DEPARTMENT OF NATIONAL RESOURCES

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1978/86

GROUNDWATER POLLUTION BY HYDROCARBONS NEAR THE CENTER CINEMA, CANBERRA CITY

by

G. Jacobson, P.D. Hohnen & R. Evans

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PART 1. INITIAL INVESTIGATIONS, MARCH-MAY 1977

by

G. JACOBSON
(with contributions from D.I. Smith, R. Evans, and T. Kaczerepa)

PART 2. ADDITIONAL INVESTIGATIONS, MAY-JULY 1977

by

G. Jacobson, P.D. Hohnen, & R. Evans
(with contributions from D.I. Smith and T. Kaczerepa)

PART 3. MOVEMENT OF THE GROUNDWATER POLLUTION PLUME, JULY-SEPTEMBER 1977

by

G. Jacobson
(with a contribution from E.G. Wilson)

PREFACE

The contents of this Record were originally issued as BMR Engineering Geology Technical Notes on 24 May, 4 August, and in October 1977. The original documents were admitted as evidence in the Canberra Coroner's Enquiry into the explosion and fire at the Center Cinema, at hearings in May, August, and October 1977. Minor amendments have been made to the original drawings and typescript in order to correct errors brought to our attention during the Enquiry.

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SUMMARY

A fatal accident occurred in the Center Cinema in Canberra City in February 1977 when hydrocarbons and explosive vapours in the cinema basement ignited while pipes were being welded. A detailed investigation of the hydrogeology has proved an area of several hectares in which groundwater is polluted by hydrocarbons.

Thirty drillholes - constructed to define the extent and thickness of the pollution, and to monitor its movement - indicate a lenticular hydrocarbon pollution plume in the groundwater, which is present in the base of alluvium and in the underlying fractured Silurian mudstone. Permeability tests were carried out in the drillholes, and a dye tracing experiment was done to investigate groundwater flow direction and velocity. The hydrocarbon pollution plume has been estimated to contain about 32 000 litres of super-grade petrol, and is believed to have originated from a service station upstream of the cinema.

Recovery operations were initiated by constructing a shaft to remove some of the pollutant, but a more effective recovery system would be by pumping from a deep bore.

PART 1

INITIAL INVESTIGATIONS, MARCH-MAY 1977

by

G. Jacobson

INTRODUCTION

A fatal explosion occurred in the Center Cinema in the Cinema Center building, Bunda Street, Canberra City, on 10 February 1977. The explosion was associated with hydrocarbon fluids that had entered the building. Subsequently the Bureau of Mineral Resources (BMR) was requested by the National Capital Development Commission to investigate the hydrogeology of the area surrounding the cinema, with particular reference to the pollution of groundwater by hydrocarbons. In a background paper written shortly after the accident, Wilson (1978) described the general nature of hydrocarbon pollution and referred to a number of case histories of similar investigations in Europe and North America.

This report deals with BMR investigations in March-May, 1977, which included the drilling of observation holes, and their testing and monitoring. It describes the groundwater regime in the area, examines its association with hydrocarbon pollution near the Center Cinema, and discusses the options for remedial measures and long-term management of the problem. Additional drilling is in progress to define the limits of the hydrocarbon pollution.

GEOLOGY OF CANBERRA CITY

A geological map of part of Canberra City is given in Figure 1. Alluvium covers the area surrounding the Center Cinema and fills in a subdued depression that probably represents an old water course. The alluvium is 4-6 m deep and consists mainly of clay (3-4 m) which overlies clayey - sandy gravel (0.5 - 2 m). The bedrock beneath the alluvium is deeply weathered, fractured mudstone in the environs of the Center Cinema.

THE GROUNDWATER CATCHMENT

The groundwater catchment of the Center Cinema approximately coincides with the topographic catchment (Fig. 2). The general direction of groundwater flow is southwards towards Lake Burley Griffin (Fig. 9).

Groundwater aquifers occur in the basal gravel of the alluvium, and in the fractured bedrock. The alluvial aquifers are unconfined and a water table is evident. In the fractured bedrock, groundwater attains a level in bores that indicates the level of the potentiometric surface.

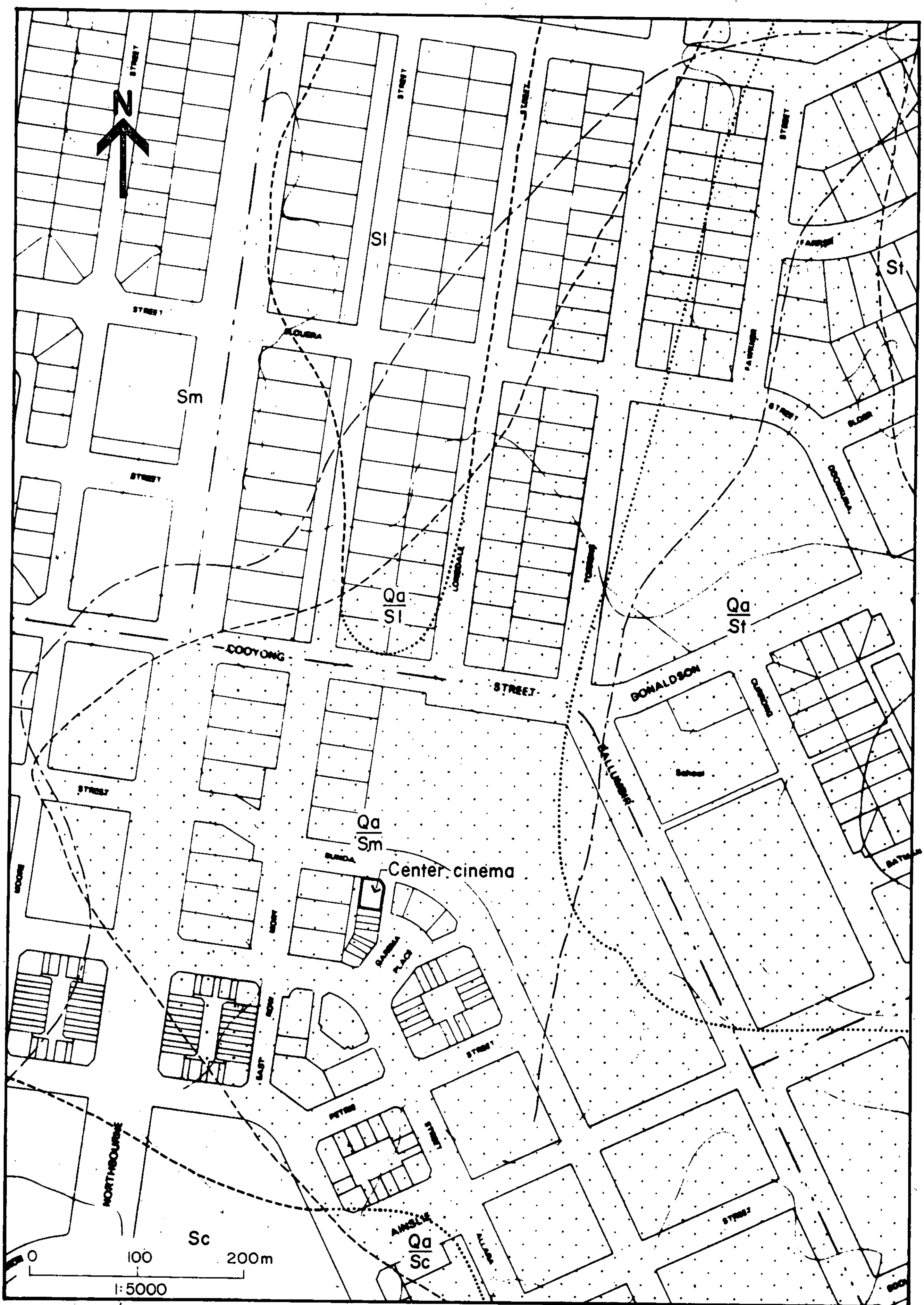

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FIG. 1 Geology of Canberra City

Reference

- - - - - - Geological boundary, approximate
. . . . Geological boundary, concealed
— - — Catchment boundary
Qa *Alluvium: clay, sand, gravel; Quaternary*

Sm *Mudstone: deeply weathered*
Sc *Calcareous mudstone: shallow weathered*
St *Tuffaceous sandstone: deeply weathered*
Sl *Limestone*
(Sm, Sc, St, Sl: *Silurian*)

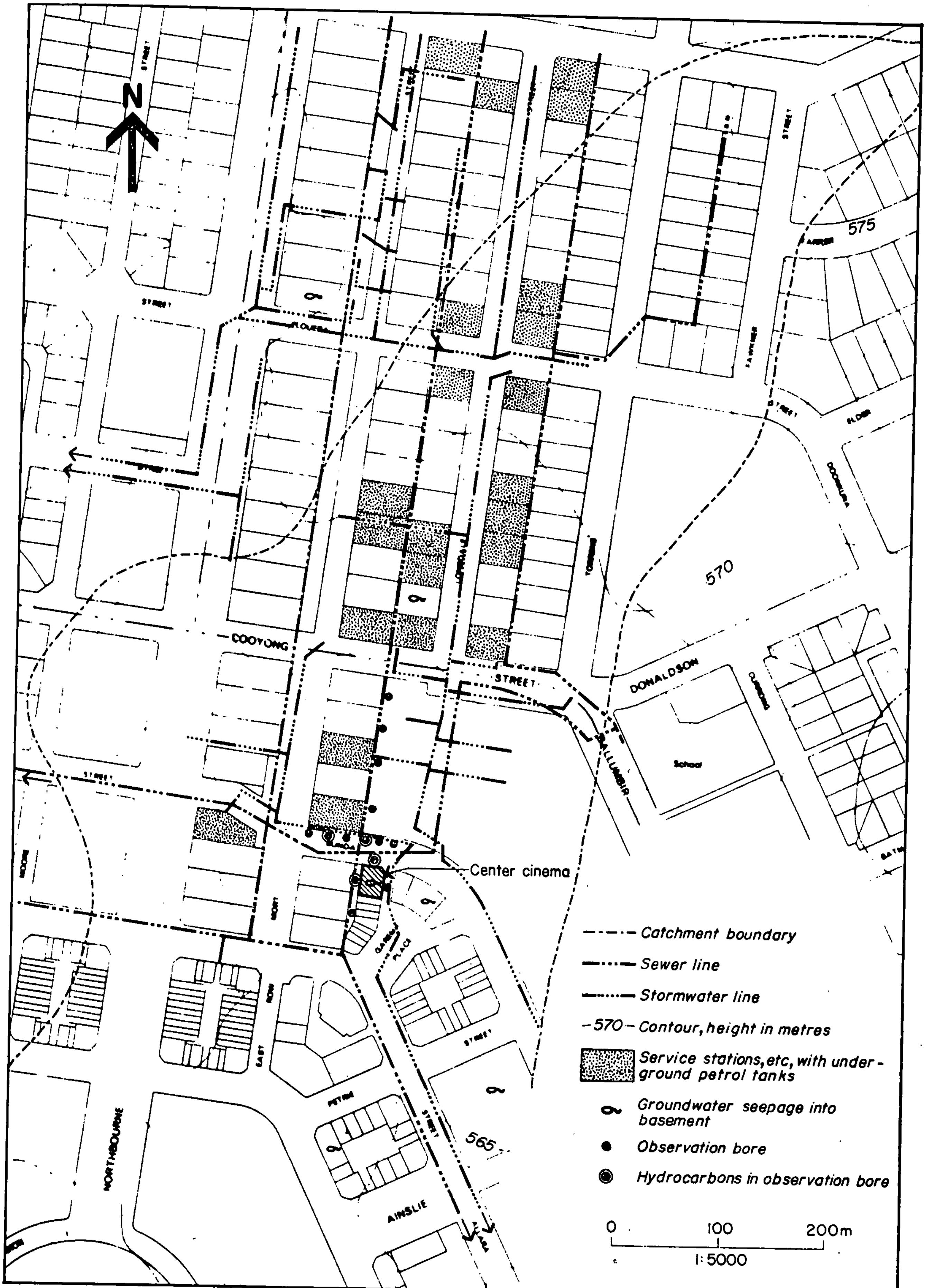

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FIG. 2 Hydrology

The locations of the main sewers and stormwater drains in the catchment are shown in Figure 2. The sewers drain southwards to join the main interceptor sewer flowing westwards along Bunda Street. The sewers are sealed pipes laid in trenches 3-5 m deep; the pipe bedding and backfill materials are sandy, and are more permeable than the surrounding alluvium. The trenches for sewers and stormwater drains provide a ready path for groundwater movement.

The catchment is entirely urban and surfaces are paved; recharge to groundwater is therefore mainly through leakage from stormwater drains. The stormwater drains are open-jointed in part and are laid in trenches 0.5 - 1.5 m deep. Intersections of trenches where stormwater drains cross sewer pipes are likely to provide access for rapid infiltration of water underground.

The catchment contains twelve service stations and numerous other motor vehicle and servicing establishments, all of which are potential sources of hydrocarbon pollution. There are about 60 underground petrol tanks in the catchment, mostly with their bases set at depths of 3-4 m, which is close to, or actually into, the alluvial gravel.

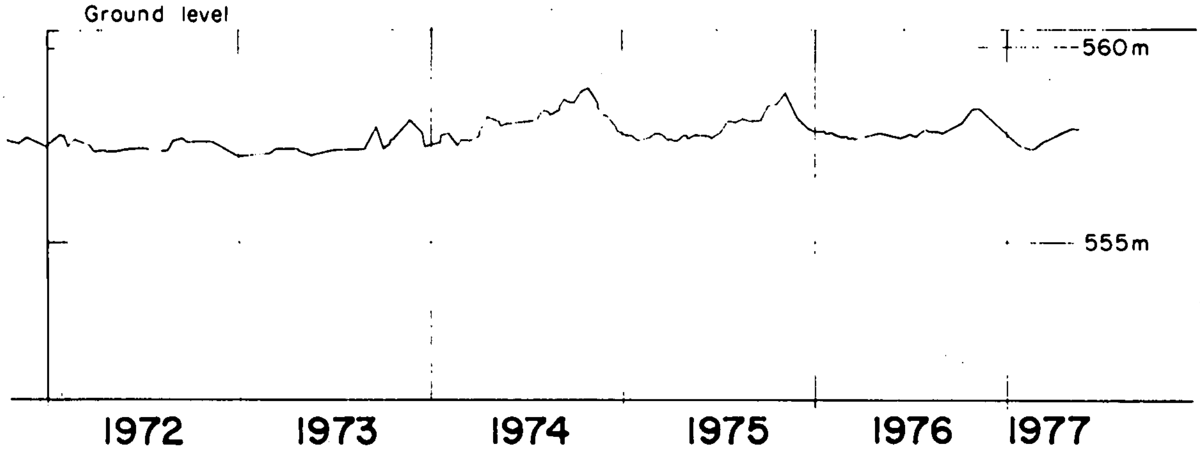
Groundwater levels were not monitored in the catchment prior to the accident. The nearest BMR observation bore is at Glebe Park, Reid; groundwater levels in this bore (Fig. 3) show a normal seasonal fluctuation with peaks in October-November after spring rainfall.

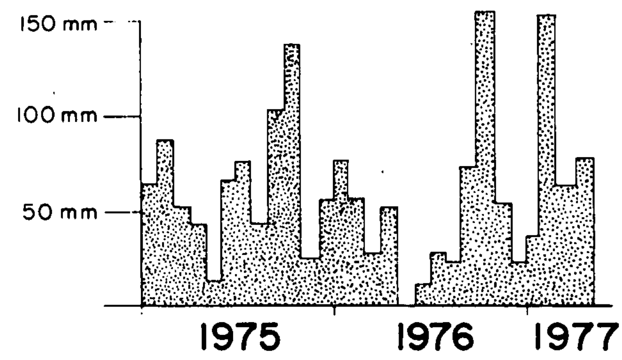
HYDROGEOLOGY OF THE CENTER CINEMA AREA

The hydrogeology* of the Center Cinema area was investigated by diamond drilling and setting open tube piezometers in March-April 1977; groundwater and hydrocarbon levels were subsequently monitored. The locations of the drillholes are shown in Figure 4, and detailed logs of the drillholes are given in Appendix 3. Drillholes numbered 6, 8, 10, 12 and 13 were constructed with slotted casing in the alluvium, and were completed at the alluvium-bedrock contact (Fig. 5). In drillholes 1, 2, 3, 4, 5, 7, 9, 11 and 14, the alluvium was sealed off and slotted casing was installed to a depth of 11 m in the fractured mudstone. Rubble was encountered in bore 2 adjacent

*A glossary of hydrogeological terms used in this report is appended to Part 3 of this Record.

Groundwater levels, BMR observation bore, Glebe Park, Reid





Canberra City rainfall

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FIG.3 Observation bore hydrograph

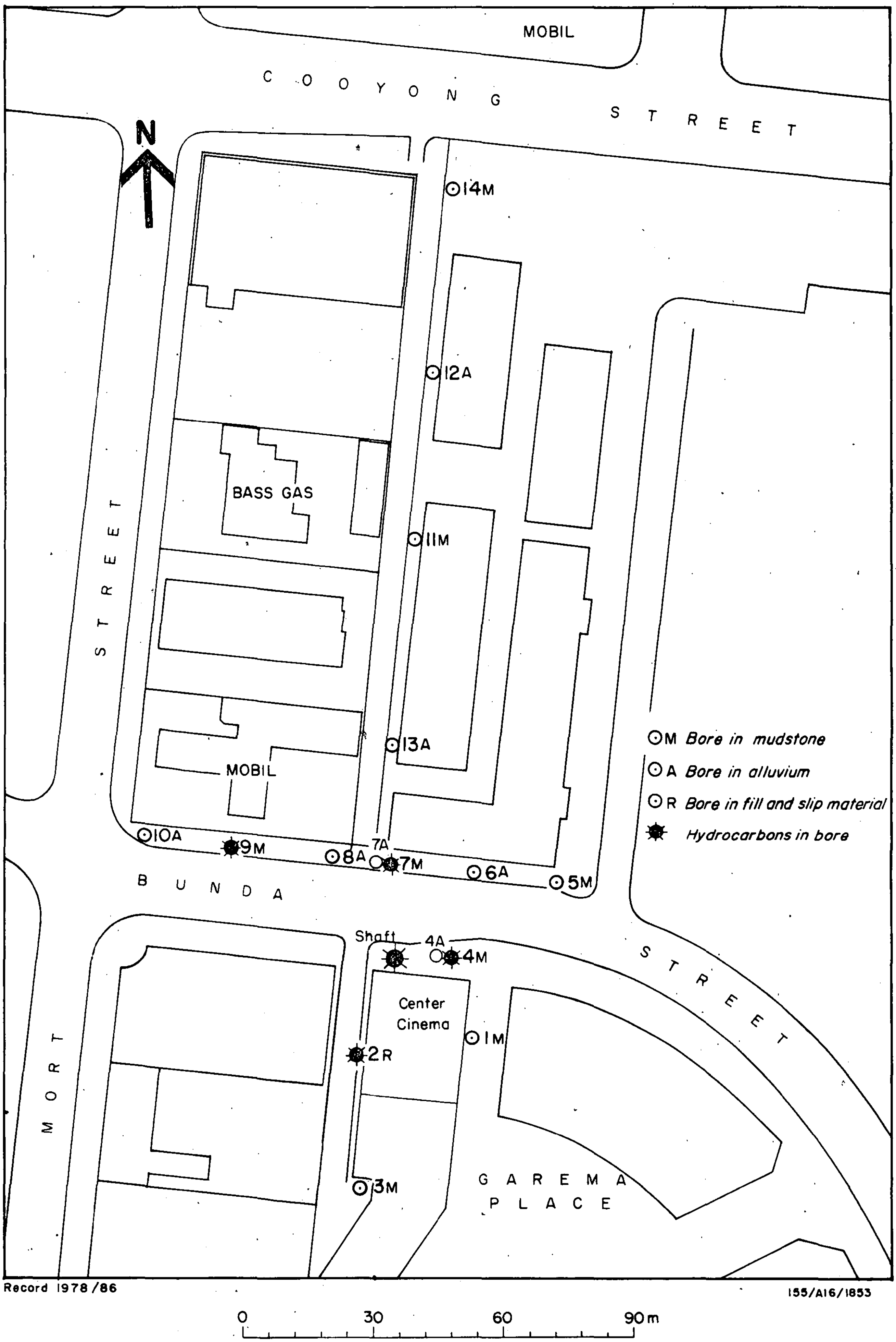
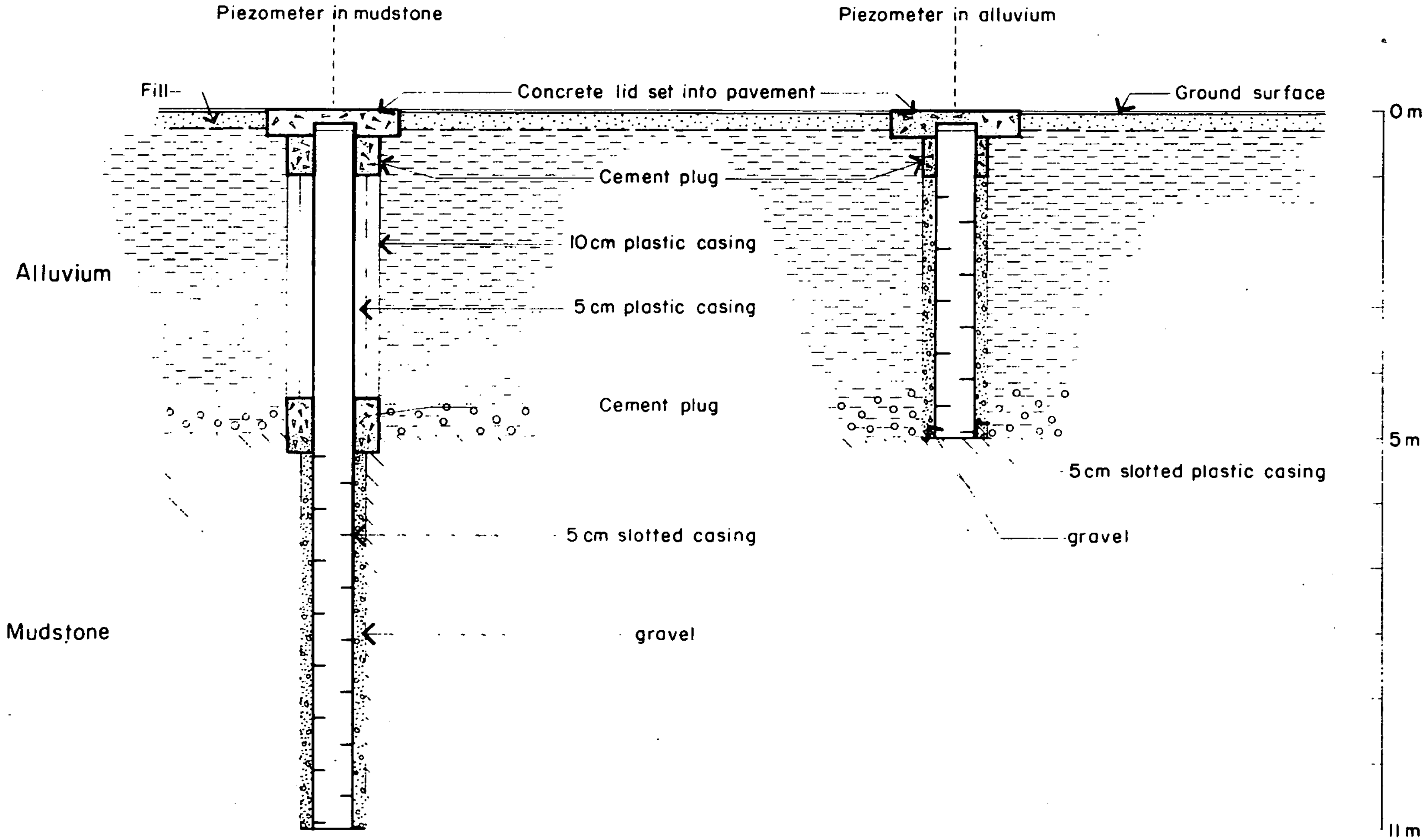


FIG. 4 Location of bores

FIG. 5 Details of piezometer construction



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to the cinema, at a depth of 7 m; this indicates that the mudstone above the rubble must have been displaced by a slip when the foundations were under construction.

Depth of alluvium

The drilling program has proved that the depth of alluvium in the vicinity of the cinema ranges from 2.9 to 5.7 m. The two deepest pockets of alluvium are underlying Bunda Street immediately north of the Center Cinema, and in the northern part of the laneway near Cooyong Street (Fig. 6). Contours on the alluvium-bedrock have been plotted (Fig. 7) and indicate a buried valley trending south to southeast in the vicinity of the Center Cinema.

Occurrence of groundwater

North-south and east-west cross-sections showing lithologies and water levels are set out in Figure 8. Groundwater has been encountered in all theebores, but two bores, 6 and 8, are generally dry. The north-south section shows the potentiometric surface of the mudstone aquifer sloping gently towards the Center Cinema, and the east-west section shows that the water level in bore 7 is depressed below the water levels in bores 9 and 5 on each side of it. The generalized water level contours in Figure 9 indicate that the potentiometric surface is depressed towards the front of the Center Cinema, and that the main groundwater flow is from the northwest towards the front of the building.

The north-south section also shows the water table of the alluvial aquifer at a higher level than the potentiometric surface of the mudstone aquifer; however, the alluvial aquifer loses water as it approaches the Center Cinema and it is shown in the section as merging with the potentiometric surface of the mudstone. The higher, alluvial aquifer is a perched aquifer, and indicates a zone of lesser permeability between it and the underlying fractured mudstone aquifer.

Fluctuations of water levels in the bores have been monitored (Fig. 10). In general, water levels in the alluvium are quicker to respond to rainfall events than those in the mudstone because of the more permeable nature of the alluvial aquifer. Borehole tests have determined the mean values of the coefficient of permeability as 0.45 m/day for alluvium and 0.05 m/day for mudstone (Appendix 2).

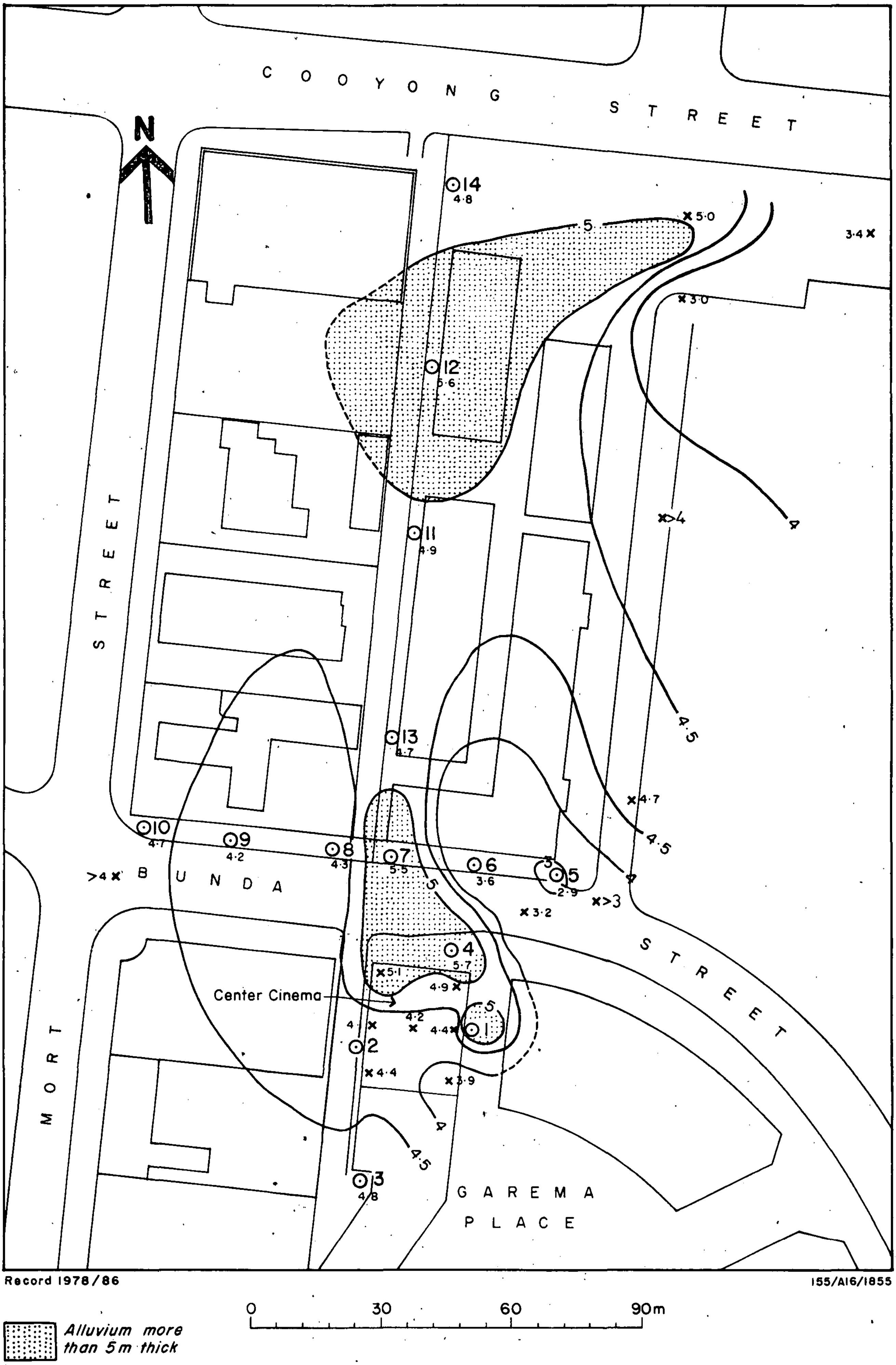
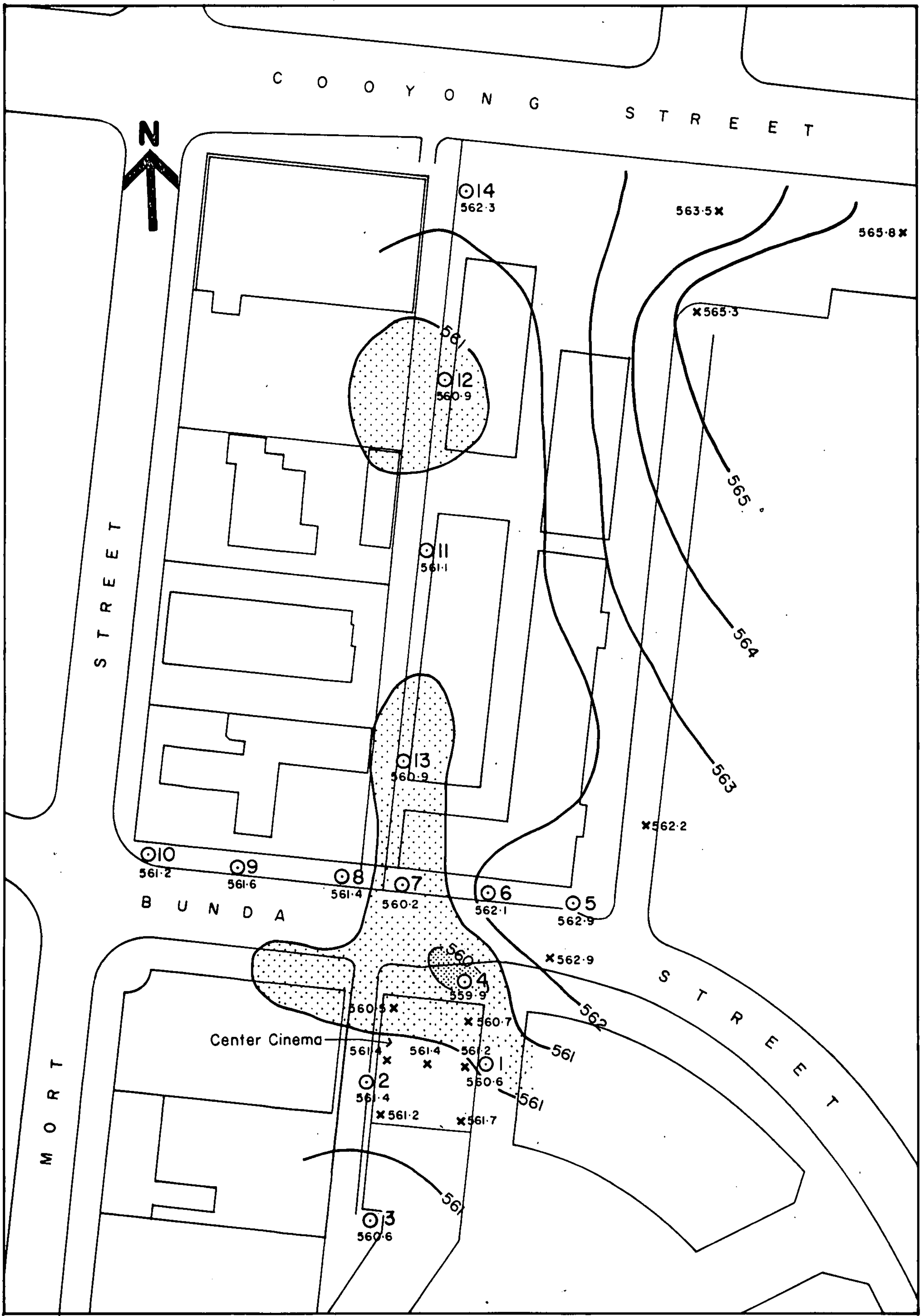


Fig.6 Thickness of alluvium

—— 4·5 —— Thickness of alluvium (in metres)



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Contact below 560 m

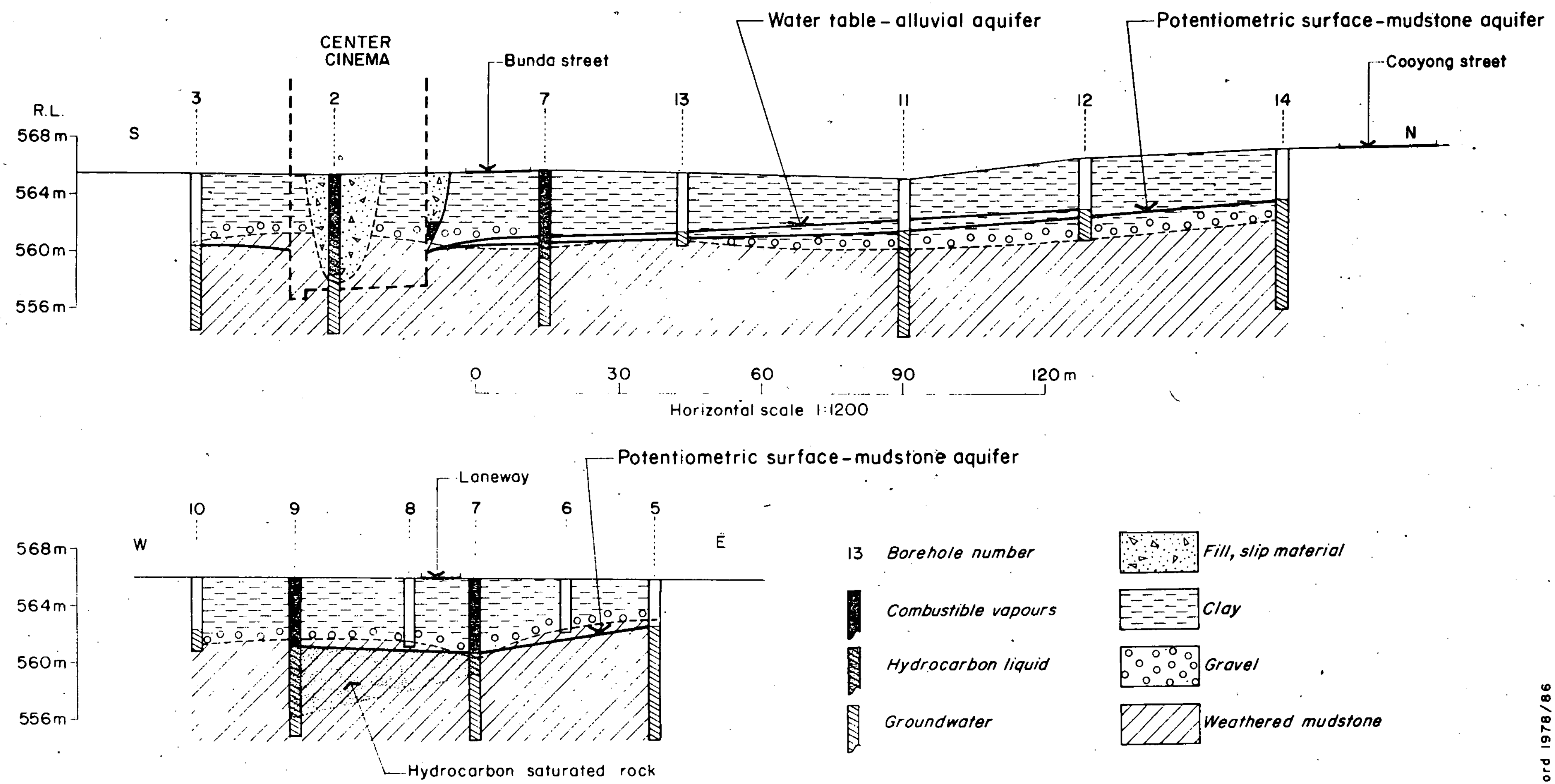
Contact 560–561 m

0 30 60 90 m

FIG. 7 Contours on the alluvium-bedrock contact

—563— Elevation of alluvium-bedrock contact (m)

FIG. 8 Geological sections



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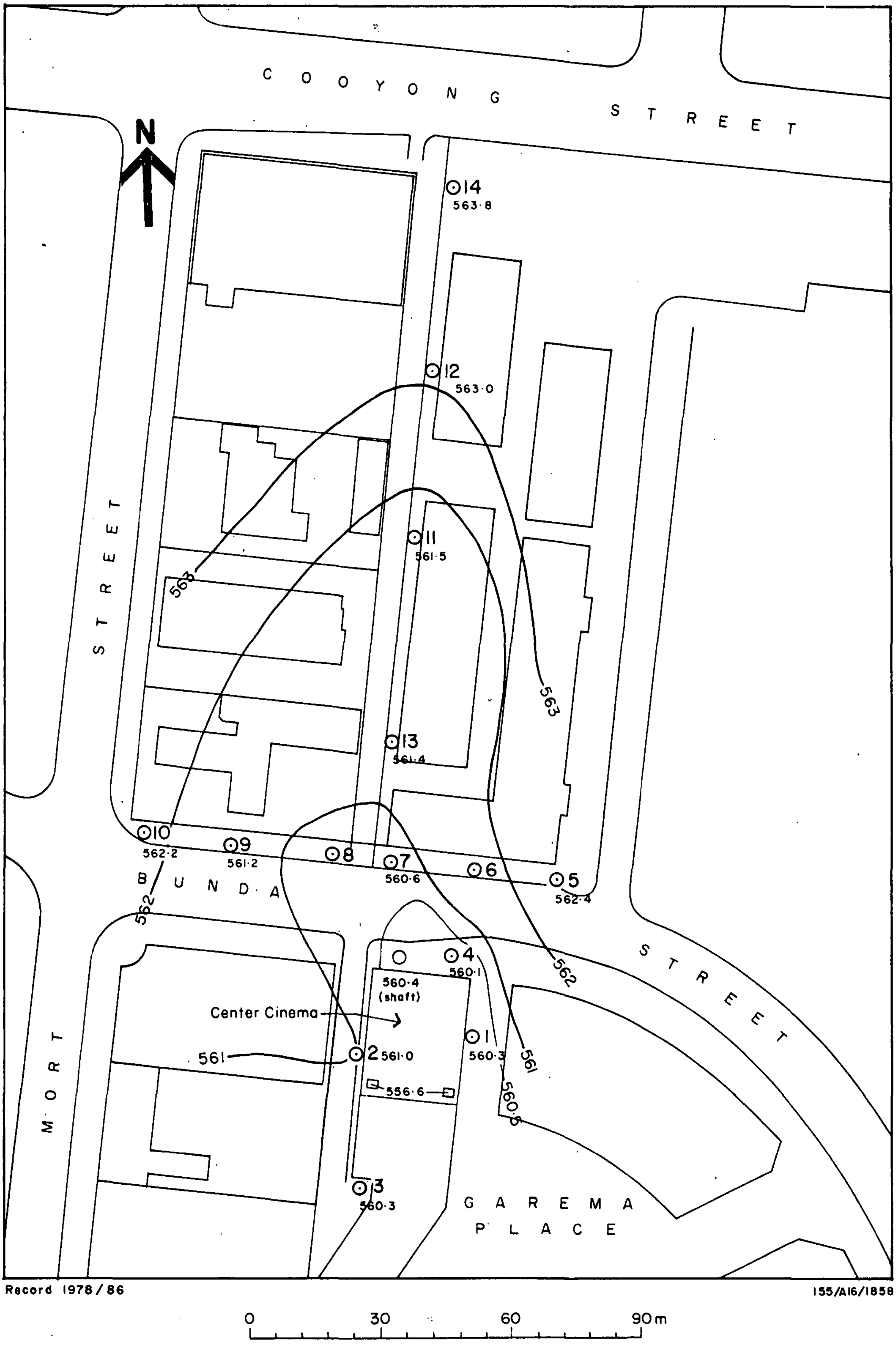

FIG. 9 Water level contours

28·3·77

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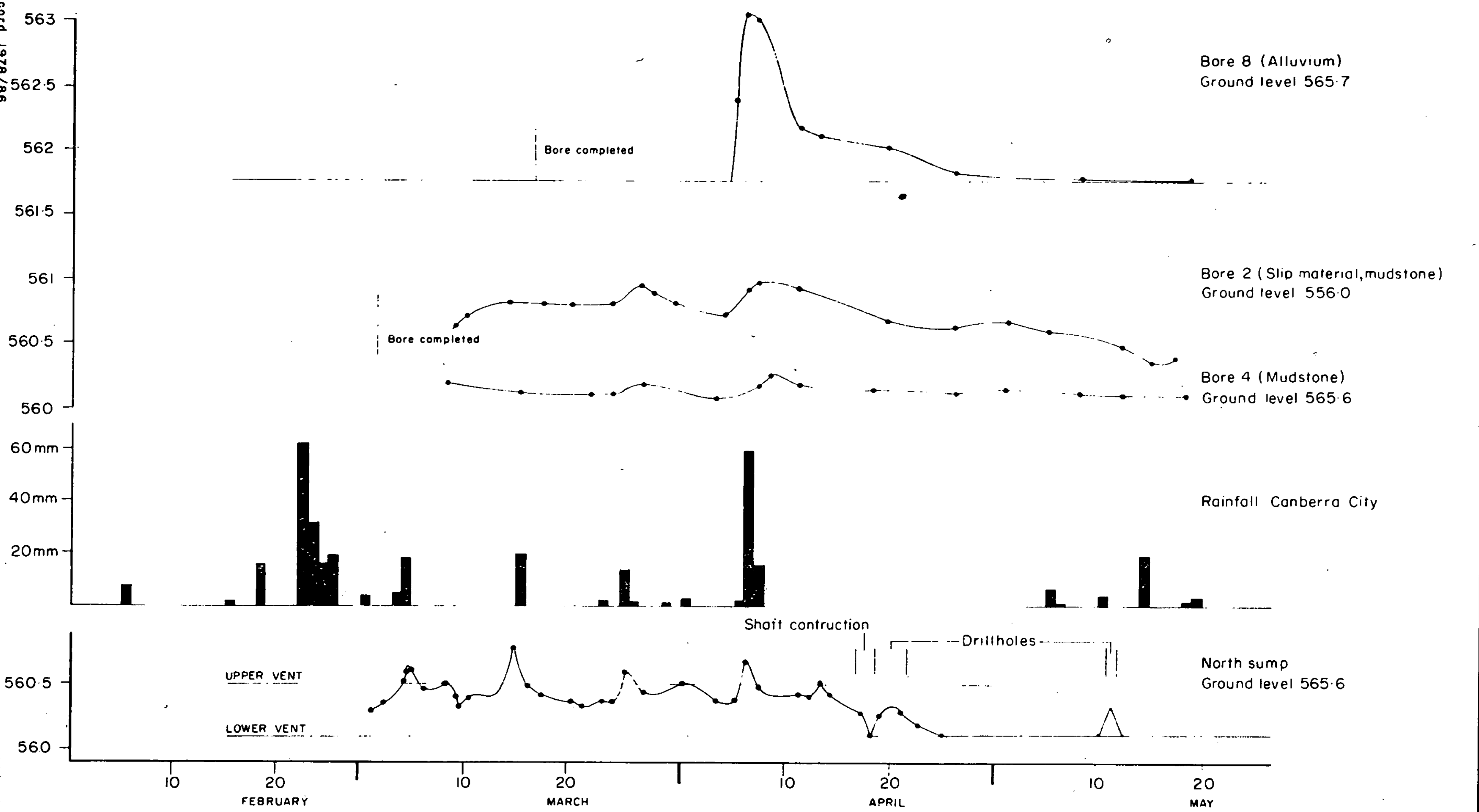

FIG.10 Water level fluctuations

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Investigations so far indicate that water entering the ground reaches the alluvial aquifer first and flows in accord with the water table gradient towards the Center Cinema. With time, water from the alluvial aquifer infiltrates down into the underlying mudstone aquifer, and flow in the alluvial aquifer ceases. This hydrogeological situation is modified in the vicinity of the Center Cinema by pumping from the cinema sumps.

A dyr tracing experiment has been conducted in conjunction with D. Ingle Smith of the Australian National University (Appendix 2). Rhodamine dye was injected into the base of the alluvium in a specially constructed borehole 7A on 19 April. The travel time of the dye into the Center Cinema and monitoring boreholes was measured as 2 to 5 m/day. The conclusions to be drawn from this experiment are set out in Appendix 2.

Occurrence of hydrocarbons

Hydrocarbons with explosive vapours have been encountered in bores 2, 4, 7, 7A, and 9. Because of the injection of large quantities of water during drilling it took several weeks for the hydrocarbons to enter the bores and establish a column indicative of the thickness of hydrocarbon-saturated ground. The thickness of hydrocarbons was measured on 12 May as follows:

Bore No.	Thickness of hydrocarbon column (m)
2	2.70
4	0.10
7	0.35
9	4.55

These measurements indicate that the main part of the pollution plume is in fractured mudstone to the west and northwest of the Center Cinema.

Hydrocarbons have also been found on top of groundwater outside the front of the Center Cinema; this pocket of fluids is shown on the north-south section (Fig. 8) as being within a wedge of rubble. The water levels have been measured over a period of time (Fig. 10), and the wedge acts as a perched aquifer when it is charged with fluids.

THE CENTER CINEMA

A plan of the Center Cinema foundations is shown in Figure 11; cross-sections are shown in Figure 12, and the surrounding hydraulic services in Figure 13. The building excavation is about 8 m deep, through 4-5 m of alluvium into weathered and fractured mudstone. There is some rubble and slipped material around the building especially on the north and east sides where subsidence of pavements is evident. Bore 2, adjacent to the west side of the cinema, encountered slipped material to a depth of 7 m.

Groundwater drainage

Groundwater is drained from beneath the concrete slab floor of the cinema into two sumps by a herringbone system of rubble drains. From the sumps the water is pumped intermittently into stormwater drains outside the building. The purpose of the groundwater drainage system is to relieve uplift pressures on the concrete floor slab.

The total groundwater inflow into the building was measured several times during March and found to average 400 litres per hour. Since the investigations began, hydrocarbons have been continually present with the groundwater, particularly in the west drainage sump.

The north sump

The north sump was the scene of the fatal explosion. It houses sewage ejection equipment, and is not connected to the foundation drainage system. Two vents, about 4 cm diameter, penetrate the north wall at 2.6 and 3.0 m above the floor of the sump; they were installed a few years ago to drain groundwater from outside the front wall of the building. Since the explosion, fluid levels outside the north wall have been monitored by fitting plastic tubes to the vents in the wall; the levels rise rapidly following railfall (Fig. 10). A layer of hydrocarbons on the water outside the north sump persisted through March and April. Figure 14 shows the rise of the fluid level outside the north sump during heavy rain on March 15. As the fluids rose, fumes built up to danger level within the sump, but once the

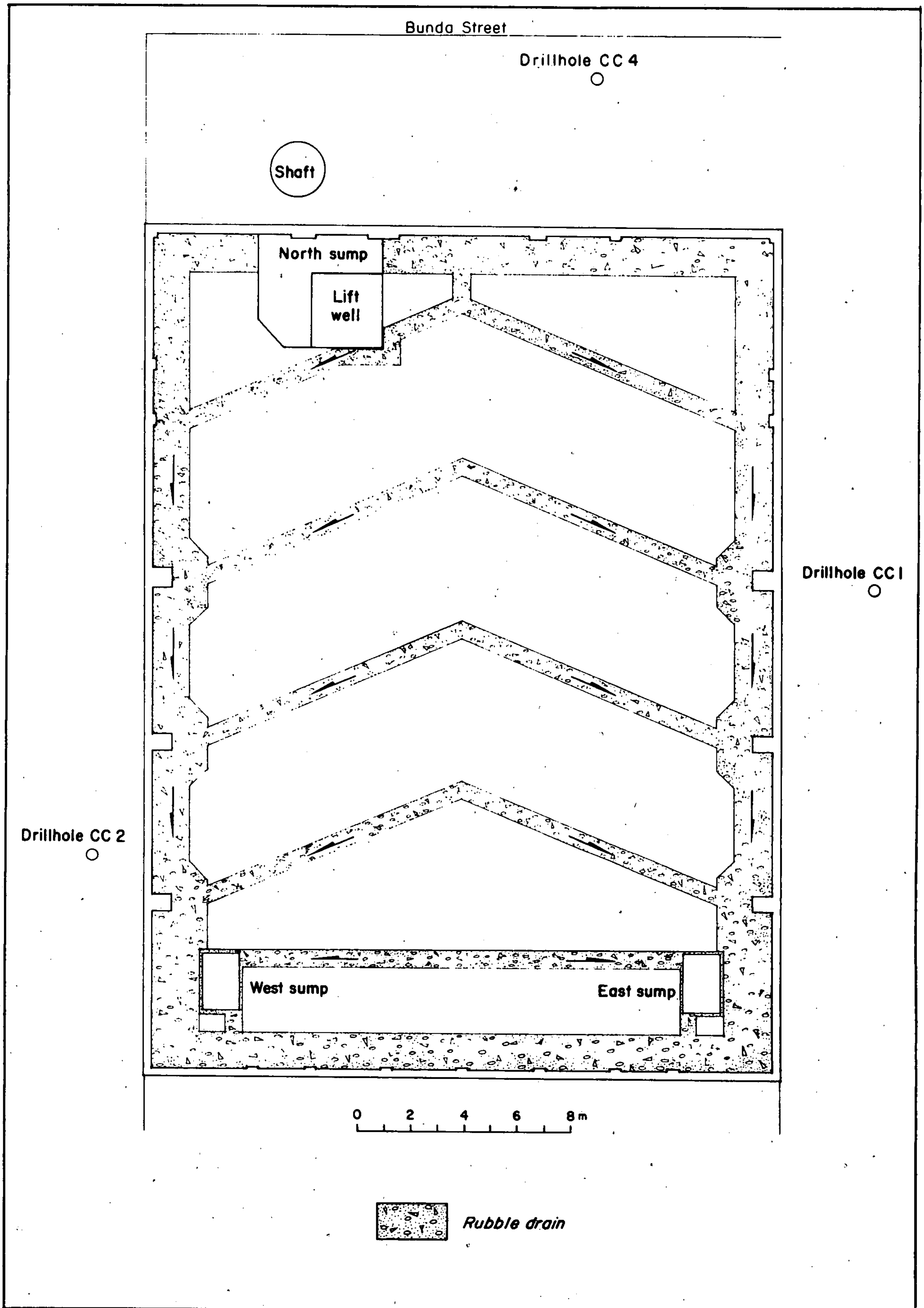

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FIG. 11 The Center Cinema–Foundation Drains

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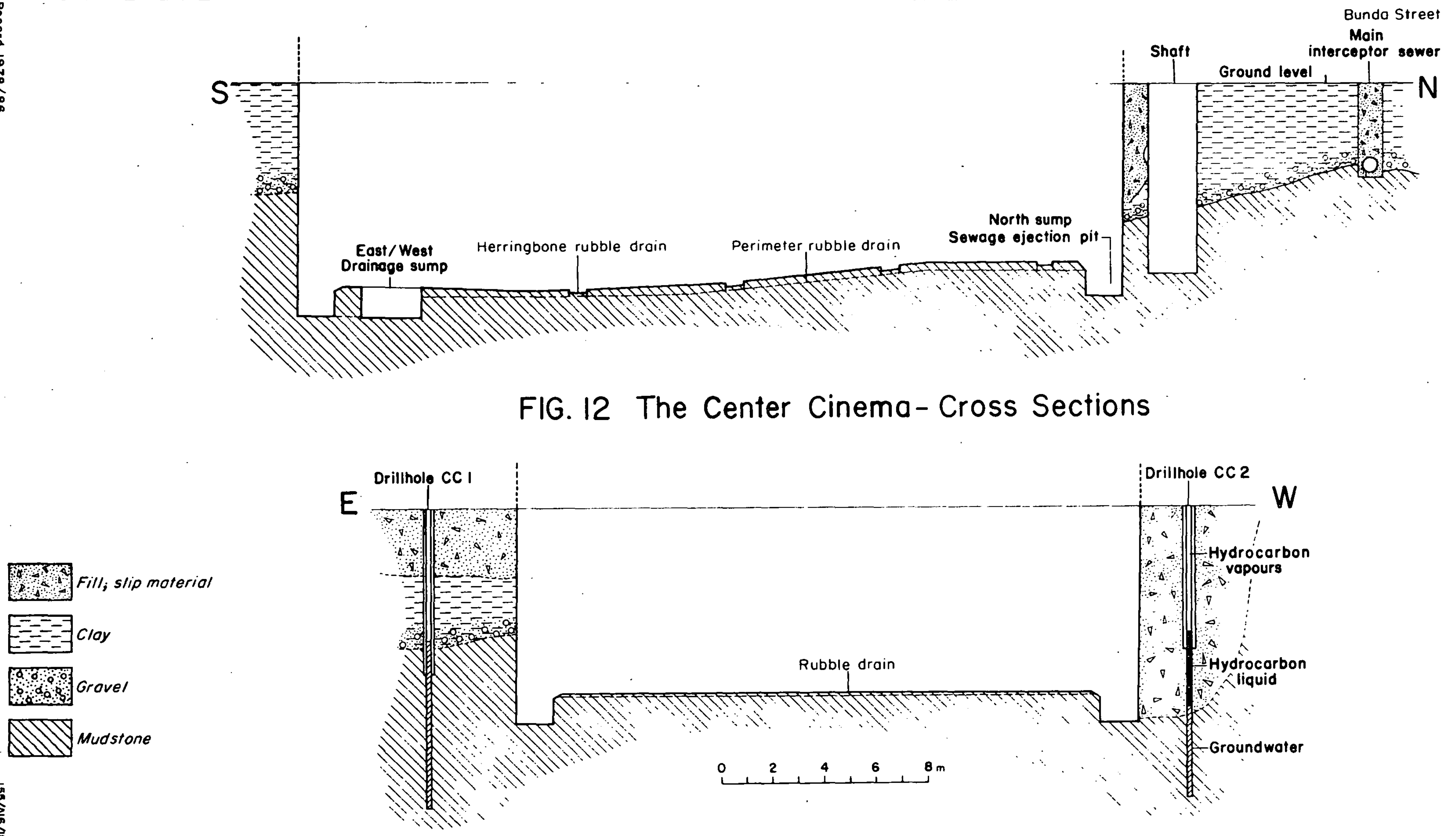

FIG. 12 The Center Cinema - Cross Sections

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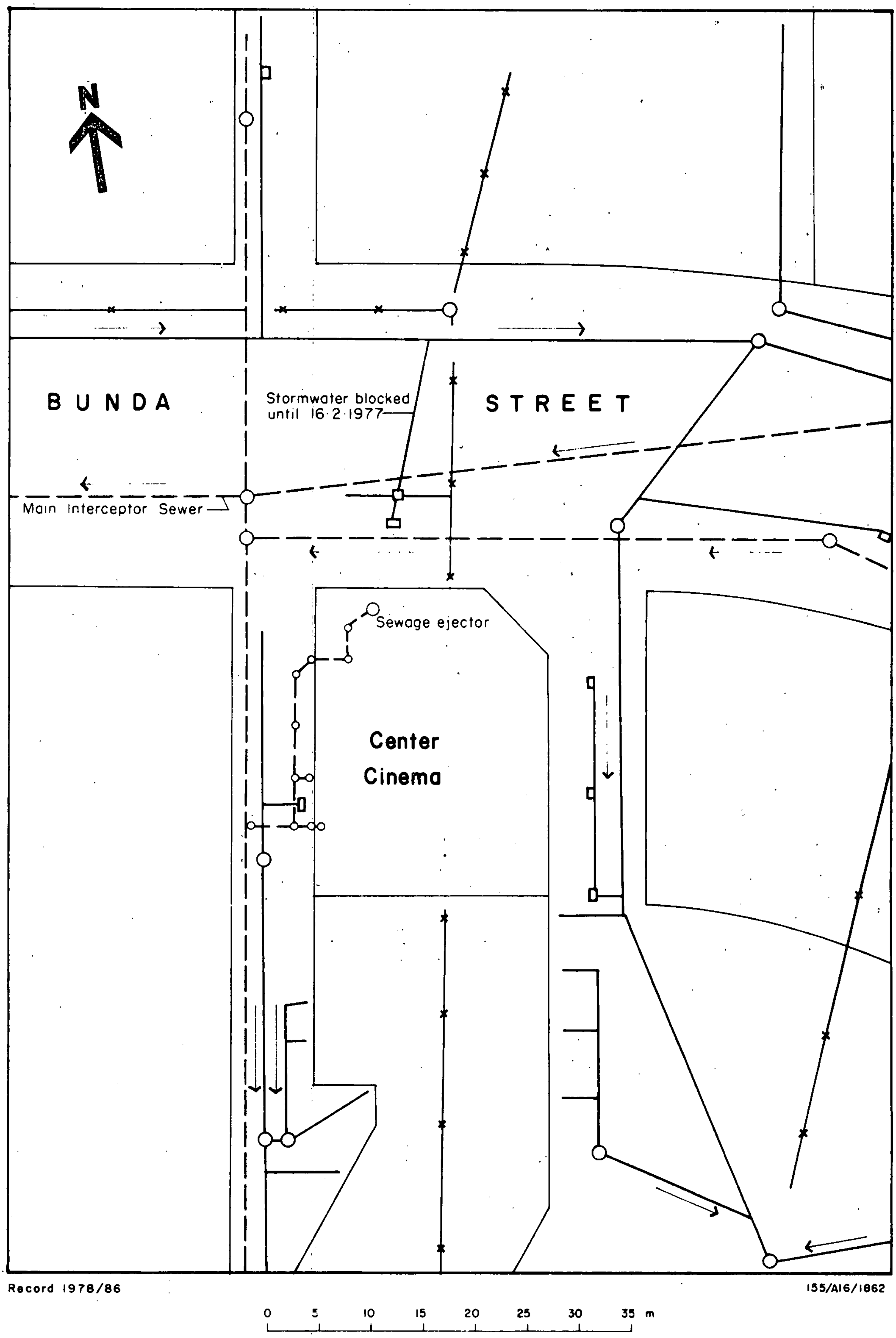

FIG. 13 Hydraulic Services

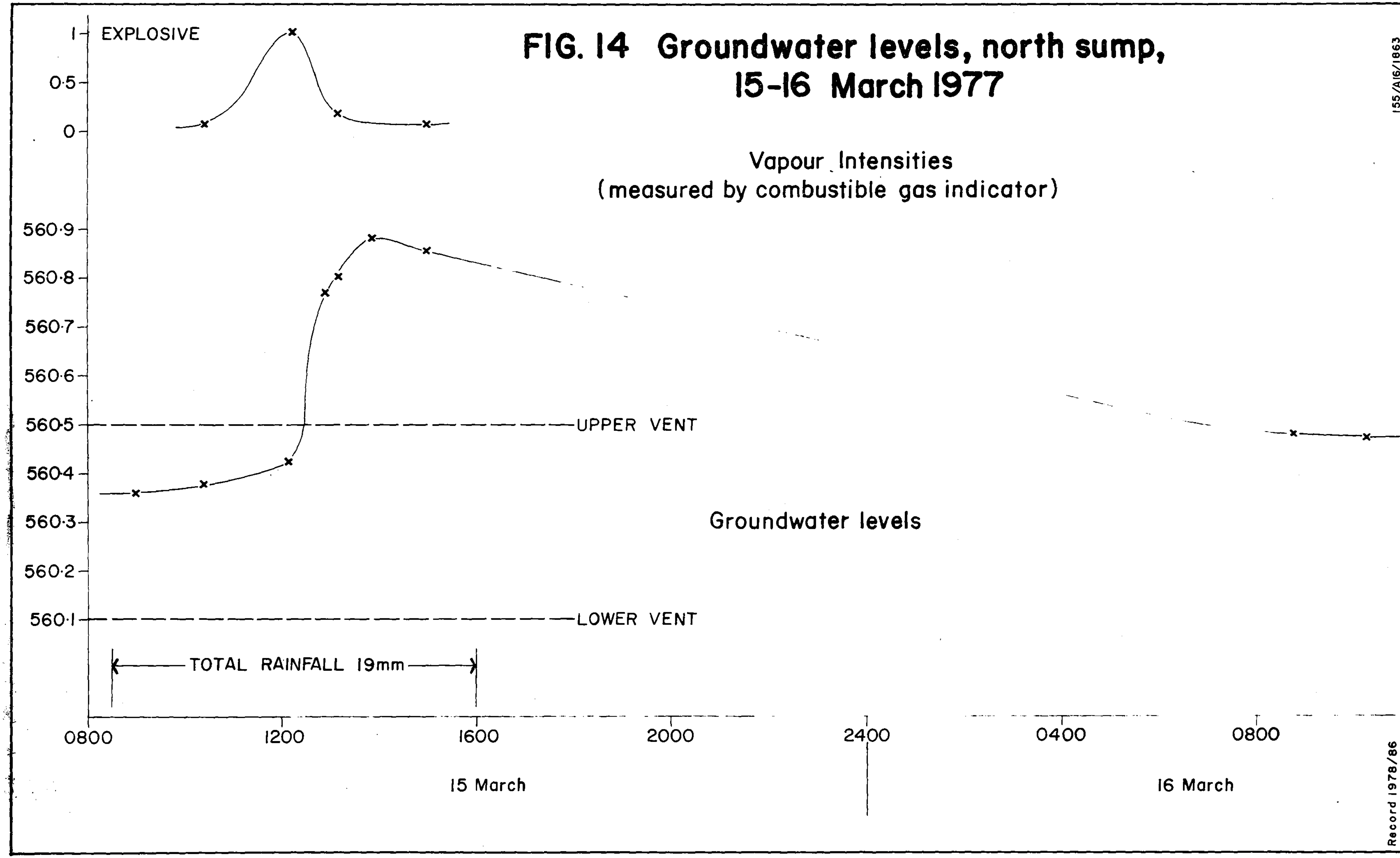
FIG. 14 Groundwater levels, north sump, 15-16 March 1977
EXPLOSIVE
1
0·5
0
Vapour Intensities
(measured by combustible gas indicator)
560·9
560·8
560·7
560·6
560·5
560·4
560·3
560·2
560·1
UPPER VENT
LOWER VENT
Groundwater levels
TOTAL RAINFALL 19mm
0800
1200
1600
2000
2400
0400
0800
15 March
16 March
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rising water had pushed the hydrocarbon layer above the level of the top vent, the high concentration of combustible gas dissipated quickly.

Water has also entered the north sump through cracks in masonry and concrete at floor level of the sump.

A stormwater main in front of the building that was found to be blocked is also considered to have contributed to groundwater recharge outside the front wall (Fig. 13).

The shaft

A shaft was sunk outside the north sump in April 1977 with drainholes radiating out to the wall of the building. The shaft (Fig. 15) was excavated from 4.5 to 7 m through closely jointed mudstone with the joint planes saturated with hydrocarbons. After construction the inflow into the shaft was 1400 litres of fluid in 10 days, including 30 litres of hydrocarbons. Additional drainholes were installed on 13 May to ensure that the pocket of hydrocarbons outside the north sump is effectively drained. Permanent ventilation is being installed in the shaft which will serve as a recovery well; fluids in the shaft will be removed by suction pump to a tanker once a week.

Entry of hydrocarbons into the building

The Center Cinema is set in the deepest building excavation in the city, and lies across the path of natural groundwater drainage from the north and northwest. The cone of depression in the water table around the cinema is maintained by the pumping of water from the east and west drainage sumps; it provides a sloping surface on top of which hydrocarbons may migrate and be trapped against the walls of the building. Fumes were first reported in the building in mid-1976, and hydrocarbons have entered the building as both liquids and gases through the groundwater drainage system, through the apertures in the wall of the north sump, and through fractures in the concrete and masonry walls of the north sump.

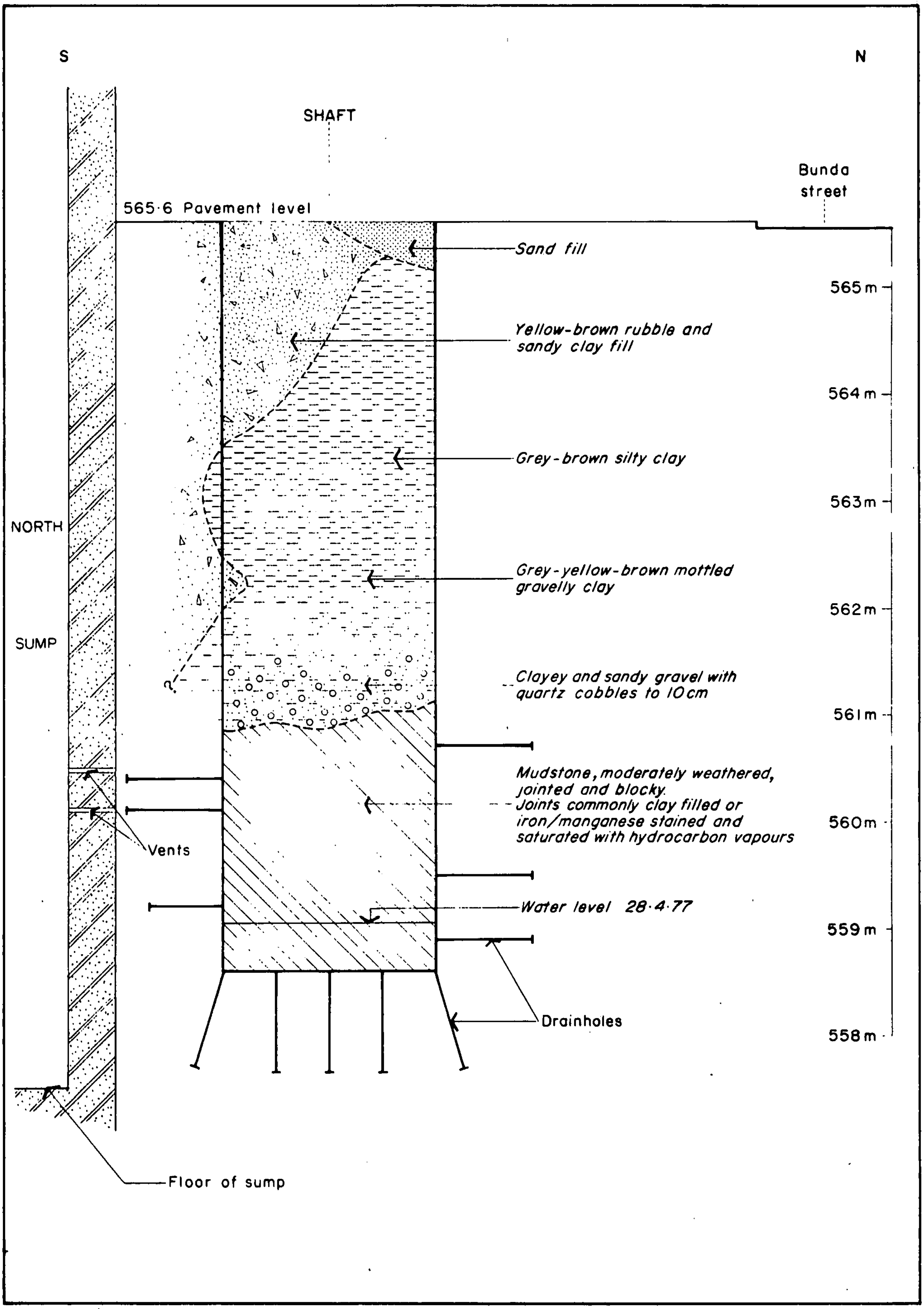

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FIG. 15 Log of shaft, north sump

SOURCE OF POLLUTION

BMR drilling has indicated that the pollution of groundwater by hydrocarbons extends across Bunda Street at least 40 m northwest of the Center Cinema to Bore 9 where the thickness of mudstone bedrock affected by hydrocarbons is 4.5 m. On the limited information available at the moment, the area affected is estimated at 1300 m^2 and the volume of affected rock is estimated to be 2500 m^3. Assuming 1 percent absorption of hydrocarbons into the rock, the volume of product remaining in the ground is at least 25 000 litres. The pollution has persisted in the area despite several months of continual pumping from the cinema; however, the amount of pollutant already removed is not known.

Another drilling programme has been initiated to outline the full extent of polluted ground. Because of the low permeability of the mudstone, the affected area is expected to be in close proximity to the source of hydrocarbons.

The analyses of hydrocarbons from the cinema and from bores are described in a separate report by McKay (1977); the pollutant is described in the report as refined petroleum product.

REMEDIAL ACTION

It is expected that hydrocarbons will continue to enter the west sump of the cinema because there is no known process that will remove the hydrocarbons completely from the surrounding area. As the amount of hydrocarbon that constitutes a potential hazard is quite small compared with the amount of pollution in the adjacent ground, remedial measures must be taken in the Center Cinema, and have been taken by the cinema management.

Some free accessible hydrocarbons can be recovered through shafts or wells, possibly with infiltration galleries; however, the removal of hydrocarbons from the mudstone bedrock will be a long slow process extending over many years, and during that period the hydrocarbons must be regarded as a potential source of explosive fluids and vapours. Movement of the hydrocarbons will be controlled by the hydrogeological situation at any one time, and the assessment of potential risk will mainly depend on an understanding of groundwater conditions in the area.

Precautions against the loss of hydrocarbons in the future could require better housekeeping by service stations in the area, and it would seem appropriate for tank and pipeline installations and operating procedures to be closely scrutinized.

CONCLUSIONS

1. The potential for hydrocarbon pollution exists because several service stations are located in the groundwater catchment, and buried tanks and pipes rest in permeable gravel that will transmit polluted groundwater.
2. The deep excavation of the Center Cinema acts as a trap for groundwater moving slowly from the northwest within the fractured bedrock, and pumping from the drainage sumps in the cinema creates a cone of depression in the water table on which hydrocarbons are drawn towards the building.
3. Groundwater contaminated by hydrocarbons has access to the cinema via the drainage system to the east and west sumps.
4. Hydrocarbon fluids and vapours have been able to enter the north sump of the cinema through vents in the wall and through cracks in the concrete.
5. The major part of the pollution zone is northwest of the cinema; however, additional drilling is required to define its extent, and to ascertain the source of the pollutant.
6. Remedial action to clean up some of the accessible hydrocarbons is feasible, but aims at confining the polluted area rather than removing the pollutant altogether; there is no known process that will remove hydrocarbons completely from the area.
7. Civic authorities should consider the long term effects of administering a built up area that contains a potential explosive hazard.

REFERENCES

McKAY, B.A., 1977 - Report on the analysis of hydrocarbons in seepage fluids from the Center Cinema and a comparison with the analysis of petrols sold in the area. Bureau of Mineral Resources Petroleum Technology Laboratory, 15 April 1977 (unpubl.).

WILSON, E.G., 1978 - The contamination of groundwater by hydrocarbons, with brief notes on the hydrogeology of Canberra City, A.C.T. Bureau of Mineral Resources, Australia, Record 1978/64 (unpubl.).

APPENDIX 1

PERMEABILITY TESTING OF BOREHOLES

by

R. Evans

Boreholes 1, 3, 5, 9, 10, and 12 were tested using the auger hole recovery method. This method consists of the withdrawal of an amount of water from the hole and the measurement of the subsequent recovery of the water level. Owing to the assumptions made in the derivation of the equations used in this test, care must be taken to use measurements taken before the inflow to the hole is governed by the cone of depression. Therefore, the relevant measurements are taken within the first 20 percent of the water-level recovery. The calculated permeabilities relate only to the immediate vicinity of the well tested.

Boreholes 4A, 6, 7A, and 8A were tested by a modified slug test and consideration of the resultant infiltration curve. Drillholes 4A and 6 did not respond to this method of testing. In this test a 'slug' of water was injected into the well and measurements of the residual head were taken at specified times. A graph of residual head against time was plotted and the hydraulic conductivity was determined from the resultant infiltration curve for large values of time, taken so that the transient effects, caused by the addition of a head of water, will have disappeared. However, as the hydraulic conductivity is a function of antecedent moisture content, among other things, the values thus obtained are conditional upon this property of the soil. In this test there is no reliable method of measuring the antecedent moisture content of the saturated zone being tested.

Results of the tests are shown in Table 1.

The mean values of permeability are K=0.450 m/day for the alluvial aquifer, K-0.047 m/day for the fractured mudstone aquifer.

TABLE 1

SUMMARY OF BOREHOLE PERMEABILITY TESTS

HOLE NO.	AQUIFER	TEST	K(m/day)
1	Mudstone	Auger-hole recovery (A.H.R.)	0.027
3	Mudstone	A.H.R.	0.085
5	Mudstone	A.H.R.	0.032
7A	Alluvium	Infiltration	0.288
8	Alluvium	Infiltration	0.865
9	Mudstone	A.H.R.	0.010
10	Alluvium	A.H.R.	0.198
12	Mudstone	A.H.R.	0.080

APPENDIX 2

DYE TRACING AND GROUNDWATER MOVEMENT IN THE VICINITY OF THE CENTER CINEMA, CANBERRA, APRIL 19 - MAY 9, 1977

by
D.I. Smith
(Senior Fellow, Centre for Resource and Environmental Studies,
Australian National University)

1. Introduction

I was asked in late March, by the Bureau of Mineral Resources, as to the feasibility of using fluorescent dye as a technique for the tracing of groundwater movement in the vicinity of the Center Cinema, Canberra. Such dyes have previously been used for the tracing of groundwater movement but usually in rocks with a high permeability and therefore with fast flow rates. To the best of my knowledge fluorescent tracer methods have not been used in strata with low permeability of the type associated with the geology adjacent to the cinema. However, it was agreed, in conjunction with the BMR and with the City Engineer, that the methods might be of value. Therefore the experiment outlined below, was undertaken.

2. Fluorescent dyes and groundwater tracing

Water tracing by the use of dyes is a straightforward procedure. A dye is added to the circulation at an input site and other sites are monitored for its reappearance. Such methods have been widely used to check leakage in underground pipes and in that case a dye, often the green dye fluorescein, is used. In this simple application, detection relies on the visual reappearance of the dye.

In recent years more sensitive methods have been employed. A dye with fluorescent properties is used and water samples are collected for analysis in a fluorometer. By using suitable dyes and carefully selected filters for the instrument the detection level is of the order of one part of dye in 10^{10} parts of water, i.e., one part in 1000 million. The visual detection level of dye is of the order of one part in 200 000.

For studying groundwater movement in alluvium and mudstones, the types of strata associated with the Center Cinema, the problems are that the groundwater movement is slow and most dyes are absorbed into the geological deposit. Previous groundwater tracing has indicated that the dye most suited for this work is Rhodamine WT. The instrument used for the analysis of the dye is a Turner Model III fluorometer. The method of operation is given by Wilson (1968).

3. Procedure in the Center Cinema investigation

After consultation with the BMR, it was decided to inject the Rhodamine dye into a borehole drilled specifically for the purpose. The hole in question was designated as CC 7A, and is located on the pavement on the northside of Bunda Street, opposite the Cinema. The position is shown in Figure 4 of the main report.

Some 1.8 litres of Rhodamine WT (that is, 360 grams of dry weight dye) were added to the borehole on April 19. The dye was carefully poured into the borehole and water was then added to fill the borehole to within approximately one metre of the top of the borehole.

The borehole was lined with a slotted plastic casing the bottom metre (at the junction of the alluvium and the mudstone), consisting of a screen mesh. This arrangement allowed the dye solution to pass easily into the surrounding strata.

4. Sample collection

Samples were coldected from a number of sites in the area surrounding the input borehole. The collection sites included other boreholes and the East and West Sumps in the Cinema itself, see Figure 4. The samples were analysed within one to three days at the Australian National University.

5. Results

Table 2 indicates the sites and dates at which sampdes were collected up to May 9 (the sampling program is still continuing). The table also gives the values for the dye concentration. All values are in microgrammes per litre (g/l).

TABLE 2. DATES AND DYE CONCENTRATION VALUES FOR ALL SAMPLES COLLECTED IN THE PERIOD APRIL 19 TO MAY 9

(All figures given are in microgrammes per litre)

	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10
CC 1	0.10	0.10	0.10	0.10				0.12	0.18	0.18	0.57			1.70		1.57		0.25	0.37		0.90	
CC 2	0.23	0.55	0.25	0.20				X	X	X	X					0.30			0.70		0.87	
CC 3																			0.85			
CC 4	0.25							0.375		0.325	0.45			1.02		0.60		0.33	0.35		0.54	
CC 4A	0.20	0.17	0.27	0.30				0.23	0.23	0.17	0.32			0.65				+	+		+	
CC 5																		0.70	0.82		1.03	
CC 6		0.18	0.27	0.20				0.28	0.20	+								4.85	*		*	
CC 7	0.35	0.78	1.06	1.28				25.00	1.55	V	V			X				V			V	
CC 8		0.50		*				0.35	*	*	+							+	+		+	
CC 9	X																	X				
CC 10																		0.47				
CC 11																		0.45	0.65		0.60	
CC 12																		0.23	0.25		0.18	
CC 13	0.23	0.30	0.15	0.15				0.27	0.27	0.28	0.23			0.50		2.00		0.62	0.54		0.75	
CC 14																		0.18			0.40	
Shaft			*	*				*	0.45	0.37	0.50			0.40		*		0.54	0.50		12.5	
West Sump		0.15	0.07	0.05				+	0.07	0.23	15.00					3.25		0.18	0.25		0.35	
East Sump	0.08	0.13	0.05	0.05				0.05	0.07	+	0.54					0.70		0.10	0.23		0.25	

X Sample consists totally of petrol, not analysed

\+ Hole dry

* Heavy sediment contamination, not analysed

V Dye visible

For a limited number of samples analysis was not possible due to:

(i) the samples being composed entirely of petrol, in such cases analysis for dye is not possible;

(ii) some samples were too heavily contaminated with sediment for analysis.

Positive dye readings were obtained from a number of sites and these can be divided into those with high or low dye concentration values.

The sites with high positive values are:

(a) West Sump. The maximum value obtained was approximately 15.0 g/l. The pattern of the results is shown in Figure 16.

(b) Borehole CC 6. The maximum value was 4.8 g/l. This positive value is from a single sample as on a number of occasions the hole was dry. The pattern is shown in Figure 17.

(c) Borehole CC 7. Values of several hundred g/l were obtained, and from April 28, all the samples have a strong visual positive. However, this borehole is located only 30 cms from the input borehole.

(d) The Shaft. This was constructed after the dye was injected and many of the samples are difficult to analyse. However the sample collected on May 9 is a strong positive with a value of 12.5 g/l.

The sites with low positive values are:

(a) Borehole CC 1. The maximum value is approximately 1.75 g/l. The pattern of results is shown in Figure 16.

(b) Borehole CC 13. Maximum value 2.20 g/l. Pattern of results shown in Figure 17.

(c) East Sump. Maximum value estimated to be 1.00 g/l. Pattern of results shown in Figure 16.

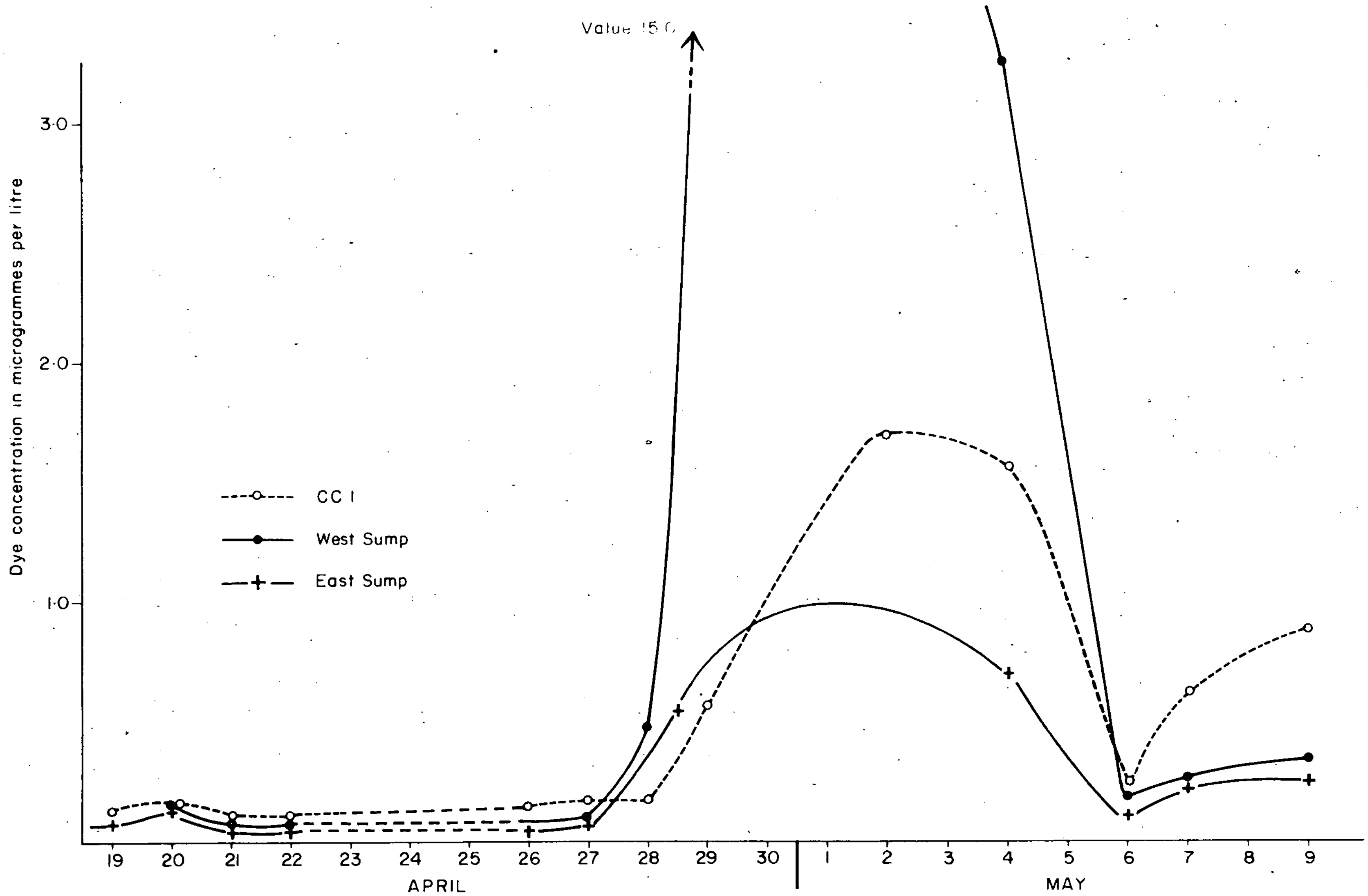
The background values for the area are generally less than 0.50 g/l.

Time of travel. The time of first appearance of the dye and the time to the peak values are shown in Figure 18.

It is possible knowing the time of travel of the dye and the distances from the input borehole to calculate the velocity of underground flow. The results are given in Table 3.

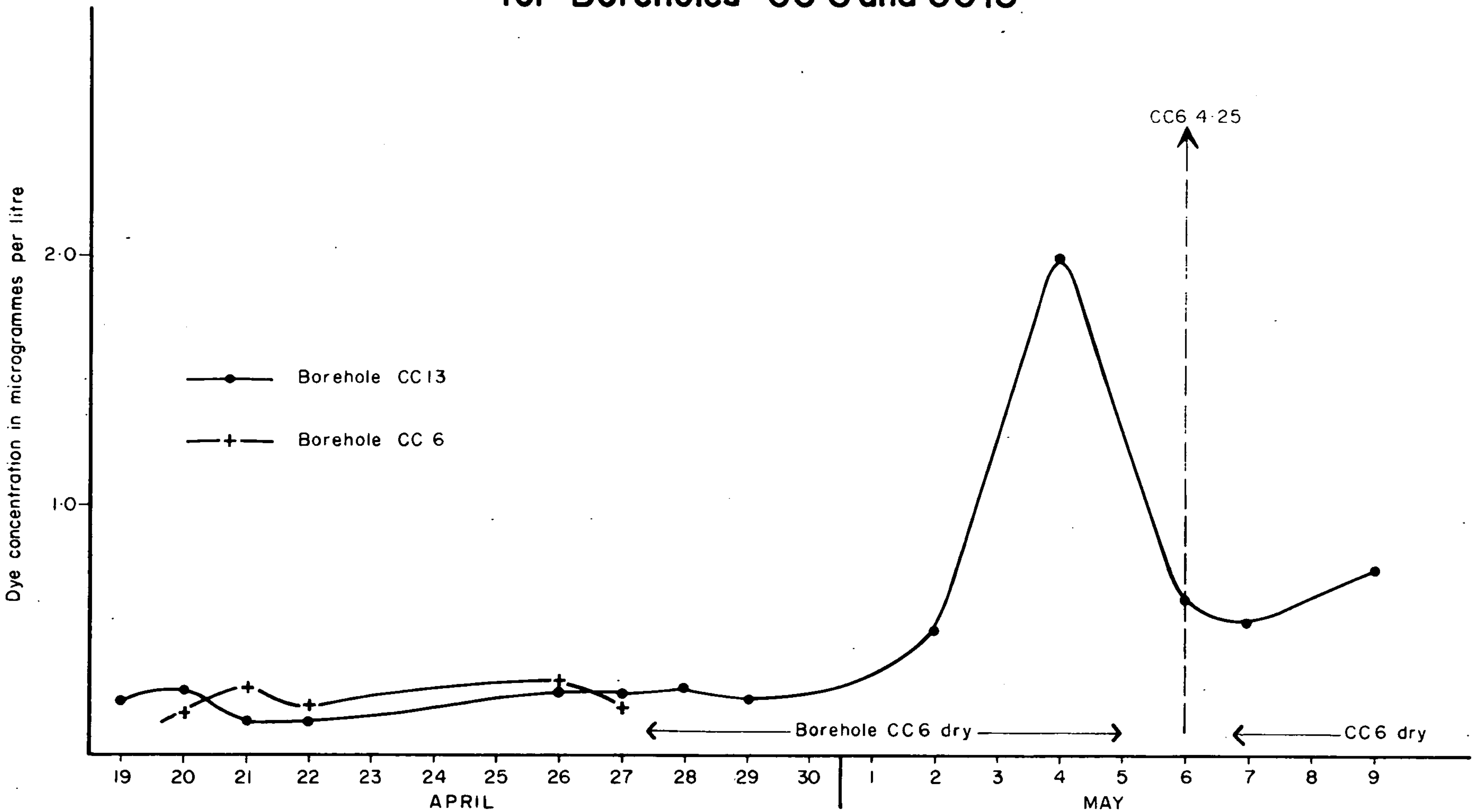
Record 1978/86

FIG. 16 Dye concentration against time, East Sump, West Sump and Borehole CC I



155/A16/1865

FIG. 17 Dye concentration against time for Boreholes CC 6 and CC 13



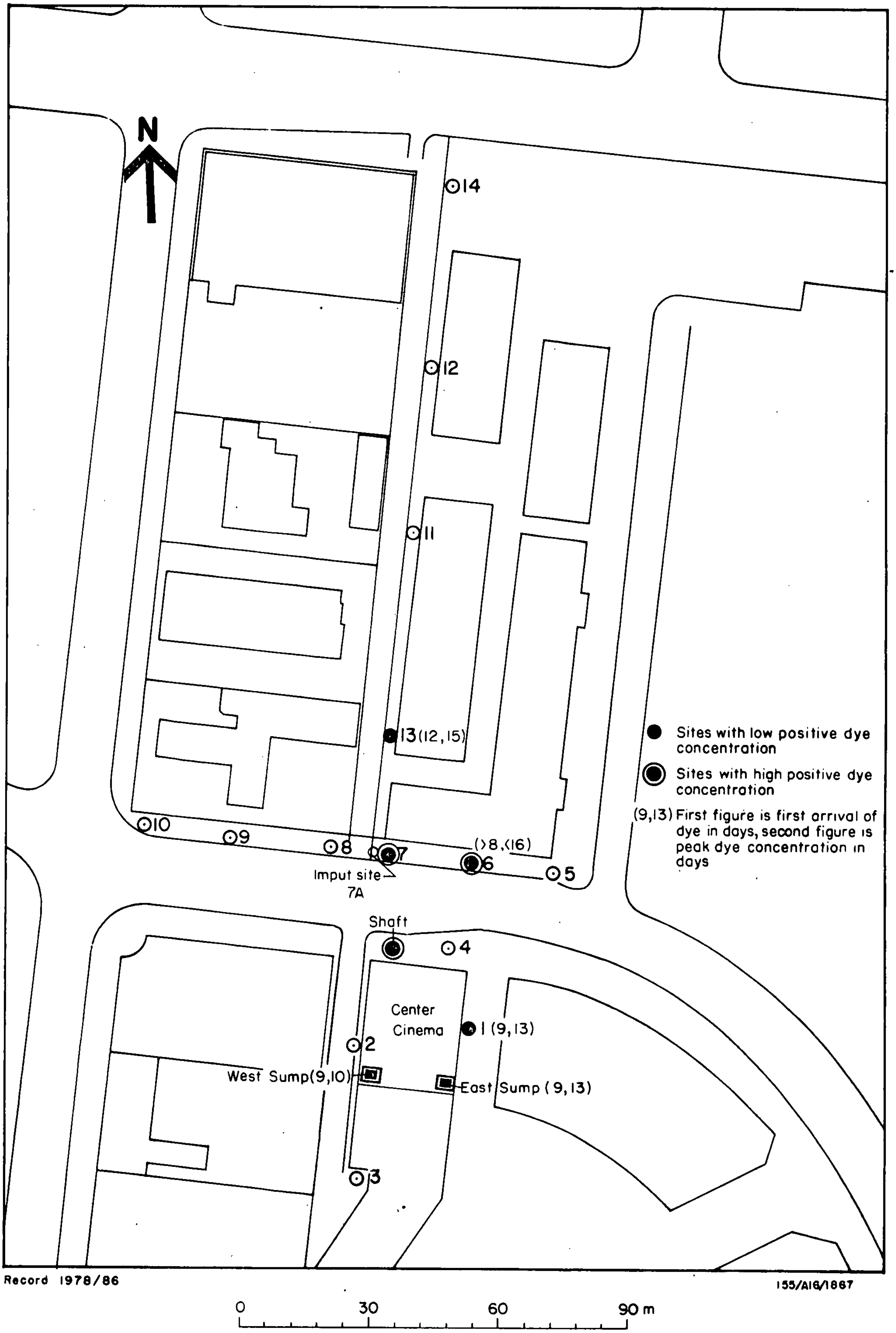


FIG. 18 Location of sites with positive dye concentrations and times of arrival

The general velocity of the groundwater movement is in the range of 2 to 5 metres per day.

In using these figures a number of points should be mentioned.

(i) The flow rates given are for groundwater movement and rates for oil movement could differ.

(ii) It is impossible to say at what underground level the fastest groundwater flow occurs but the indications are that the measured water movement is most likely to occur near to the junction of the alluvium and the weathered top of the mudstones.

(iii) The dominant flow direction indicated is from the input borehole (CC 7A) south towards the cinema and also to the east. However, it must be stressed that samples suitable for analysis could not be obtained to the west of the input site. There is an indication that a relatively small quantity of the dye moved northwards from the input site and this is indicated by the low positive dye values in borehole CC 13.

The experiment is still continuing and further information relevant to the groundwater movement may be obtained.

6. Summary

The method proved satisfactory for groundwater tracing and velocities of groundwater movement have been presented and are in the range of 2 to 5 metres per day. Indications of groundwater flow direction are also presented in Figure 18.

In my opinion the information presented regarding groundwater flow is meaningful although variations in velocity could be expected in response to heavy rain or prolonged drought. The experiment described was conducted under relatively dry conditions.

7. Reference

WILSON, J.P., 1968 - Fluorometric procedures for dye tracing. Chapter A12 in Techniques for surface water investigation. United States Geological Survey.

TABLE 3: VELOCITIES OF GROUNDWATER MOVEMENT FOR COLLECTION SITES WITH POSITIVE DYE CONCENTRATIONS

	Distance in metres	First arrival in days	Arrival of dye peak in days	Velocity of first arrival	Velocity of dye peak arrival
CC 7A - CC 1	43.0	9	13	4.8 m/day	3.3 m/day
CC 7A - CC 6	19.2	More than 8 days, less than 16 days		1.2 to 2.4 m/day	
CC 7A - West Sump+	30.0	9	10	3.3 m/day	3.0 m/day
CC 7A - East Sump+	30.0	9	13	3.3 m/day	2.3 m/day
CC 7A - CC 13	27.5	12	15	2.3 m/day	1.8 m/day

+ In these cases distance is taken to the drains feeding the sumps.

APPENDIX 3

LOGS OF DRILLHOLES

by

T. Kaczerepa

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

R.L. 565·68 (Top of casing)

Project: CENTER CINEMA Hole: 1 Date: 21/2/77 Logged by: G.J.

DEPTH (metres)	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R–B, Y–B	Moisture D, M > < PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0 – 2.6	Fill				Auger hole recovery tests K = 0·02 m/day K = 0·03 m/day		10cm. outer plastic / 5cm inner		Fill
2.6 – 4.6	Gravelly Clay		yell.-brown						Alluvium
4.6 – 5.2	Gravel				W.L. 8/4/77				Alluvium
5.2 – 10	Extremely weathered mudstone		light brown		4·4·77		5cm. slotted plastic		weathered bedrock

Sheet 1 of 2

Driller: BMR. Drill type: Gemco (diamond core) Not sampled Checked by: GJ

155/A16/1877
M (Pt) 208

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema Hole: 1 Date: 21/2/77 Logged by: GJ

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M < PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
	[not sampled]	No Core								weathered bedrock
11										
		Hole completed at 11.00 m. on 21 Feb 1977								
12										

Sheet 2 of 2

Driller: BMR Drill type: Gemco Not sampled Checked by: G J

155/A16/1877 M (Pt) 208

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

R.L. 565·33 (Top of Casing)

Project: CENTER CINEMA Hole: CC2 Date: 1/3/77 Logged by: TK.

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M, >, <, PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–3.9		Gravel fragments only recovered	GW			explosive vapour level 28.3.77		10cm pvc inside	3	Fill, alluvium, and highly weathered to extremely weathered bedrock. - probably slipped material to 7.75 m.
3.9–4.7		Clayey gravel- Highly Weathered rock fragments	GC	Yellow-brown		liquid level 12/5/77		5cm.	70	
4.7–5.1		Clay	CH	mottled yellow-brown					90	
5.1–6.5		Highly weathered, friable mudstone.		Yellow-brown pple.		hydrocarbon layer			90	
6.5–7.8		Clayey gravel - rock fragments.	GC	Yellow-brown				5cm. pvc.	5	
7.8–8.1		H.W. Bedrock, gravel (mudstone)		Yell. br. pple.					60	
8.1–8.7		E.W. mudstone (clay)		dark yell. brown! pple				Slotted	70	Highly to extremely weathered mudstone bedrock.
8.7–		HW. Mudstone.		dark yellow brown. pple.					5	

Sheet 1 of 2

Driller: BMR. Drill type: Gemco (diamond core) Not sampled Checked by: G J

155/A16/1878

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: CENTER CINEMA Hole: CC2 Date: 1/3/77 Logged by: TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M > < PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
11		HW. to MW. mudstone, closely fractured		Yell. brown mottled red & pple.					70	Weathered mudstone
12										

Completed at 11:00 am. on 1st. March 1977

Water level on completion. 4.82m. below ground level

Hydrocarbons first observed in drillhole on 7th. March.

Column of liquid hydrocarbons in bore 2.70 m. thick, 12 may.

Sheet 2 of 2

Driller: BMR Drill type: Gemco (diamond core) Not sampled Checked by: G J

155/A16/1878

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

R.L. 565.38 (Top of casing)

Project: CENTER CINEMA Hole: CC3 Date: 3/3/77 Logged by: T.K.

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text. plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D.M.>PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0 – 4.2		Gravel fragments and fill	GW					5cm inner 10cm. outer pvc casing	5	Fill and alluvium
4.2 – 4.9		Clayey gravel rock fragments	GC	yellow brown		Water level 8.4.77			40	Alluvium
4.9 – 5.6		Reamed - no core.							0	extremely weathered bedrock
5.6 – 5.8		clay	CH	yell. brown		4.4.77			95	EW bedrock
5.8 – 6.9		Extremely to highly weathered mudstone		Yell. brown mottled pple		auger hole recovery test. K = 0.85 m/day		5cm. slotted pvc.	80	Weathered Bedrock
6.9 – 9.6		Highly weathered to moderately weathered mudstone		yellow brown pink & purple mottled.					95	
9.6 – 10.10		HW.-EW. mudstone		Yell. brown pple.					100	

10.10

Sheet 1 of 2

Driller: BMR Drill type: Gemco (diamond core) [redacted] Not sampled Checked by: G J

155/A16/1879

M (Pt) 208

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: CENT. CINEMA Hole: CC3 Date: 3/3/77 Logged by: TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M>< PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		HW.-EW. Mudstone - friable		Yell. brown pple.					100	Weathered bedrock.
11										
12										

Completed at 11.00 m. on 3 march 1977
Water level 4.95m. below top of casing after completion of drillhole; dropped to 5.28m. by 15 march.

Sheet 2 of 2

Driller: BMR Drill type: Gemco Not sampled Checked by: GJ

155/A16/1879
M (P) 208

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
R.L. 565·49 (Top of casing)

Project: CENT. CINEMA Hole: CC4 Date: 8/3/77 Logged by: TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M > < PL, W	Permeability (k) / Groundwater Observations	Structure: Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0 – 5.8		Clayey, gravel & sand	GC	Light yellow brown-grey mottled.		explosive vapour level 29/3/77 (approx. 0.7); liquid level 12·5·77 (approx. 4.6); hydrocarbon layer			50	Fill & alluvium
5.8 – 6.1		friable clay	OH	yell. brown					100	Extremely weath bedrock.
6.1 – 7.5		No Core								Weathered bedrock.
7.5 – 10		Moderately to slightly weathered mudstone		yellow-brown mottled pple. & pink.					95	

Depth scale: 1, 2, 3, 4, 5, 6, 7, 8, 9

Sheet 1 of 2

Driller: BMR. Drill type: Gemco (diamond core) Not sampled Checked by: G J

155/A16/1880
M (Pt) 208

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema   Hole: CC4   Date: 8/3/77   Logged by: TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M, <PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
10–11		HW.-MW. Mudstone		Yell.-brown pple mottled					100	Weathered bedrock

Completed at 11.00am. on 8 March 1977

On completion of drilling water level 5.42 m. below top of casing

Hydrocarbons first observed in drillhole on 22 March

Column of hydrocarbons (liquid) in bore 0.10 m. thick, 12 May

Sheet 2 of 2

Driller: BMR   Drill type: Gemco (diamond core)   Not sampled   Checked by: GJ

155/A16/1880
M (PF) 208

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole R.L. 565·62 (Top of casing)

Project: Center Cinema **Hole:** CC5 **Date:** 9/3/77 **Logged by:** TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M, <PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
1, 2		Clayey sand and gravel	GM	Dark yellow-brown		Water level 8·4·77		5cm. inside 10cm plastic	10	Fill
		Clayey sand	GC	Light grey yellow-brown					100	Alluvium
3		Gravelly clay		Light grey brown mottled		4·4·77			50	
4		Extremely to moderately weathered mudstone closely fractured								
5, 6, 7, 8, 9		Moderately weathered to highly weathered mudstone		Light grey red & brown mottle.		Auger hole recovery tests K=0·02 m./day K=0·04 m./day		5cm. slotted plastic	90	Weathered Bedrock.

Sheet 1 of 2

Driller: BMR **Drill type** (Gemco diamond core) **Not sampled** **Checked by:** G J

155/A16/1881
M (P) 208

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema **Hole:** CC5 **Date:** 9/3/77 **Logged by:** TR

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D.M.><PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		MW. - HW mudstone		dark grey red & brown mottle					100	Weathered bedrock.
11		Completed at 11.0m. on 9 March 1977.								
12										

Sheet 2 of 2

Driller: BMR **Drill type:** Gemco (diamond core) [redacted] Not sampled **Checked by:** G J

155/A16/1881

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

R.L. 565·66 (Top of casing)

Project: Center Cinema **Hole:** CC6 **Date:** 9/3/77 **Logged by:** TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text. plast.)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D.M.<>PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–1–2		Clayey sand & gravel. Some rock fragments.	GM	Dark yellow-brown-grey			5cm. slotted PVC		10	Alluvium & Fill.
3		Sandy clay & gravel	CL	Grey & yell. brown		Water level 8·4·77			40	alluvium
4		Extremely weathered mudstone (friable clay)		Grey & yellow brown					5	Weathered b'rock

Completed at 4.00 m. on 9 March 1977
Hole dry on completion - has water intermittently.

5
6
7
8
9

Driller: BMR. **Drill type:** Gemco (diamond core) [redacted] **Not sampled** **Checked by:** GJ

155/A16/1882

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
R.L. 565.66 (Top of casing)

Project: Center Cinema Hole: CC7 Date: 11/3/77 Logged by: TK.

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text. plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D.M.>PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–2.5 (1, 2)		Silt-Sandy clay	GW	light grey brown		Explosive / Vapour level 20-4-77		10cm outer PVC	5	Alluvium
2.5–5.5 (3, 4, 5)		Clay sand & gravel with large quartz cobbles.	GC	Light grey brown		liquid level 12/5/77 / hydrocarbon layer		5cm inner	8	Alluvium
5.5–7.2 (6, 7)		Clay (Extremely weathered mudstone)	OH	Yellow-brown					50	Weathered Bedrock
7.2–10 (8, 9)		E.W. - H.W. Mudstone, closely spaced, manganese stained joints.		yellow-brown purple mottle.				5cm slotted PVC	30	Weathered Bedrock.

Sheet 1 of 2

Driller: BMR Drill type: Gemco (diamond core) [redacted] Not sampled Checked by: G J

155/A16/1883
M (P1) 306

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema Hole: CC7 Date: 11/3/77 Logged by: TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text. plast.)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D.M.><PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
11	▨	HW-MW mudstone closely jointed		Yellow brown mottled					20	Weathered bedrock.
12										

Completed at 11.00m. on 11 March 1977.
Water level on completion 5.05 below top of casing
Explosive vapours observed in hole 15 March
and hydrocarbons sampled 23 March.
Column of liquid hydrocarbons in bore 0.35m.
thick 12 may.

Sheet 2 of 2

Driller: BMR Drill type: Gemco [redacted] Not sampled Checked by: G J

155/A16/1883
M (Pt) 200

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

R.L. 565.62 (Top of casing)

Project: Center Cinema Hole: CC8 Date: 15/3/77 Logged by: TK.

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text. plast)	Unified symbol	COLOUR Pale or dark Comb. col. R–B, Y–B	Moisture D, M > < PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–3		Clay sand & gravel	GM	grey brown		Slug tests K=0.43 m/day K=0.37 m/day; water level 8.4.77			10	Fill & alluvium
3–4.6		gravel & clay		yellow brown					40	Alluvium

Completed at 4.60 m. on 15 March 1977
Hole dry on completion - has water intermittently.

Depth scale: 1, 2, 3, 4, 5, 6, 7, 8, 9

Driller: BMR Drill type: Gemco (diamond core [redacted] Not sampled Checked by: G J

155/A16/1884
M (PT)/200

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
R.L. 565.74 (Top of casing)

Project: Center Cinema **Hole:** CC9 **Date:** 17/3/77 **Logged by:** I.K.

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text. plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M > < PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–2.7 (1, 2)		Clay & sand	GM	Light grey brown		Explosive vapour level. Auger hole recovery test K = 0.01 m./day.		10cm outer pvc.	5	Fill & Alluvium
2.7–3.6 (3)		Clay	CH	Light grey brown				5cm. inner	50	Alluvium
3.6–4.2 (4)		Gravel and Clay (moderately weathered mudstone boulder)		Light brown		liquid level 12.5.77				Alluvium
4.2–5.4 (5)		Extremely weathered mudstone friable & clayey		Yellow brown mottled purple & white		hydrocarbon layer.		5cm. slotted pvc.	95	Weathered Bedrock
5.4–9.3 (6, 7, 8, 9)		EW. – HW. closely fractured Mudstone.								
9.3–		MW. – HW mudstone								

Log amended 23/12/77 by G. Jacobson. Section from 3·6 – 4·2 m is considered to be a mudstone boulder in the base of the alluvium

Sheet 1 of 2

Driller: BMR **Drill type:** Gemco (diamond core) **Not sampled** **Checked by:** G J

195/A16/1885
M (P1) 20

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema **Hole:** CC9 **Date:** 17/3/77 **Logged by:** IK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text. plast.)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M<PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
10 – 11		HW. Mudstone - closely fractured.		red-yell.-brown					100	Weathered Bedrock.

Hole completed at 11.00 m. on 17 March 1977

Water level on completion 4.69 m. below top of casing.

Explosive vapours first observed 31 March.

Column of liquid hydrocarbons in bore 4.55 m. thick, 12 May.

Sheet 2 of 2

Driller: BMR **Drill type:** Gemco **Not sampled** **Checked by:** GJ

155/A16/1885
M (PT) 108

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

R.L. 565.80 (Top of casing)

Project: Center Cinema Hole: CC10 Date: 18/3/77 Logged by: IK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D.M.<PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		fine sand & silt		chocolate brown				5cm. slotted PVC	70	alluvium
1		Silt-sand & clay		light choc. brown					50	alluvium
2		gravelly clay		yell.-brown					10	alluvium
3		gravel				Water level 8.4.77			10	alluvium
4		clayey gravel		yell-brown		4.4.77			5	alluvium
		Not cored								bedrock
5		Hole completed at 4.90m on 18 March 1977. Water in hole on completion.								
6										

Driller: BMR Drill type (Gemco Diamond core) Not sampled Checked by: G J

155/A16/1886

M (Pt) 208

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

R.L. 565·88 (Top of casing)

Project: Center Cinema   Hole: CC11   Date: 21/3/77   Logged by: TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M<PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
1, 2		Clay sand silt & gravel	GM	dark grey brown					10	Alluvium
3, 4									3	
		clay - gravel		yell. brown		Water level 8.4.77			50	
		No Core				4.4.77				
5, 6		Extremely to highly weathered mudstone friable and highly fractured		dark yell. brown					90	Weathered Bedrock.
7, 8		EW. - HW. Mudstone fractured & friable		dark yell. brown					100	
9		MW-SW Mudstone stained & fractured.		light yell-grey brown purple mottle.					95	

Sheet 1 of 2

Driller: BMR   Drill type (Gemco Diamond core)   Not sampled   Checked by: G J

155/A16/1887
M (PT)

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema Hole: CC11 Date: 21/3/77 Logged by: TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D. M >< PL. W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		MW-HW Mudstone friable		yell.-grey brown.						Weathered Bedrock.
11										
12										

Hole completed at 11.00 m. on 21 March 1977
Water level on completion 4.46 below ground.

Sheet 2 of 2

Driller: BMR Drill type: Gemco [redacted] Not sampled Checked by: GJ

155/A16/1887
M (PT) 208

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

R.L. 566.27 (Top of Casing)

Project: Center Cinema Hole: CC12 Date: 21/3/77. Logged by: TK.

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast.)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M<PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
1, 2		Sandy silty clay		Choc. brown		Auger hole recovery tests K=0.05 m. per day K=0.11 m. per day			30	Alluvium
3		Clay, sand & silt		Choc. brown		Water level 8.4.77			60	
4, 5		Clayey gravel		yellow brown		4.4.77		5cm slotted PVC	30	
6		Hole completed at 5.60 m. on 21/3/77.								

Driller: BMR Drill type: Gemco (diamond core) [redacted] Not sampled Checked by: G J

155/A16/1888

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

R.L. 565·53 (Top of casing)

Project: Center Cinema Hole: CC13 Date: 22/3/77 Logged by: TK.

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D,M,>PL,W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
1, 2	– o	Clayey gravel	GC	yellow-grey-brown				5cm. slotted pvc.	10	alluvium
3	o	gravel								
4	– o	clayey gravel		yellow brown		Water level 8·4·77; 4·4·77			30	
5, 6		Hole completed at 4·80 m. on 22-3-77 Water level on completion 4·21 m. below ground								

Driller: BMR Drill type: Gemco (diamond core) [redacted] Not sampled Checked by: GJ

155/A16/1889 M(P)1204

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

RL. 567.02 (Top of casing)

Project: Center Cinema Hole: CC14 Date: 23/3/77 Logged by: TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text. plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D.M<PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–2		Clayey sand	GM	Dark Choc Brown				5cm. inner 10cm. outer pvc.	3	Alluvium
2–5		Clayey gravel	GC	yellow-brown		Water level 8.4.77; 4.4.77			7	
5–5.6		Extremely weathered mudstone							2	
5.6–6		No Core						5cm. slotted pvc.		
6–6.8		Extremely weathered mudstone - friable		yellow-brown					50	Weathered Bedrock
6.8–8.8		HW, closely fractured mudstone								
8.8–10		EW - HW mudstone								

Sheet 1 of 2

Driller: BMR Drill type: (diamond drillcore) Gemco [redacted] Not sampled Checked by: G J

155/A16/1890

M (P1) 208

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema Hole: CC14 Date: 23/3/77 Logged by: TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M > < PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
10 11		Extremely–highly weathered mudstone						5cm. slotted		

Hole completed at 11·10 m. on 23 March 1977

Driller: BMR Drill type: Gemco (diamond core) [redacted] Not sampled Checked by: G J

155/A16/1890

PART 2

ADDITIONAL INVESTIGATIONS, MAY-JULY 1977

by

G. Jacobson, P.D. Hohnen, & R. Evans

INTRODUCTION

This report describes additional investigations from May to July, 1977, of the hydrocarbon pollution problem in the vicinity of the Center Cinema, Canberra City, and is supplementary to earlier BMR reports by Wilson (1978) and Jacobson (Part 1 of this Record) that discussed the background to the problem and the hydrogeology of the area. Other relevant reports (McKay, 1977) include analyses of hydrocarbon samples from the area, and their comparison with petrol samples obtained from nearby service stations.

Additional drilling was undertaken to define the extent of the hydrocarbon pollution and to provide monitoring bores. Drilling contractors, Stewart Bros. of Sydney, drilled 15 bores, numbered 15-29 inclusive on the locality plan (Fig. 1). These bores were drilled to 12 m; casing was set at 4-5 m to seal off the alluvium, and drilling continued through the casing to 12 m. Slotted casing was set in the fractured mudstone below the alluvium. Logs of the drillholes are given in Appendix 3.

HYDROGEOLOGY*

The drilling program has confirmed and extended our knowledge of the configuration of the alluvium. Elevations of the alluvium-bedrock interface have been plotted (Fig. 2), and show that the former valley drained to the south and southwest with its deepest part in Bunda Street near the Center Cinema. The valley is now filled with 4-5 m of alluvium, including a basal gravel bed up to 1 m thick.

The fluid levels in the bores are shown in Figure 3, and Table 1 lists the water level fluctuations from March to July 1977. Assuming that the bores are representative of conditions elsewhere in the mudstone, the upper surface of the fluids has been plotted and is referred to as the potentiometric surface of the mudstone aquifer (Fig. 3). Because the fluid in many of the bores consists of hydrocarbons overlying water, the distribution of the hydrocarbons can be regarded as a lens floating in the water (Text Fig. 1), and this lens raises the potentiometric surface and shows up as a bulge in the contours between bores 9 and 18.

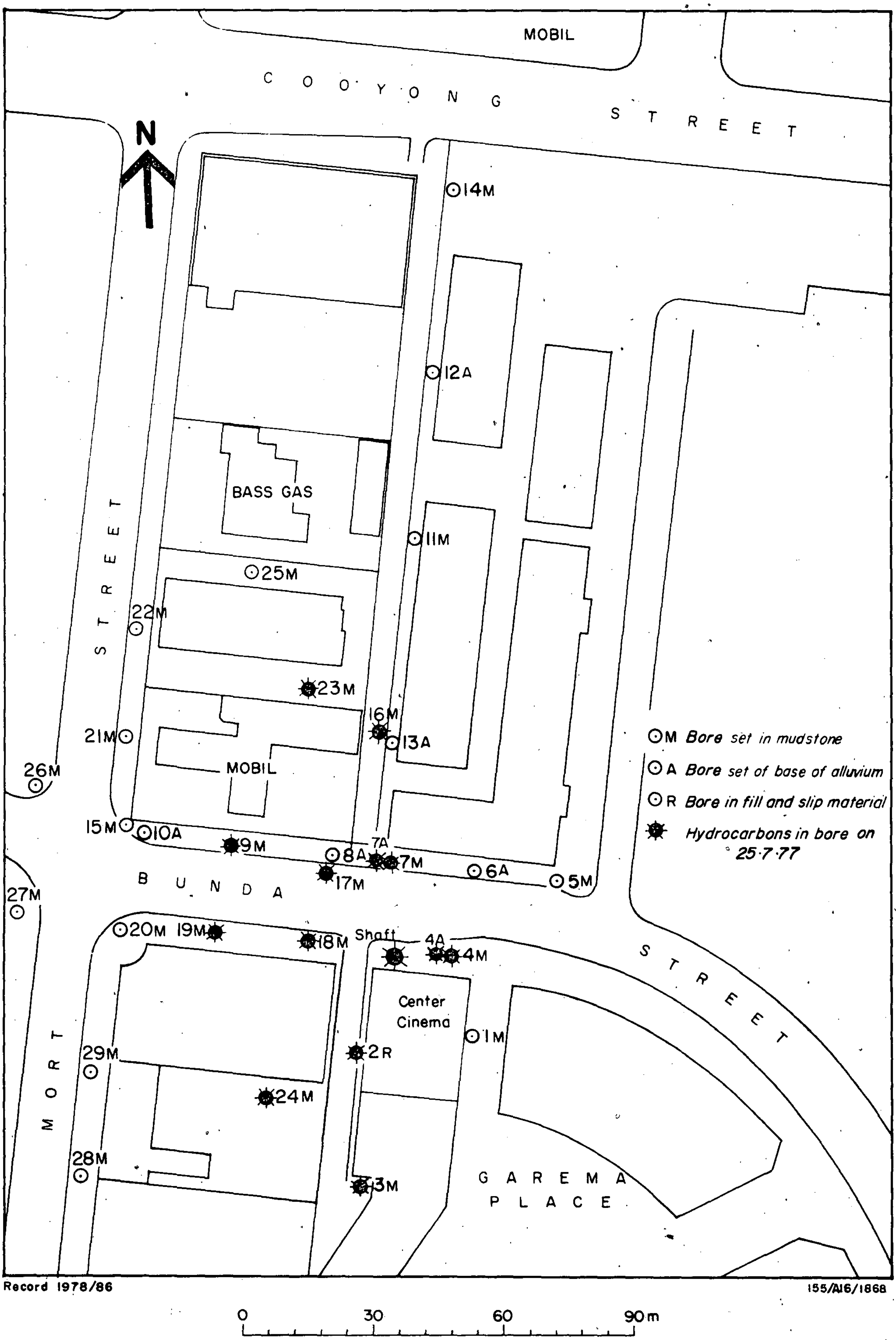


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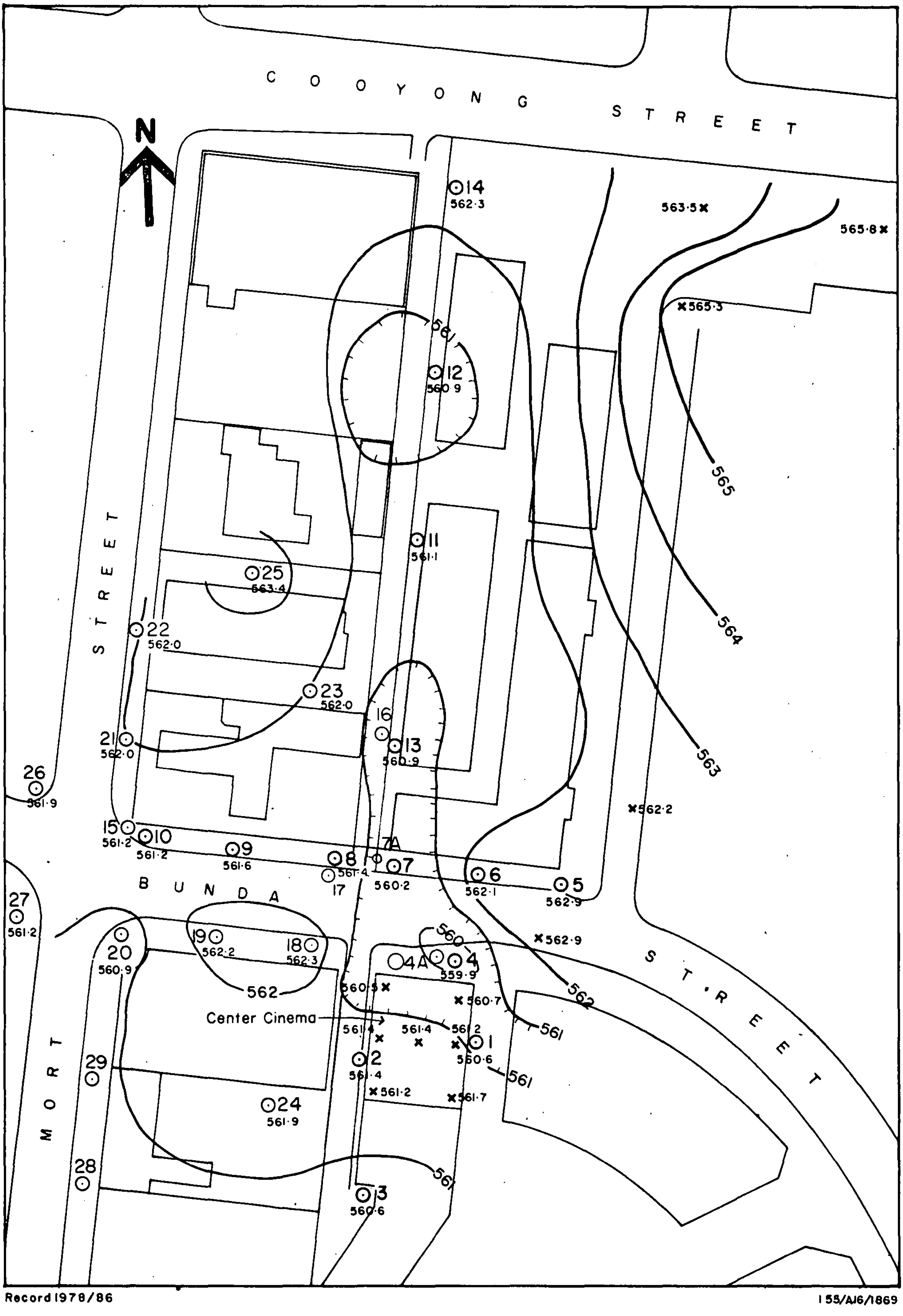
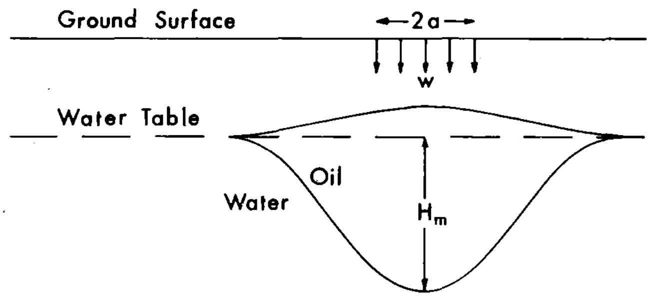
FIG. 1 Location of bores and hydrocarbon pollution



561.4 Bore
x 560.6 Hole or trench
} Showing reduced levels of alluvium - bedrock contact

FIG. 2 Contours on the alluvium-bedrock contact

—563— Elevation of alluvium-bedrock contact (m)



Text
Fig. 1. Cross section through hypothetical oil lens.
After Holzer, 1976

Text Fig. 1

The broken contours in Figure 3 have been drawn to correct for the effect of the hydrocarbon lens, and show what the potentiometric surface would be if there were no hydrocarbons present. The flowlines in Figure 3 have been drawn to intersect the modified potentiometric contours at right-angles, and indicate the movement path of underground fluids in this area.

TABLE 1

WATER-LEVEL FLUCTUATIONS, MARCH-JULY, 1977

Bore	Aquifer	Water-level below ground (m) Max	Min	Fluctuation (m)
1	Mudstone	5.34	5.61	0.27
2	Mudstone	4.21	4.90	0.69
3	Mudstone	5.25	5.62	0.37
4	Mudstone	5.38	5.55	0.17
4A	Alluvium	2.24	4.84 (dry)	2.60
5	Mudstone	2.12	4.83	2.71
6A	Alluvium	2.80	3.47 (dry)	0.67
7	Mudstone	4.98	5.29	0.31
7A	Alluvium	4.51	4.83	0.32
8A	Alluvium	2.65	3.92 (dry)	1.27
9	Mudstone	4.11	4.52	0.41
10	Mudstone	3.53	4.25	0.72
11	Mudstone	4.39	4.69	0.30
12A	Alluvium	2.98	3.73	0.75
13A	Alluvium	4.13	4.41	0.28
14	Mudstone	3.06	3.49	0.43

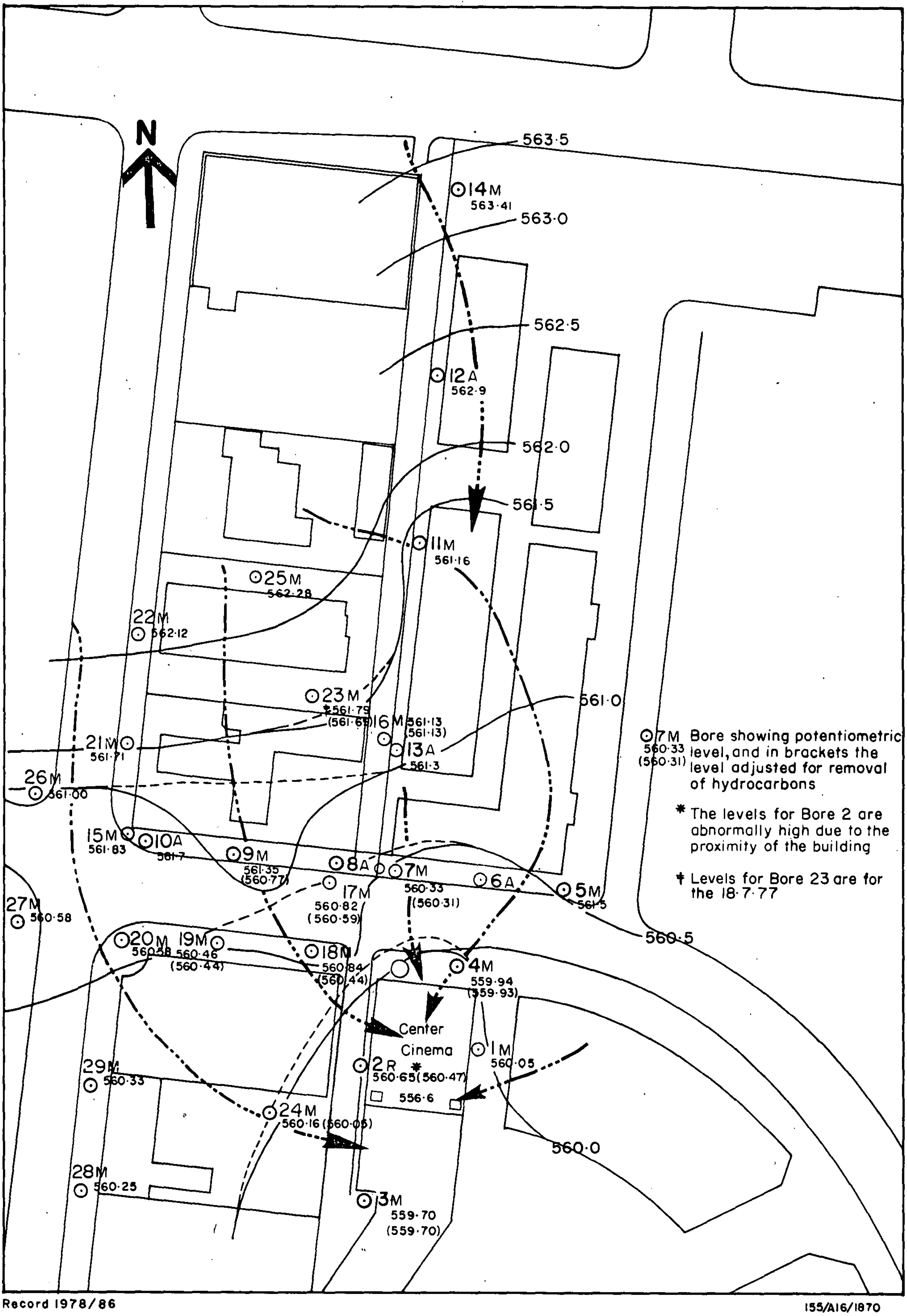


FIG. 3 Potentiometric contours of the mudstone aquifer 25·7·77

Broken lines show position of contour if hydrocarbon pollution removed. - - - -➤ Flow line

Dye tracing experiment

A dye tracing experiment that was being conducted in conjunction with D. Ingle Smith of the ANU was mentioned in the earlier report (Jacobson, Part 1 of this Record). The experiment was continued to July 12. The later results are set out in Appendix 1 of this report. The dye experiments were designed to trace the movement of water in the affected area. Dye movements of 2-5 metres per day were initially recorded under normal flow conditions, and values of greater than 50 metres per day were arrived at after periods of heavy rain.

Velocities of 2-5 metres per day would be considered reasonable in sections of the gravel and in moderately weathered and jointed mudstone, but it is difficult to reconcile velocities of over 50 metres per day with the low groundwater gradient existing in the area. As the high velocities followed heavy rainfall, it is considered that factors other than normal groundwater processes were involved, and that an influx of water into the system via the stormwater drains may have set up transitory conditions responsible for the high velocities.

Permeability in the mudstone

Permeabilities in the mudstone derived by the Auger-Hole Method ranged from 0.01 to 0.085 metres per day (Jacobson, Part 1 of this Record); however, these were conducted in extremely to highly weathered mudstone, which contains a high percentage of clay, and the values may not be representative of the mudstone affected by the pollution plume which ranges from an extremely weathered to a slightly weathered condition. At greater depths the jointed mudstone is less weathered, the joints have fewer clay coatings, and the permeability will be higher.

A subsequent analysis of permeability based on inflows to the shaft and joint frequency in the mudstone indicated that a permeability of about one metre per day is to be expected in the moderately weathered mudstone with slightly open joints at depths of about 7-10 metres.

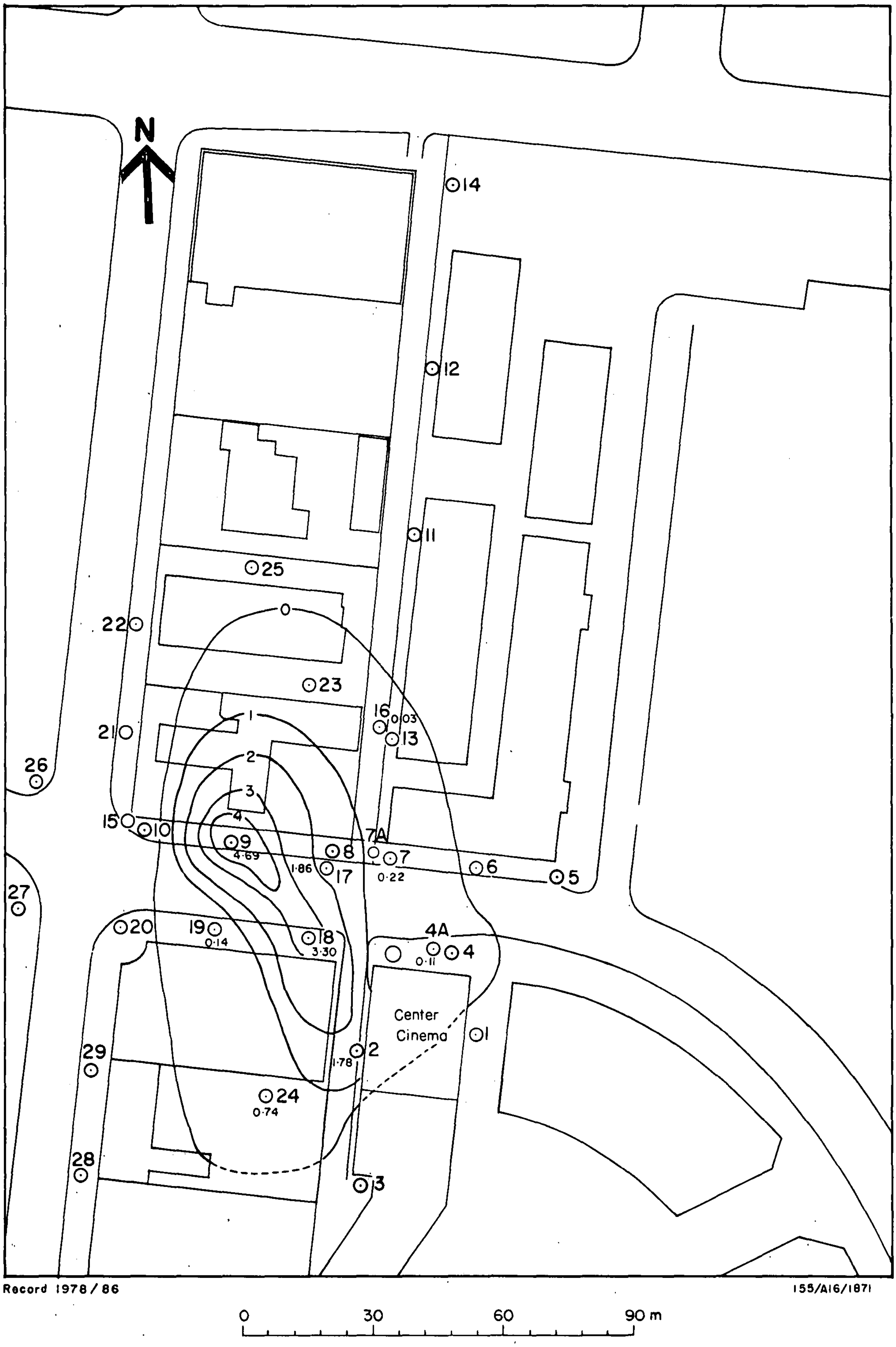


FIG. 4 Isopachs of pollution plume in metres

4·7·77

A relationship exists between the velocity of movement of dye and the permeability of the medium in which it moves; the permeability indicated by a dye velocity of from 2 to 5 metres per day would range from 1 to 2.5 metres per day assuming an effective porosity of one percent.

The mudstone affected by the pollution plume is in a variably weathered and jointed condition, and it is expected that the permeability will range between 0.1 and 1 metre per day. The higher permeabilities derived from dye velocities have been disregarded because they are thought to contain a component of higher permeability attributable to the overlying alluvium.

THE POLLUTION PLUME

The pollution plume comprises free hydrocarbons overlying a diffusion zone of water and hydrocarbons held in fractures and pores in the rock (Wilson, 1978).

The thicknesses of hydrocarbons measured in drillholes from May to July are listed in Table 2. The extent of the pollution plume is shown by the isopachs of hydrocarbon thicknesses in the drillholes (Figure 4A). The area of the plume on 25 July was about 5318 m^2, and it extended beneath the neighbouring Civic Theatre and the car park at the rear of the Manchester Unity building. Bores intersecting the pollution plume receive slow inflows of water and hydrocarbons and take some time to attain a stable condition after being drilled, and in each borehole the base of the hydrocarbons equates to the base of the pollution plume at that point.

Isopachs have been constructed to show the thickness of rock affected by the pollution plume; a thickness of 4.9 m was measured in bore 9 in Bunda Street on 18 July, and the deepest part of the pollution plume is on the north side of Bunda Street at a level of about 556.8 m (see Fig. 5). Some variation in the thicknesses of hydrocarbons has been noticed with time, and hydrocarbons are being found in bores that were not previously contaminated (3M).

Values for porosity of the rock have been estimated from measurements of joints in drill core as 1.3 percent. Estimates of porosity by relating porosity to the flow velocity of the dye tracer gives 0.15, 0.6 and

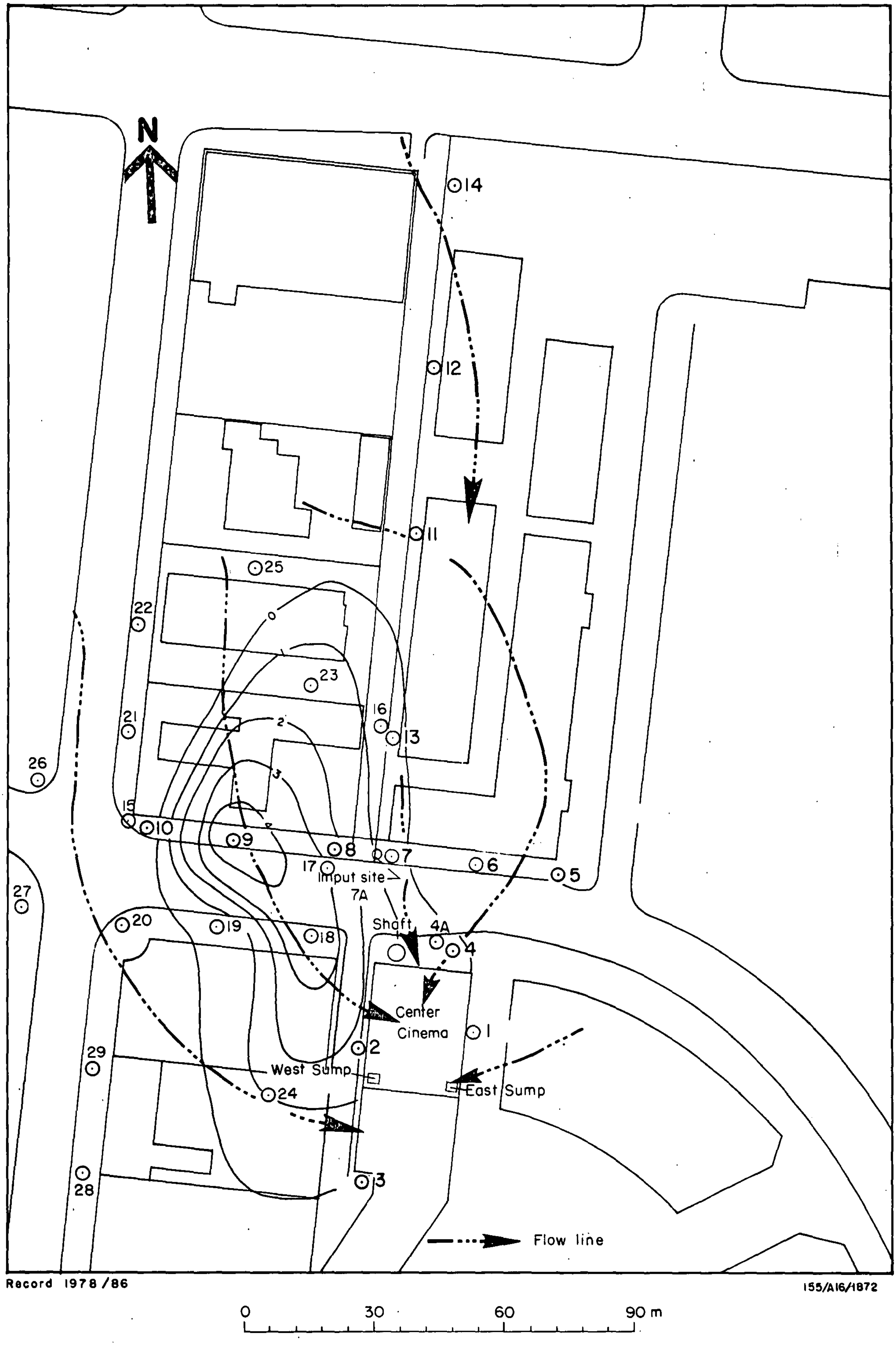


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FIG. 4a Isopachs of pollution plume in metres showing flow lines 25·7·77

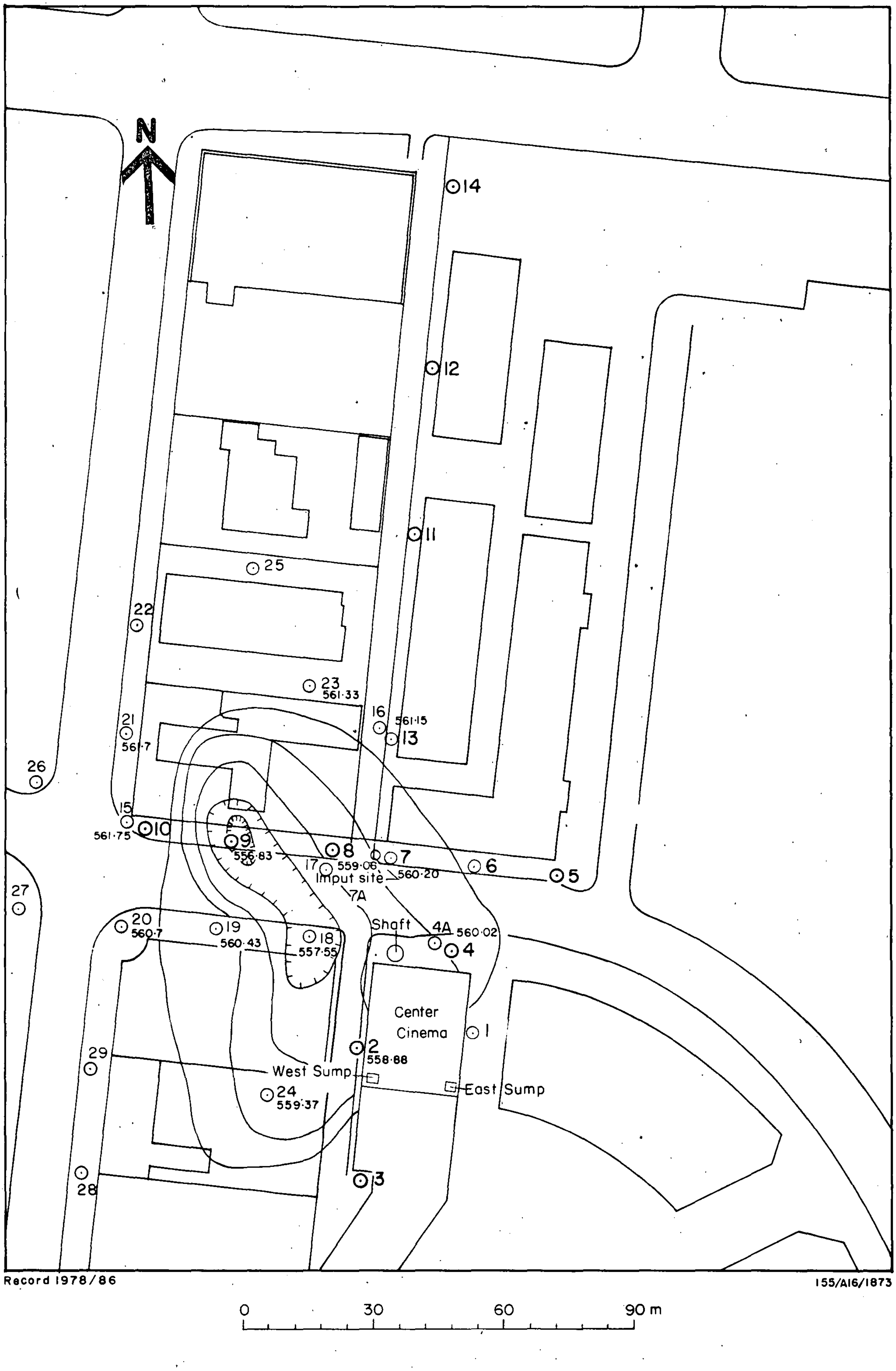


FIG. 5 Contours on base of pollution plume, in metres, 4·7·77

1.0 percent for different parts of the groundwater system near the Cinema. Not all fluid in the pollution plume consists of hydrocarbons, and percentage of hydrocarbons in the pollution plume has been calculated as 41 percent (see Appendix 2).

TABLE 2

MEASUREMENTS OF HYDROCARBON COLUMN IN BOREHOLES

Measurements in metres

Bore	12 May	27 June	4 July	11 July	18 July	25 July
2	2.70	1.78	1.78	1.82	1.78	1.80
3	-	-	-	-	trace	0.03
4	0.10	0.17	0.11	0.14	0.12	0.11
4A	-	0.05	0.01	film	0.01	film
7	0.35	0.27	0.22	0.30	0.29	0.30
7A	-	0.02	0.01	film	film	film
9	4.55	4.78	4.69	4.68	4.90	4.65
16	-	-	0.03	0.01	0.01	0.03
17	-	1.82	1.86	1.91	2.06	2.22
18	-	4.44	3.30	3.38	3.37	3.50
19	-	0.13	0.14	0.17	0.24	0.20
23	-	0.11	0.12	0.38	1.02	1.17
24	-	0.54	0.74	0.92	0.98	1.18

The volume of rock containing the pollution plume is estimated to be about 7840 m^3. Assuming one percent volume of the rock consists of water and hydrocarbons in fractures and pores, the volume of fluids in the ground would be 78 400 litres, of which about 32 000 litres (7000 gallons) has been estimated to be hydrocarbons (see Appendix 2).

The pollution plume is not necessarily stationary; the recent entry of hydrocarbons into bore 3 about 5 months after it was drilled means that the plume could be spreading laterally and/or moving southward. If the source of pollution has been cut off, then the pollution plume will become thinner as it spreads; however, there is as yet no evidence that would indicate whether hydrocarbon leakage has ceased or is continuing. Monitoring of the plume will be required until its location has been stabilized.

The pollution plume is elongated to the south-southeast. If the flow lines derived from the corrected potentiometric surface (Fig. 3) are superimposed on the plume (Fig. 4A), then it is expected that the source of the pollution will be found to lie to the north-northwest upslope along the flow lines.

REMEDIAL MEASURES

The present recovery operation from the shaft outside the Center Cinema is removing about 200 litres of hydrocarbon liquid per month. In addition, an unknown amount is removed as vapour by the exhaust fans over the drainage sumps of the Center Cinema, or is pumped out as a liquid with the water.

A proportion of the hydrocarbon pollutant could be recovered by pumping from a bore. A recovery point would generally be located near the thickest part of the pollution plume, but because of the slow movement of the pollution plume to the south-southeast, it would be more effective to locate such a bore in the lane near the Center Cinema to the northwest of bore 2. An assessment of pumping from a bore for the removal of hydrocarbons from this area is made in Appendix 2.

The bore should be about 20 cm diameter with a casing of about 15 cm diameter set in a sand and gravel pack; the depth of the bore should be about 30 metres. The bore should be pumped to give a low yield of less than 12 m^3 per day almost continuously, and the amount of hydrocarbons in the outflow should be monitored.

A pocket of hydrocarbons remains against the west side of the Center Cinema near bore 2, and is considered to be close to an entry point into the cinema's drainage system. If required at a later date, a bore could be used for the recovery of hydrocarbons by regular pumping with a vacuum pump. However, it is considered that the bore recommended above would probably remove hydrocarbons from this pocket.

CONCLUSIONS

The following conclusions should be regarded as additional to those stated by Jacobson (Part 1 of this Record).

1. The hydrocarbon pollution plume has a maximum thickness of more than 4.65 m, it occupies an area of over 5318 m^2 and contains about 78 400 litres of contaminated fluid including about 32 000 litres of hydrocarbons (7000 gallons).

2. The source of the pollution lies upslope along the flow lines to the north-northwest from the centre of the pollution plume.

3. The pollution plume has not stabilized; it may be spreading laterally as well as moving slowly down gradient in the direction of the flow lines.

4. The investigations so far do not indicate whether the source of hydrocarbon pollution is still contributing additional pollutants, or has ceased.

5. Pumping from a bore will remove some of the hydrocarbons, and would be expected to help stabilize the pollution plume.

RECOMMENDATIONS

1. That a bore be sunk in the area for the purpose of removing water and hydrocarbons by pumping, and that the volume of hydrocarbons pumped from this bore be monitored; and

2. that any building located above the pollution plume be closely inspected for possible entry points of vapours, and that the need for long-term surveillance be considered for such buildings.

REFERENCES

HOLZER, T.L., 1976 - Application of groundwater flow theory to a subsurface oil spill. GROUND WATER, 14(3), 138-145.

McKAY, B.A., 1977 - Report on the analysis of hydrocarbons in seepage fluids from the Center Cinema and a comparison with the analysis of petrols sold in the area. Bureau of Mineral Resources Petroleum Technology Laboratory, 15 April 1977 (unpublished).

WILSON, E.G., 1978 - The contamination of groundwater by hydrocarbons, with brief notes on the hydrogeology of Canberra City, A.C.T. Bureau of Mineral Resources, Australia, Record 1978/64 (unpublished).

APPENDIX 1

RESULTS OF DYE TRACING EXPERIMENT

by

D.I. Smith
(Senior Fellow, Centre for Resource and Environmental Studies,
Australian National University)

This report should be read in conjunction with the preliminary report presented as Appendix 2 of Part 1 of this Record.

In that report an account was given of the technique of groundwater tracing using fluorescent dyes. The locations of the boreholes and the details of the dye injection were also described and preliminary results presented for the period April 19, to May 9. This final account of the expermient includes the analysis of samples collected up to July 12.

The total number of sample sets collected was 38 and the only major addition to the sampling scheme previously described was that, from May 15, samples were collected from borehole CC9. Previously the collection of samples from beneath the thick layer of hydrocarbons in that borehole had not been possible. Other minor breaks in the collection record for individual holes are due to the interference of various construction works and the fact that a limited number of boreholes were occasionally dry.

Results of dye collection and analysis

In general, dye did not appear in the sampled boreholes until April 27, and a detailed account of this sampling period is given in the preliminary report. After the first pulse of dye subsequent samples show that the concentration in individual boreholes varies greatly with time. This is illustrated in Figure 6, for boreholes 3, 4 and 5; the rainfall throughout the period is also shown. These boreholes are typical of the dye concentration pattern exhibited by all the boreholes although the absolute dye concentration shows considerable variation.

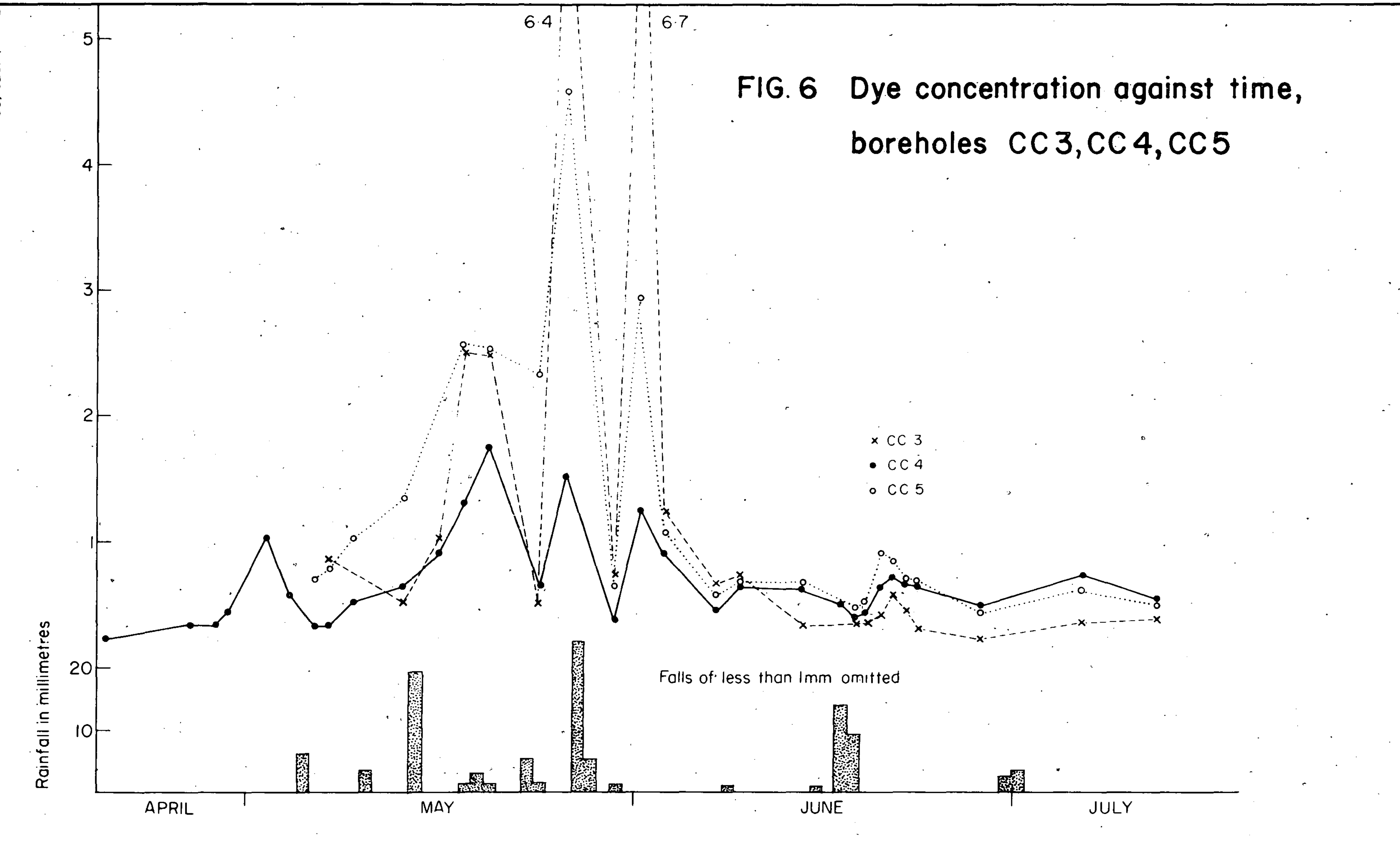


FIG. 6 Dye concentration against time, boreholes CC3, CC4, CC5

Table 3 lists the maximum dye concentration for each sampling site and the date of its occurrence. Figure 7 shows the spatial pattern of maximum dye concentration for the various sites.

This data shows that there is a relationship between periods of heavy rainfall and peaks of dye concentration, the peaks lagging the rainfall. In order to investigate this lag in greater detail several sets of samples were collected in the period following the rain of June 17 and June 18. Eight sets of samples were collected over a period of a week. All the boreholes sampled exhibited a peak of dye concentration within this period. Figure 8 shows representative dye patterns for this period; the boreholes used for illustration are CC3, CC9, and CC13. The time of the onset of dye increase and the time to peak concentration are given in Table 4.

It should be noted that high dye concentrations persist in both the input borehole, number CC7, and in the adjacent borehole CC7A.

Interpretation of the dye data

The preliminary report suggested that the dominant flow direction was from the input borehole (CC7A) south towards the cinema and also the east. These observations have been confirmed from the later studies, and the maximum dye values given on the map in Figure 7 can be used to suggest the dominant underground groundwater flow direction.

TABLE 3: MAXIMUM DYE CONCENTRATION FOR INDIVIDUAL BOREHOLES

Borehole	Maximum dye concentration (in micrograms per litre)	Date of occurrence of maximum dye concentration
CC1	21.60	June 1
CC2	1.45	June 1
CC3	7.53	June 1
CC4	1.76	May 20
CC4A	1.12	June 1
CC5	4.60	May 26
CC6	4.85*	May 6
CC9	1.86*	June 9
CC11	0.78*	June 21
CC13	9.80	June 17
East Sump	10.10	May 30
West Sump	15.00	April 29
Shaft	12.50*	May 10

* Indicates a limited number of samples

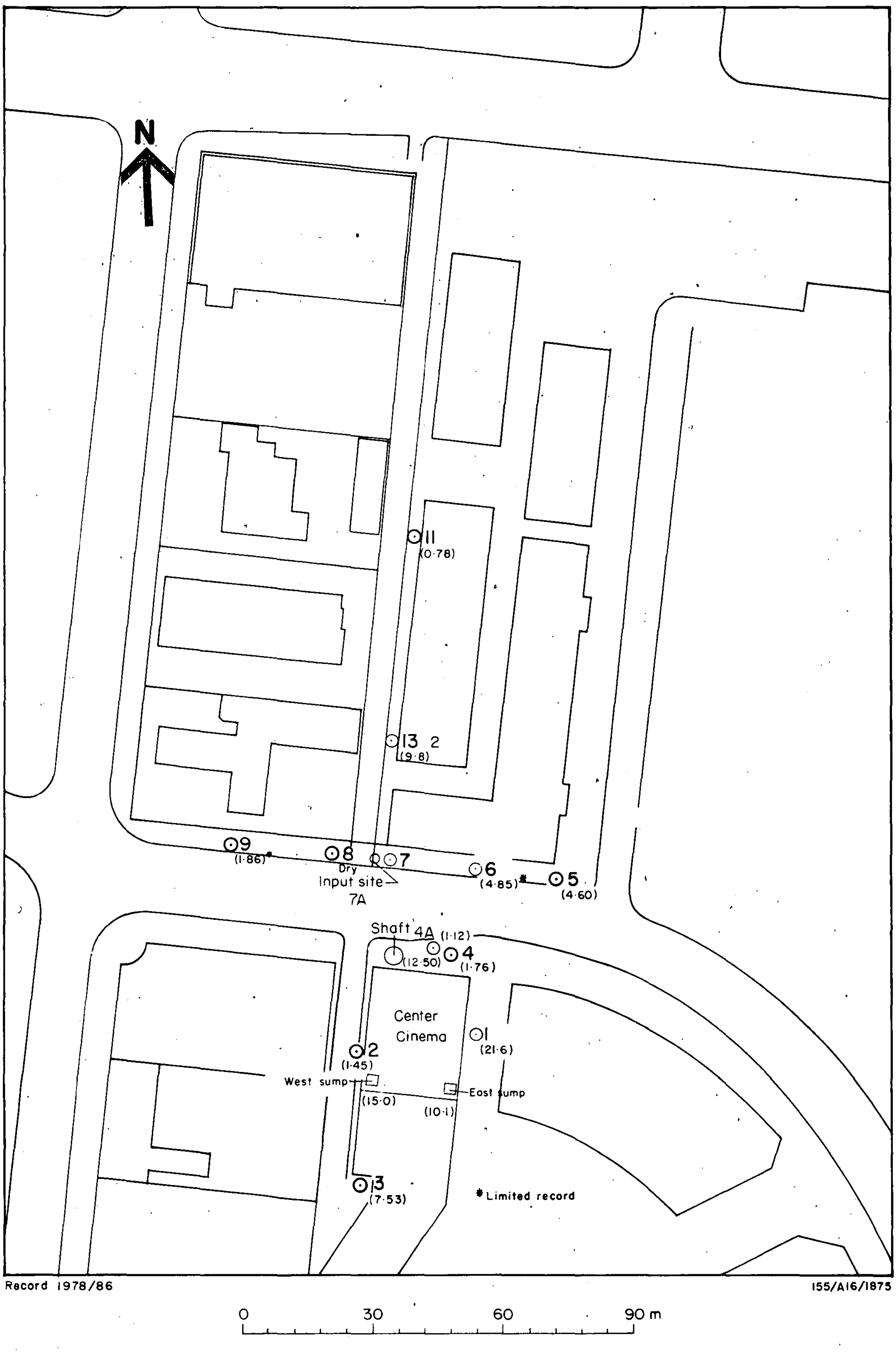


FIG. 7 Maximum dye concentration (values in microgrammes per litre)

TABLE 4: DETAILS OF DYE CONCENTRATION, June 17-23

Borehole	Hours after maximum rainfall to dye increase	Peak dye concentration in g/1	Hours after rainfall to dye peak
CC1	32-52	3.50	78
CC2	32-52	1.05	78
CC3	20-32	0.58	78
CC4	10-20	0.65	78
CC4A	32-52	0.50	104
CC5	Less than 10	0.92	52
CC9	32-52	1.54	52
CC11	32-52	0.78	78
CC13	32-52	2.20	78

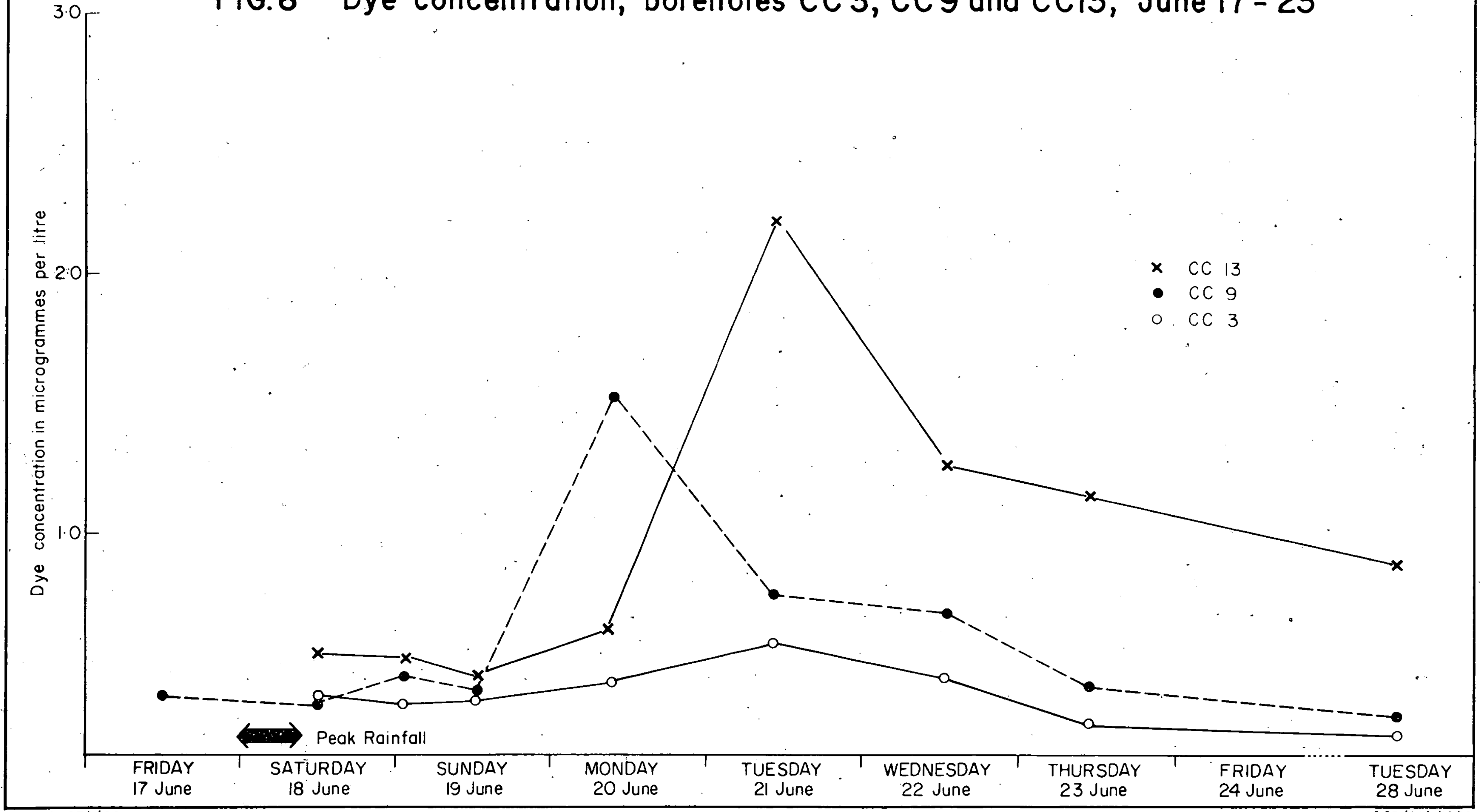
The preliminary report indicated that groundwater flow velocities were in the range of 2 to 5 metres per day. This flow rate can be considered as applicable to flow under normal conditions (there was no rainfall in the period). The dye peaks in Figure 6, and more particularly those in Figure 8, are related to heavy rainfall events. If the assumption is made that these individual peaks represent a new pulse of dye from the area of the input hole velocities can be calculated that represent fast flow velocities. These velocities are given in Table 5 and are in the range of 8-80 metres per day.

These velocities are high by groundwater standards and this may reflect the contribution to the groundwater flow from the various storm water drains in the area of the experiment.

Conclusions

1. The technique has been successful in that it has produced information on the velocity and direction of groundwater movement. However, in presenting these results it must be emphasised that there need be little relationship between the direction and especially the velocity of the groundwater and any overlying pool of hydrocarbons. It is not technically possible to use fluorescent

FIG. 8 Dye concentration, boreholes CC 3, CC 9 and CC 13, June 17 - 23



 I 55/A16/1876

dye techniques to trace hydrocarbons directly (i.e., by adding dye directly to the hydrocarbons) although suitable radioactive tracers may well be satisfactory in this respect.

2. It is impossible to say at what underground level the fastest groundwater flow occurs but the indications are that the velocities calculated from the dye studies are most likely to occur near to the junction of the alluvium and the weathered top of the mudstones.

3. The movement of groundwater is dominantly to the south with a secondary component to the east. This reinforces the interpretation of the groundwater contours and the form of the hydrocarbon plume discussed elsewhere in this report.

4. The velocities are fast by groundwater standards, in the range of 2-5 metres per day under normal flow conditions and increasing to values of greater than 50 metres per day after periods of heavy rain. To some extent these values may be enhanced by the effects of the stormwater drains within the area.

TABLE 5: SUMMARY OF GROUNDWATER VELOCITIES

		For peak of June 12 - June 23		For period April 19 - May 9 (see preliminary report, Table 3)	
	Distance from input	Velocity for first arrival*	Velocity for dye peak arrival	Velocity for first arrival	Velocity for dye peak arrival
1	43 m	24.5 m/day	13.2 m/day	4.8 m/day	3.3 m/day
2	44 m	25.2 m/day	13.4 m/day	-	-
3	78 m	78.0 m/day	24.0 m/day	-	-
4	26 m	41.5 m/day	7.9 m/day	-	-
4A	26 m	14.9 m/day	6.0 m/day	-	-
5	38 m	91.2 m/day	17.5 m/day	-	-
6	19 m	-	-	1.2 to 2.4 m/day	-
9	37 m	21.1 m/day	17.0 m/day	-	-
11	75 m	41.7 m/day	23.0 m/day	-	-
13	27 m	15.4 m/day	9.4 m/day	2.3 m/day	1.8 m/day
West Sump	30 m	-	-	3.3 m/day	3.0 m/day
East Sump	30 m	-	-	3.3 m/day	2.3 m/day

* Average value taken from Table 4

APPENDIX 2

AN ASSESSMENT OF PUMPING FROM A WELL FOR THE REMOVAL OF HYDROCARBONS AND GROUNDWATER FROM THE POLLUTION PLUME BENEATH BUNDA STREET

by

P.D. Hohnen & R. Evans

This section compares the effectiveness of a bore of 20 cm diameter and a shaft of 2 m diameter in creating a cone of depression that will entrap hydrocarbons from the pollution plume that extends from the north side of Bunda Street to the south of the Center Cinema.

Analyses have been carried out for unsteady state conditions, i.e. dewatering of the aquifer until a recharge boundary is intersected, and for steady state conditions corrected for partial dewatering, where the recharge rate (R) equals the pumping rate (Q_w).

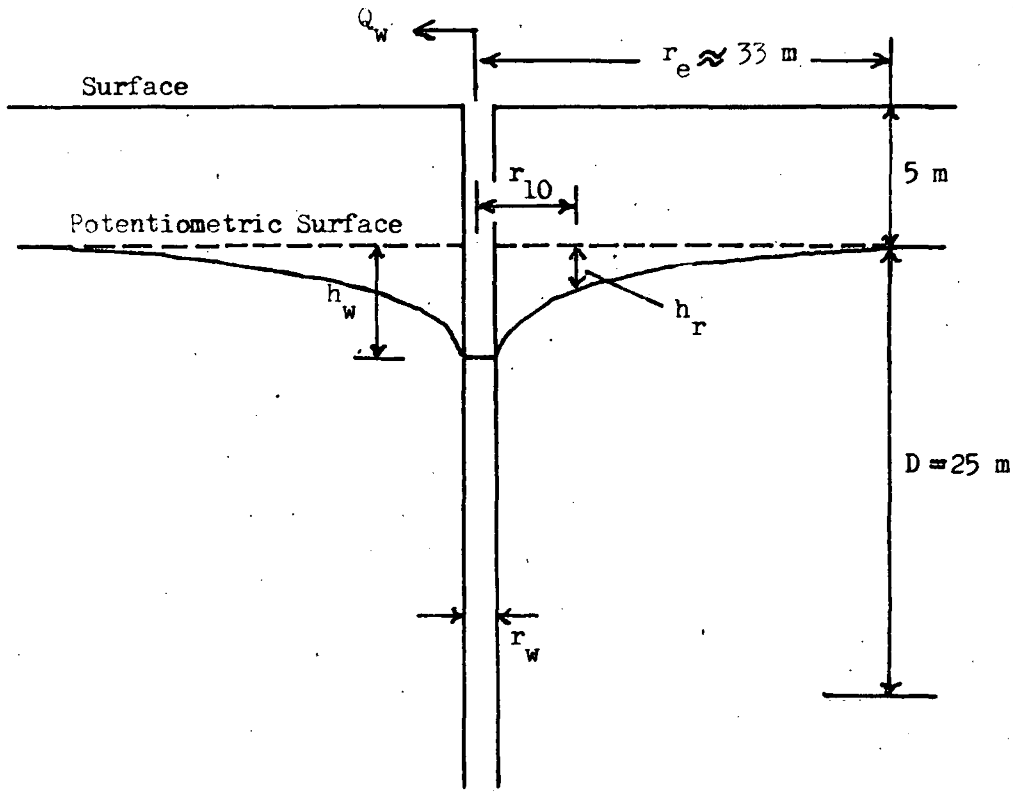
UNSTEADY STATE ANALYSIS

Before carrying out an unsteady state analysis, the radius of the cone of depression was calculated that would be needed to intersect sufficient cross-sectional area of aquifer to give a recharge equal to the selected pumping rates of 6 m^3/day and 12 m^3/day. This assessment of recharge used natural hydraulic gradients and hydraulic conductivity calculated for the mudstone, and indicated that a radius of influence of about 30 m would give recharge equal to the pumping rate.

Using the equation $h_w = \frac{Q_w}{4\pi kD} . \ln \frac{2.25.kDt}{r_e^2 S}$ which is a valid approximation for small values of $\frac{r^2 S}{4kDt}$ (See Fig. 9 for explanation of terms), where S is equal to the effective porosity, calculated earlier to be about 0.01, and r_e equals the radius of influence, then the time necessary for the development of the cone of depression to assumed steady state conditions

FIGURE 9

EXPLANATION OF HYDRAULIC PARAMETERS



h_w drawdown in bore or shaft (m)

h_r drawdown at radius r from pumping bore (m)

Q_w constant pumping rate (m^3/day)

D saturated thickness of aquifer (m)

r_e effective radius of cone of depression

k hydraulic conductivity of aquifer (m/day) of $r_e \approx 30$ m would be two days. Thus, after t= 2 days pumping at 12 m^3/day, the predicted drawdown in the pumping bore would be about 4.4 m, and this should be the steady state drawdown.

STEADY STATE ANALYSIS

The steady state equation is the Thiem equation in which the distance to the closest piezometer to the pumping well in the Thiem derivation is assumed to approach the radius of the pumping well.

The aquifer is considered to be unconfined.

The coefficient of permeability (k) ranges from about 0.10 to about 1.0 m/day, and values at both ends of this range were used in the analysis.

The saturated thickness of the aquifer has been estimated at 25 m.

The proposed pumping rate was selected by determining the theoretical yield of bores for diameters of 0.2 m and 2.0 m, intersecting aquifers with coefficients of permeability of 0.5 and 1.0 m per day.

The most important constraint is that the foundations of the Center Cinema not be dewatered, as it would facilitate the entry of additional hydrocarbon vapours into the drainage system beneath the foundations of the theatre. This condition dictates a maximum withdrawal rate of 12 m^3/day from the pumping well.

TABLE 6

DRAWDOWNS WITHIN THE CONE OF DEPRESSION

Calculated for various values of k and Q_w from the Thiem equation corrected for partial dewatering.

$$h_w - h_r = \frac{Q_w}{2\pi kD} \cdot \ln\left(\frac{r_e}{r_w}\right) \quad \text{Steady state equation}$$

	r_w = 0.1 m	r_w = 1 m	r_{10}= 10 m	Pumping rate, hydraulic conductivity
h_r	0.19 m	0.13 m	0.06 m	k 1.0, Q_w = 6; or, k = 0.5, Q_w = 3
h_r	0.44 m	0.26 m	0.08 m	k = 1.0, Q_w=12; or, k = 0.5, Q_w = 6
h_r	2.17 m	1.3 m	0.96 m	k = 0.1, Q_w = 6; or, k = 0.2, Q_w=12
h_r	4.36 m	2.6 m	0.83 m	k = 0.1, Q_w = 12; or, k=0.05, Q_w = 6

Calculations of drawdowns of the potentiometric surface have been made for various likely combinations of hydraulic parameters and these are tabulated in Table 6.

EFFECT OF RADIUS OF BORE ON THEORETICAL MAXIMUM YIELD

From the equation in Table 6

$$Q_w = \frac{h_w 2\pi kD}{\ln \frac{r_e}{r_w}}$$

The effect of increasing the radius of the bore by a factor of 10, from 0.1 to 1.0 m, will, for the same drawdown, increase the theoretical yield of the bore by 66 percent, or provide the same yield as the smaller bore at a lesser drawdown.

If h_w = 4.43 m, K = 0.1 m/day, D = 25 m, r_e = 33 m, and r_w = 1.0 m, then Q_w = 20 m^3/day.

If r = 0.1 m, and the other conditions remain unchanged, then Q_w = 12 m^3/day.

Conclusions

1. The shape of the cone of depression after pumping for a long time is independent of the well diameter; at a constant pumping rate, a change in the radius of the pumping well will change only the drawdown in the well.

2. A bore should fully penetrate the fractured mudstone aquifer to a depth of 30 metres from the surface, and will ensure a higher yield and a steeper cone of depression from which it should be possible to draw off hydrocarbons.

3. There is no advantage to be gained by a large diameter shaft because the predicted drawdown levels set out in Table 6 are small, and the increase in drawdown that would take place with a 20 cm diameter bore in preference to a 2 m diameter shaft would not be detrimental to the performance of the installation.

4. A bore 30 m deep and 20 cm diameter would cost in the order of $5000, whereas a 2 m diameter shaft of depth capable of performing the same

task, about 20 m deep, would cost of the order of $25 000. The above figures include the cost of a basic pumping installation, but other special equipment associated with the recovery of hydrocarbons would add to the cost.

REDUCTION OF LEVELS OF THE POTENTIOMETRIC SURFACE TO REMOVE THE DOMING EFFECT OF THE HYDROCARBON POLLUTION PLUME

In order to generate flow lines to indicate the movement of groundwater, the doming effect of hydrocarbons in the pollution plume had to be removed. A modification of the Ghyben-Herzberg relationship used for determining the shape of a fresh-water lens in salt water was adapted for this purpose.

The pollution plume has a lens shape. In the thickest part of the plume, the depth of the base of the lens below the surrounding water table was seven times the height of the top of the lens above the water table (see Text Fig. 1). Because part of the pollution plume is a diffusion zone in which water and hydrocarbons are present in various proportions, the distribution and volume of hydrocarbons for various parts of the plume were required in order to calculate an adjustment to the fluid surface.

From graphs for Australian oilfields in which water saturation is plotted against height of the hydrocarbon column above water table, the proportion of hydrocarbons in each bore was estimated and the thickness of the plume reduced to a thickness representing 100 percent hydrocarbon saturation. The column heights for 100 percent hydrocarbons were reduced to the heights of equivalent columns of water by the Ghyben-Herzberg relationship which in this case was $\frac{1.00 - 0.75}{1.00}$. An average hydraulic conductivity of 0.5 m per day was assumed for the rock containing the pollution plume.

The reduced levels were then plotted on Figure 3 and the water levels contoured; flow lines were then plotted in the direction of maximum gradient across the contours.

The volume of hydrocarbons contained in the pollution plume was calculated at 32 000 litres, 41 percent of the total fluids.

APPENDIX 3

LOGS OF DRILLHOLES

by

R. Evans & T. Kaczerepa

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 565.90 (Top of casing)

Project: CENTRE CINEMA Hole: 15 Date: 20/6/77 Logged by: RE & TK

Depth (metres)	Log	Engineering soils description (Text, plast)	Unified symbol	Colour (Pale or dark, Comb. col. R-B, Y-B)	Moisture D. M < PL W	Permeability (k) / Groundwater Observations	Structure (Massive, Porous, Crumb etc.)		Core Recovery (%)	Geological Pedological Description (Eolian Residual, Alluvial Colluvial, Decomposed rock, Horizon A, B, C, Buried soil)
0–1		Clay		dark grey brown				50mm. inner, 100mm outer PVC.	50	alluvium
1–2		Gravelly clay		dark grey brown					50	
2–3		Clayey gravel							60	
3–4.75		4.75							0	
4.75–8.8		Moderately to highly fractured, yellow brown to brown. Mudstone M.W. joints show some manganese staining. Vertical joints. Some layers of red-brown, due to weathering		Yellow brown to brown		Water Level 11/7/77		50mm. slotted PVC	100	Moderate to highly weathered bedrock.
8.8–9.6		Highly fractured Mudstone Manganese stained joints							100	
9.6–10		Moderate to highly fractured mudstone.								

Sheet 1 of 2

Driller: Stewart Bros. Drill type: Gemco diamond ■ Not sampled Checked by: GJ

155/A16/1891

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Centre Cinema Hole: 15 Date: 20.6.77 Logged by: RE & TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-G	Moisture D, M, W	Permeability (k) / Groundwater Observations	Structure [illegible]		Core Recovery (%)	GEOLOGICAL [illegible] DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		As above								
11									100	
12										

Steet 2 of 2

Driller: Stewart Bros Drill type: Gemco [illegible] sampled Checked by: G J 155/A16/1891

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 565.63 (Top of casing)

Project: Centre Cinema Hole: 16 Date: 20.6.77 Logged by: RE & TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M×<PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–1		Clay		dark grey brown				50mm inner, 100mm outer PVC	70	Alluvium
1–2		Sandy clay		dark grey brown					70	
2–3		Sandy clay and cobbles		brown, dark grey					60	
3–5.6						Fluid level 18/7/77; hydrocarbon layer			0	
5.6–10		Mod. to highly weathered. Highly fractured mudstone Shows decomposition to clays. Mang. stain on some joints MW. - SW. Mod. fracturing Joints showing Mang. staining		Yellow brown to brown				50 mm slotted PVC	100; 100	Bedrock

Sheet 1 of 2

Driller: Stewart Bros. Drill type: Gemco diamond Not sampled Checked by: G J 155/A16/1892

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Centre Cinema Hole: 16 Date: 20.6.77 Logged by: RE & TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text. plast.)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-G	Moisture D M W S	Permeability (k) / Groundwater Observations	[illegible]	Structure	Core Recovery (%)	GEOLOGICAL CLASSIFICATION [Aeolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
11 12		As above Mw. Mod. fracture Has well developed rough jointing. Mang. & Fe. Staining clay lined (chlorite)		Olive Brown					100	Bedrock
		(11.6 - 12.0) highly fractured.								

Sheet 2 o 2

Driller: Stewart Bros. Drill type: Gemco diamond [redacted] completed Checked by: GJ

155/A16/1892

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 565.72 (top of casing)

Project: Center Cinema Hole: 17 Date: 20.6.77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M, ≈PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–3 (1, 2)		Clay		Dark yellow brown				50mm inner, 100mm Outer PVC	50	Alluvium
3–4		Gravel - clayey sand		Yellow brown					60	
4		E.W. Bedrock (mudstone)		"					50	EW Bedrock
		Clayey gravel		yell brown		Fluid level 18/7/77			90	Alluvium
5–7 (6, 7)		EW. Mudstone bands of stiff clay highly fractured		yell brown some mang. stain also red brown		hydrocarbon layer			100%	EW Bedrock
8		MW. Mudstone - joints 1mm wide		red brown				50 mm slotted PVC	100	MW - HW b'rock
		clay		yell brown					100	EW b'rock
		MW - HW mudstone fract. - mang stain		red brown					100	
9		clay		yell brown					100	
		MW - HW mudstone fract. mang. stain 2 joint ~~sets~~		red brown					100	

Sheet 1 of 2

Driller: Stewart Bros. Drill type: Gemco diamond. [redacted] Not sampled Checked by: GJ

155/A16/1893

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema Hole: CC17 Date: 20/6/77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text. plast.)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M > < PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Cracks etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		MW-HW Mudstone							100	
11		EW.-HW. 4mm. joints mang. stain		yellow brown					100	Bedrock
		MW mudstone		red brown					100	
12		EW-HW mudstone		yell. brown					100	

Sheet 2 of 2

Driller: Stewart Bros Drill type: Gemco [redacted] Not sampled Checked by: GJ

155/A16/1893

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 565.65 (top of casing)

Project: Center Cinema Hole: CC18 Date: 21·6·77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D,M>< PL,W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–1		Clay · sand · gravel		dark grey brown				50 mm inner, 100 mm outer PVC	30	
1–2		Clayey sand		dark grey brown					40	Alluvium
2–3		Clay		light grey brown					30	
3		Clay		yell.-grey brown					60	
4		EW M'stone general mang stain		yell-grey brown		Fluid level 18/7/77			80	EW Bedrock
5–9		MW. Mudstone Manganese stain in joints 2 sets angle joints Moderately fractured		Red-Brown		Hydrocarbon level		50 mm slotted PVC	100	MW. Bedrock

Sheet 1 of 2

Driller: Stewart Bros. Drill type: Gemco (diamond) Not sampled Checked by: GJ

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M (PT) 200

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema Hole: CC18 Date: 21·6·77 Logged by: IK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M, >, <, PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
11		as above							100	as above
12										

Steet 2 of 2

Driller: Stewart Bros Drill type: Gemco [redacted] Not sampled Checked by: GJ

155/A16/1894
M (Pt) 208

BUREAU OF MINERAL RESOURCES,
GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 565·76 (Top of casing)

Project: Center Cinema Hole: CC19 Date: 21·6·77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M>, <PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–1		Clay		dark grey brown				50 mm inner, 100 mm outer PVC	30	Alluvium
1–2		Sand & clay		dark grey brown					30	
2–3	Not sampled								0	
3–3.6		Clay		yell brown					30	
3.6–4.2		EW Mudstone mang. stain		yell grey brown					100	
4.2–4.7	Not sampled								0	
4.7–10		HW. M'stone Mang. stain in joints 2 sets (low & high incidence) Mod. fracturing One joint 85 cm. long on 50 mm. width core Clay bands at 5.95 & 6.4				Fluid level 18/7/77; Hydrocarbon layer		50 mm. slotted PVC	100	HW. Bed-rock

Sheet 1 of 2

Driller: Stewart Bros. Drill type: Gemco (diamond) ■ Not sampled Checked by: GJ

155/A16/1895
M (P7)

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema Hole: CC19 Date: 21·6·77 Logged by: RE & TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M > < PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Cracks etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
11–12		as above							100	as above

Sheet 2 of 2

Driller: Stewart Bros **Drill type:** Gemco **Not sampled** **Checked by:** G J

155/A16/1895

M (PT)/200

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 565.84 (Top of casing)

Project: Center Cinema Hole: CC20 Date: 21·6·77 Logged by: IK & RE

Depth (metres)	Log	Engineering Soils Description (Text, plast.)	Unified symbol	Colour (Pale or dark; Comb. col.; R-B, Y-G)	Moisture (D, M, W, Pl, Ll)	Permeability (k) / Groundwater Observations	Structure / [illegible]		Core Recovery (%)	Geological [illegible] Description (Eolian, Residual, Alluvial, Colluvial, Decomposed rock, Horizon A, B, C, Buried soil)
0–1									0	
1–2		Sandy clay		dark grey brown				50 mm inner, 100 mm outer O/C.	60	
2–3		clayey silt		yell. brown					50	Alluvium
3–4		clayey sand		grey brown					50	
4–5		gravel; clayey gravel		yell.-brown					100	
5–5.7		Ew. Mudstone; 2cm gravel at 5.25		yell-grey brown		Fluid level 18/7/77			100	Ew Bedrock
5.7–10		Mw. - Hw. Mudstone; 5cm. clay at 6.0 m.; 10 cm. Highly fractured at 7.1 & 7.5 to 7.8 - reddish colour. 8.2 - 8.4; 8.5 - 8.6; 2 set joints; mang stain, rough joints		red-yell. brown				50 mm. slotted P/C.	100	Mw - Hw Bedrock

Sheet 1 of 2

Driller: Stewart Bros. Drill type: Gemco (Tungsten) [redacted] samples Checked by: GJ

155/A16/1896

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Centre Cinema Hole: CC20 Date: 21·6·77 Logged by: RE & TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M, W	Permeability (k) / Groundwater Observations	Structure / [illegible]		Core Recovery (%)	GEOLOGICAL DESCRIPTION [Aeolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		as above								
11		Highly fractured zone at 11·35 - 11·65 vert joints set tight		Red-yell brown					100	MW-HW bedrock.
12										

Sheet 2 of 2

Driller: Stewart Bros Drill type: Gemco [illegible] sampled Checked by: G J

155/A16/1896

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 565.95 (Top of casing)

Project: Centre Cinema Hole: CC21 Date: 21/6/77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D.M.<PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–1		Clay - gravel - silt		V. dark brown & red yell. brown				50mm inner, 100mm outer PVC	50	
1–2		Sandy clay		grey brown					80	Alluvium
2–3		Sandy Clay		grey brown					60	
3–4		Clayey sand		red-yell. grey brown					60	
4–5		HW.-MW. Mudstone joints clay lined				Fluid level 18/7/77				
5–8		HW-MW Mudstone joints manganese stained & rough. Highly fractured zone at 6.2-6.6. 2 joint sets.						50mm slotted PVC	100	HW-MW Bedrock
8–10									100	

Sheet 1 of 2

Driller: Stewart Bros. Drill type: Gemco (Tungsten) [redacted] Not sampled Checked by: G J

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BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Centre Cinema Hole: CC21 Date: 21/6/77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M > < PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Cracks etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		as above 20 cm. fracture zone at 11-11.2 m.								
11									100	
12										

Sheet 2 of 2

Driller: Stewart Bros Drill type: Gemco Not sampled Checked by: GJ

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M (PT)266

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 566·14 (Top of casing)

Project: Center Cinema   Hole: CC22   Date: 21/6/77   Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B.Y-B	Moisture D.M.<PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–1		Clayey silt		V. dark brown				50mm inner, 100mm outer PVC	30	Alluvium
1–2		Silty clay		"					40	
2–4		Sandy clay		yellow brown		Fluid level 18/7/77			30	
4–10		Highly weathered to moderately weathered E.W. zones at 4·3 - 4·9 6·6 - 6·8 Fractured zones at 7·60 - 7·95 8·20 - 8·85 (bleached) 9·60 - 9·80 Manganese stains and iron. Rough joints.		Red yellow				50 mm. slotted PVC	100	HW - MW Bedrock

Sheet 1 of 2

Driller: Stewart Bros.   Drill type: Gemco (tungsten)   [redacted] Not sampled   Checked by: G J

155/A16/1898
M (P1) 250

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Inter Cinema Hole: CC22 Date: 21/6/77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text. plast.)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D.M.<PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		Fracture zones at 10.0 – 10.2 10.9 – 12.00 Mod. - high frad. 10.95 – 3cm. black clay								
11									100	
12										

Sheet 2 of 2

Driller: Stewart Bros. Drill type: Gemco (tungsten) [redacted] Not sampled Checked by: GJ

155/A16/1898

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 566·02 (Top of casing)

Project: Center Cinema Hole: CC23 Date: 21/6/77 Logged by: RE & TK

| DEPTH (metres) | LOG | ENGINEERING SOILS DESCRIPTION (Text, plast) | Unified symbol | COLOUR Pale or dark Comb. col. R-B, Y-B | Moisture D, M>

<PL, W | Permeability (k) / Groundwater Observations | Structure Massive Porous Crumb etc. | | Core Recovery (%) | GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil] |
|---|---|---|---|---|---|---|---|---|---|---|
| 0–1 | | Sandy - silty clay | | V. dark brown | | | | 50 mm inner, 100 mm outer PVC | 30 | Alluvium |
| 1–2.5 | | Silty Clay | | light grey brown | | | | | 50 | |
| 3 | | Sandy clay - some small gravel peices | | " | | | | | 40 | |
| 4 | | Gravelly clay | | yell brown | | | | | 30 | |
| 4–9 | | EW. to 8 m. in places stiff clay & moderate weathering of mudstone | | grey-yellow red-brown | | Fluid level 18/7/77; Hydrocarbon layer | | 50 mm. slotted PVC | 100 | EW Bedrock |
| 9– | | EW. - MW. Mudstone | | " | | | | | 100 | EW-MW Bedrock |

Sheet 1 of 2

Driller: Stewart Bros. Drill type: Gemco (tungsten) ■ Not sampled Checked by: GJ

155/A16/1899
M (Pt) 258

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema Hole: CC23 Date: 2/6/77 Logged by: RE & TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M, >PL, W	Permeability (k) / Groundwater Observations	Structure Massive, Porous, Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
11		EW-MW Mudstone 11.75 - 11.95 highly fractured zone joints up to 2mm. wide		grey-yellow red-brown					100	EW-MW Mudstone
12										

Sheet 2 of 2

Driller: Stewart Bros Drill type: Gemco [redacted] Not sampled Checked by: G J

155/A16/1899

M (PT) 208

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 565.90 (top of casing)

Project: Center Cinema Hole: CC24 Date: 21/6/77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M>, <PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
	Not sampled								0	
1		Silt-sand-clay		dark grey brown				50mm inner, 100mm outer PVC	40	
2		Silty Clay		grey brown					40	Alluvium
		Clay							90	
3		Sandy clay		yellow brown					40	
4, 5		Highly fractured and EW. to 8.7 m. Manganese stains on mudstone.		Red & yellow brown - grey brown					100	EW Bedrock
	Not sampled								0	
6, 7						Fluid level 18/7/77; Hydrocarbon layer			100	
	Not sampled							50mm slotted PVC	0	
8									100	
9		MW to HW Mudstone 2mm. joints Manganese stains		yellow brown / Red brown					100	MW-HW Bedrock

Sheet 1 of 2

Driller: Stewart Bros Drill type: Gemco (tungsten) ▬ Not sampled Checked by: G J

155/A16/1900
M (PT) 204

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema Hole: CC2A Date: 21/6/77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M >< PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Cracks etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Aeolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
11		MW-HW Mudstone joint set and horiz as above. Fractured zone at 11.0-11.2		Red-yellow brown					100	MW-HW Bedrock.
12										

Sheet 2 of 2

Driller: Stewart Bros Drill type: Gemco Not sampled Checked by: G J

155/A16/1900

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 566·42 (Top of casing)

Project: Center Cinema Hole: CC25 Date: 21/6/77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D.M.<PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
1		Silt		V. dark grey brown				50mm inner, 100mm outer PVC	20	
2		Sand-silt-clay		"					50	Alluvium
3		Clay		yellow brown		Fluid level 18/7/77			70	
4, 5, 6, 7, 8, 9		EW. Mudstone Highly fractured Some clay seams Very little mang. stain		Red-yell-grey brown				50mm slotted PVC	100	EW. Bedrock
		Clay		yell brown					100	Bedrock

Sheet 1 of 2

Driller: Stewart Bros. Drill type: Gemco (tungsten) [redacted] Not sampled Checked by: G J

155/A16/1901

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 566·42 (Top of casing)

Project: Center Cinema Hole: CC25 Date: 21/6/77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast.)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M >< PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		Clay		yell-brown					100	Bedrock
11		EW Mudstone Mod. fractured Manganese stains Horizontal joints		yellow-brown Red stains					100	EW Bedrock.
12										

Sheet 2 of 2

Driller: Stewart Bros Drill type: Gemco [redacted] Not sampled Checked by: GJ

155/A16/1901
M (P1) 258

BUREAU OF MINERAL RESOURCES,
GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 565.87 (Top of casing)

Project: Center Cinema   Hole: CC26   Date: 21/6/77   Logged by: IK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M, >, <, PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION (Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil)
0–1		Silty sandy Clay		V. dark brown				100mm outer, 50mm inner PVC	20	Alluvium
1–2		Silty Clay		dark yell. brown					30	
2–4		Gravelly clay		yell brown & grey					40	
4–10		EW-HW Mudstone Highly fractured zones 4.5 – 4.6 8.35 – 9.0 9.3 – 9.8 Clay zones → grey 4.7 – 4.8 8.7 – 8.8 Vertical joint smooth, mang stain Mod. fracture.		Red yell brown. grey (clay zones)		Fluid level 18/7/77		50 mm slotted PVC	100	EW-HW Bedrock.

Sheet 1 of 2

Driller: Stewart Bros.   Drill type: Gemco (tungsten)   [redacted] Not sampled   Checked by: GJ

155/A16/1902

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema **Hole:** CC26 **Date:** 21/6/77 **Logged by:** TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M, W, <PL, W	Permeability (k) / Groundwater Observations	Massive Porosity Contd. etc. Structure		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
11		EW-HW Mudstone Highly fractured zone at 10.4 - 10.65 Horiz. joints 2mm. wide		Red Brown					100	EW-HW Bedrock.
12										

Sheet 2 of 2

Driller: Stewart Bros **Drill type:** Gemco **[redacted] completed** **Checked by:** GJ

155/A16/1902

BUREAU OF MINERAL RESOURCES.
GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 565.87 (Top of casing)

Project: Center Cinema Hole: CC22 Date: 21/6/77 Logged by: IK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text. plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M, <PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
0–1		Sand		grey brown				50 mm inner 100 mm outer PVC	50	Alluvium
1–2		Sandy clay		"					50	
2–3		clay		"					30	
3–4		gravelly clay							30	
4–4.5									0	
4.5–5.5		EW. Mudstone & clays Highly fract. ~~zone at~~ Clay zone at 5.0 – 5.2				Fluid level 18/7/77			100	EW Bedrock
5.5–10		MW-HW Mudstone Vertical joints, few horiz. Manganese & iron stains Highly fractured zone at 6.85 – 7.2 10mm. clay at 6.15 & 6.25		Red-yell. brown – grey clay bands.				50mm slotted PVC		MW - HW Bedrock

Sheet 1 of 2

Driller: Stewart Bros. Drill type: Gemco (Tungsten) Not sampled Checked by: GJ

155/A16/1903
M (PT) 266

BUREAU OF MINERAL RESOURCES,
GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema Hole: CC27 Date: 21/6/77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast.)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D, M, >, <, PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
11		MW-HW Mudstone high fract. core at 8.6 - 8.8, 11.9 - 12.00		Red-yell. Brown.					100	MW-HW Bedrock.
12										

Sheet 2 of 2

Driller: Stewart Bros **Drill type:** Gemco [redacted] **Not sampled** **Checked by:** GJ

155/A16/1903
M (PT) 200

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 566·96 (Top of casing)

Project: Centre Cinana Hole: CC28 Date: 21/6/77 Logged by: RE & TK

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D.M>< PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
1		Sand		grey brown				50mm inner, 100mm outer PVC.	50	
2		Sand & clay		grey to yell. brown					70	Alluvium
3		Silty sandy clay		yellow brown					100	
		Sandy clay		"					30	
4									0	
5		EW - HW Mudstone							100	
		Fractured throughout Manganese staining		Red yellow					0	EW - HW Bedrock
6		Joints indistinguishable		brown		Fluid level 18/7/77			100	
7										
8								50mm. slotted PVC	0	
9									100	

Sheet 1 of 2

Driller: Stewart Bros. Drill type: Gemco (Tungsten) Not sampled Checked by: GJ

155/A16/1904
M (P)/208

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Center Cinema Hole: CC28 Date: 21/6/77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Contrasting col. R-B, Y-B	Moisture D, M < PL, W	Permeability (k) / Groundwater Observations	Hardness Porosity Consolid. etc.	Structure		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
		as above								0	
11										100	as above
12										0	

Sheet 2 of 2

Driller: Stewart Bros Drill type: Gemco [redacted] sampled Checked by: G-J

155/A16/1904

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole
RL. 566·51 (Top of casing)

Project: Center Cinema Hole: CC29 Date: 21/6/77 Logged by: IK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-G	Moisture D, M < PL, W	Permeability (k) / Groundwater Observations	Structure Massive Porous Cracked etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
1		Sandy clay		Black-Red-Brown				100 mm outer PVC. 50 mm inner,	30	
2		Gravelly clay		red brown					20	Alluvium
3		Clay		yell brown					40	
4		gravelly clay		red brown					20	
5		EW to 5·4 m. Mudstone. Then clay		yell. grey brown					100	EW Bedrock
6		MW-HW Mudstone Vertical fractures. Mang. & iron staining				Fluid level 18/7/77				
7		High fract. zones at 8·2-8·3 10·25-10·35		Red yell brown					100	MW-HW Mudstone
8								50 mm slotted PVC.		
9										

Sheet 1 of 2

Driller: Stewart Bros. Drill type: Gemco (tungsten) [redacted] sampled Checked by: GJ

155/A16/19C5

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

Geological Log of Auger Hole

Project: Centre Cinema Hole: CC29 Date: 21/6/77 Logged by: TK & RE

DEPTH (metres)	LOG	ENGINEERING SOILS DESCRIPTION (Text, plast)	Unified symbol	COLOUR Pale or dark Comb. col. R-B, Y-B	Moisture D.M.<PL.W	Permeability (k) / Groundwater Observations	Structure Massive Porous Crumb etc.		Core Recovery (%)	GEOLOGICAL PEDOLOGICAL DESCRIPTION [Eolian Residual Alluvial Colluvial Decomposed rock Horizon A, B, C Buried soil]
11		as above Highly fractured zone at 11.6 - 11.7		Red yellow Brown					100	MW-HW Mudstone
12										

Sheet 2 of 2

Driller: Stewart Bros **Drill type**: Gemco [redacted] **Not sampled** **Checked by**: G J

155/A16/1905
M (PT) 258

PART 3

MOVEMENT OF THE GROUNDWATER POLLUTION PLUME, JULY-SEPTEMBER 1977

by

G. JACOBSON

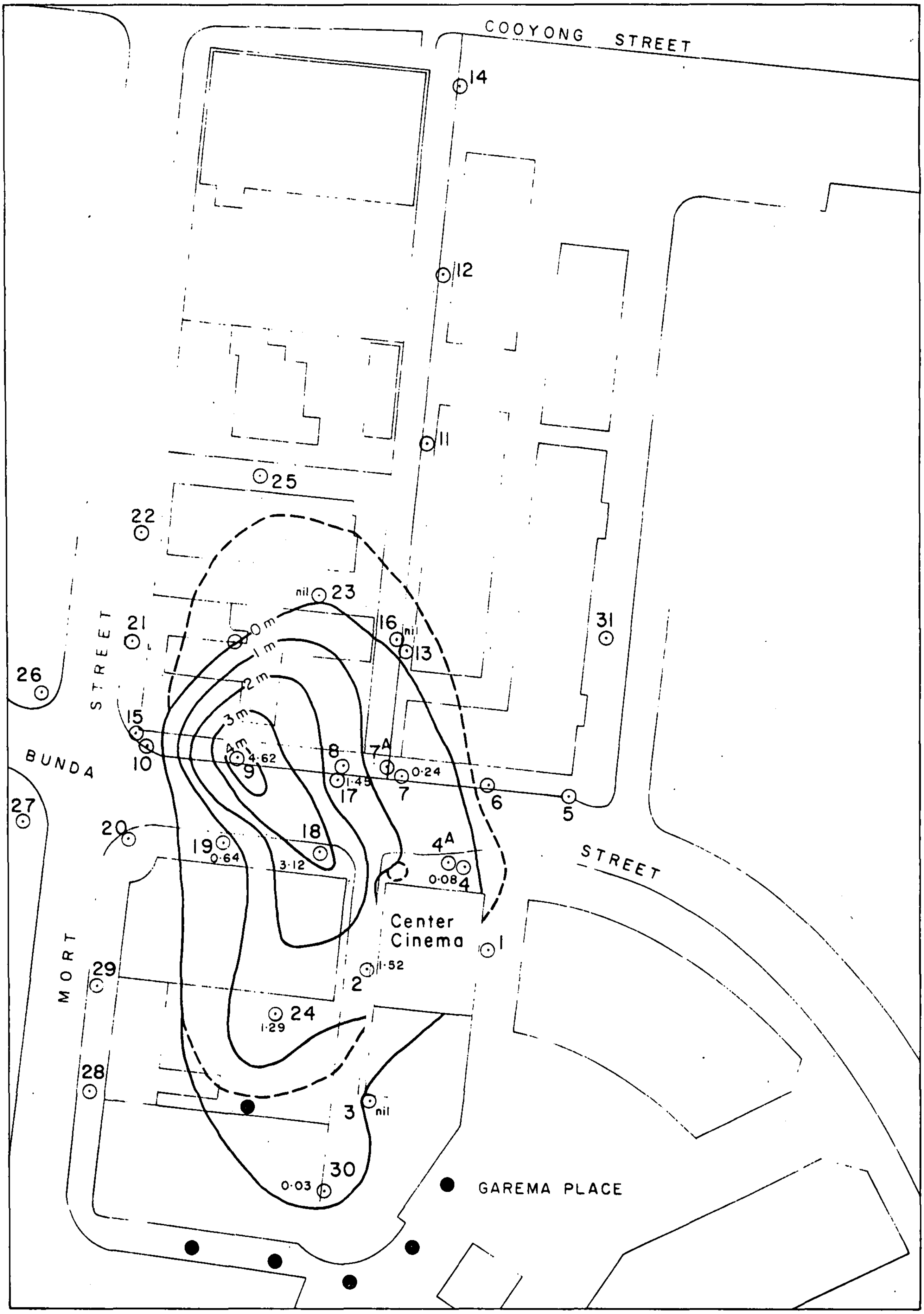
MOVEMENT OF THE GROUNDWATER POLLUTION PLUME

The groundwater pollution plume in the vicinity of the Center Cinema, Canberra City, has been monitored in observation bores for several months. Two additional bores, 30 and 31, were constructed in August. Measurements of the thickness of the column of hydrocarbon pollutant in the bores have been done using a measuring stick covered with water finding paste, and the results are summarised in Table 1.

The variations of hydrocarbon thicknesses in individual bores over several months are summarised as follows.

Bore	Variations in thickness of hydrocarbons
2	Erratic; probably monitors a pocket of hydrocarbons trapped against Center Cinema basement wall.
3	Hydrocarbons first observed in July after several months observation; only a trace remains.
4	Thickness constant at about 10 cm.
7	Thickness constant at about 25 cm.
9	Thickness generally about 4.5 m; slight fluctuations.
16	Formerly a few centimetres thick; only a trace remains.
17	Originally over 2 m, but appears to be thinning.
18	Over 3 m and becoming slightly thinner.
19	Becoming thicker from 20 cm to 64 cm.
23	Over 1 m of hydrocarbons in July. None remains.
24	Thickness increasing, greater than 1 m.
30	Borehole recently completed. A few centimetres of hydrocarbons observed.

Isopachs of hydrocarbon thickness at 29 September 1977 are shown in Figure 1, and have been compared with the position of the pollution plume early in July. The tail of the plume has extended southwards along the direction of groundwater flow, and a substantial amount of the pollutant has now bypassed the Center Cinema. The plume has retracted slightly on the north side; however, little change is apparent in the thickest parts of the plume.



—3m— *Isopachs of pollution plume in metres, 29 September 1977*
– – – – *Inferred extent of plume, 4 July 1977*
● *Proposed additional observation bores*

0 30 60 90 m

Fig. 1 Inferred movement of pollution plume between 4 July and 29 September 1977

Record 1978/86

I 55/A16/2177

There is as yet no measurable change in the volume of pollutant in the ground.

There is no positive indication that the source of the pollutant is a continuing active one.

Pumping from the shaft at the northwest corner of the Center Cinema has had no observable effect on fluid levels in nearby boreholes.

The slow movement of the plume, its "half pear" shape, and the absence of pollutant in the observation bores 22, 25 and 11, are consistent with the source of pollutant being close to, and north of, bore 9.

TABLE 1

MEASUREMENTS OF HYDROCARBON COLUMN IN BOREHOLES

(measurements in metres)

Bore	25 July	1 August	8 August	16 August	9-12 Sept	21 Sept	29 Sept
2	1.80	1.79	-	1.57	2.59	2.60	1.52
3	0.03	0.01	film	film	-	film	-
4	0.11	0.12	0.05	0.12	-	0.07	0.08
7	0.30	0.26	0.21	0.24	-	0.25	0.24
9	4.65	-	4.45	4.48	4.40	4.37	4.62
16	0.03	0.04	film	film	-	-	-
17	2.22	2.04	2.00	1.73	1.57	1.58	1.45
18	3.50	3.44	3.32	3.27	3.13	3.07	3.12
19	0.20	0.18	0.15	0.17	0.80	0.61	0.64
23	1.17	0.12	0.08	0.04	-	-	-
24	1.18	1.15	1.20	1.20	1.36	1.47	1.29
30	-	-	-	-	0.08	0.05	0.03

APPENDIX

GLOSSARY OF HYDROGEOLOGICAL TERMS

by

E.G. Wilson

AQUIFER

An aquifer is a body of saturated permeable rock or soil that will yield quantities of groundwater to wells and springs. A confined aquifer is one from which water will rise under pressure when tapped; water in an unconfined aquifer has a free surface and is at atmospheric pressure.

POTENTIOMETRIC SURFACE

The potentiometric surface is an imaginary surface representing the levels to which water will rise in wells or bores. It refers to a particular acquifer, and if the aquifer is confined (artesian) the potentiometric surface may be above the surface of the ground.

WATER TABLE

The water table is the upper surface of the zone of groundwater saturation of rock or soil; it is a particular potentiometric surface that exists when groundwater is unconfined.

HYDROCARBON POLLUTION PLUME

The hydrocarbon pollution plume comprises fluids held in fractures and pores in soil or rock that are contaminated by hydrocarbons; the fluid in the pollution plume will range from pure hydrocarbons at the upper surface of the plume to pure water at its base.

ISOPACH MAP

An isopach map shows the thickness of a tabular or lenticular body. Isopachs are lines of equal thickness.

FLOW LINE

A flow line is the direction of movement of fluids deduced from the form of the potentiometric surface; the direction of flow is the direction of the steepest gradient of the potentiometric surface.

POROSITY

Porosity is a property of a rock, soil or other material that contains voids; voids may be spaces between sand grains, open fractures or solution cavities. Porosity is commonly expressed as the percentage of voids in a material.

PERMEABILITY

Permeability is the capacity of a rock, sediment or soil to transmit a fluid through its voids. A rock containing voids is porous, but it is only permeable when the voids are interconnected and will allow fluid to flow.

CONE OF DEPRESSION

The cone of depression is the potentiometric surface of a body of groundwater that has the shape of an inverted cone. It develops around a well from which water is being withdrawn.