

AAEC/E421



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AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS

POSSIBLE METHODS OF DISPOSAL OF THE AAEC'S LOW AND
MEDIUM LEVEL SOLID RADIOACTIVE WASTE AND AN
ENVIRONMENTAL IMPACT ASSESSMENT OF THE
REOPENING OF AN EXISTING BURIAL GROUND

by

W.R. ELLIS

October 1977

ISBN 0 642 59626 3

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ABSTRACT

In Part I, various alternatives for disposing of the low and medium level solid radioactive waste from the Australian Atomic Energy Commission Research Establishment at Lucas Heights, New South Wales, are examined. Because only a small quantity of radioactivity is involved, only trivial human exposure could arise from this waste. The direct disposal costs of these alternatives are considered and it is shown that burial in an existing, but presently disused, burial ground at Little Forest, near Lucas Heights, is by far the cheapest.

The environmental impact of re-using this burial ground is assessed in Part 2. It is concluded that no pathway exists by which members of the public could receive a significant radiation dose, and that the alienation of the Little Forest area would not be increased over that which has already occurred due to the waste previously buried there.

National Library of Australia card number and ISBN 0 642 59626 3

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RADIOACTIVE WASTE DISPOSAL; UNDERGROUND DISPOSAL; RADIOACTIVE WASTES;
SOLID WASTES; AUSTRALIA; ENVIRONMENT;

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PART 1

POSSIBLE METHODS OF DISPOSAL OF LOW AND MEDIUM
LEVEL SOLID RADIOACTIVE WASTE FROM THE AAEC
RESEARCH ESTABLISHMENT

1.1 INTRODUCTION

During the period 1960-68, the Australian Atomic Energy Commission (AAEC) buried low and medium level solid radioactive waste from its Research Establishment at Lucas Heights, New South Wales, in its burial ground sited nearby at Little Forest. Because of the uncertainty of future land use in the area, no waste has been buried there since 1968, and low and medium level waste accumulated since then has been temporarily stored at Lucas Heights.

Part 1 of this report examines options available to the AAEC for disposal of this accumulated waste together with waste which will arise from future operations at the Research Establishment. Part 2 is an environmental impact statement concerning one of the options, namely, the reopening of the Little Forest burial ground. This statement modifies and updates an earlier draft prepared by an AAEC committee. It draws on recent laboratory and field experimental results obtained by Isaacs & Mears [1977].

1.2 DESCRIPTION AND QUANTITY OF WASTE

The waste consists of two fractions; dried sludge, and laboratory trash and unserviceable equipment.

The sludge is the solar dried product of the low level effluent treatment plant and is essentially hydrated aluminium oxide, containing most of the radioactivity and other impurities from the low level effluent stream. It is packed in 200 l (44 gallon) steel drums, the maximum dose rate at the surface of the drum being about 10 mrad h^{-1} .

Over 90 per cent of the second category consists of laboratory trash including paper, plastic, broken glassware, etc., most of which contains very little (if any) radioactivity. It is packed either in sisal supported, bitumen impregnated, kraft paper bags of 42 l capacity or fibreboard drums (with lids) of 42 l capacity, or is compacted into 200 l steel drums. The dose rate at the surface of the containers is less than (and usually well below) 200 mrad h^{-1} . The remainder of this category consists of larger contaminated items which cannot be packed in small containers without being broken up, e.g. ventilation ducting, discarded furniture, etc. These items are contained in a manner which prevents dispersion of radioactive material during handling and are, where feasible, filled with packaged waste before disposal.

Each container of waste has less than the following amounts of radioactivity*:

0.5 mCi of Group I radionuclides[†] (includes 10 mg ²³⁹Pu)

or

20 mCi of Group II radionuclides (includes 2 g ²³³U and mixed fission products),

or

1 Ci of radionuclides of Group III and higher groups (excluding natural U, ²³⁵U and natural Th),

or

150 g of soluble natural U, depleted U or natural Th,

or

2 kg of insoluble natural U, depleted U or natural Th,

or

10 g of ²³⁵U.

Because the waste containers (steel or fibreboard drums, etc.) are expected to last at least several months after disposal before disintegration, amounts of radioisotopes with half-lives less than 100 days which can be disposed of are unlimited. When mixtures of radioisotopes from the various groups are present the amount from each group is reduced accordingly.

From the closure of the burial ground in 1968, to December 1975, the Research Establishment accumulated some 800 m³ of waste (originally uncompacted) including sludge packed in drums and trash now compacted (approximately 4:1 ratio) into drums. About 1180 such drums are in storage (~ 300 sludge and ~ 880 compacted trash).

From early 1976, the rate of production of waste has been 100-125 m³ per year (uncompacted) including about 30 drums of sludge per year.

1.3 ALTERNATIVE METHODS OF DISPOSAL

1.3.1 Introduction

Several possibilities exist for the disposal of waste produced at Lucas Heights, including

- (a) above-ground storage within the AAEC Research Establishment;

* As specified in the staff handbook, the AAEC Safety Manual, Section X1A in which general principles are outlined for the disposal of radioactive waste from the Research Establishment.

† See Part 2, Table 2.12.

- (b) below-ground storage on land owned by the AAEC in the Lucas Heights area;
- (c) uncontained burial in
 - (i) the Lucas Heights/Little Forest area,
 - (ii) other areas;
- (d) sea disposal by
 - (i) ocean dumping,
 - (ii) sewerage systems;
- (e) incineration;
- (f) municipal refuse systems; and
- (g) a combination of these methods.

1.3.2 Above-ground Storage

Regardless of the future of the AAEC Research Establishment, there will always be a need for continuing radiological surveillance of storage pits and tanks for high level waste, and the HIFAR reactor spent fuel element storage block. If the low and medium level compacted solid waste was also stored permanently at Lucas Heights, the demand for continuing surveillance would not be increased significantly. The annual costs of this method of disposal would be*:

Provision of storage building(s)	\$13 100	†
Compaction	5 600	
Surveillance (including overhead)	500	
Periodic repacking (10 drums/year)	600	
	<u>\$19 800</u>	

The environmental impact of this method of disposal is small.

1.3.3 Below-ground Storage

Wastes could be stored in roofed, concrete lined trenches excavated in sandstone at the Research Establishment or in the clay/shale Little Forest area. One trench 25 m x 2 m x 3 m deep would be required each year. The annual cost would be:

	<u>Research Establishment</u>	<u>Little Forest</u>
Excavation	\$6 800	\$4 600
Concrete placement and waterproofing	\$8 800	\$8 800
Total	\$15 600	\$13 400

* A.T. Duff, A/Head, Waste Management Section - private communication.

† All prices in this section are given in 1976 Australian dollars.

This method would have negligible environmental impact apart from preventing utilisation of previously alienated land.

1.3.4 Uncontained Burial

Lucas Heights/Little Forest Area

Sites at the Research Establishment and within the area owned (or likely to be owned) by the AAEC at Lucas Heights have been investigated for their suitability for disposal of uncontained waste. It was concluded that on all criteria - cost, environmental impact, operational convenience and public relations - the existing Little Forest burial ground is the most suitable*. A detailed environmental impact statement on the reopening of this burial ground is given in Part 2. It shows that no population exposure routes associated with the Little Forest burial ground can be identified.

If the use of the Little Forest area were being considered for the first time, other environmental and economic factors would be relevant, e.g. the valuable shale deposits underlying the buried waste, which have been alienated by past practice. However, there is no land use of the area which would be acceptable now but not in the future should burial of waste be resumed.

The annual costs of operating the Little Forest burial ground are (for 100 m³ year⁻¹ of waste)[†]:

Labour	\$1 250
Fuel	30
Tractor maintenance	250
Area maintenance	<u>300</u>
Total	<u>\$1 830</u>

Other Areas

There are two possible sites:

- . a former quarry near Melbourne which is used by the Australian Radiation Laboratory (ARL) for disposal of low level solid radioactive waste, and
- . the atomic weapons testing site at Maralinga, South Australia, where waste from the weapons tests of the 1950s is buried.

* AAEC New Burial Ground Working Party - minutes of meetings, 1972 and 1973

† A.T. Duff, A/Head, Waste Management Section - private communication.

Available information is insufficient for detailed assessment of the additional environmental impact of waste burial at either site. However, it can be assumed that it would not significantly increase the current overall environmental impact (particularly at Maralinga) and that the impact at either location would be no higher than that at the Little Forest burial ground. Transport of waste to either site would be expensive - Maralinga is about 2250 km from Sydney (50 km from Ooldea on the transcontinental railway), and Melbourne about 800 km. Because of Maralinga's isolation, operating costs there would be high, whereas operating costs at the Melbourne site would be about the same as for the Little Forest burial ground. In order to comply with the transport regulations of the appropriate States, it might be necessary to alter the packaging mode; this would involve repackaging of the drums now in storage.

A proposal to use Maralinga would need a comprehensive study which would be unlikely to cost less than \$25 000. Annual costs are likely to be for the ARL quarry at least 5 times that of operating the Little Forest burial ground and, for Maralinga, 10 times, *i.e.* about \$10 000 to \$20 000.

1.3.5 Sea Disposal

Dumping

Waste disposal areas reasonably close to Sydney would be (i) the Tasman Basin and (ii) the South Australian Basin. Respective sea distances from Sydney are 300-800 km and 2000-3000 km.

Steel drums of 200 litre capacity could be used as containers. To ensure that they reach the seabed, addition of ballast would be necessary to give a total drum weight of not less than 240 kg. This would reduce the volume available for waste and increase the number of containers for disposal. Shielding in transit might be required; this could form part of the disposal container or it might be re-usable. Containers which could not be completely filled would require pressure equalising devices. The drums of waste stored at the Research Establishment would therefore have to be repacked into suitable containers before disposal. Shipping hire cost estimates for disposal into the Tasman Basin are \$12 000 per year on an annual disposal basis, or \$5000 per year on a five yearly disposal basis (1976 estimates). These estimates assume an annual accrual rate of 200 drums of compacted waste.

At this time, only a crude estimate of the total economic cost of

this method is possible. Engineering effort of the order of one man-year would be required for the design and development of an acceptable disposal container and the equipment required for compacting, ballasting, etc. The cost of a 200 l drum is \$15 so the cost of a disposal container is unlikely to be less than \$50. This would give an annual cost of \$10 000. Packaging of the waste in a disposal container would require not less than four man-hours per container, equivalent to \$20 per drum and an annual cost of \$4000.

Hence, the estimated annual cost for sea disposal of 200 drums per year would be at least:

Disposal containers	\$10 000
Packaging labour	\$4 000
Ship hire	<u>\$5 000</u>
Total	<u>\$19 000</u>

This estimate takes no account of

- . transport from Research Establishment to wharf and cost of transfer to ship;
- . supervision of the disposal operation;
- . cost of storage space used in the 5 year accumulation period between disposal campaigns; or
- . the fact that as well as the 200 drums per year there would be more than 1000 drums of waste already stored to be repackaged and sent for disposal.

A more detailed estimate would probably place the annual cost at about \$40 000. In addition, it is unlikely that government approval would be obtained for sea dumping of radioactive wastes.

Disposal into a Sewerage System

A reduction in the volume of solid waste for disposal could be achieved if the low level radioactive liquid effluent of the Research Establishment could be discharged untreated to the sewers of the Metropolitan Water Sewerage & Drainage Board (MWS&DB) instead of producing solid sludge in the effluent treatment plant. The reduction would be about 18 per cent of the volume of compacted waste, or about 5 per cent of the volume of uncompacted waste.

Existing MWS&DB regulations do not permit discharge of untreated AAEC effluent to the sewer and a special discharge authorisation would have to be negotiated. Current indications are that the MWS&DB would be reluctant to grant the authorisation.

The environmental impact of this scheme would not be high. All the radioactivity in the low level effluent, the major fraction of which now appears in the sludge and the remainder in the discharge to the Woronora River, would be directed to the sewer, and that fraction which was not retained in the system would be discharged at the ocean outfall in Bate Bay.

The exposure route involving oysters in the Woronora would be eliminated, thus leading to a reduction (of up to 10 man-rem per year, the integrated dose that results from current procedures) in the exposure of members of the general public.

This reduction might be partially offset by the establishment of other exposure routes including exposure of sewerage workers from accumulations of radioisotopes in the sewers or the treatment plant and exposure of people eating seafoods taken in the vicinity of the outfall.

The economics of the proposal would be unattractive. The cost of connecting the Research Establishment to the sewer would be about \$150 000, which, amortised over 50 years, would be \$3000 per year, plus interest. The MWS&DB would impose a service charge of about \$10 000 per year and, to cope with emergencies, the effluent treatment plant would have to be kept operable, at a cost of about \$40 000 per year. Compacting and storing of the remainder (~ 80 per cent) of the solid waste would continue, with an annual cost of about \$18 000. A reduction in the salaries bill for the effluent treatment plant (about \$25 000 per year) would decrease the net cost to about \$46 000*. The scheme would be expensive and would have little effect on the solid waste disposal problem.

1.3.6 Incineration

If the combustible fraction of the solid waste were incinerated, the volume to be disposed of, including the ash, would be reduced by about 35 per cent. The existing incinerator at the Research Establishment is not suitable for this purpose as the waste contains polyvinyl chloride which would first have to be removed by hand picking. If this were done, the volume of waste for disposal, including ash, would be reduced by only about 12 per cent.

An incinerator designed to burn all the combustible waste would cost at least \$250 000 which, amortised over 25 years, would represent

* A.T. Duff, A/Head, Waste Management Section - private communication.

\$10 000 per year. Other nuclear establishments have found such a facility difficult and expensive to operate. The gas cleaning equipment associated with it would also produce solid and liquid wastes requiring treatment.

Annual operating costs would include:

Amortisation	\$10 000
Compaction and storage of non-combustible waste	\$13 000
Labour costs for incinerator operation	\$14 000
	<hr/>
	\$37 000
	<hr/>

Thus the cost of this system would be high with only a modest reduction in the volume of waste for disposal.

1.3.7 Municipal Refuse Systems

This category includes landfill systems and incinerators operated by local government or state authorities. Municipal incinerators, such as that at Waterloo, NSW, have a throughput very large compared with the rate of waste production at the Research Establishment (about 500 m³ day⁻¹ and 100 m³ year⁻¹ respectively); they can handle material containing PVC and are fitted with off-gas cleaning equipment. They could thus handle Research Establishment wastes if the latter were blended with the main stream.

Such an incinerator could thus provide for disposal of about 35 per cent of the waste, probably with low environmental impact, at a price which would include the cost of segregating the combustible fraction, packaging and transport, and a service charge. These charges would total about \$7500 per year. Disposal of the remaining 65 per cent of the waste would also be required; if this were compacted and stored, the annual cost would be about \$13 000; thus the total disposal cost would be \$20 500 per year*.

A municipal garbage tip or industrial solid waste disposal site might be suitable for disposal of the waste, without a significant increase in the environmental impact of the operation. Until a specific site is under consideration, it is not possible to make firm statements, but the cost of such an operation would perhaps be no more than three or four times that of disposal to the burial ground, *i.e.* about \$7000 per

* A.T. Duff, A/Head, Waste Management Section - private communication.

year. An additional expense would arise from the need to prepare an environmental impact statement of the proposed operation.

As stated in Section 2.4.2, the NSW Metropolitan Waste Disposal Authority (MWDA) has proposed the use of an area to the north of the Research Establishment (including the Little Forest burial ground) as a site for the disposal of solid industrial waste. No decision has been reached on this proposal.

1.3.8 Combination of Methods

The combination which would produce the greatest reduction in the volume of waste for subsequent disposal would be discharge of untreated low level effluent to the sewer, and incineration of all the combustible waste. This would approximately halve the volume of waste for disposal, *i.e.* a reduction of about 35 per cent by incineration and about 18 per cent by sewer discharge. The incinerator ash and the non-combustible fraction of the waste (about half the total volume) would remain. The cost of compacting and storing the latter at the Research Establishment would be about \$12 000 per year.

The cost of this combination would be high, namely:

Incineration (Municipal), transport and service charge	\$7 500
Sewerage disposal (\$53 000-\$25 000 see Section 3.5.2)	\$28 000
Compaction and storage of non-combustible fraction	\$12 000
Total	<u>\$47 500</u>

1.4 SUMMARY AND CONCLUDING REMARKS

The various alternatives, considered above, are summarised in Table 1.1.

The quantity of radioactivity contained in the low and medium level solid waste is small and the human exposure that could feasibly arise from it is trivial in both absolute and relative terms. A logical decision on its disposal would therefore be based on economic assessment. Of the alternatives considered, burial at Little Forest is by far the cheapest.

TABLE 1.1
COMPARISON OF VARIOUS ALTERNATIVES

Disposal Method	Economic Cost* (\$ year ⁻¹)	Environmental Impact	Operational Convenience
Compaction plus above-ground storage	20 000	Very low	Very low
Below-ground storage } (no compaction) }	13 000 to 16 000	Very low	High
Uncontained burial:			
(a) Little Forest	1 800	Low	High
(b) ARL Facility	10 000(?)	Probably low	Very low
(c) Maralinga	20 000(?)	Probably low	Very low
Sea disposal:			
(a) Dumping	40 000	Low	Very low
(b) Sewerage system (plus compaction and storage)	46 000	Low	Very low
Incineration (plus compaction and storage of non-combustible waste)	37 000	Low	Very low
Municipal disposal:			
(a) Incineration (plus compaction and storage of non-combustible waste)	20 500	Probably low	Very low
(b) Earth burial	7 000(?)	Probably low	High
Combination:			
Sewerage system plus incineration and com- paction and storage of non-combustible waste	47 500	Low	Very low

* Note that little or no consideration has been given to costs of environmental studies, future environmental monitoring, preparation of an environmental impact statement or other formal inquiries.

PART 2

AN ASSESSMENT OF THE ENVIRONMENTAL IMPACT OF
REOPENING THE LITTLE FOREST BURIAL GROUND .

ERRATUM

Note that, in the text, references to the figures which
read 2.1, 2.2, ... 2.10
should read 1, 2, 3, ... 10.

2.1 DESCRIPTION OF AREA

Little Forest is about 1.5 km north of the AAEC Research Establishment, New Illawarra Road, Lucas Heights, NSW (see Figure 2.1). Its elevation is about 130 metres and it comprises a remnant (approximately 80 ha) of Wianamatta Shale some 8 m deep overlying a sandstone stratum which forms a dissected tableland. Surface drainage and any groundwater flow from the area is towards Mill and Barden's Creeks which join and discharge into the Georges River, some 7 km north of the burial ground. There is no regular habitation in the Little Forest area and no known use of groundwater or water from the creeks. Originally, the area supported a dense brush forest and many trees of 12-18 m height. Undisturbed areas still support such vegetation.

Portions 251, 252 and 253 at Little Forest are owned by the AAEC. An area measuring 349 m (north-south) x 116 m (east-west), comprising approximately four hectares within portions 251 and 253, was cleared, fenced, and used as a burial ground for low and medium level solid radioactive waste from 1960 to 1968. The types and amounts of waste buried during the period are shown in Table 2.11.

Excavations (about 8 m deep) resulting from the mining of clay and shale for the manufacture of ceramics, bricks, tiles, etc. lie to the west, north-west and north of the burial ground (Figure 2.1). Some have been, and are being, filled (by other organisations) with non-radioactive liquid and solid trade wastes and covered by soil. A small triangular area in the north-west corner of portion 251 has been similarly treated. Figure 2.2 shows the burial ground with surface contours (in metres), the area used previously for burial and the location of boreholes.

The waste buried in the past and that which would be buried in the future has been described in Section 1.2.

2.2 BURIAL MODE

The method to be used for routine burial of uncompacted waste would be similar to that used from 1960 to 1968. Trenches spaced on 2.7 m centres would be excavated 0.6 m wide, 25 m long and to a maximum depth of 3 m. A trench would be dug only when sufficient waste had accumulated to fill it to capacity. The waste would be placed in the trench which would then be backfilled; the volume would be such that, after natural compaction, a minimum of 1 m of consolidated backfill would cover the waste. Each such operation would take about five days, i.e. about two days to dig a trench, one day to transfer the waste and two days to

backfill. If the waste transfer operation required more than one working day, that portion of the trench in which waste had been deposited would be backfilled before ceasing operation for the day. The trenches would be marked by placing a numbered hardwood peg at each end of the centre line.

A slightly different burial mode would be used to dispose of the accumulated drums of sludge and compacted waste. Trenches of the same length and depth but about 1.8 to 3 m wide would be excavated. The drums would be placed in them and covered with backfill as for the uncompacted waste. About four such trenches would be necessary to bury the drums accumulated so far, and they would be dug in the northern section of the burial ground.

About 1 tonne of uranium and about 190 kilograms of thorium, each in the form of metal or oxide, may be available for burial. The possibility of recovering this material is being examined. It would be buried only if recovery is shown to be uneconomical. This waste is in the form of swarf, saw cuttings, crucible skulls, etc., packed in kerosene in 18 l drums. A 2.7 m deep trench would be dug and a single layer of drums placed in the bottom of the trench which would then be backfilled.

It might be necessary to erect a waste storage shed within the fenced area. It would be a steel-framed asbestos-cement sheet building on a concrete foundation slab. Waste would be stored there temporarily, the amount not exceeding 30 m³ and the residence time of any parcel not exceeding three months.

If the capacity of the present burial ground became exhausted, part or all of the remainder of portion 251 would be cleared, fenced and used in the same way and under the same conditions as the existing burial ground.

2.3 SAFEGUARDS

Adequate safeguards against the possibility of radiation damage and any other undesirable effect would be provided by the above procedure and by the provisions of Section 2.5 (Interactions with the Environment).

The rigidly enforced system for selection of the waste to be buried ensures that the amount of radioactivity deposited in the ground does not exceed the capacity of the ground to receive it. This capacity is assessed most rigorously (Section 2.5). The area is isolated, enclosed by a security fence whose integrity is maintained and kept under surveillance by Commonwealth Police.

Because the area is rarely visited by the public, and because only one trench would be open at any time and then only for a few days, the visual impact of the operation would be insignificant.

Because portions 251 and 253 are owned by the AAEC, there is little possibility that some future development of the area could occur which did not take account of the fact that radioactive waste is buried there.

2.4 DESCRIPTION OF THE ENVIRONMENT

2.4.1 Geography

The district comprises part of an uplifted sandstone plateau and, because of the ramplike orientation of its dissected surface, streams in the area flow northwards. The drainage pattern also reflects structural controls by joints in the sandstone. Access to the area is by various sealed roads, bush tracks and fire trails.

The main climatic characteristics of the region are illustrated in Figure 2.3.

2.4.2 Land Use

Because of the poor soil, there is little agriculture in the Lucas Heights area, but there are scattered poultry farms and some market gardens in the Menai district.

Sutherland Shire Council holds leases over certain areas at Lucas Heights for sanitary and garbage disposal and others hold leases for clay and shale mining. Brambles Holdings Ltd has rights to use abandoned shale pits at Little Forest for disposal of industrial liquid and solid waste.

Recreational uses of the bushland north of New Illawarra Road and east of Heathcote Road include a gun-club firing range, motor cycle trail riding and horse riding. Other uses may follow the development of the Menai district.

Future use of the area surrounding the Research Establishment is dependent on various proposals including urban and industrial development of the area. According to the NSW State Planning Authority much scrub and forest will be cleared in the Menai district for housing and other development. Figure 2.4 shows one Menai plan in three possible development stages, and also the site of a proposed oil refinery. Clearly some of the proposed land uses are mutually exclusive. The Menai plan envisages an eventual population for the district in excess of 50 000, centred on Menai, some 4 km to the north-east of the burial ground. The plan provides for residential development to the east,

north-east and north of the burial ground at distances from 1.5 km to more than 2.5 km. It also makes tentative proposals for light industry in an area whose boundary lies a few hundred metres to the north of the burial ground and in another area about 1.5 km to the east. A proposed main road serving the northern industrial area and joining the Liverpool/Heathcote and New Illawarra Roads would pass within a few hundred metres of the north-east corner of the burial ground. All other land within a 2 km radius of the burial ground has been designated 'open space', 'non urban', 'military' or 'special reserve'.

It is understood that Brambles Holdings Ltd is negotiating for tipping rights in an area immediately east of their existing tip, i.e. east of the mined-out shale pits.

The MWDA has proposed use of an area to the north of the Research Establishment as a disposal site for solid industrial waste from the southern region of Sydney. The area includes the northern half of the exclusion zone (1.6 km radius from HIFAR) and the Little Forest area including the mined-out shale pits to the north and west of the burial ground.

The NSW Department of Main Roads is planning a southern expressway which will probably be a short distance to the north of the existing New Illawarra Road and, in general, parallel to it.

All land within the 1.6 km exclusion zone from HIFAR (except the Research Establishment and portions 253, 272 and 274) is NSW State land. Negotiations are continuing between the Commonwealth and NSW Governments for the transfer of this land to the Commonwealth and eventually to the AAEC, but a final decision on this and other matters concerning future land use is not expected for some time. However, as emphasised in Sections 1.3.4 and 2.5 the proposed action (reopening the burial ground) would produce no new limitation on the use of this area.

2.4.3 Geology

The dominant rock formation outcropping on the Woronora Plateau is medium to coarse Hawkesbury Sandstone of Triassic age. The low regional dip is believed to be about 19 m km^{-1} in a northerly direction.

The upper weathering zone probably extends to a maximum depth of 7 m whereas the lower zone extends from the base of the upper zone to the water table which is generally quite deep.

Little deep drilling information is available but a diamond drill

hole put down about 0.4 km from the main gate of the Research Establishment by the NSW Mines Department in the 1960s penetrated about 192 m of sandstone.

Several remnant patches of once extensive Triassic shale beds overlie the sandstone. Eroded patches of shale which are markedly similar, occur in the Menai area. The burial ground, within the Little Forest shale area, is composed of such Triassic shale.

The principal constituents of the unweathered parent shale, which is dark coloured, are quartz, kaolinite, illite (including degraded illite), siderite and organic matter, with quartz the most abundant and kaolinite slightly in excess of illite.

Weathering of the shale has resulted in a relatively deep weathered profile which includes a leached shale zone, a mottled zone and a soil zone at the surface. The leached shale zone overlies the dark parent shale and, in the burial ground area, is about 6 m thick. It is light to mid-grey in colour (lighter than the parent shale) and fairly soft and silty.

Some of the illite in the parent shale has been converted through loss of potassium ions to montmorillonite-illite interlayered minerals. Loss of organic matter and the mobilisation of the iron to form segregations has also occurred, otherwise there is apparently little difference in mineralogy to that of the unweathered shale.

Towards the surface, the weathered shale zone passes into the structureless mottled zone, which is between 1 and 2 m thick. Although this earth material consists basically of clay, there should be a marked change in clay mineralogy from the bottom to the top of this particular zone with the interlayered minerals increasing at the expense of illite, and kaolinite increasing at the expense of both minerals.

The uppermost zone in the weathered profile is the soil zone, where maximum leaching occurs. The montmorillonite-illite interlayered minerals again tend to form kaolinite, which thus attains its maximum development in this zone, whereas quartz is reduced to a subordinate role. This zone consists essentially of two layers - an upper layer of brown soil, about 0.3 m thick, and a lower red soil sub-stratum about 0.6 m thick.

Chemical analyses, by the NSW Department of Mines, on shale from the adjacent Barden's Road quarries, which should be representative of the shale deposits in the Menai district, show that weathering processes

have proceeded for a long geologic time with partial loss of silica, magnesia and potash and simultaneous enrichment of alumina and titania [Loughnan *et al.* 1962].

Cation exchange capacity measurements [Isaacs & Mears 1977] on weathered shale samples from the burial ground gave an average value of 7.9 meq/100 grams of dry soil for the total exchange capacity (Table 2.1). Soil pH figures are shown in Table 2.2.

Deposits of clay and shale occur both as discontinuous shale lenses in the Hawkesbury Sandstone formation and, as mentioned above, as erosional remnants of Ashfield Shale resting on the sandstone. These deposits form the basis of a ceramics industry.

2.4.4 Hydrology

Surface Water

Surface contours (Figure 2.1) indicate that surface water runoff is in a general northerly and easterly direction towards Mill and Barden's Creeks which, particularly in their upper reaches, flow only after heavy rain.

River flow data for the general region indicate that the annual runoff from precipitation is about 37 per cent.

Underground Water

Hawkesbury Sandstone forms the principal aquifer and, although the sandstone itself is generally impermeable, joints and fractures render it permeable and provide storage of underground water. As there are no deep bores to provide information about the existing water table, and as no piezometric levels are available, it is not possible to determine the general direction of groundwater movement in this aquifer.

The Little Forest shale deposit has an area of some 81 ha and a topographic relief of approximately 18 m. Because of its low permeability, it inhibits water infiltration and percolation so that it has a shallow water table, as indicated by the exceptional growth of forest in the area. The perched aquifer is about 9 m thick at its deepest part.

Radioisotope tracers were used to measure groundwater velocity (and hence permeability) by the single borehole method [Isaacs & Mears 1977]. Velocities between 0.21 and 1.9 cm day⁻¹ were obtained, depending on location of the measurement point and the height of the water table. The range would be greater from very dry to very wet conditions. The above figures correspond to permeabilities within the range 0.08-0.62 m³

$\text{day}^{-1} \text{ m}^{-2}$ (unit gradient) $^{-1}$ which is typical of stratified clays, etc. classified as 'poor aquifers'.

Piezometric data from bores indicate that groundwater from the northern section of the burial ground flows in a northerly direction while that from the southern part flows south-east to east towards the low-lying area. On the extreme western boundary, flow is towards the shale pits. This flow direction was partly confirmed by preliminary radiotracer tests [Isaacs & Mears 1977]. Figures 2.5, 2.6, 2.7 and 2.8 show typical groundwater levels, flow being always at right angles to the contours.

During very wet periods the lower areas of the burial ground connect with surface drainage routes to Mill and Barden's Creeks. Discharge then often occurs by spring action in addition to seepage.

The Barden's/Mill Creeks drainage basin empties into the Georges River and has a catchment of approximately 1.8×10^3 ha. The average annual rainfall in this drainage basin from hydrologic data averaged over a ten-year period, is estimated at 2.1×10^{10} l year $^{-1}$. Thus, the basin considerably dilutes runoff and seepage from the burial ground.

Hydrologic Background to the Little Forest Shale Area

The source of the groundwater in the shale lens is rainfall on the shale outcrop itself which is about 10^9 l year $^{-1}$ (area of shale \sim 80 ha, annual precipitation \sim 1130 mm).

Losses from the groundwater are mainly due to evapotranspiration and seepage. Direct leakage to the underlying sandstone aquifer through the base of this shale bed is believed to be negligible. Although the transpiration losses are difficult to estimate, they are believed to be of the order of 2.2×10^4 l day $^{-1}$ ha $^{-1}$, based on studies of other comparable forested areas. Assuming that the effective tree cover is 40 ha (as the remaining part has been stripped for shale mining), the annual transpiration losses are estimated to be around 3.2×10^8 l.

Direct evaporation from the soil overlying the shale lens also forms an important component of groundwater loss from this area. Although estimation of the average yearly evaporation losses from the perched water table is complicated by the varying physiography, vegetation and soil cover, an upper limit can be derived by assuming that the ground surface is completely saturated within the area occupied by the

shale. Under such circumstances, the evaporation from the top 10 cm of soil is about half of that given by the standard Australian evaporimeter [Trumble 1948]. As the annual evaporation for this area is about 76 cm the total evaporation from this patch of Ashfield Shale is thus about 3.0×10^8 l year⁻¹. Hence the total annual evapotranspiration losses are about 6.2×10^8 l and the annual runoff about 3.8×10^8 l (38 per cent of the annual precipitation). This runoff will heavily dilute any radioactivity which comes to the surface during heavy rain.

The daily height of the water table and the corresponding rainfall during the period July-December 1974 are shown in Figure 2.10. This shows that the boreholes in the south-eastern section often overflow and hence this area should not be used for burial. The bores on the higher ground overflow only after heavy rain; hence this northern section is the most suitable for burial of waste.

2.5 INTERACTIONS WITH THE ENVIRONMENT

2.5.1 Nature of Waste

Because of the method of collection, the temporary storage prior to burial, and the time taken for water to penetrate the steel drums, kraft paper bags and fibreboard drums, many months elapse from the production of waste to its contact with the groundwater of the burial ground. Thus radioisotopes with half-lives less than about three months can be ignored as potential environmental pollutants.

The radioactive sludge produced at Lucas Heights is of low specific activity, and the only isotopes which have been identified by gamma spectrometry are manganese-54 (0.4 nCi g^{-1}), cobalt-60 (2.2 nCi g^{-1}) and caesium-137 (1.9 nCi g^{-1}). Fission products other than ¹³⁷Cs, and corrosion products other than ⁵⁴Mn, might also be present. It is possible that the relative activities in the sludge are similar to those found in large nuclear plants. Table 2.3 is based on this assumption and shows the relative abundance of isotopes in the sludge as an average of all USA plant [USAEC 1973].

Waste arising from laboratory trash is more variable than the sludge, but it is of the same order with respect to identified isotopes and relative abundance with the addition that tritium may be present in the trash. Table 2.3 is assumed to apply to packaged laboratory trash as well as to sludge.

Natural uranium and natural thorium would be buried as metals or as oxides. Although both elements are radioactive, the final limitation on

concentrations in the environment arises from chemical toxicity to the biota (see Section 2.8.4).

2.5.2 Relative Importance of the Range of Radioisotopes

Because of the radiation dose they could subsequently deliver to man and the biota, radioisotopes discharged to the biosphere are potential pollutants. For unit concentration the dose delivered to the biota is, to a first approximation, related to the product of the biological concentration factor of the organism for the particular element and the decay energy of the isotope. For man, other factors include, for unit consumption, the biological half-life of the ingested isotope and the extent to which it is further concentrated into the critical organ. These factors are included if the decay energy is replaced by the inverse of maximum permissible daily intake as defined and tabulated by the ICRP [1959].

Table 2.4 presents these weighting factors for the range of isotopes listed in Table 2.3. Since any radioisotopes dispersed by groundwater and surface runoff from the Little Forest area would, in time, enter both freshwater and marine systems, the highest concentration factor for either system is listed. The last two columns of this table show that most of the potential dose to the biota arises from ^{60}Co , ^{54}Mn , ^{134}Cs and ^{137}Cs , whereas that for man arises from ^{60}Co , ^{90}Sr , ^{134}Cs , ^{54}Mn , ^{137}Cs and ^{55}Fe . However, because of their comparatively short half-lives, ^{54}Mn (291 days), ^{134}Cs (2.2 years) and ^{55}Fe (2.9 years) are of much less significance than ^{60}Co , ^{137}Cs and ^{90}Sr . Further discussion is limited mainly to these last three isotopes.

2.5.3 Source Strengths

It was found experimentally [Isaacs & Mears 1977] that when a drum of sludge was washed with 10 x 5 ℓ quantities of water followed by immersion in 75 ℓ of water for 7 days (a total of 125 ℓ of water), the following amounts of activity were leached:

^{137}Cs	480 nCi	^{54}Mn	300 nCi
^{60}Co	710 nCi	^{90}Sr	0.07 nCi

[No figure was obtained for the quantity of ^{90}Sr leached but because the K_d values (defined in Section 2.5.4) for ^{90}Sr and ^{60}Co are similar, we may assume that they would behave similarly during the leaching process. A drum of sludge contains about 0.04 μCi of ^{90}Sr and about 352 μCi ^{60}Co (Table 2.3) so the ratio of ^{90}Sr to ^{60}Co leached would be 0.04/352 = 10^{-4} . Thus the quantity of ^{90}Sr leached would be $710 \times 10^{-4} = 0.07 \text{ nCi}$.]

The average groundwater velocity is about 1 cm day^{-1} (3.7 m year^{-1}) [Isaacs & Mears 1977] and hydrographs of the area (Figure 2.10) show that the buried waste is under water almost continuously. The diameter of a 200 l drum is 58 cm so, assuming the permeability of the waste is greater than that of the surrounding shale, the effective volume of water passing through the drum per year is about $3.7/0.58 =$ approximately six drum volumes or about 1200 litres. Therefore, assuming comparable leaching conditions and multiplying the above figures by 1200/125, we obtain the following figures as the amount leached out of one drum of sludge/year:

^{137}Cs	4.6 μCi	^{54}Mn	2.9 μCi
^{60}Co	6.8 μCi	^{90}Sr	0.67 nCi

At present (1976), there are about 300 drums of sludge in storage, accumulated at the rate of about 43 drums per year (for 7 years). Thus the yearly accumulation of 'leachable' activity is:

^{137}Cs	198 μCi	^{54}Mn	125 μCi
^{60}Co	292 μCi	^{90}Sr	29 nCi

Thus, the total amount of leachable ^{137}Cs in sludge at present (1976) in store is about 1296 μCi .*

The annual arising of sludge is now about 30 drums/year, *i.e.* 138 μCi leachable ^{137}Cs /year. Thus in 1980 the total amount of ^{137}Cs leachable from sludge will be 1720 μCi **. The amount of leachable ^{137}Cs from sludge in the years 1990 and 2000 was calculated similarly (Table 2.5).

Other leaching experiments indicate that the following amounts of activity would be leached from a typical drum of uncompacted trash by 125 l of water under the same conditions as for the sludge drum:

^{137}Cs	8 nCi	^{54}Mn	24 nCi
^{60}Co	390 nCi	^{90}Sr	0.007 nCi

The waste at present stored in drums is compacted (4:1 ratio), thus the amount of activity that would be leached by 125 l of water from one drum of compacted waste is:

* This takes account of the decay of the radioactivity of the accumulated waste. For a regular annual storage (or burial) of a unit quantity of a radionuclide of decay constant λ ($= 0.693/\text{half-life}$) over a period of T years, the source term at the end of the year T is $\exp^{-\lambda T} - 1 / (\exp^{-\lambda} - 1)$.

** $1296 \exp\left(\frac{-0.693 \times 4}{30}\right) + 138 \exp\left(\frac{-0.693 \times 4}{30}\right) - 1 / (\exp\left(\frac{-0.693}{30}\right) - 1)$
 $= 1720 \mu\text{Ci}$.

^{137}Cs	32 nCi	^{54}Mn	96 nCi
^{60}Co	1560 nCi	^{90}Sr	0.03 nCi

Therefore, following the previous argument for the sludge drums, the following figures are obtained as the amount leached from one compacted waste drum per year:

^{137}Cs	308 nCi (32 x 1200/125)	^{54}Mn	920 nCi
^{60}Co	15 μCi	^{90}Sr	0.29 nCi

With about 880 compacted waste drums in storage, accumulated at the rate of about 125 per year for seven years, the yearly accumulation of leachable activity is:

^{137}Cs	38 μCi (308 nCi x 125)	^{54}Mn	115 μCi
^{60}Co	1875 μCi	^{90}Sr	36 nCi

Thus the total amount of leachable ^{137}Cs in stored waste (in 1976) is 249 μCi (see footnote, p.20).

The yearly arisings are now about $100 \text{ m}^3 \text{ year}^{-1}$ of uncompacted waste, *i.e.* about 500 uncompacted drums, *i.e.* about $500 \times 8 \times 1200/125$ nCi, or 38 μCi leachable ^{137}Cs per year. The amount of leachable ^{137}Cs arising from waste in the years 1980, 1990 and 2000 is calculated similarly and is shown in Table 2.5.

The figures for ^{60}Co and ^{90}Sr were determined similarly from the drum experiments and these are also shown in Table 2.5.

The amount of water available per year to dilute this leached activity is found as follows: assume that future burials would be made in the northern section of the burial ground (extending it northwards if necessary) and assume that the four trenches (each 25 m long) are placed right across the burial ground giving an effective trench length of 100 m. The shale is 8 m deep and, with the rise and fall of the groundwater, activity will be mixed gradually throughout this depth. If we assume the porosity to be 10 per cent and average groundwater velocity 1 cm day^{-1} , then the yearly amount of water available for dilution

$$= \frac{100 \times 8 \times 3.65}{10} = 300 \text{ m}^3 .$$

Using these assumptions, and the figures calculated for the total amount of leachable activity for the appropriate nuclide, the maximum concentration of each nuclide in the immediate vicinity of the trenches in various years was found. These figures are also given in Table 2.5. As discussed earlier, these concentrations will decrease rapidly with distance from the trench, due to adsorption, dispersion, dilution, etc.

In Table 2.6, these figures are compared with ICRP recommendations and those allowable under the NSW Radioactive Substances Act and the NSW Clean Waters Act 1970. The predicted maximum concentrations are well below the allowable limits, except for caesium-137 and cobalt-60 in relation to the Clean Waters Act, and for cobalt-60 in relation to the ICRP figure.

However, the predicted maximum levels apply to the concentration adjacent to the trenches and, by the time this activity reaches Mill or Barden's Creeks (if it ever does), its concentration will be below the figures specified in these acts (see Section 2.6 for dilution factors, etc.).

2.5.4 Salt Transport in Soils

The groundwater flow rate in the Little Forest area was measured, by the single well method, to be about 2 cm day^{-1} (maximum) [Isaacs & Mears 1977].

Because the water table is perched, there would be only an extremely slow percolation of groundwater through 100 m of sandstone to the Woronora water table. Transport of the solute would be mainly by molecular or ionic diffusion. The diffusion coefficient for ion transport in soil is less than for bulk solution which, for many aqueous solutions, is about $10^{-9} \text{ m}^2 \text{ s}^{-1}$ [Talsma & Philip 1971]. This is due in part to the solution phase occupying only a fraction (often ~ 10 per cent) of the soil volume.

An ion with diffusion coefficient $10^{-10} \text{ m}^2 \text{ s}^{-1}$ will diffuse a distance of about 0.07 m in one year. It would thus take well over 1000 years for an ion to reach the Woronora water table, by which time even the longest-lived isotope (^{137}Cs , $t_{1/2} = 30$ years) would have almost completely decayed. This would still apply even if the flow paths intercepted fault lines, which are never continuous in a vertical plane. The adsorption of ions on the surface of faults is also quite efficient.

The rate at which radionuclides (or other ions) move through soil is related to the groundwater velocity by, *inter alia*, the distribution coefficient (between the soil and water) for that particular nuclide; the distribution coefficient is defined as:

$$K_d = \frac{\text{concentration of nuclide adsorbed on soil}}{\text{concentration of nuclide in groundwater}}$$

If V_0 is the velocity of the groundwater, V_c the velocity of contaminant, P the porosity of the soil, and ρ its density, then [Inoue 1967]

$$\frac{V_0}{V_c} = 1 + \frac{1-P}{P} \rho K_d.$$

The value of K_d depends on the element involved, the concentration of (gross) ions in the groundwater and soil, and on the density of exchange sites in the particular soil. It also varies rapidly with pH, at least for values well removed from neutrality. The K_d values for the nuclides of interest have been determined by laboratory tests [Isaacs & Mears 1977]; average representative figures (ml g^{-1}) are: ^{137}Cs , 2430; ^{60}Co , 14; and ^{90}Sr , 8.

Taking the typical (high) groundwater velocity as 2 cm day^{-1} , the porosity as 10 per cent and the density as two, the following values for the migration velocities of the radionuclides of interest are obtained:

	<u>cm day^{-1}</u>
^{137}Cs	4.6×10^{-5}
^{60}Co	7.9×10^{-3}
^{90}Sr	1.4×10^{-2}

At these velocities, the radionuclides would be completely decayed before reaching the boundary of the burial ground.

2.6 COMPARISON WITH MONITORING RESULTS

Because the direction of flow of some of the groundwater is in a general northerly direction (owing to the groundwater contours), some of the activity released from the waste already buried will move towards boreholes A, B, C, D, BH1, BH2 and OS3 (see Figure 2.2). Water samples from all bores have been taken regularly since 1959 [Giles *et al.* 1966-70; Dudaitis *et al.* 1972-76]. Generally the highest α readings have been obtained at borehole D and the highest β readings at OS3. Only traces of γ activity have been detected at any borehole.

The α readings obtained at D are too low and too variable ($5-113 \text{ pCi l}^{-1}$) to be of significance. Also borehole D is approximately 100 metres from the nearest buried waste and most α emitters are readily adsorbed on soil. Hence this very low level of α activity is almost certainly due to natural activity, *e.g.* traces of uranium, thorium, *etc.* in the soil, and not to the presence of radioactivity originating at the Research Establishment. This view is supported by the fact that a gamma spectrum of water from borehole D indicates natural (equilibrium) distribution of uranium and thorium daughters.

Beta levels at OS3 are also very erratic, varying from 8 to 106 pCi ℓ^{-1} in the last few years. The β activity includes that due to naturally occurring potassium-40. However, even assuming that all the β activity is due to the most restrictive nuclide, ^{90}Sr , (a most unlikely situation), this level is still less than 4 per cent of the discharge concentration permitted under the NSW Radioactive Substances Act. In addition, OS3 is within the burial ground, so the concentration at the boundary would be even less than the above figure. The presence of very small amounts of β activity at OS3 and other boreholes, when calculations involving K_d values indicate that no activity would have travelled that far since burial, could be due to the action of some complexing agents on the buried waste.

Because the upper soil zone is aerated, conditions are suitable for the formation of organic complexes which are not adsorbed by soil. In addition, percolating rainwater will carry with it significant quantities of humic acid from the heavily grassed areas of the burial ground and this solution could act as an eluting agent. However, if burials were to be made in the northern section of the burial ground then, even if the radionuclides suffered no adsorption and travelled at the velocity of the groundwater ($\sim 4 \text{ m year}^{-1}$), they would be completely decayed before reaching the northern boundary.

In 1975 and 1976, water from several boreholes, including some drilled specifically for the purpose, was assayed for tritium. Results are given in Table 2.7.

The origin of this tritium is unknown but, although unaccountable for in the records of the burial ground operation, it must have come from the inadvertent burial of an unknown tritium source. However, even the highest level recorded ($10.4 \mu\text{Ci } \ell^{-1}$ at D10) is only about 10 per cent of the discharge concentration permitted under the NSW Radioactive Substances Act.

Groundwater contours indicate that water from boreholes D7, D8, D9 and D10 will flow initially approximately north-east, then north towards boreholes A-E (see Figures 2.5-2.8). The typical tritium concentration at D7-D10 is about $5 \mu\text{Ci } \ell^{-1}$ and at A-E about $2 \text{ nCi } \ell^{-1}$ (see Table 2.7); the dilution is thus about 2500. Similarly, water from D10, D11 and D12 will move south-east towards the 'runoff' area and the dilution is again about 2500. It is probable that some or all the tritium reaches boreholes A-E and the runoff area by surface flow (when the groundwater comes to

the surface after heavy rain) instead of groundwater flow. Thus, we may assume that the dilution (irrespective of sorption) of the other nuclides is also about 2500 and would be very much more by the time the activity reached Mill or Barden's Creeks (if it ever did). Thus the concentration levels for ^{137}Cs , ^{60}Co and ^{90}Sr given in Table 2.5 would be reduced enormously (by dilution, sorption and/or decay) by the time the activity had moved a significant distance from its burial site.

Table 2.8 shows the concentration of some nuclides in the ash of vegetables grown in an 'active' garden (directly over the most recently buried waste) compared to that for vegetables grown in a 'control' garden (see Figure 2.2). The 'active' vegetables contained no significant amounts of uranium or radium, but showed some concentration of ^{90}Sr , which is to be expected considering the location of the 'active' garden. The high result for maize is probably due to the fact that this species is more deep rooted than the others and the roots probably penetrate close to the waste itself.

2.7 EFFECT ON MAN

2.7.1 Exposure Routes

The paths by which radioactivity reaches man are known as exposure routes. For their evaluation, account must be taken of physical and biological dispersion and reconcentration factors and the fate of radioactive material ingested by man.

Drinking Water

On the basis of published plans for the development of the Menai area, it is most unlikely that bore water would be used as a source of drinking water. However, Table 2.6 shows that even the maximum predicted concentration of radionuclides in the groundwater (adjacent to the trenches) is about the same or less than the ICRP recommendation for drinking water. As explained above, by the time this activity could move to areas where boreholes for drinking water are present (if it ever did) its concentration would be negligible.

Bore Water for Market Garden Irrigation

To assess the radiological consequences of the use of bore water for the irrigation of market gardens, three parameters are required - the number of days per year on which irrigation would be used, the consumption of vegetables and the concentration factor of each vegetable for each radioisotope.

Comprehensive data on concentration factors for a range of vegetables irrigated with water containing the isotopes of interest are not available. The many variables involved include - soil characteristics, method of irrigation, use of fertilisers, age at harvesting, etc. However, from published data on Co, Mn, Cs and U [Cline 1960; Rediske & Hungate 1961] and AAEC work on Pb, Cu, Zn and U [Davy & Conway 1974], it appears that the concentration factors are approximately unity.

If the maximum consumption of vegetables is 100 g day^{-1} per person (equivalent to 100 ml water per day) and irrigation is used on 100 days per year, the equivalent amount of water is 10 l year^{-1} . The average consumption of water is 2.2 l day^{-1} or 800 l year^{-1} . The dose associated with the 'vegetable' route is thus only about 1 per cent of that arising from the 'borewater' route which, as explained above, is negligible.

Milk Contamination

The Research Establishment has an exclusion area of 1.6 km radius centred on the reactor HIFAR. This area (800 hectares or 8 km^2) would not be used for urban development but it is not impossible for pasture to be introduced and the area grazed for milk production. From fallout studies, it is known that milk contains $1 \text{ pCi } ^{90}\text{Sr} (\text{g Ca})^{-1}$ for each $\text{mCi } ^{90}\text{Sr km}^{-2}$ grazed per year by a cow. For a child drinking 2 l milk per day, the derived maximum level for ^{90}Sr in milk is $800 \text{ pCi} (\text{g Ca})^{-1}$. For this level to be reached, $800 \text{ mCi } ^{90}\text{Sr km}^{-2}$ grazed per year would be required, i.e. a total of 6.4 Ci year^{-1} for the 8 km^2 exclusion area. The calculated rate of release from the burial ground is less than $2 \text{ } \mu\text{Ci } ^{90}\text{Sr year}^{-1}$ (see Table 2.5), a minute fraction of the above estimate.

External Radiation Exposure over the Trenches and Contaminated Ground

Measurements have shown that, with a high packing density of waste and with the trench refilled only to the top of the drums, the dose rate is only about twice the normal background, i.e. about $170 \text{ mrem year}^{-1}$. Shielding by overlying soil reduces this average dose rate to a level almost indistinguishable from normal background. The same situation applies to external radiation exposure from contaminated ground. Most of the activity released to the groundwater from the waste is re-adsorbed onto the soil within a very short distance of its origin, so the source geometry is essentially the same as that of freshly buried waste. The re-use of the burial ground would extend the area over which these insignificant dose rates apply but would not affect the dose rate at any one point.

Contamination of Building Clay

The distribution coefficients in clay for the range of radioisotopes of interest are high. The dose arising from brick walls manufactured from contaminated clay is shown in Table 2.9.

The maximum allowable dose rate for continuously exposed members of the general public is $500 \text{ mrem year}^{-1}$. Thus, if the clay from the pits along the western side of the burial ground is contaminated and the high dose rates shown in Table 2.9 apply, this exposure route would be the most limiting for any future operations. However, as explained in Section 2.5.4, the velocity of the radioactive front is such that the radionuclides from the currently buried waste would be completely decayed before reaching the boundary of the burial ground.

Assume that further waste to be buried liberates $4 \text{ mCi } ^{137}\text{Cs}$ and $15 \text{ mCi } ^{60}\text{Co}$ per year into the soil (Table 2.5). The ^{137}Cs will decay to a negligible amount ($4 \text{ }\mu\text{Ci}$) in about 300 years and the ^{60}Co to $1.5 \text{ }\mu\text{Ci}$ in about 70 years.

Taking the velocities given in Section 2.5.4, the ^{137}Cs will travel $\sim 5 \text{ cm}$ in 300 years and the ^{60}Co $\sim 2 \text{ m}$ in 70 years. Thus in future operations, even assuming that the direction of groundwater flow is towards the clay pit on the western boundary of the burial ground, waste may be buried to within a few metres of the boundary. An additional safety factor is that the clay pit is on the far side of a 20 metre wide road along the boundary. In any event, it is expected that all commercially recoverable clay will have been mined from the area by the 1980s.

Clay samples from the pits are routinely monitored. They show no measurable amount of activation products (e.g. ^{60}Co) which would have originated at the Research Establishment, and only traces of long-lived fission products (e.g. ^{90}Sr and ^{137}Cs) which arise from fallout (dry and wet deposition) and which are also buried at Little Forest. If the ^{90}Sr and ^{137}Cs originated from the burial ground then ^{60}Co would also be present since the distribution coefficient of cobalt is much less than that of caesium and about the same as that of strontium.

2.8 EFFECT ON BIOTA

2.8.1 Internal Dose Arising from Contaminated Creekwater

An upper limit to the dose delivered to organisms as a result of ingestion of contaminated creekwater is estimated by combining Tables 2.4 and 2.5, to give Table 2.10. However, this limit is extremely

conservative as it assumes that the radioactivity of the creekwater is the same as that of the maximum activity of the groundwater within the burial ground, whereas, in practice, as explained earlier, most of the activity would be adsorbed and the remainder would be greatly diluted by water from other sources. In fact, it is very unlikely that contaminated water would ever reach the nearby creeks.

2.8.2 External Dose to Benthos

The sediments at the bottom of creeks have high distribution coefficients (assume 300 for ^{137}Cs and 100 for ^{60}Co). Thus, the concentration of ^{60}Co and ^{137}Cs in the sediment at the bottom of a pool supplied only by water of maximum radioactivity from the burial ground could be as high as 5.3×10^{-3} and $3.3 \times 10^{-3} \mu\text{Ci g}^{-1}$ respectively (see Table 2.5 - figures for 1990).

The external dose delivered to an organism living in this sediment would then be $C_v \cdot E \cdot S^{-1} \times \text{constant rad h}^{-1}$ where C_v is concentration in sediment, E is effective energy, S is the relative stopping power, soil/tissue (~ 0.86), and the constant (2.13) combines the conversion factors of μCi to disintegrations per hour and for MeV g^{-1} to rads.

Thus the maximum external dose arising from the ^{60}Co contamination is 19.7 mrad h^{-1} and from the ^{137}Cs , 4.8 mrad h^{-1} . Practical doses would be very much less than these figures.

2.8.3 Effect of Irradiation

From the above sections it follows that crustacea would be the most exposed organism with the dose rate being $\sim 1719 \text{ mrem h}^{-1}$ (1694 internal, 25 external). Little is known about the effect of dose rates of this order on crustacea, but for higher organisms (mice, honey-bees, fish larvae) no life shortening would occur.

For naturally occurring visible genetic defects, doubling doses as low as 50 rads have been reported. It is therefore possible that non-lethal individual defects would be induced, but it is also evident that, in terms of the isolated water pools (even if they derive all their water as seepage from the burial ground), these changes can have no influence on total creek populations.

It is again emphasised that the radioactivity of the creekwater (if present at all) will be very much lower than the maximum values quoted above. The tritium figures given in Section 2.6 indicate the extreme dilution that occurs when the activity moves only a short distance from its burial site. Environmental surveys in the past have shown no

increase in the background levels of water from Mill and Barden's Creeks [Giles et al. 1966-1970; Dudaitis et al. 1972-1976].

2.8.4 Chemical Toxicity

Solutions of uranium salts can be toxic to fish. AAEC work in the Northern Territory (with water softer than that seeping from the burial ground) has established the Median Tolerance Level (50 per cent survival after 96 hours' exposure) concentration as $\sim 3.2 \text{ mg } \ell^{-1}$. An appropriate application factor for these conditions is 0.05 so that contaminated borewater from the burial ground (estimated uranium content $0.2 \text{ mg } \ell^{-1}$) is acceptable for these conditions. Again in practice, the uranium content of the creekwater would be much lower than $3.2 \text{ mg } \ell^{-1}$.

TABLE 2.1
CATION EXCHANGE CAPACITY OF SOILS
FROM BURIAL GROUND

Depth	Cation Exchange Capacity (meq/100 g)
Top 50 cm	7.3
Next 45 cm	9.0
Next 50 cm	7.1
Shale	8.3
Sandstone	4.5

TABLE 2.2
SOIL pH MEASUREMENTS

Location in Burial Ground	pH
BH1	5.25
BH2	5.40
BH3	5.40
BH4	5.45
BH5	5.70
BH6	5.20

TABLE 2.3
POSSIBLE RADIOACTIVE CONTENT (OF HALF-LIFE > 3 MONTHS)
PER 160 kg DRUM OF SLUDGE

Radionuclide	Half-life	Activity (μ Ci)
^{90}Sr	27.7 year	0.04
^{127}Te	109 day	0.9
^{134}Cs	2.05 year	340
^{137}Cs	30.0 year	300
^{144}Ce	284 day	0.12
^{147}Pm	2.62 year	0.01
^{54}Mn	303 day	60
^{55}Fe	2.6 year	158
^{60}Co	5.25 year	352
^{65}Zn	250 day	0.02

TABLE 2.4
RELATIVE SIGNIFICANCE OF THE RANGE OF RADIOISOTOPES PRESENT IN THE SOLID WASTE

Radionuclide	Dose to biota			ΣE (MeV)	1/MPD I* (arb.units)	Abundance (from Table 2.3)	Relative importance	
	System	Class	C.F.**				For biota	For man
^{90}Sr	Fresh	Algae	500	1.1	100	0.04	22	2×10^3
^{127}Te	"	(Fish)	(400)	0.24	1×10^{-4}	0.9	216	0.09
^{134}Cs ^{137}Cs	"	Fish	10^3	1.1 0.59	3×10^{-3} 2.5×10^{-3}	340 300	3.74×10^5 1.77×10^5	1×10^3 750
^{144}Ce	"	Algae	10^4	1.3	3×10^{-3}	0.12	1.56×10^3	3.6
^{147}Pm	Fresh Marine	" (Molluscs)	10^4 (10^3)	0.51	2×10^{-4}	0.01	51	0.02
^{54}Mn	"	"	5×10^4	0.51	2.5×10^{-4}	60	1.53×10^6	750
^{55}Fe	"	"	2×10^4	0.0065	5×10^{-5}	158	2.05×10^4	158
^{60}Co	"	Crustacea	10^4	1.5	10^{-3}	352	5.28×10^6	3.5×10^3
^{65}Zn	"	Molluscs	5×10^4	0.32	3×10^{-3}	0.02	320	3

* MPD I - Maximum Permissible Dose to Individual

** C.F. - Concentration Factor

TABLE 2.5
PREDICTED AMOUNTS OF ^{137}Cs , ^{60}Co AND ^{90}Sr LEACHED FROM
SLUDGE AND WASTE AND THE RESULTING MAXIMUM CONCENTRATION
IN GROUNDWATER ADJACENT TO THE TRENCHES IN VARIOUS YEARS

Radio-nuclide	Year	Leachable Activity (μCi)			Maximum Concentration in Groundwater ($\mu\text{Ci ml}^{-1}$)
		Sludge	Trash	Total	
^{137}Cs	1976	1296	249	1545	5.2×10^{-6}
	1980	1720	374	2094	7.0×10^{-6}
	1990	2610	640	3250	1.1×10^{-5}
	2000	3320	852	4172	1.4×10^{-5}
^{60}Co	1976	1428	9170	11177	3.7×10^{-5}
	1980	1524	11654	13178	4.4×10^{-5}
	1990	1626	14290	15916	5.3×10^{-5}
	2000	1654	15000	16654	5.6×10^{-5}
^{90}Sr	1976	0.19	0.23	0.42	1.4×10^{-9}
	1980	0.25	0.34	0.59	2.0×10^{-9}
	1990	0.37	0.57	0.94	3.1×10^{-9}
	2000	0.47	0.75	1.45	4.8×10^{-9}

TABLE 2.6

COMPARISON OF PREDICTED MAXIMUM CONCENTRATION OF RADIONUCLIDES
IN GROUNDWATER WITH ICRP RECOMMENDATIONS AND CONCENTRATIONS
ALLOWABLE UNDER THE NSW RADIOACTIVE SUBSTANCES ACT AND THE
NSW CLEAN WATERS ACT 1970

Radio-nuclide	Predicted Concentration (1990) ($\mu\text{Ci ml}^{-1}$)	ICRP ⁽¹⁾ ($\mu\text{Ci ml}^{-1}$)	NSW ⁽²⁾ Radioactive Substances Act ($\mu\text{Ci ml}^{-1}$)	NSW ⁽³⁾ Clean Waters Act ($\mu\text{Ci ml}^{-1}$)
^{137}Cs	1.1×10^{-5}	2×10^{-5}	7×10^{-4}	See (3) below
^{60}Co	5.3×10^{-5}	5×10^{-5}	2×10^{-3}	"
^{90}Sr	3.1×10^{-9}	2×10^{-7}	3×10^{-6}	"

1. ICRP recommendations for continuous exposure of members of the general public from contaminated drinking water.
2. Maximum allowable concentration of nuclide at point of discharge from any premises.
3. Maximum allowable concentration of nuclide in wastes discharged to controlled waters and restricted waters. Gross beta activity not to exceed $3 \times 10^{-7} \mu\text{Ci ml}^{-1}$.

TABLE 2.7
TRITIUM LEVELS IN BOREHOLE WATER (nCi ℓ^{-1})

Borehole	Nov.-Dec.1975 (Drought)	Feb. 1976 (After rain)	April 1976
D7	800	300	
D8	5400	4000	
D9	3800	1800	
D10	10400	5700	
D11	1400	1600	
D12	2400	800	
D13	200	60	
D14	2300	1300	
D15	7200	700	
D17		900	
BH2/3		4	
OS2/W		500	
A		10.3	9
B		2.0	0
C		0.7	51
D		0.7	0
E		3.7	0
Run off area		2	
" (9/3/76)		60	
" (19/3/76)		7	
" (24/3/76)		1	
" (31/3/76)		90	
" (7/4/76)		0	

TABLE 2.8
CONCENTRATION OF NUCLIDES IN ASH OF VEGETABLES GROWN
IN AN 'ACTIVE' AND A 'CONTROL' GARDEN
(JANUARY 1975) (SEE FIGURE 2.2)

Vegetable	⁹⁰ Sr (pCi g ⁻¹ Ash)		U (µg g ⁻¹ Ash)		Radium (pCi g ⁻¹ Ash)	
	Active	Control	Active	Control	Active	Control
Beans	19	~ 2	0.5	1.2	0.7	0.8
Carrots	2.4	1.2	0.8	0.8	0.5	0.9
Sweet Corn	0.7	0.4	0.6	0.9	0.3	0.2
Potato	1.0	0.2	0.3	0.3	0.6	0.2
Spinach	3.4	1.3	0.4	0.6	0.4	0.3
Maize	147	0.1	0.4	0.1	0.5	0.1

TABLE 2.9
CALCULATED DOSE RATE FROM A FOUR-WALLED BRICK
ENCLOSURE CONSTRUCTED FROM CONTAMINATED CLAY

Radio-nuclide	Assumed Kd	Dose rate (rem year ⁻¹)
⁶⁰ Co	300	125
¹³⁷ Cs	1000	32

TABLE 2.10
UPPER LIMIT FOR INTERNAL DOSE TO BIOTA (1990)

Emitter	Predicted max. conc. in creek- water ($\mu\text{Ci mL}^{-1}$)	Organism	Maximum Conc. Factor	ΣE (MeV)	Dose rate mrad h^{-1}	Conc. $\mu\text{g g}^{-1}$
^{60}Co	5.3×10^{-5}	Crustacea	10^4	1.5	1694*	5.3×10^{-1}
^{137}Cs	1.1×10^{-5}	Fish	10^3	0.59	13.8	1.1×10^{-2}

$$* \text{ D.R.} = \frac{5.3 \times 10^{-1} \times 3.7 \times 10^4 \times 1.5 \times 1.6 \times 10^{-6} \times 3600 \times 1000}{100} \text{ mrad/hour}$$

$$= 1694 \text{ mrad/hour} \quad (1 \text{ MeV} = 1.6 \times 10^{-6} \text{ erg})$$

$$(1 \text{ rad} = 100 \text{ ergs/gram})$$

TABLE 2.11
WASTE BURIED IN LITTLE FOREST BURIAL GROUND (1960-1968 INCLUSIVE)
From records of Site Operations Section, AAEC, Research Establishment

Activity (mCi) Groups			Fissile Content (g)			Fertile Content (kg)		Be Content (kg)	Volume (m^3)
I	II	III	Pu	U^3	U^5	U	Th		
19.3	1050	3017	6.88	5.21	91.96	59.27	50.65	1730	1675

TABLE 2.12
SELECTION OF RADIOACTIVE NUCLIDES [IAEA 1967]

<u>Group I</u>
^{227}Ac , ^{241}Am , ^{237}Np , ^{230}Pa , ^{231}Pa , ^{210}Po , ^{239}Pu , ^{240}Pu , ^{241}Pu , ^{226}Ra , ^{228}Ra , ^{228}Th , ^{230}Th , ^{232}U .
<u>Group II</u>
^4A , ^{210}Bi (RaE), ^{154}Eu , Mixed Fission Products, ^{233}Pa , ^{210}Pb , ^{223}Ra , ^{224}Ra , ^{222}Rn , ^{90}Sr , ^{233}U , ^{135}Xe .
<u>Group III</u>
^{140}Ba , ^{144}Ce , ^{36}Cl , ^{60}Co , ^{131}I , ^{133}I , $^{114\text{m}}\text{In}$, ^{192}Ir , ^{85}Kr , ^{106}Ru , ^{124}Sb , ^{125}Sb , ^{46}Sc , ^{89}Sr , Th_{nat} , ^{204}Tl , ^{235}U , ^{238}U , U_{nat} , ^{133}Xe , ^{91}Y , ^{95}Zr .
<u>Group IV</u>
^{198}Au , ^7Be , ^{82}Br , ^{14}C , ^{45}Ca , ^{38}Cl , ^{58}Co , ^{51}Cr , ^{135}Cs , ^{137}Cs , ^{64}Cu , ^{18}F , ^{55}Fe , ^{59}Fe , ^{42}K , ^{140}La , ^{99}Mo , ^{24}Na , ^{95}Nb , ^{63}Ni , ^{32}P , ^{103}Ru , ^{35}S , T-(in any other form other than Group VII), ^{99}Tc , ^{132}Te , ^{65}Zn .
<u>Group V</u>
^4A (uncompressed), ^{135}Xe (uncompressed).
<u>Group VI</u>
^{85}Kr (uncompressed), ^{133}Xe (uncompressed).
<u>Group VII</u>
T (as T_2 or HT, or tritium activated luminous paint or tritium gas adsorbed on a solid carrier).

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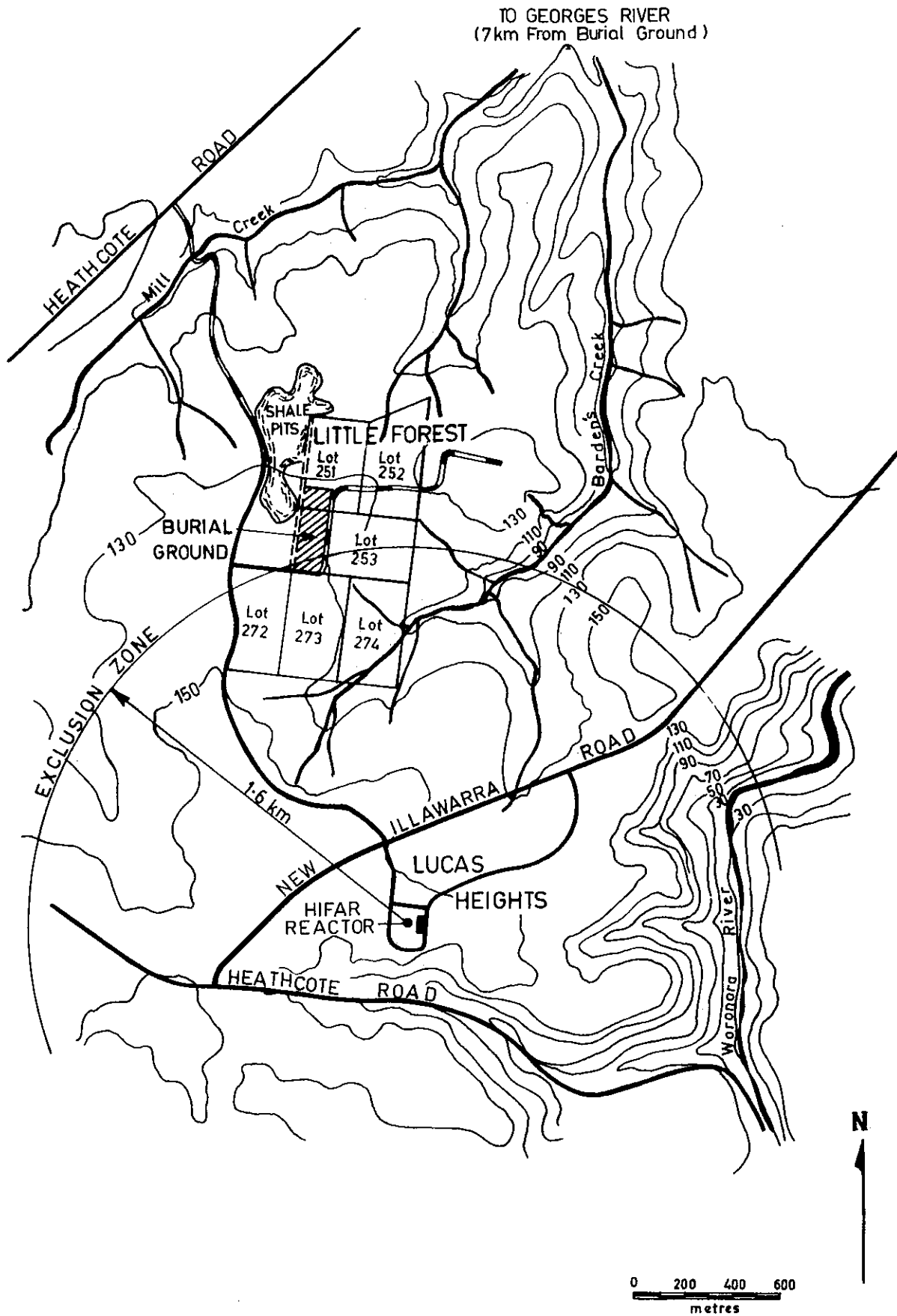


FIGURE 1. LOCATION OF LITTLE FOREST BURIAL GROUND

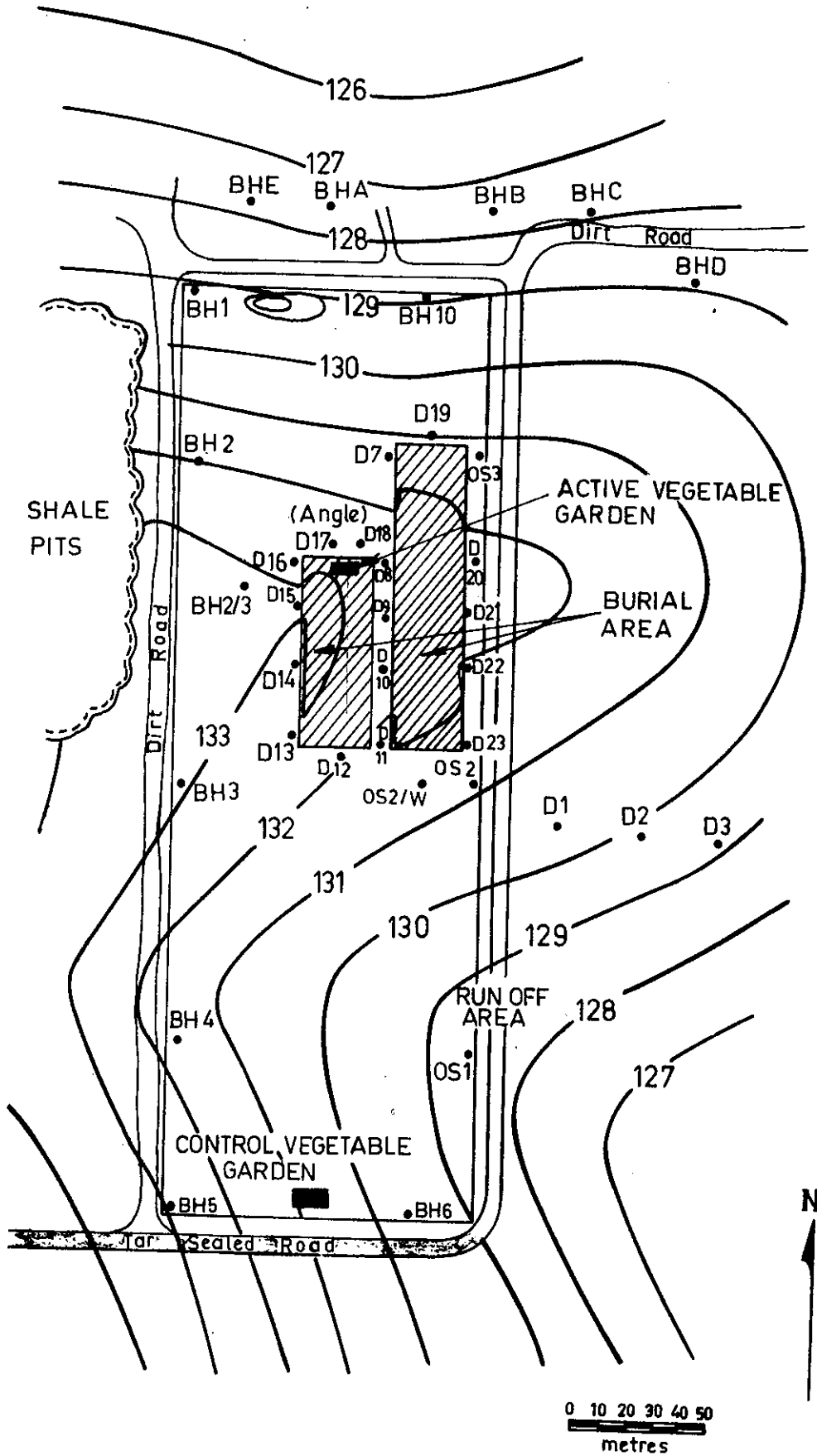


FIGURE 2. BURIAL GROUND SHOWING BURIAL AREA, LOCATION OF BOREHOLES AND SURFACE CONTOURS (IN METRES)

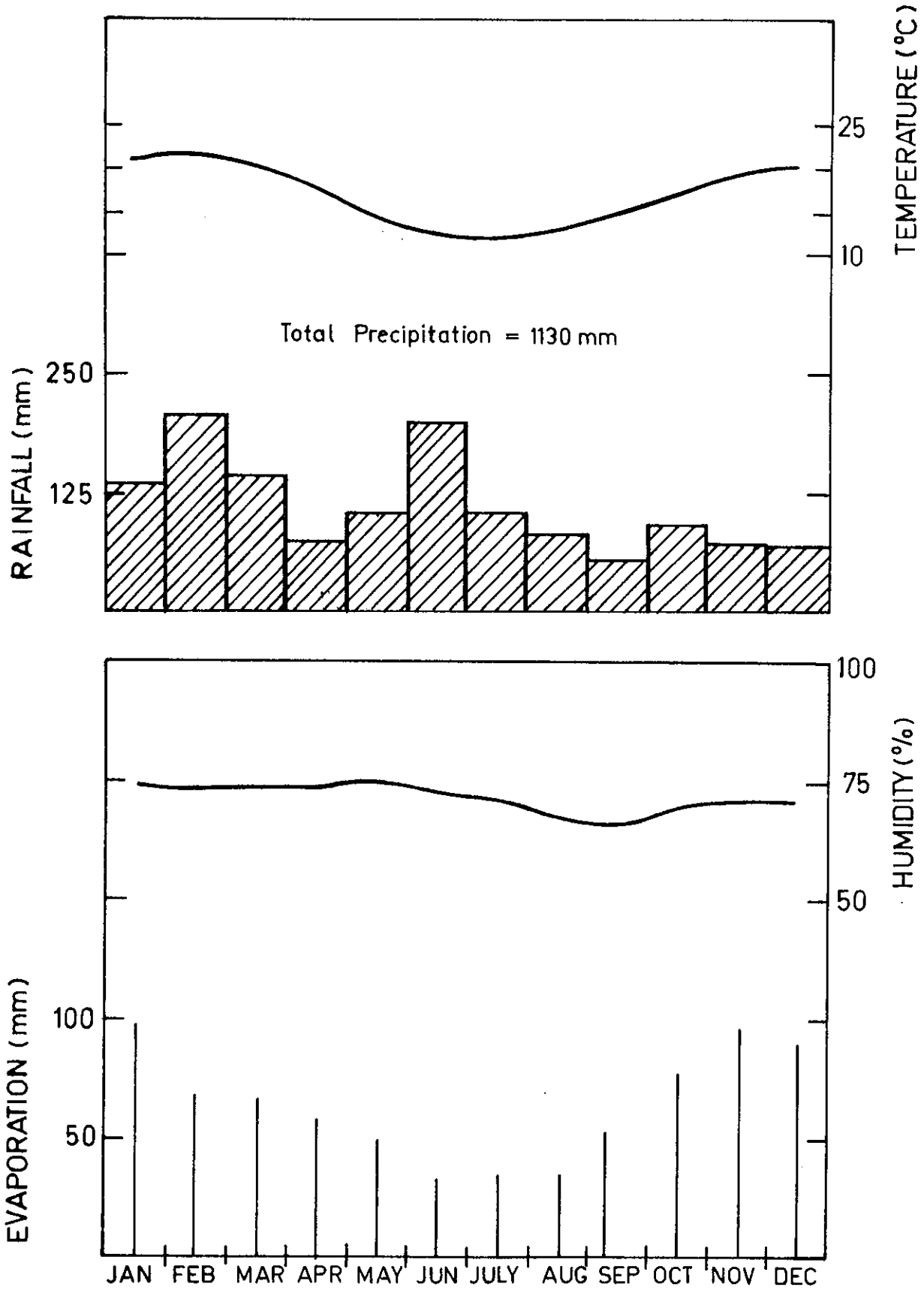
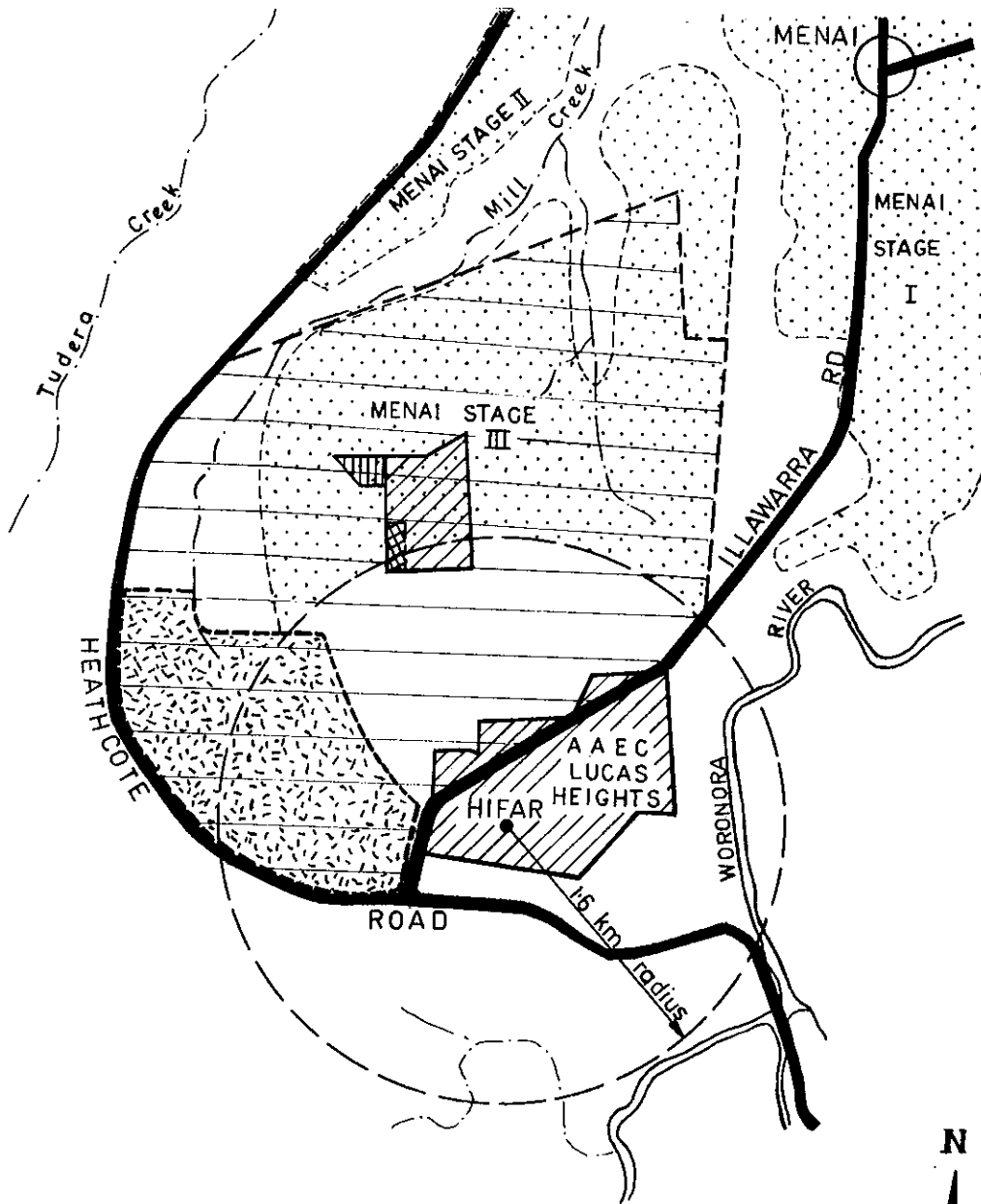


FIGURE 3. CLIMATIC CHARACTERISTICS OF REGION (AVERAGED OVER TEN YEAR PERIOD)



LEGEND







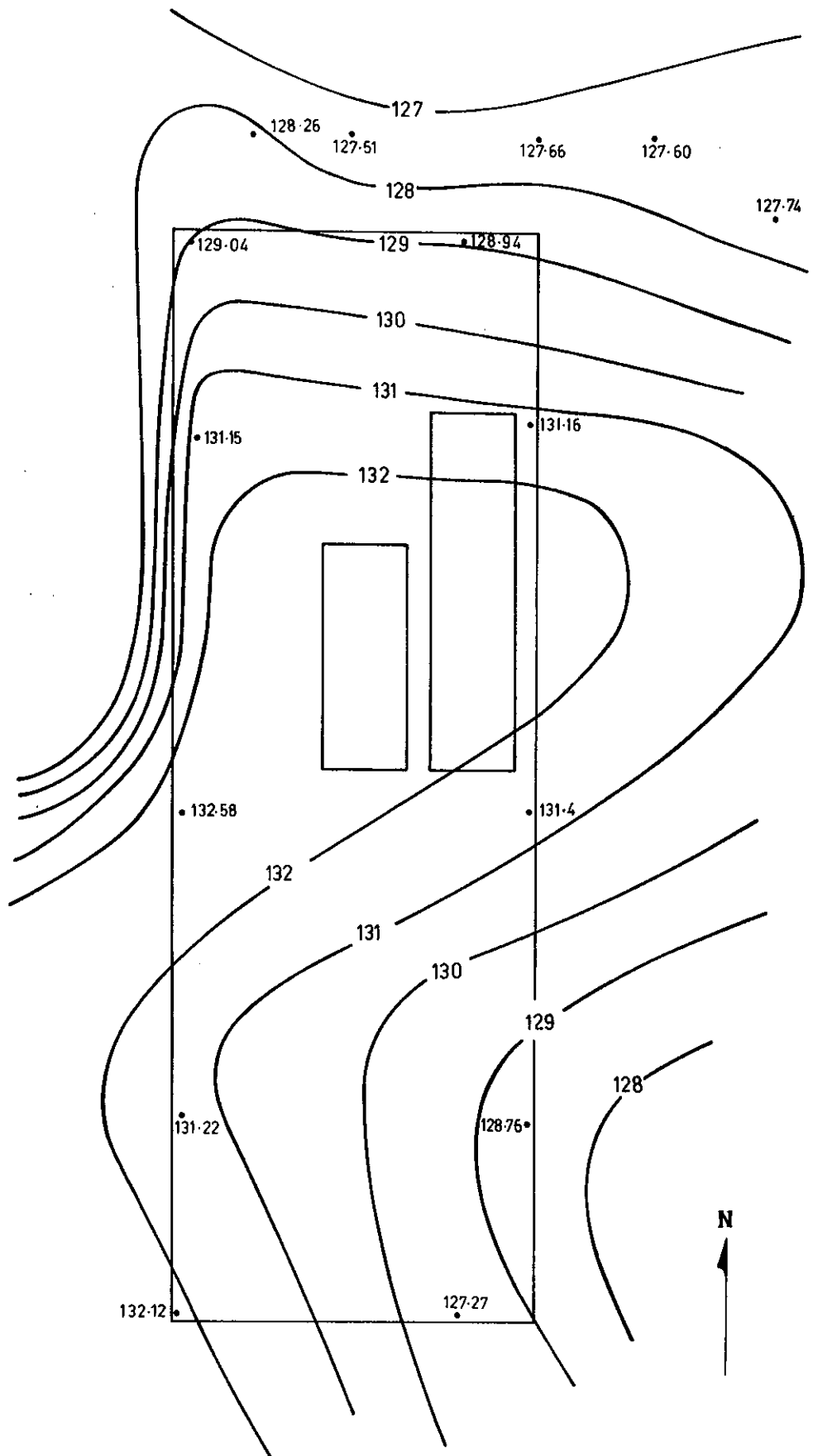
-  LAND OWNED BY AAEC
-  LAND PROPOSED FOR WASTE DISPOSAL BY BRAMBLES HOLDINGS LTD
-  AAEC DISPOSAL SITE
-  PROPOSED URBAN DEVELOPMENT SSC
-  PROPOSED OIL REFINERY
-  PROPOSED REGION WASTE DISPOSAL CENTRE BY MWDA



FIGURE 4. MAP SHOWING LAND USE PROPOSALS IN MENAI, LUCAS HEIGHTS, LITTLE FOREST AREA



**FIGURE 5. BURIAL GROUND WATER LEVELS ABOVE SEA LEVEL
(10.9.74)**

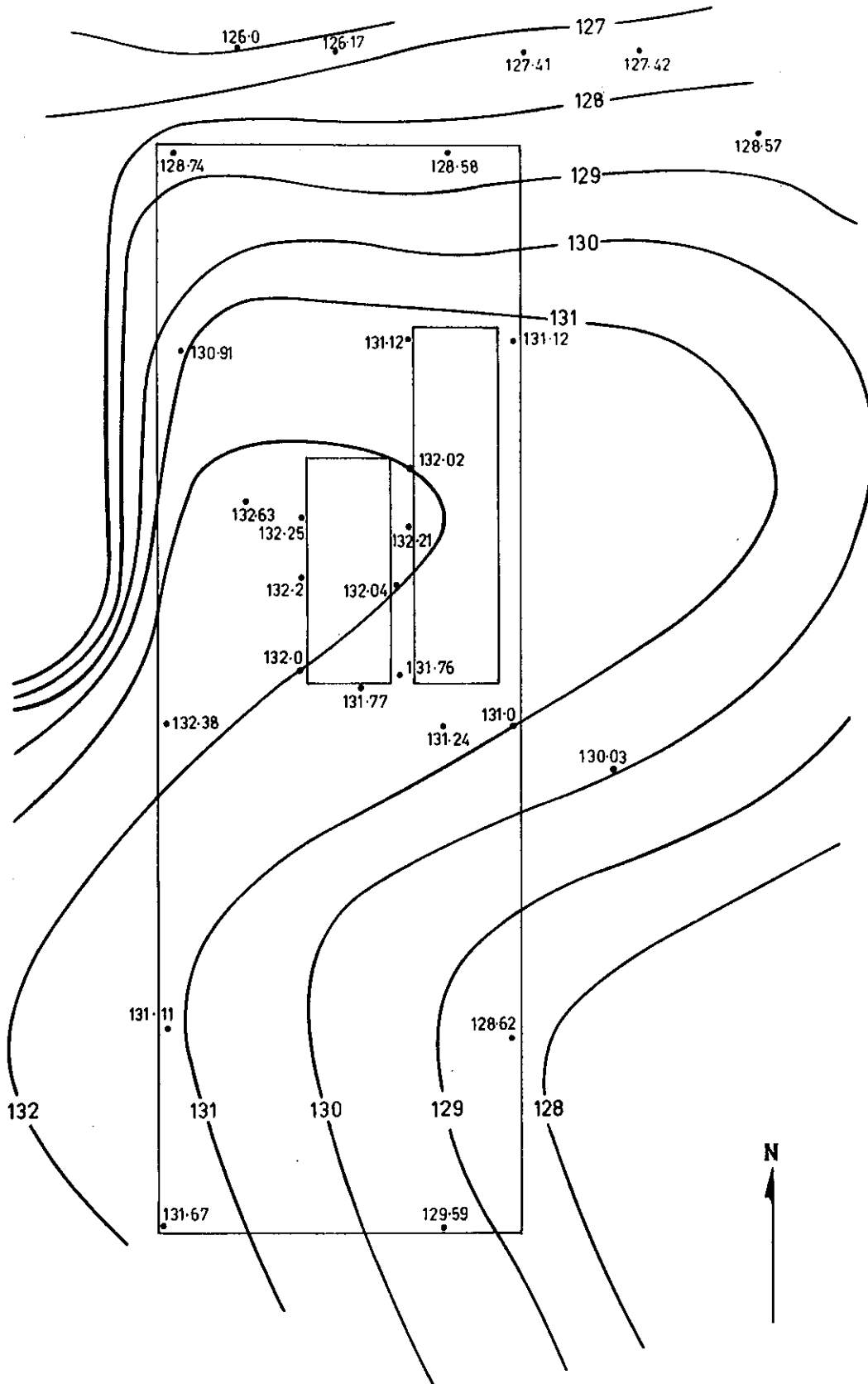


FIGURE 7. BURIAL GROUND WATER LEVELS ABOVE SEA LEVEL (28.1.76)

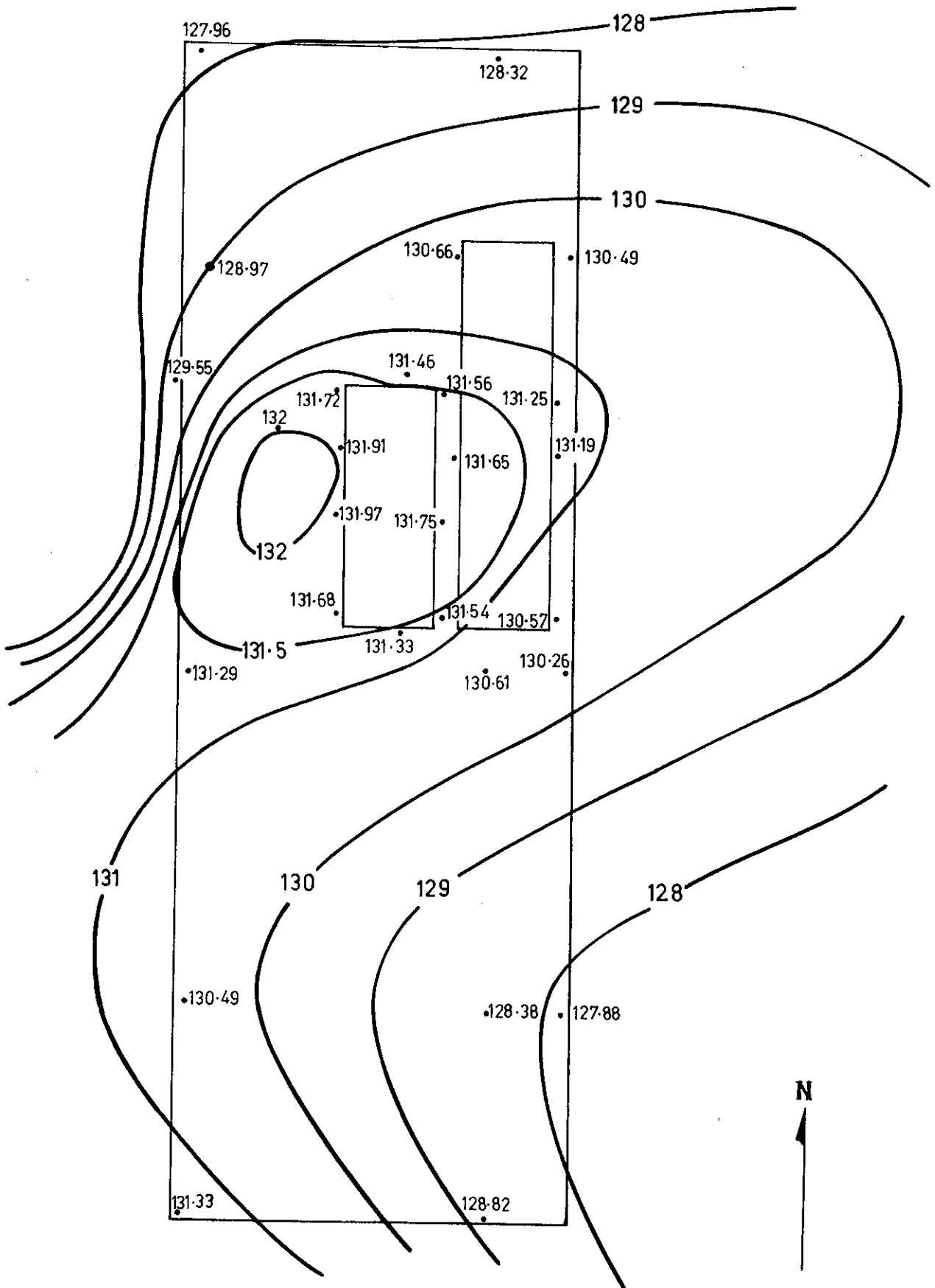


FIGURE 8. BURIAL GROUND WATER LEVELS ABOVE SEA LEVEL (29.6.76)

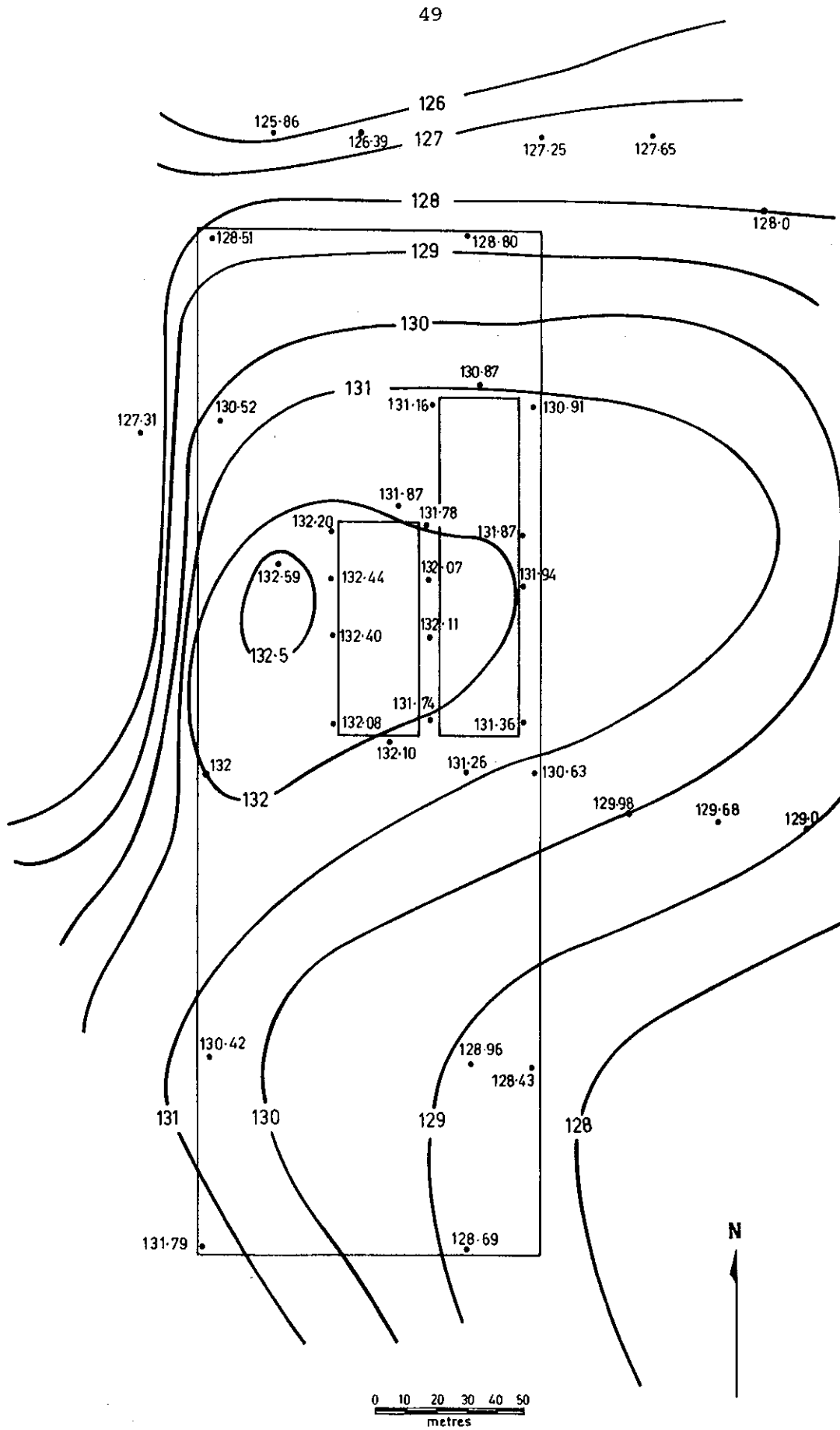


FIGURE 9. BURIAL GROUND WATER LEVELS ABOVE SEA LEVEL (6.5.76)

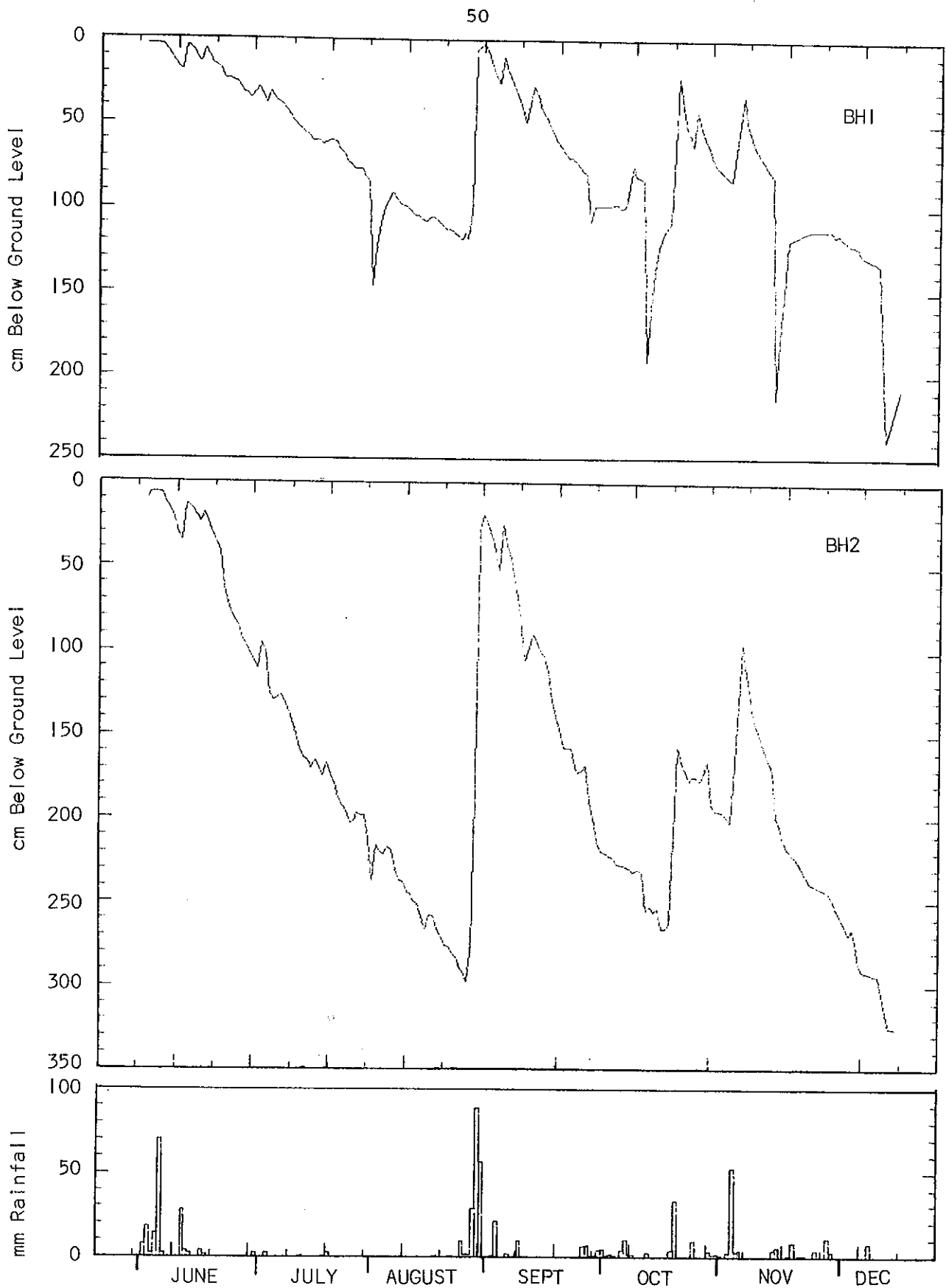


FIGURE 10. DAILY HEIGHTS OF WATER TABLE IN VARIOUS BOREHOLES AND CORRESPONDING RAINFALL DURING JULY-DECEMBER 1974

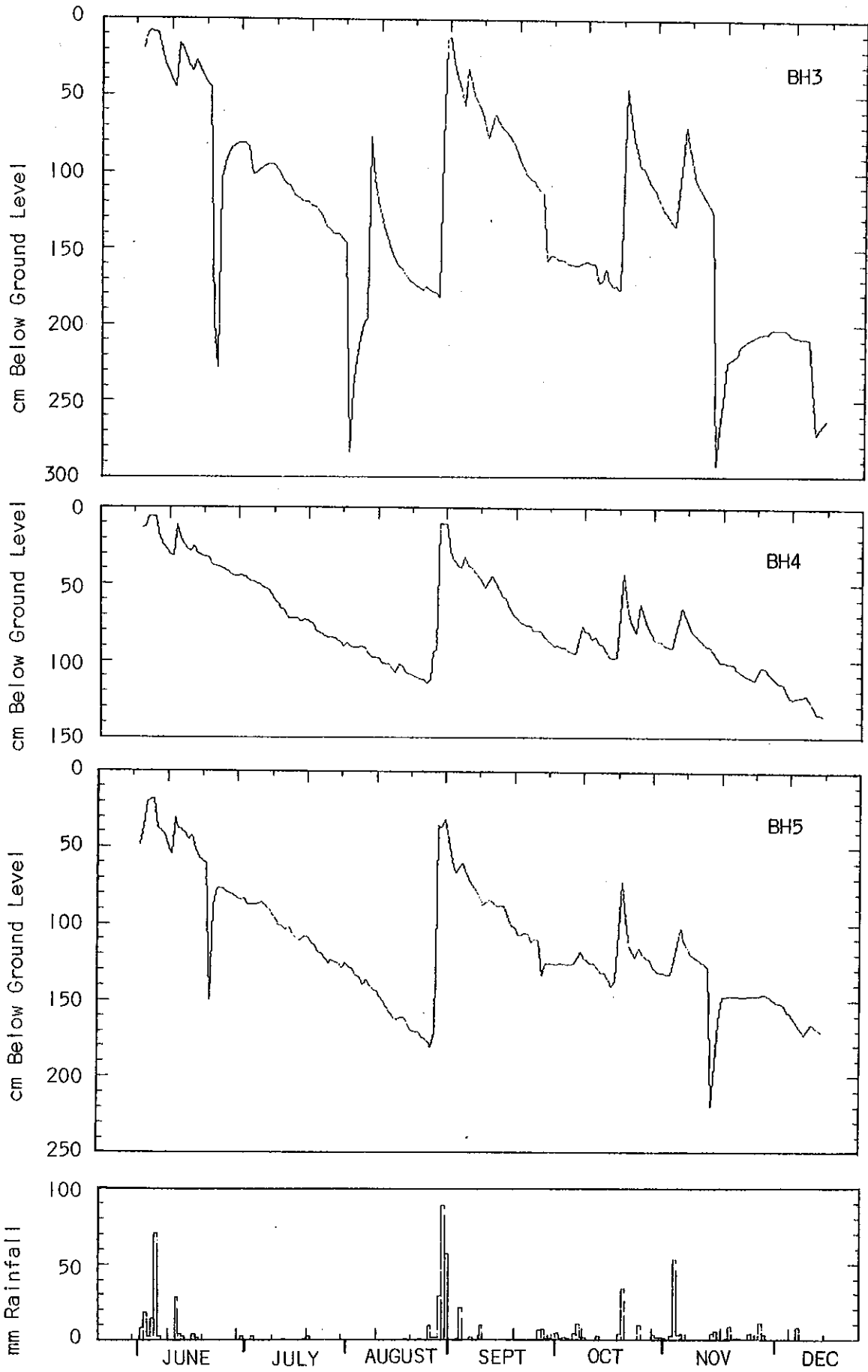


FIGURE 10. (CONTINUED)

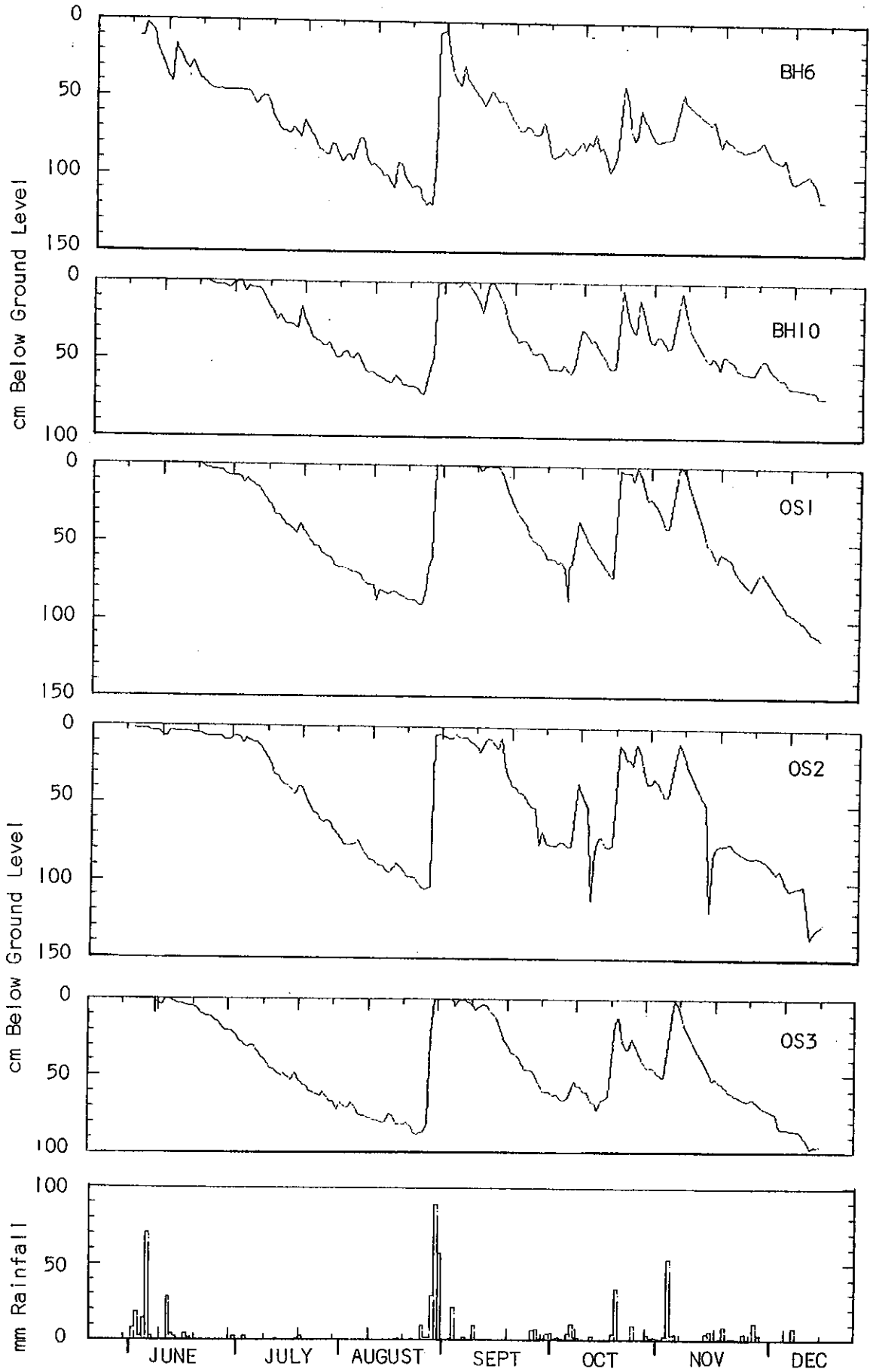


FIGURE 10. (CONTINUED)

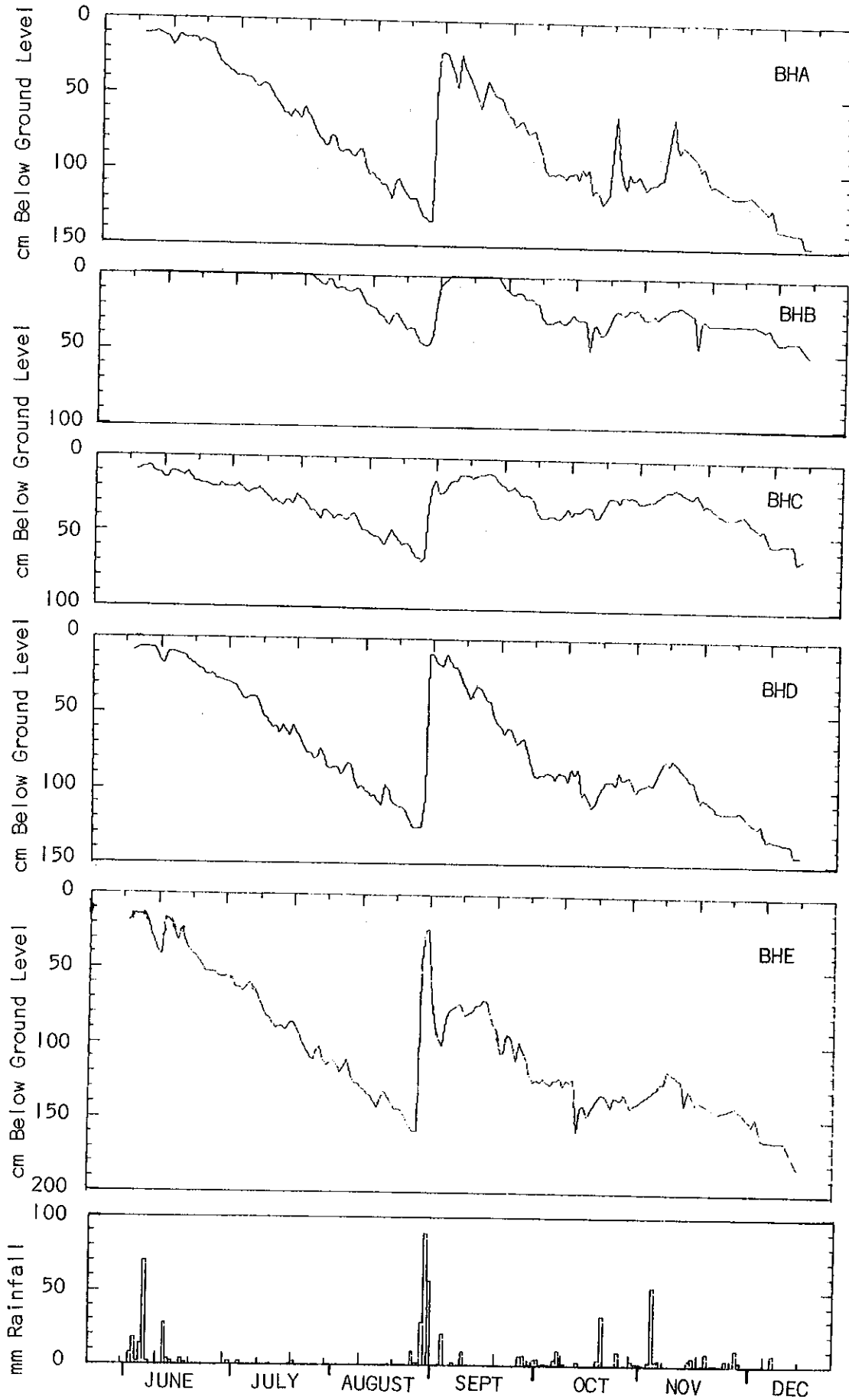


FIGURE 10. (CONTINUED)

