 in 1963/4 and 1985/6.

Back Valley Creek has an estimated average discharge of about 1.7 million m^3 (Dames & Moore,1988). It apparently did not flow in the wet season of 1989-90.

GROUNDWATER HYDROLOGY

The regional hydrogeology has been mapped by McGowan (1989). Most of the Conservation Zone is underlain by fractured rocks considered to be local aquifers with bore yields of 0.5 to 5 L/s. At Coronation Hill, known aquifers are dolomite in the Koolpin Formation, a unit that also contains siltstone,phyllite and slate; and basalt in the overlying Coronation Sandstone, a unit that also contains sandstone,siltstone,shale and tuff.These rocks are faulted and fractured,and deeply weathered. The dolomite is believed to be cavernous.

The hydrogeology of the mine site was investigated by Australian Groundwater Consultants (1987a) for the Joint Venturers. They drilled 12 holes, ranging in depth from 20 to 150 m , which intersected groundwater in fractured and faulted bedrock zones; one drillhole was in alluvium of the South Alligator River. Bore locations are shown in Figure 2 and some details are given in Table 1. Airlifted yields ranged from less than 1 L/s in fractured volcanics to about 10 L/s in dolomite. Standing water levels in bores are listed in Table 2; records are sparse but suggest considerable seasonal variations. The contoured potentiometric surface based on water levels measured in July 1990, is shown in Figure 8.

The wellfield for mine supply was proposed by AGC (1987a) to be centred on bores 7, 8 and 11. The analytical model used by AGC to simulate the borefield assumed a long continuous aquifer in dolomite and volcanics. The drawdown cone would extend for 2 km along strike and a lesser distance across strike. More recently, the Joint Venturers have indicated a lesser requirement for groundwater, and this would be extracted from a wellfield centred on bore 11.

Aquifer hydraulic boundaries deduced from pump tests by AGC indicate that the dolomite aquifer is about 700 m wide, and the basalt aquifer in the Back Valley is about 200 m wide. Figure 9 shows the distribution of transmissivity and hydraulic conductivity values based on aquifer tests. Transmissivity ranges from 1 to 800 m^2/d, with the three dolomite bores averaging 300 m^2/d. Transmissivity is the product of hydraulic conductivity and aquifer thickness, so that the indicated hydraulic conductivity ranges from 0.02 to 16 m/d, with the 3 dolomite bores averaging 9 m/d. Drilling and aquifer testing results indicate partially confined conditions in the aquifer,that is, intersected groundwater may rise in the bore to a potentiometric level that is above the aquifer level.

Available potentiometric and river stage levels suggest that the dolomite aquifer is recharged both by groundwater flow from higher ground to the south and by water from the South Alligator River. At periods of low flow, the river level at Gimbat Crossing is about 83 m AHD, and the groundwater level in bore 8 is about 79 m. At periods of high flow, river level is about 87 m, which is close to the top of bore 8. Under natural low flow conditions the low permeability and hydraulic gradient between the river and the dolomite suggest that there is little hydraulic connection in the vicinity of bore 8, that is , the river is perched above the groundwater level. As originally calculated, the proposed drawdown for the initial stages of mine water supply extraction was about 30 m, and the drawdown cone would extend beneath the river (Fig. 10). This would increase the hydraulic gradient beneath the river and the aquifer, creating conditions where the dry-season river flow would be affected.

Elsewhere in the project area, potentiometric levels (Fig. 8) indicate that groundwater flow is generally northwards from higher ground towards the dolomite aquifer which acts as a sink. The higher ground is recharged by direct infiltration of rainfall, in permeable colluvium. There may be a significant component of bed underflow down Back Valley Creek. Discharge from the dolomite aquifer is possibly to a lower reach of the river, near Pul Pul.

A numerical model of groundwater potential and flow in the mine area is being developed by Mackie Martin & Associates (1990). The basis for the model is the known geology, including major faults, updated from Figure 3 by the inclusion of more recent structural geological information; anisotropy due to the structural "grain" is taken into account. Available river stage information (Fig. 6), potentiometry (Fig. 8) and permeability (Fig. 9) are being incorporated. The model is being used to simulate the effects on the groundwater flow regime of aquifer withdrawal, seepage from dams and the mine pit excavation.

HYDROCHEMISTRY

In July 1990, groundwater samples were obtained from 8 water bores at Coronation Hill by pumping, after purging the bores of a volume of water equivalent to three times that in the bore casing. Samples were also taken from a bore at El Sherana and from a number of surface water sites in the Conservation Zone. On site determinations were made of pH, Eh, electrical conductivity, dissolved oxygen and temperature. Alkalinity was determined the same day in a field laboratory. Samples were filtered on site, and aliquots for cation and radionuclide determination were acidified to pH 2 with nitric acid. An aliquot for cyanide determination was firstly tested for the presence of oxidising agents or sulphide and neutralised if necessary, then treated with sodium hydroxide to pH 12.

Chemical analyses of Coronation Hill groundwater samples are given in Table 3. Groundwater salinity and hydrochemical type are shown in Figure 11. Salinity of groundwater ranges from 160 to 415 mg/L total dissolved solids (TDS). The groundwater is a bicarbonate water with very little chloride or sulphate; magnesium and calcium are the dominant cations.

The pH ranges from 6.4 to 7.2, and groundwater temperature is about 33°C. Positive Eh values in bores 1, 5 and 12 indicate oxidising conditions, and probably, recent recharge. High dissolved oxygen values in bores 1 and 4 also suggest recent recharge.

Excessive concentration levels of iron or zinc or radionuclides preclude several of the bores from being used for drinking water. Otherwise the groundwater is a useful water supply for most purposes, although it is generally hard. Concentration levels of cyanide were below detection limits.

The isotopic composition of the Coronation Hill groundwaters is shown in Table 3. Interpretation of tritium activity values is based on criteria by Calf (1988). Tritium values of between 0.2 and 2 T.U. for most samples indicate that most of the groundwater has residence times of between 25 and 50 years in the system. Bore 10, with 0.1 T.U., is in a pocket of slightly older water, and bore 5, with 2.7 T.U., has modern water. Stable isotope (deuterium and oxygen-18) values for the groundwater samples all plot close to the World Meteoric Water Line, confirming their derivation from modern rainfall.

Chemical analyses of surface water samples are shown in Tables 4 and 5. The South Alligator River water varies in salinity inversely with discharge. Previous analyses by the Joint Venturers (Dames & Moore,1988) show a variation in water chemistry just downstream of Gimbat Crossing. Salinity ranges from 15 mg/L TDS in high flow conditions (HCO_3-Mg-Na-Ca water) to 133 mg/L in low flow conditions (HCO_3-Mg-Ca water). The river water is alkaline.

The composition of the groundwater and river water can be considered in terms of percent milliequivalents per litre. On this basis the South Alligator River waters contain between 20 and 30% Ca relative to total cations. Most of the Coronation Hill groundwaters contain between 40 and 60% Ca. However, groundwater from bores 7 and 11 contain between 30 and 40% Ca and this suggests that they are derived from river recharge, probably from the upstream reach of the South Alligator River southeast of Coronation Hill.

Determinations of minor and trace elements in surface waters are shown in Tables 4 and 5. Radioactivity levels are above Australian drinking water quality guidelines in the abandoned mine pit at Saddle Ridge and in one of the three sediment traps on Coronation Hill. Concentration levels of cyanide were below detection limits in all samples.

GROUNDWATER ISSUES

1. Will seepage of cyanide-bearing water pollute the aquifers?

Very low levels of free cyanide in the aquatic environment can cause damage . At Coronation Hill the design of the process water recovery system is such that cyanide-bearing water is unlikely to pollute surface waterways except in the event of catastrophic dam collapse. However the water storage and tailings dams will impose a head on the fractured rock aquifer (Fig. 12), creating conditions where seepage of cyanide-bearing water is probable. The heterogeneity of the fractured rock beneath the dams (Fig. 13) means that the proposed foundation treatment can reduce but not stop seepage. According to BHP (1988), foundation treatment for the water storage dam will comprise a cut-off trench, partial clay blanket, and single row grout curtain, and this is expected to reduce seepage to 265 m^3/d at full supply level. Seepage of waters beneath the dams is being modelled by Mackie Martin & Associates (1990); it is necessary to allow for some natural absorption or degradation of cyanide in the subsurface.

The evidence for natural cyanide degradation in aquifers is equivocal. A number of recently published reports assert that processes of dilution, volatilisation, reaction and oxidation in aquifers will reduce cyanide concentrations (Sparrow & Woodcock,1988; Miller & others,1987; Longe & Devries,1988). Leaching tests have confirmed the capacity of clay columns to absorb cyanide (Parton & Wharton,1987; John,1988). However at a site in New South Wales free cyanide concentrations in tailings dam leakage water were observed to be 10% of those found in the dam (Brooks & McGlynn,1987). There are at least two documented incidents of persistence of cyanide in groundwater systems. Cattle were killed drinking cyanide-polluted bore water near the Wellington Springs gold mine, in central Queensland (Gormley & Poplawski,1988); and underground miners were overcome with hydrocyanic gas derived from tailings dam seepage at Mt Isa (Brady,1960).

The adequacy of proposed cyanide monitoring and recovery schemes has been questioned in responses to the project EIS. Since the publication of the EIS (Dames & Moore,1988) the technology for monitoring bores with volatile gases has improved. A multi-level sampler based on the dialysis-cell method could be used for the development of an early warning monitoring system (Ronen & others, 1987). In the fractured rock aquifer, pollutants might travel rapidly in particular open fractures, and the efficiency of the recovery bores depends on their intersecting these fractures. According to Burgess (1989) about 50% of the seepage at Coronation Hill should be recoverable; it is possible that modelling will assist the optimal siting of the recovery bores.

2. Will the drawdown of the wellfield affect river flow?

Available information suggests that the effects of wellfield drawdown could be considerable over the life of the mine. AGC (1987a) assumed a long term pumping rate of 24 L/s and predicted that the maximum drawdown in the dolomite aquifer would be about 26 m and 33 m below natural groundwater levels for 2 and 5 year pumping periods respectively. The drawdown cone would extend for several kilometres along the strike of the dolomite, and would steepen the hydraulic gradient away from the river. This was regarded as advantageous in terms of aquifer recharge and the mine water supply would in fact depend on recharge induced from the South Alligator River (AGC, 1987a). In times of high river flow the induced seepage would be a small proportion of river discharge. However in times of low river flow, which may coincide with peak seasonal water demands, seepage induced by the drawdown cone would be an appreciable proportion of river discharge. Concern has been expressed in public responses to the EIS about possible deleterious effects on the river flow and ecology.

The mine pit excavation will extend about 90 m below the water table to a base level of 10 m AHD. The pit will be surrounded by a drawdown cone which will be , in fact, deeper than that induced by wellfield extraction. Studies by consultants to the Joint Venturers (AGC,1987b) suggest that long term inflows of groundwater to the pit are likely to be about 20 L/s. These studies discount the possibility of inflow of water to the pit affecting the mining operation, because of evaporation of seepages (AGC, 1987b). However it is probable that the drawdown cone will extend beneath the river, eventually affecting dry season flows.

Examination of 4 years of river stage records at Gimbat Crossing (Fig.4) suggests that the lowest recorded stage height of 1.18 m equates to, or is close to, zero flow; this has occurred on two days in one of the 51 months for which data are available. Stage height of 1.25 m is equivalent to flow of 250 L/s according to information on the stage/discharge relationship supplied by the Northern Territory Power and Water Authority. Flows of this magnitude or less have occurred on 84 days, in 8 out of the 51 months. The Joint Venturers have recently stated (F.Leckie, G.Johnston, personal communication, October 1990) that the currently proposed withdrawal of groundwater is 5 L/s long term, and 30 L/s in the first dry season of project establishment. An additional 20 L/s will eventually seep into the mine pit. Table 6 quantifies the percentage of river flow likely to be drawn off by different amounts of groundwater extraction. The average long term total extraction from wellfield and pit is about 25 L/s. This is equivalent to 10% or more of river flow in the low flow conditions that occur in 84 days out of 51 months. Data are insufficient to partition the predicted groundwater extraction into river-recharge and rainfall-recharge components.

In order to quantify this more exactly, information is needed on the nature of the hydraulic connection between the aquifer and the river, and on natural groundwater level fluctuations. If the mine goes ahead, then a minimal impact borefield should be designed, with widely spaced bores and low pumping rates to minimise aquifer drawdown in the dry season. Criteria should be developed for managing the groundwater system to avoid ecological damage at low river stages.

CONCLUSIONS

1. Seepage of about 130 m^3/d of cyanide-bearing water is probably not recoverable; some attenuation of the pollutants is likely; the movement and ultimate extent of the pollution plume may be predicted by modelling with the proviso that in the fractured rock aquifer, movement could be controlled by specific large fractures.

2. The amount of proposed extraction of groundwater from the wellfield has been reduced by the Joint Venturers since the publication of the EIS. Drawdown of the wellfield plus pit inflow may average 25 L/s long term, and this equates to about 10 % of river flow in low-flow months (8 months out of 51). The design of the mine water supply should be based on minimal drawdown, and groundwater management should incorporate criteria for avoiding ecological damage in low-flow conditions.

3.To firm up knowledge of the river /aquifer interaction, monitoring of existing bores through a wet and dry season should be undertaken. The stage/discharge relationship at the Gimbat Crossing gauging station should be determined more precisely, so that the groundwater level information can be calibrated against river discharge.

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Table 1 List of water bores, Coronation Hill (after AGC,1987a)

Bore	Total Depth (m)	Aquifer Interval (m)	Airlift Yield (L/s)	Aquifer type & lithology
1	54	-	-	Fractured dolerite
2	150	84-86	4.7	Fractured siltstone
3	150	27-29	minor	Fractured porphyry
4	66	30-40	0.2	Fractured volcanics
5	62	22-26	0.2	Fractured volcanics
6	74	12-13	0.5	Fractured volcanics
7	80	24-28	minor	Fractured schist
		68-70	9.0	Fault in schist
8	71	28-30	3.0	Fault breccia between volcanics & dolomite
		62-63	7.0	Fault breccia & solution cavity in dolomite
9	20	11-15	0.4	Alluvial gravels
10	66	16	0.5	Fault breccia in volcanics
		37-38	3.0	Fractured volcanics
11	69	18	minor	Fractured volcanics
		36-41	13.0	Fault breccia between volcanics & dolomite
		49-57	1.0	Fractures & cavities in dolomite.Brecciated volcanics
12	56	20	0.5	Weathered siltstone (?tuff)
		26	2.0	Fractures & minor fault breccias
		40-42	3.0	in siltstone (?tuff)

Table 2 Standing water levels in Coronation Hill bores

Bore	R.L. Ground Level (m AHD)	S.W.L. (m below ground level)		
		July 87	July 90	Nov 90
1	95.9	14.67	-	-
2	-	31.11	-	18.87
3	-	21.90	-	-
4	88.43	4.28	5.50	5.46
5	100.60	11.31	11.89	12.68
6	-	12.36	-	-
7	109.65	22.35	22.21	22.01
8	86.40	7.24	7.80	8.46
9	-	6.02	-	-
10	101.12	11.85	12.49	-
11	98.79	17.36	15.56	16.64
12	-	12.42	13.40	13.74

Table 3 Chemical analyses of groundwater samples, Coronation Hill, July 1990
Values in mg/L.

No.	CHWB 1 900726	CHWB 4 900727	CHWB 5 900728	CHWB 7 900729	CHWB 8 900730	CHWB 10 900731	CHWB 11 900732	CHWB 12 900733
pH	7.2	7.1	7.0	6.4	7.2	7.1	6.9	6.7
T°C	33.4	32.5	31.8	33.7	33.1	33.2	32.9	33.7
Eh mV	+160	-70	+150	-72	-54	-77	-121	-
DO	2.6	5.5	0.27	0.20	0.73	0.55	0.32	0.51
EC uS/cm	511	559	231	330	400	560	460	-
TDS	322	366	152	188	276	372	304	322
Ca	43.2	49.7	27.8	19.8	38.7	51.8	40.9	45.8
Mg	31.8	33.5	10.0	22.3	29.0	30.8	28.4	24.3
Na	13.1	16.0	4.49	4.85	3.84	16.4	20.3	11.1
K	2.14	4.73	1.42	1.61	3.27	3.60	4.43	4.24
HCO_3	288	333	131	150	245	307	245	240
Cl	3.56	2.82	1.58	2.49	2.10	2.58	22.6	2.48
SO_4	6.87	7.49	0.90	4.02	4.01	23.0	10.0	32.3
Al	0.016	0.022	0.014	0.023	0.018	0.019	0.024	0.021
Fe	0.045	0.38	0.083	<0.005	0.59	0.24	<0.005	0.70
Mn	0.29	0.16	0.22	0.30	0.046	0.14	0.13	0.30
Cu	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zn	0.022	0.024	0.012	0.031	0.023	0.034	0.02	0.066
Sr	0.059	0.20	0.036	0.011	0.041	0.10	0.062	0.042
Li	0.008	0.005	<0.005	0.007	0.005	0.012	0.042	0.021
Si	16.1	12.7	5.48	14.7	7.30	13.9	9.45	17.8
B	0.074	0.071	0.046	0.059	0.060	0.091	0.096	0.065
Ba	<0.005	0.46	0.80	0.015	0.30	0.19	0.069	0.035
V	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Br	0.020	0.030	0.020	0.010	0.020	0.020	0.13	0.020
F	0.15	0.28	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
I	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
NO_3	<0.100	<0.100	<0.100	0.79	<0.100	<0.100	<0.100	<0.100
PO_4	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100
Ag	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Au	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cd	0.2	0.1	<0.1	<0.1	0.1	0.1	0.1	<0.1
Cr	<1	<1	<1	<1	<1	<1	<1	<1
Mo	<2	<2	<2	<2	4	<2	<2	<2
Ni	<1	<1	<1	<1	<1	<1	<1	<1
Pb	<0.5	<0.5	<0.5	1.5	1.0	1.0	0.5	0.5
Pd	1	2	2	1	<1	<1	<1	<1
Be	<1	<1	<1	<1	<1	<1	<1	<1
CN	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
As	<5	<5	<5	<5	<5	<5	<5	<5
Se	<5	<5	<5	<5	<5	<5	<5	<5
^{3}H TU	2.0	1.4	2.7	0.8	0.8	0.1	1.0	0.6
U ppb	0.044	2.09	0.69	0.07	1.09	0.44	0.72	0.56
^{226}Ra dpm/kg	0.15	3.75	2.40	1.97	32.1	0.02	7.78	2.37
Gross alpha Bq/L	<0.02	0.03	0.02	<0.02	0.18	<0.02	0.10	<0.02
Gross beta ($-^{40}K$) Bq/L	0.03	0.08	0.04	0.03	0.24	0.05	0.10	0.07

Table 4 Chemical analyses of water samples, Conservation Zone, July 1990
Values in mg/L.

	Rain	Mine Koolpin	Sediment traps C.Hill	C.Hill	C.Hill
No.	900734	900735	900736	900737	900738
pH units	7.1	7.8	8.3	8.1	7.5
T°C	-	27.3	22.8	19.2	24.5
Eh mV	-	+143	+178	+176	+146
DO	-	9.1	8.3	8.4	8.3
EC uS/cm	-	72	206	179	55
TDS	20.0	60.0	146	134	58.0
Ca	0.73	4.54	9.26	3.35	0.85
Mg	0.08	5.55	17.3	16.7	1.43
Na	0.33	1.13	2.03	1.94	2.31
K	0.24	1.82	1.86	3.41	6.00
HCO_3	3.00	39.0	87.5	70.0	10.5
Cl	0.730	1.71	2.68	3.77	6.60
SO_4	0.600	0.290	11.4	8.52	1.21
Al	0.008	0.005	0.23	0.061	0.35
Fe	<0.005	0.167	0.143	0.280	0.77
Mn	<0.005	<0.005	0.061	0.059	0.090
Cu	0.030	<0.005	<0.005	<0.005	<0.005
Zn	0.17	0.012	0.011	0.009	0.014
Sr	<0.005	0.010	0.008	<0.005	<0.005
Li	<0.005	<0.005	<0.005	<0.005	<0.005
Si	0.653	4.68	2.09	0.368	0.330
B	0.14	0.099	0.034	0.021	0.026
Ba	<0.005	0.014	0.043	0.021	0.019
V	<0.005	<0.005	<0.005	<0.005	<0.005
Br	<0.010	<0.010	0.020	0.040	0.060
F	<0.10	<0.10	<0.10	<0.10	<0.10
I	-	<0.010	<0.010	0.010	0.05
NO_3	<0.10	<0.10	<0.10	<0.10	<0.10
PO_4	<0.10	<0.10	<0.10	<0.10	<0.10
Ag	-	<0.2	<0.2	<0.2	<0.2
Au	-	<0.5	<0.5	<0.5	<0.5
Cd	-	0.6	0.4	0.7	0.5
Cr	-	<1	<1	<1	<1
Mo	-	<2	<2	<2	<2
Ni	-	1	2	1	1
Pb	-	<0.5	<0.5	<0.5	<0.5
Pd	-	<1	<1	<1	<1
Be	-	7	2	1	1
CN	-	<0.01	<0.01	-	<0.01
Hg	<0.1	<0.1	<0.1	-	<0.1
As	<5	<5	<5	-	<5
Se	<5	<5	<5	-	<5
^{3}H TU	-	3.6	2.7	2.9	2.9
U ppb	-	0.61	13.5	25.7	1.12
^{226}Ra dpm/kg	-	0.85	3.22	6.59	2.26
Gross alpha Bq/L	-	<0.02	0.06	0.21	0.07
Gross beta (-^{40}K) Bq/L	-	0.08	0.20	0.46	0.05

Table 5 Chemical analyses of water samples, Conservation Zone, July 1990 (cont.)

No.	Bore El Sherana 900739	S.Alligator R. El Sherana 900740	Mine Saddle Ridge 900741	S.Alligator R. Gimbat Xg 900742	Spring nr Scinto5 900743
pH	6.9	8.2	8.05	8.1	7.2
T°C	33.3	24.8	30.0	21	23.5
Eh mV	-66	+168	+128	+70	+110
DO	1.68	9.55	8.4	7.6	9.4
EC uS/cm	501	117	34	108	44
TDS	322	72.0	58.0	86.0	52.0
Ca	49.9	5.18	0.22	4.88	4.62
Mg	18.5	8.77	0.24	9.05	2.00
Na	20.2	1.64	4.39	1.49	0.970
K	0.79	0.69	0.92	0.49	0.021
HCO_3	270	50.0	5.00	50.0	23.0
Cl	2.57	2.58	4.03	2.28	0.09
SO_4	2.05	2.53	0.34	2.74	0.20
Al	0.023	0.015	0.61	0.014	0.015
Fe	0.43	0.24	0.68	0.20	0.086
Mn	0.35	0.017	0.023	0.007	<0.005
Cu	<0.005	<0.005	<0.005	<0.005	<0.005
Zn	0.021	0.005	0.010	0.007	0.005
Sr	0.093	<0.005	<0.005	<0.005	<0.005
Li	0.015	<0.005	<0.005	<0.005	<0.005
Si	20.3	7.26	5.00	7.33	6.99
B	0.063	<0.005	<0.005	<0.005	<0.005
Ba	0.023	0.008	0.027	0.005	<0.005
V	<0.005	<0.005	<0.005	<0.005	<0.005
Br	0.010	<0.010	0.010	<0.010	<0.010
F	<0.100	<0.100	<0.100	<0.100	<0.100
I	<0.010	<0.010	0.030	<0.010	<0.010
NO_3	<0.100	<0.100	<0.100	<0.100	<0.100
PO_4	<0.100	<0.100	<0.100	<0.100	0.080
Ag	<0.2	<0.2	<0.2	<0.2	<0.2
Au	<0.5	<0.5	<0.5	<0.5	<0.5
Cd	0.3	0.2	0.4	0.2	0.1
Cr	<1	<1	<1	<1	<1
Mo	<2	<2	<2	<2	<2
Ni	<1	<1	<1	<1	<1
Pb	<0.5	<0.5	<0.5	<0.5	<0.5
Pd	<1	<1	<1	<1	<1
Be	<1	<1	2	<1	<1
CN	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	<0.1	<0.1	<0.1	<0.1	<0.1
As	<5	<5	<5	<5	<5
Se	<5	<5	<5	<5	<5
^{3}H TU	1.3	1.2	3.3	1.2	2.5
U ppb	0.064	0.151	18.62	0.210	0.329
^{226}Ra dpm/kg	0.15	0.082	18.8	0.25	0.52
Gross alpha Bq/L	<0.02	<0.02	0.22	<0.02	<0.02
Gross beta ($-^{40}K$) Bq/L	0.04	<0.04	0.61	<0.04	0.05

Table 6 Percentage of river flow possibly drawn off by groundwater abstraction

Stage (m)	Flow (L/s)	Total abstraction as percentage of flow 15 L/s	25 L/s	35 L/s	45 L/s	Cumulative frequency * (days)
1.18	0-100	7%	25%	35%	45%	2
1.25	250	6%	10%	14%	18%	84
1.30	320	5%	8%	11%	14%	335
1.40	500	3%	5%	7%	9%	876
1.50	750	2%	3%	5%	6%	1034

*Total number of days in period 4 Dec 85 -26 Mar 90 for which stage records exist is 1548

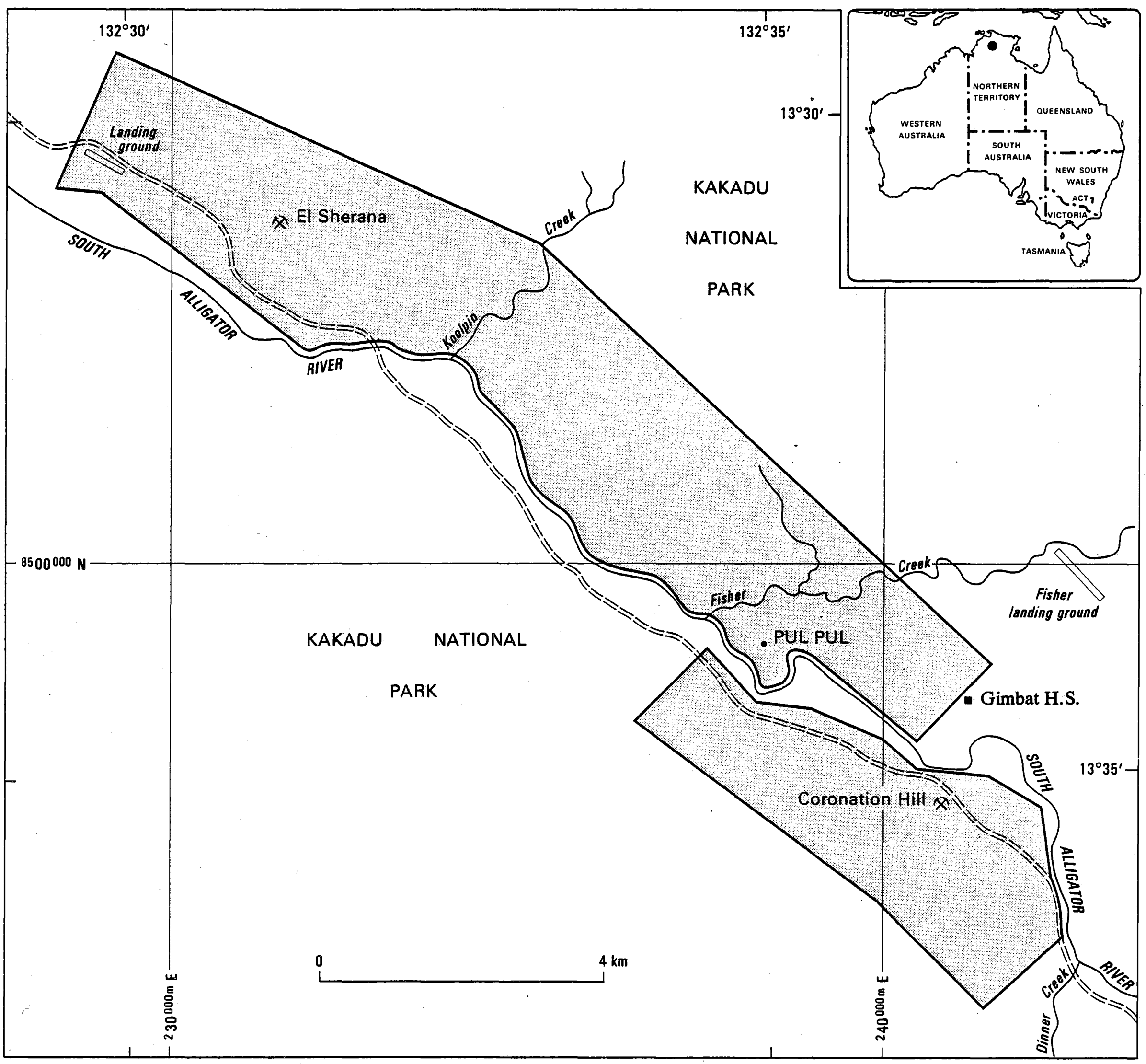
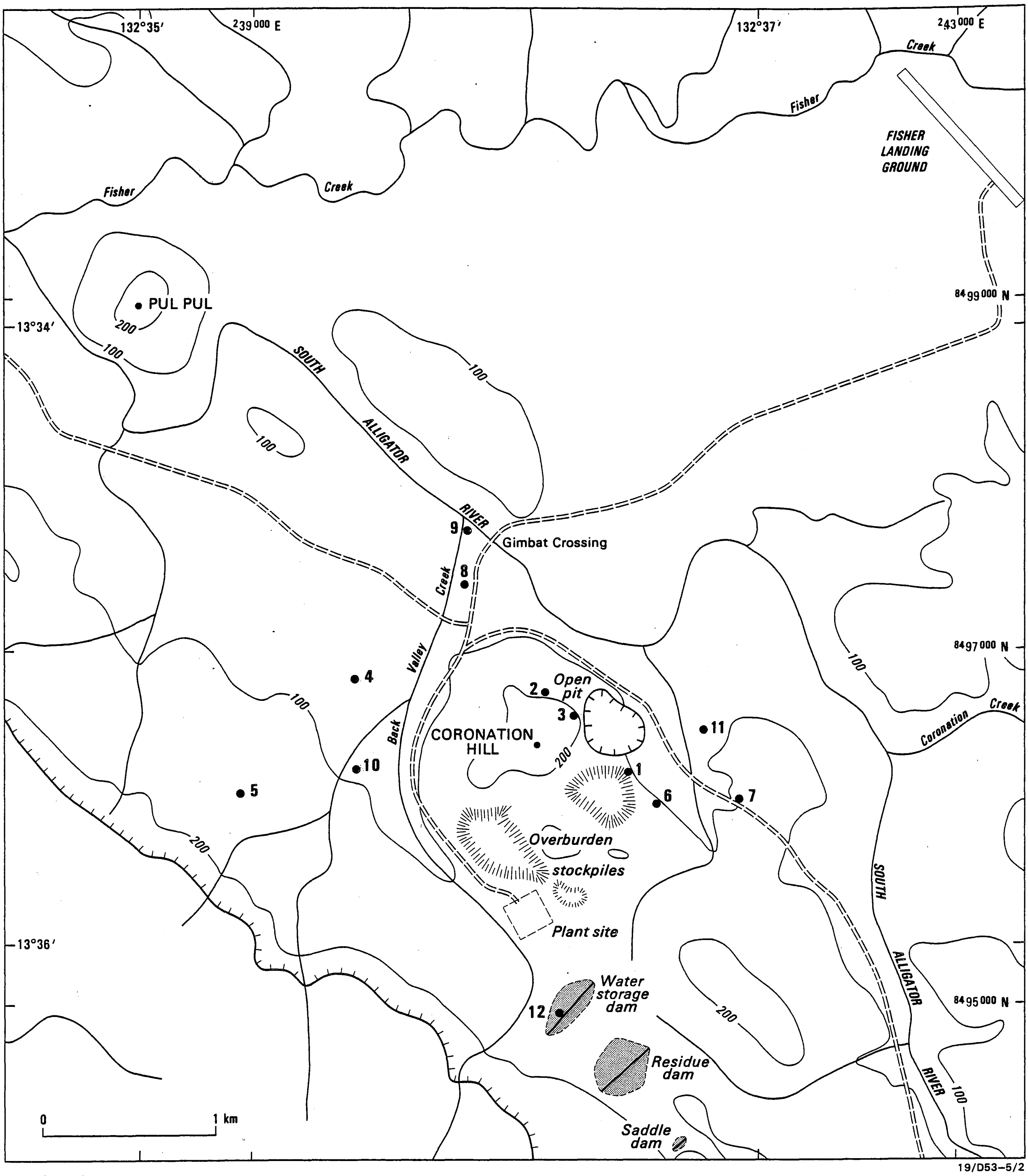


Fig 1. Location plan; Coronation Hill Conservation Zone



• Water bore

Fig 2. Coronation Hill; proposed project layout

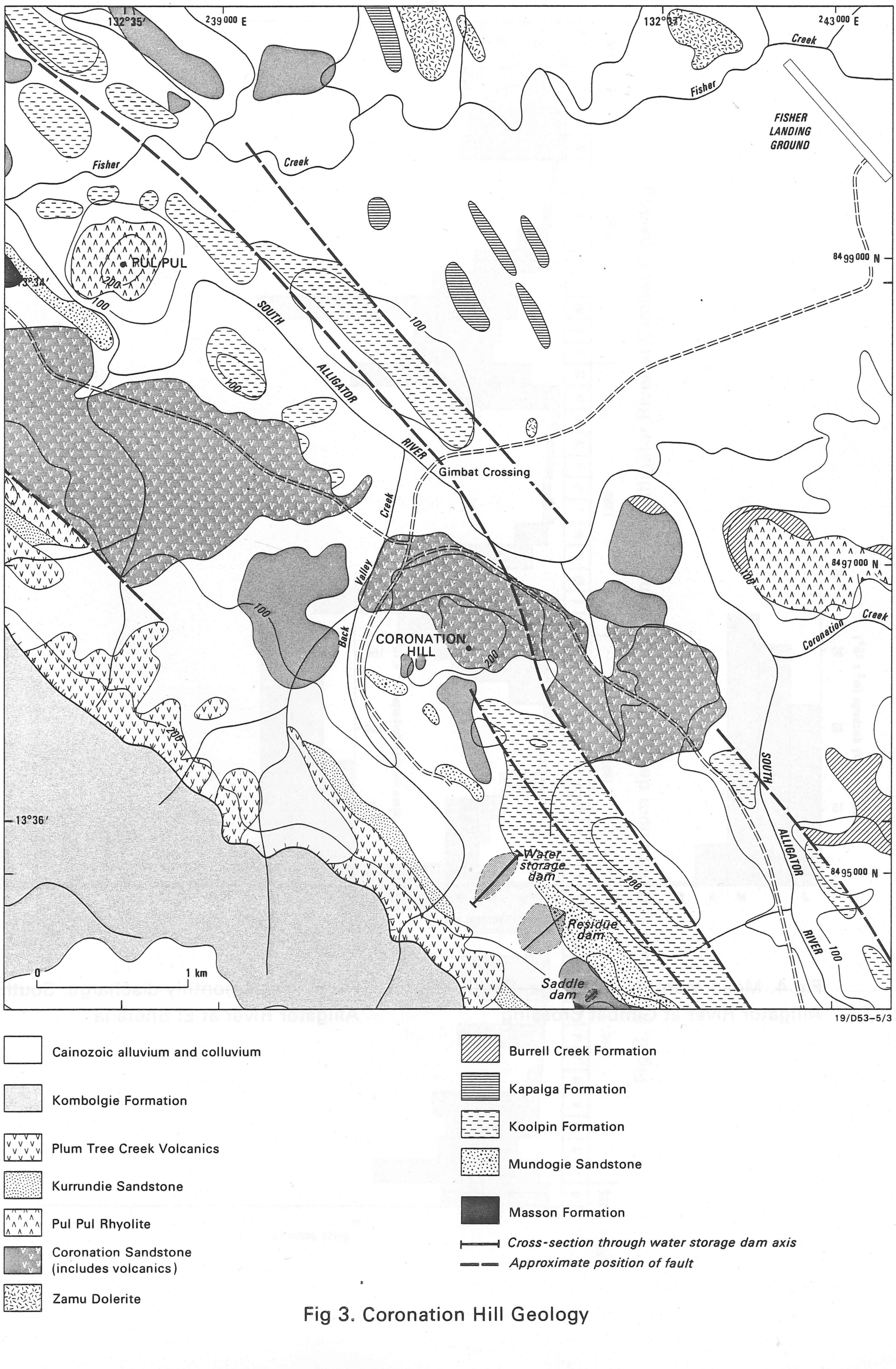


Fig 3. Coronation Hill Geology

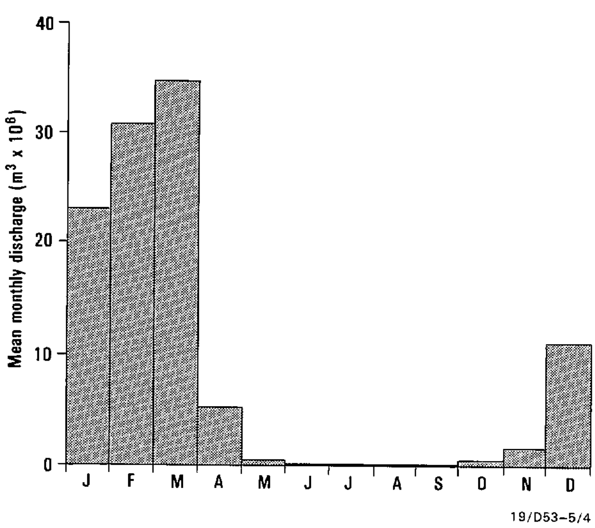


Fig 4. Mean monthly discharge, South Alligator River at Gimbat Crossing

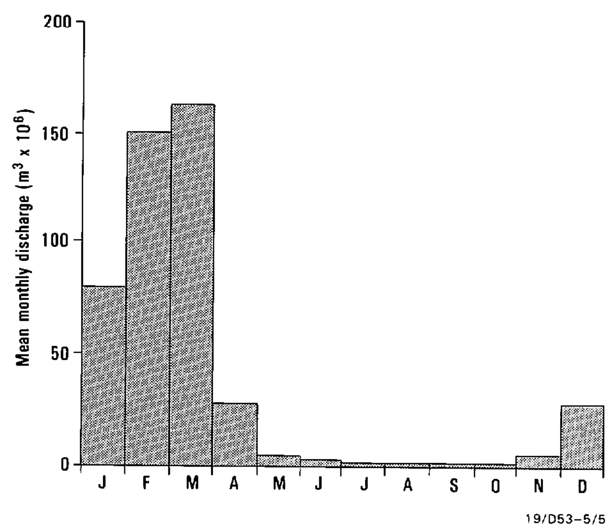


Fig 5. Mean monthly discharge, South Alligator River at El Sherana

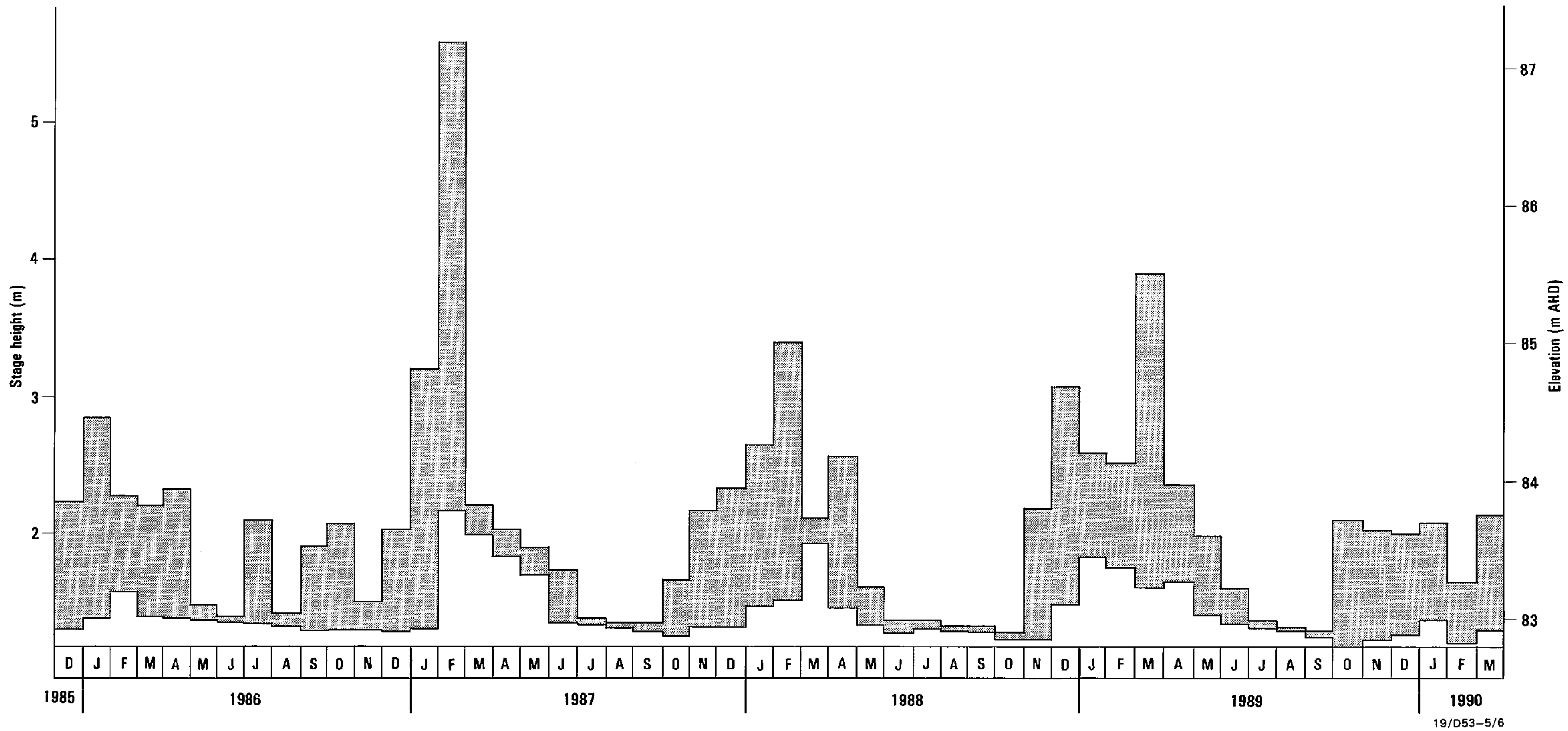


Fig 6. Maximum and minimum daily stage, per month, South Alligator River at Gimbat Crossing

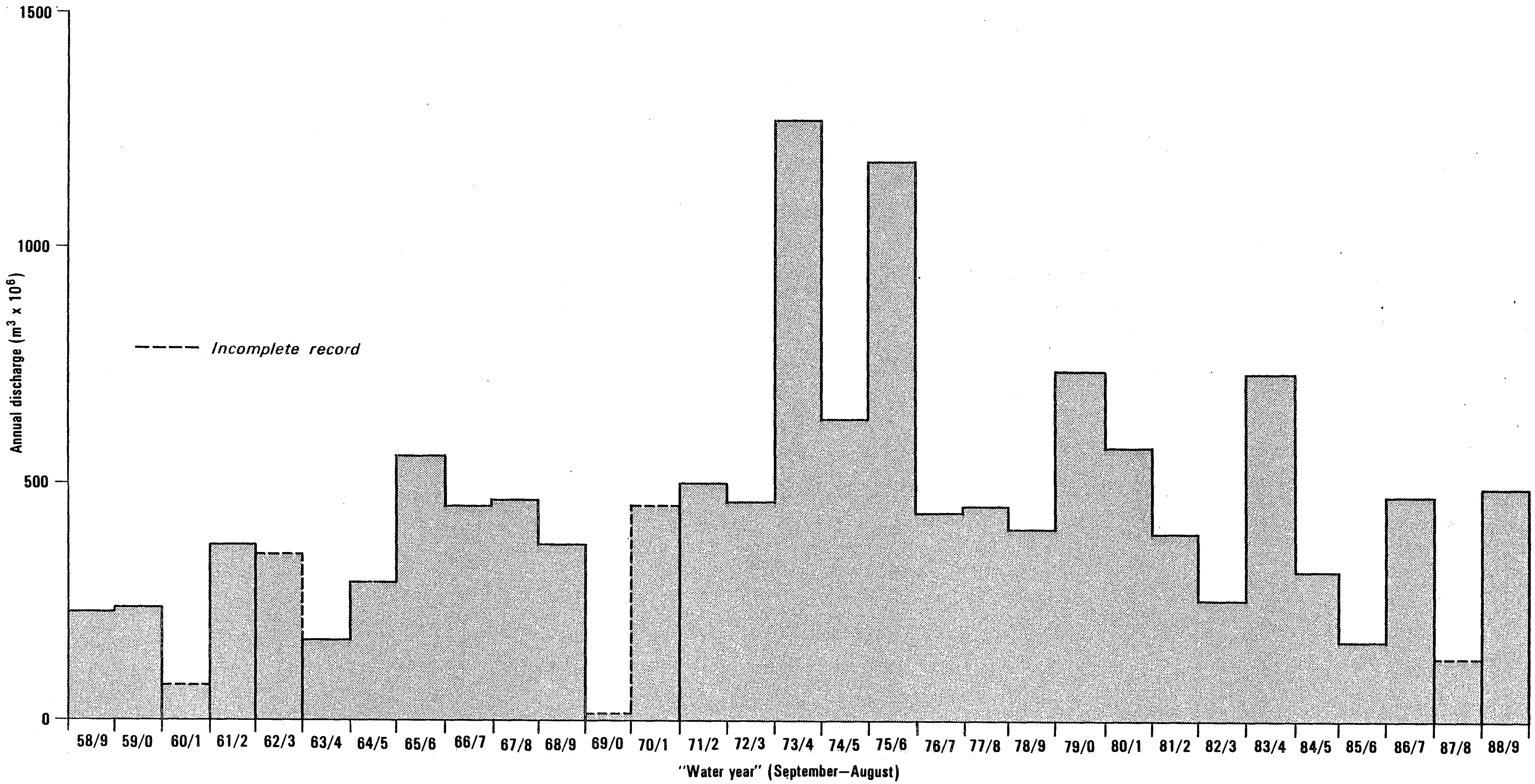
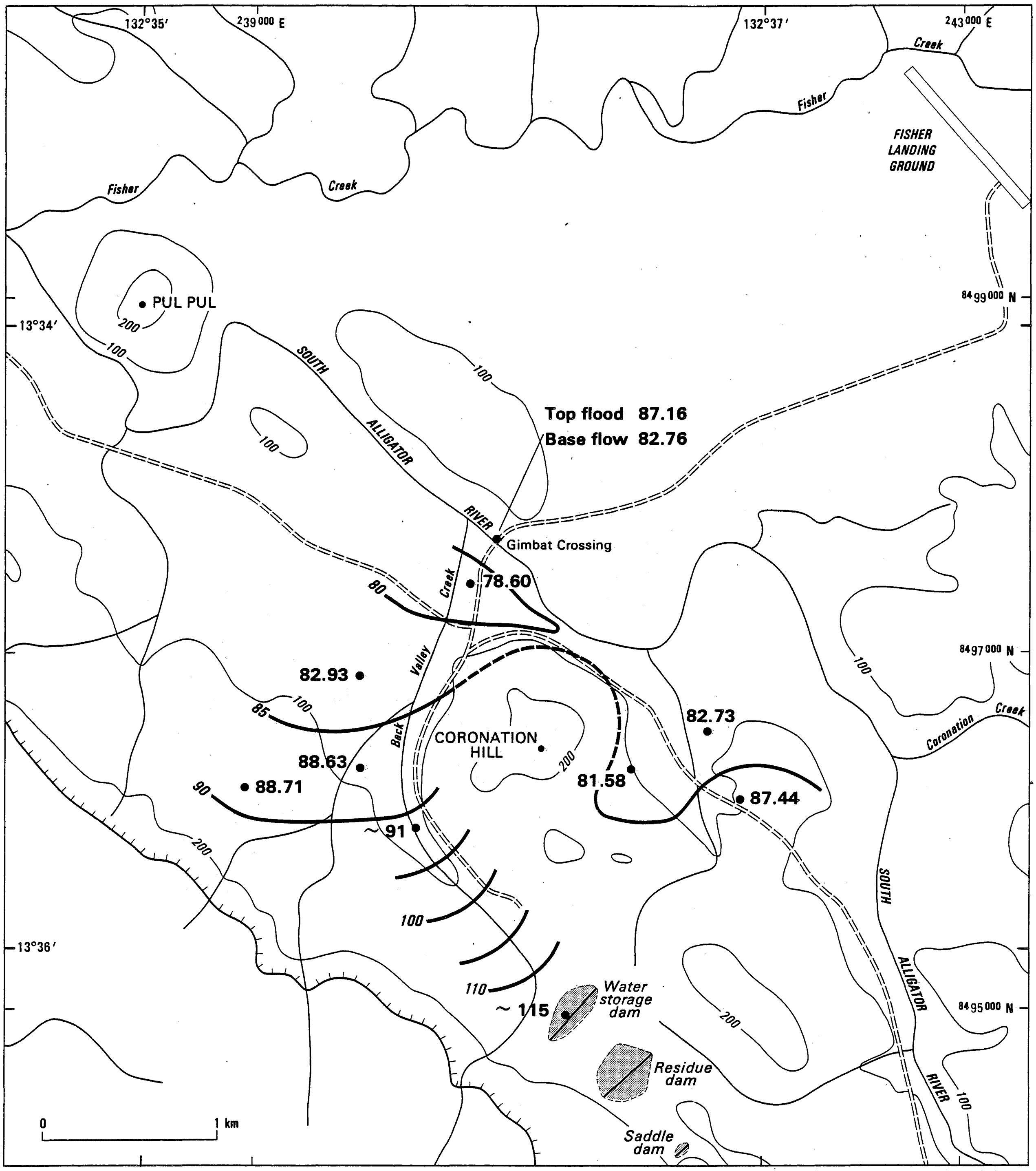


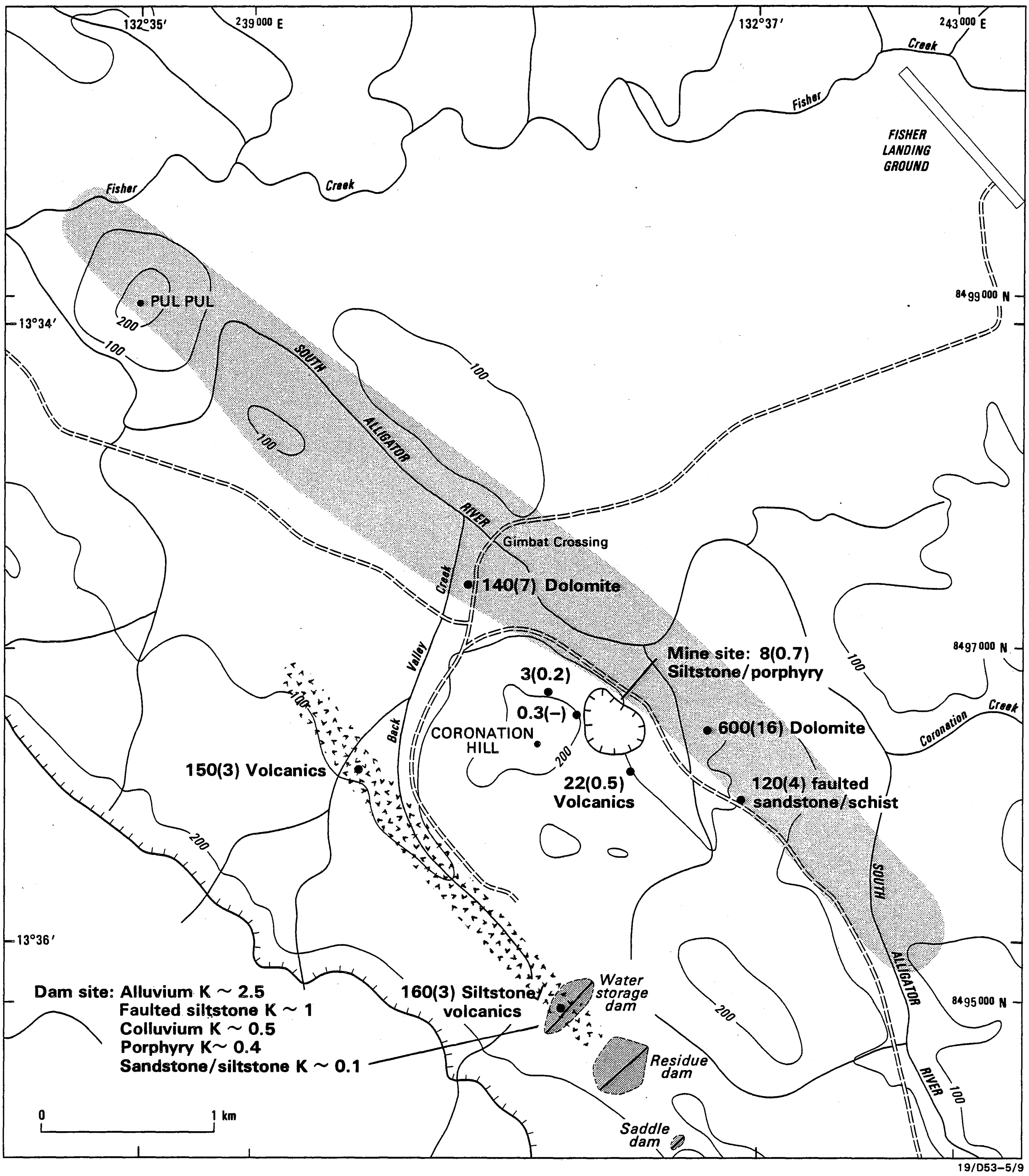
Fig 7. Annual discharge, South Alligator River at El Sherana, 1958-89

19/D53-5/7



● *Water level (m AHD)*   —*100*— *Potentiometric contour (m)*

Fig 8. Coronation Hill Potentiometry



Inferred extent of dolomite aquifer

Inferred extent of volcanic aquifer

● **140** *Transmissivity (m^2/d)*

● **(7)** *Hydraulic conductivity (m/d)*

Fig 9. Coronation Hill Transmissivity and hydraulic conductivity values

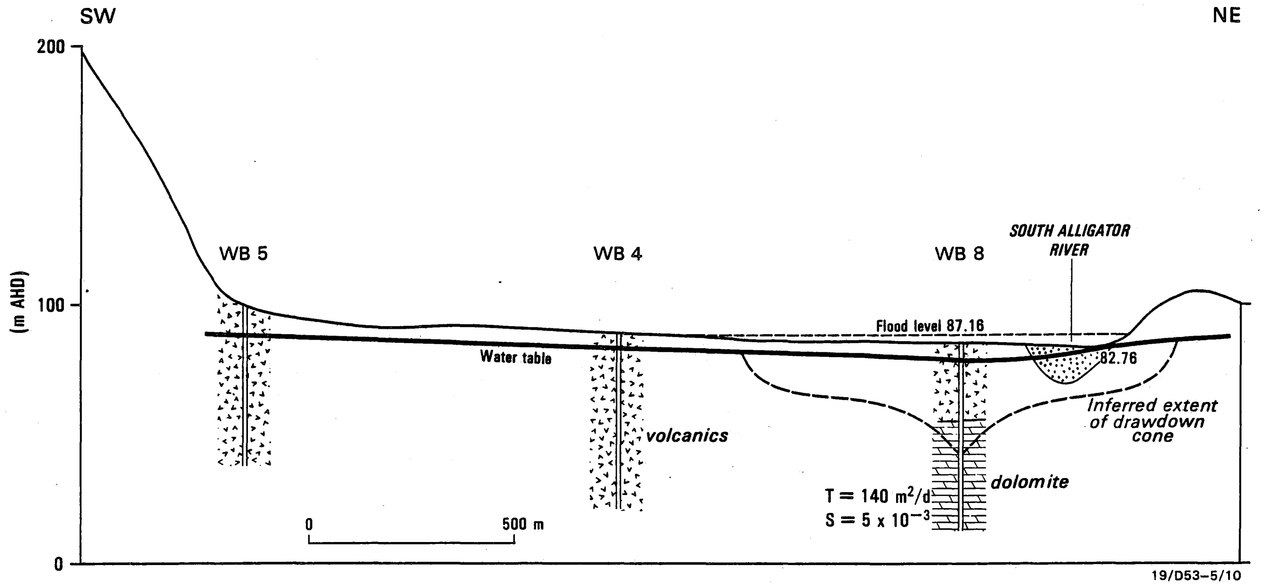


Fig 10. Cross-section showing river-aquifer relationship

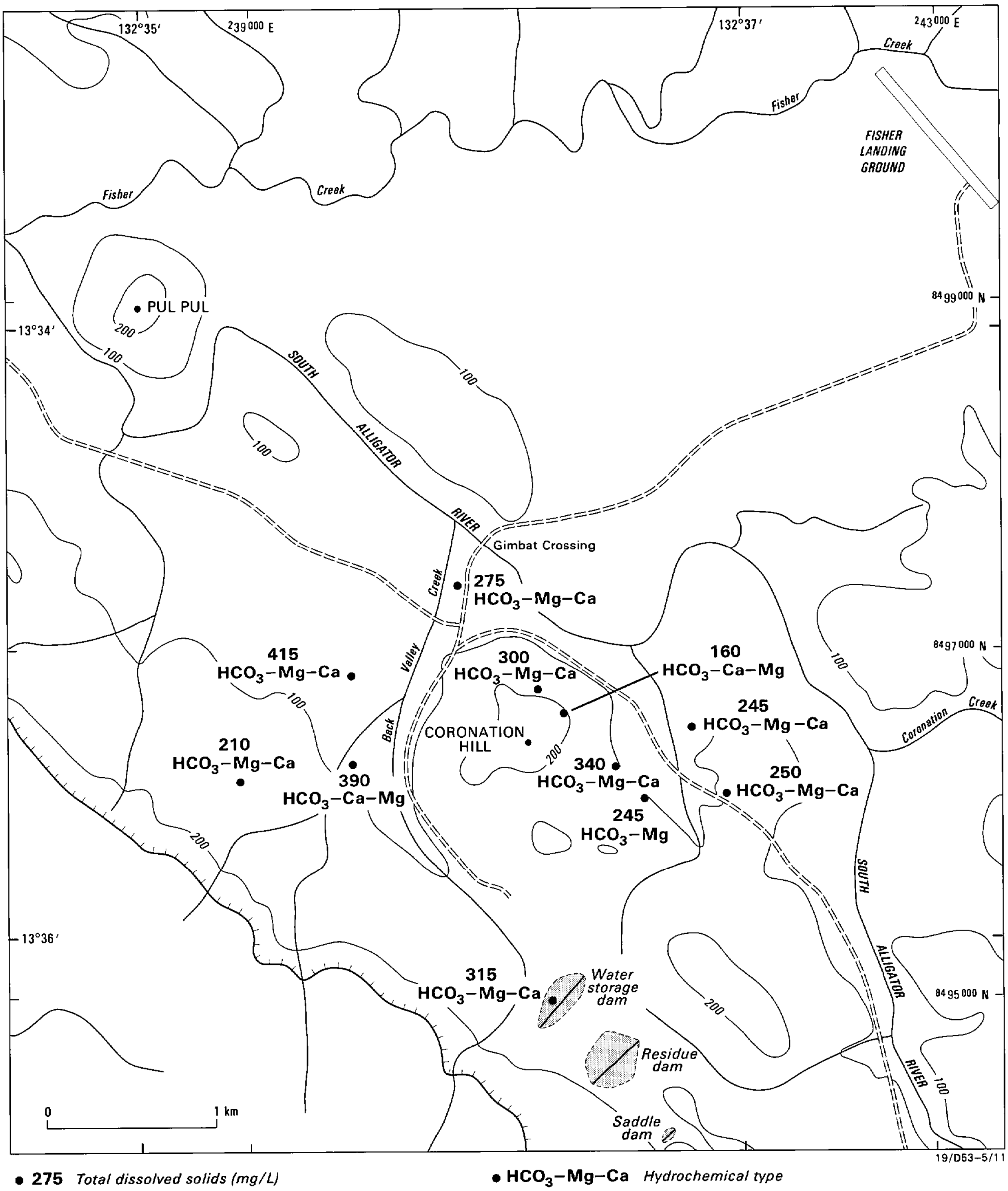


Fig 11. Coronation Hill groundwater salinity and hydrochemical type

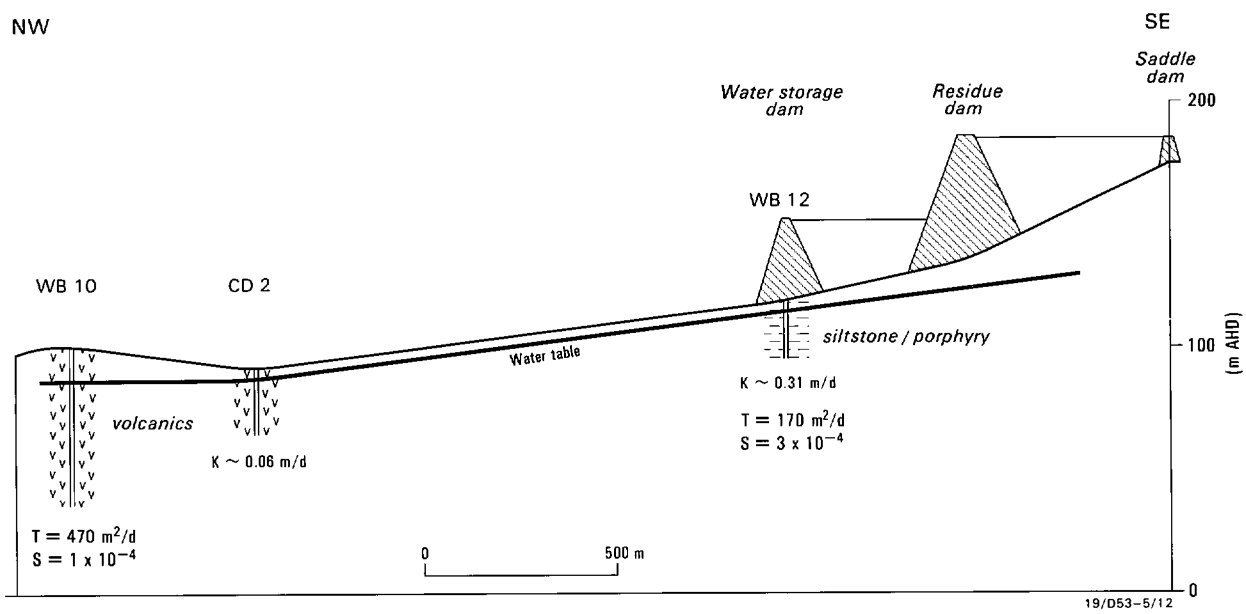


Fig 12. Section through proposed dams, Back Creek

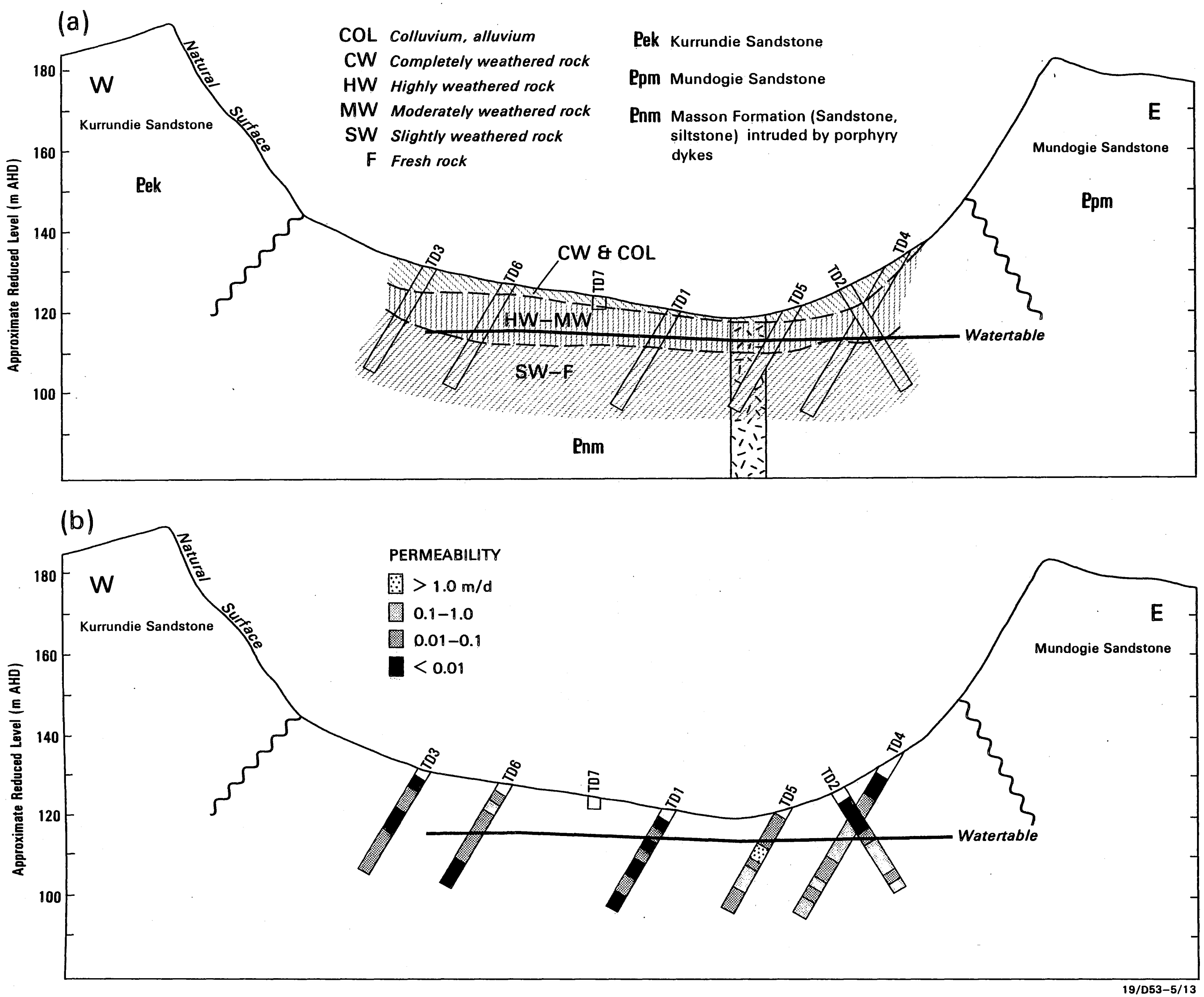


Fig 13. Cross-section of water storage dam axis showing (a) weathering zones (b) permeability