DEPARTMENT OF
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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1976/62

A groundwater investigation on Norfolk Island.

by

R.S. Abell

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ERRATA

Page 6	para 1 line 5 "Kingstone" should read "Kingston"
Page 14	para 4 line 4 delete "1:50"
Table 7	Column 3 line 8 "were" should read "near"
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SUMMARY

The currently exploited underground water storage on Norfolk Island is a high-level unconfined aquifer corresponding to a deeply weathered profile formed on a succession of basalt lava flows and volcanoclastic rocks by subtropical weathering. The products of weathering, which are porous and moderately permeable, have considerable groundwater storage capacity and support a water-table with elevations exceeding 100 m above sea level. There are 297 groundwater extraction points which tap groundwater almost exclusively in the weathered profile. At the base of the profile, ground water moves mainly through vertical joints and fractures in unweathered volcanic rocks towards sea level, where it may accumulate as basal groundwater. The occurrence and geometrytof a basal groundwater body, and the nature of the rocks in which it is stored, need evaluation.

Groundwater in the weathered mantle contains mainly sodium chloride salts derived initially from oceanic spray dissolved in rainwater. Groundwater is suitable for domestic, garden, livestock, and irrigation use. Groundwater pollution due to the disposal of sanitary and livestock waste, refuse disposal, and seawater contamination is not presently a widespread problem.

Total water consumption is estimated at 2.4×10^5 m^3/annum. Groundwater consumption is about 40 percent of total water use. Water balance calculations indicate that the volume of groundwater recharge is 6.3×10^6 m^3/annum, which is sufficient to meet demands for groundwater over the next few years.

INTRODUCTION

In October 1973 the Department of the Capital Territory requested the Bureau of Mineral Resources (BMR) to investigate groundwater conditions on Norfolk Island, with the ultimate aim of establishing whether a source of fresh water underlies the island near sea level.

Data collection and fieldwork were undertaken over a ten-week period between July and September 1974. The first six weeks were spent locating and examining all the wells and bores on the island. The remainder of the investigation - including one day on Philip Island- was devoted to hydrogeological field-work. The general geology of the island was studied mainly from outcrops along the accessible parts of the coast. A visual assessment of the water-bearing properties of the volcanic sequence was attempted, and coastal seepages were mapped. Field observations were made with reference to the extent of surface water; consequently, the drainage network - particularly the distribution of inland seepages and the nature of the catchments- was mapped. Surface-water extraction points were located as part of an assessment of surface-water use.

Throughout the investigation, colour and black and white aerial photographs were used to assist in bore and well location, outlining fracture traces, drainage mapping, and hydrogeological interpretation. At different times during the investigation aerial photographs at nominal scales of 1:4000 (colour, 1968), 1:17 000 (black and white, 1968) and 1:50 000 (single-frame black and white, 1968) were used.

Groundwater samples were collected for chemical analysis, to assess water quality and pollution. Field measurements of the electrical conductivity of groundwater were carried out to obtain a general idea of groundwater salinity in the study area.

As only a little groundwater data was available for Norfolk Island, local residents were asked to provide information and discuss matters relating to water use, consumption, and general water-supply problems.

This report contains a preliminary analysis of the hydrogeological data collected during the survey and from earlier water-resource investigations. From the data, it was apparent that only generalized conclusions can be made about the occurrence, nature, and extent of groundwater on the island. Recommendations are made for further investigations before any schemes are planned for developing a possible groundwater supply near sea level.

Previous water-supply investigations

The first documented water-supply investigation on Norfolk Island was made by the Commonwealth Department of Works (NSW Branch) in 1949-51 (unpublished file report) for improving the water supply at the aerodrome. As part of the investigation a short stream-gauging program was undertaken in Watermill and Broken Bridge Creeks; this program provided what is still the only source of stream-discharge data.

The first water-resources investigation carried out on the island was prompted by a serious drought in 1965. Groundwater conditions were broadly outlined by Eden (1965), who made suggestions for the improvement of both groundwater and surface-water supplies; commented on water qualith - particularly the dangers of potential groundwater pollution from septic-tank waste; and advocated legislative control of water supplies.

Wood (1968) compiled a water-supply and sewerage development report for the Commonwealth Department of Works (NSW Branch). The report gives an overall assessement of water-supply problems with much of the groundwater data quoted directly from Eden (1965). Other reports containing groundwater information, maybe found in Stephens & Hutton (1954), Butland (1974), and unpublished file reports held by BMR and the Norfolk Island Administration.

Location and size

Norfolk Island has an area of 35 km^2, and is the largest and only inhabited island of an isolated group of three islands located in the southwest Pacific Ocean at latitude 29^{o}S and longitude 168^{o}E (Fig. 1). Philip Island, 6 km south of Kingston (Norfolk Island's administrative centre), is an uninhabited and precipitous island with an area of about 5 km^2. Nepean Island is a flat-topped islet of 4 ha close to Norfolk Island's southern shoreline.

Access

Access to Norkfolk Island is by either sea or air. Ships call regularly to deliver cargo to the island, but, as there are no harbour facilities, ships stand off outside either Kingston or Cascade (depending on the weather) and the cargo is brought ashore by lighters. During World War II an airstrip was built on the southwest portion of the island, and aircraft now provide the main means of passenger transport to Norfolk Island.

Internal access is served by an extensive network of roads; there is roughly 80 km of road, of which about one third is sealed. Forestry tracks have been developed in and around

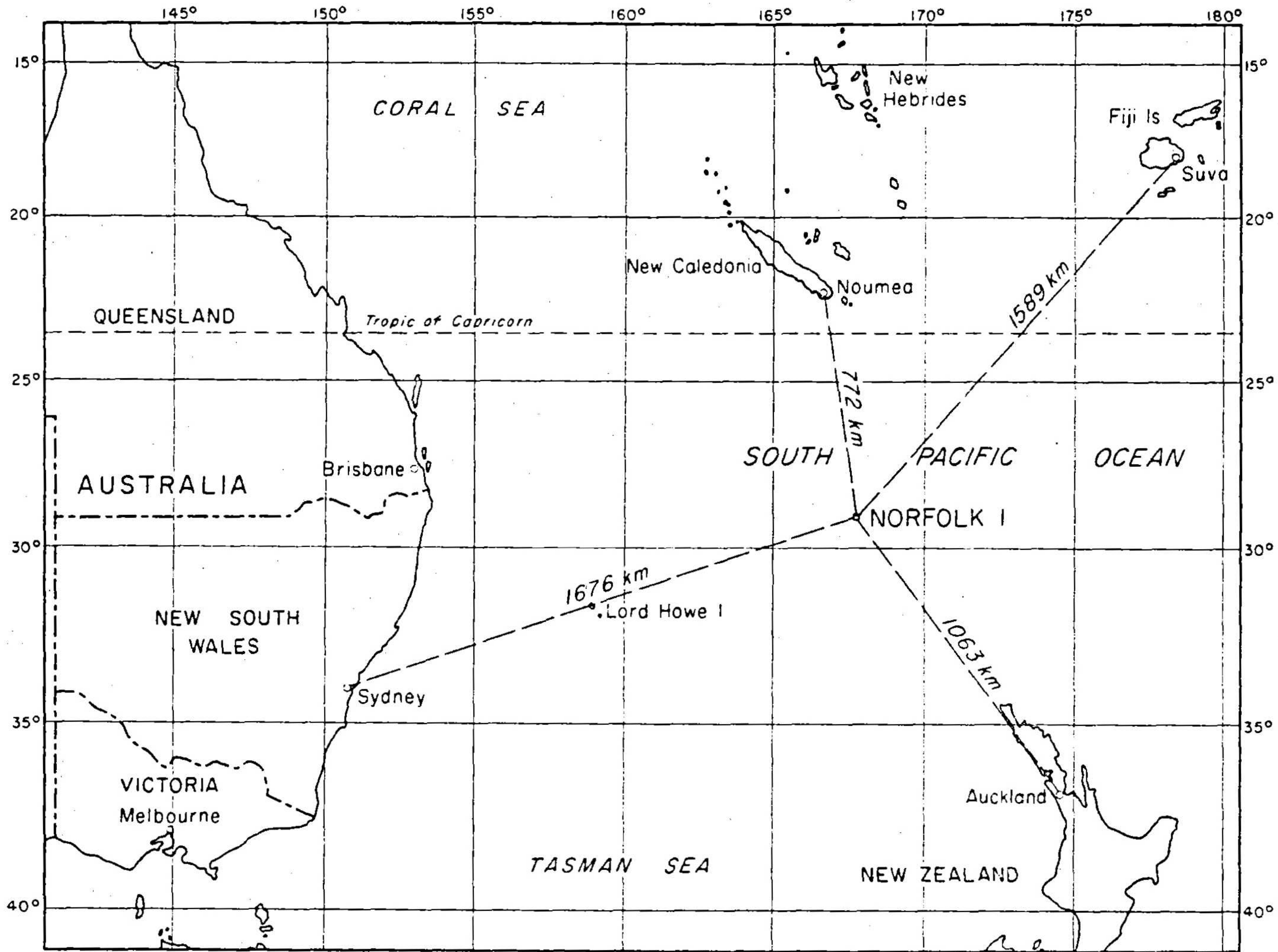

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Fig. 1 Location of Norfolk Island

Mount Pitt Reserve but become temporarily impassable after heavy rain and are best negotiated by four-wheel-drive vehicles. Foot tracks are present at many places along the coastal perimeter.

Climate

The subtropical climate of Norfolk Island, with its well distributed rainfall and mild temperature, presents an equable climatic environment for animals and plants. Climatological data (Table 1) supplied by the Bureau of Meteorology, Melbourne, is based on records taken from the meteorological station at the airport. Although the station is not situated centrally on the island, the records are considered to adequately reflect the climate on the island.

The mean annual rainfall is 1335 mm. Figure 2 is a graph of the mean monthly distribution of rainfall based on a record between 1890 and 1974; it shows a winter maximum between June and July, and a summer minimum between November and January. The mean number of rain days/annum since records began is 175. July with a mean of 21 days has the largest number of rain days in any month of the year (Fig. 2). Cyclonic storm rainfall may occur in summer, but, as Norfolk Island lies sufficiently far south of the tropics, most cyclones weaken and are not normally a serious threat to the island.

The mean annual relative humidity calculated from wet and dry bulb temperatures is 79 percent. Relative humidity is fairly constant throughout the year, being slightly higher in summer than winter. The moderate values are characteristic of an island that has persistent winds and small temperature variation.

The annual wind rose for Norfolk Island (Fig. 3) shows that the island lies in the path of prevailing winds which blow mainly from east to southeast. Monthly wind roses show a considerable variation in wind direction- particularly in the winter months (May-September), when winds may be expected from almost any direction. Average wind velocities oscillate around 3-5 m/sec.

Maximum mean tidal range for the island is 1.6 m (Australian National Tide Tables, 1974). The relatively small tidal range is typical of an oceanic tide operating around a remote island far from any extensive land area.

Population

The residential population is spread widely over the island, with the exception of Mount Pitt Reserve. The greatest concentrations of people are in the Burnt Pine/Middlegate residential/business complex and to a lesser extent, in Kingston.

TABLE 1. SUMMARY OF CLIMATIC DATA

Month	Mean rainfall (mm)	Mean temperature °C Max.	Min.	Mean	Dry bulb °C	Wet bulb °C	Relative Humidity (%)	Sunshine (hrs)
Jan	88	24.4	18.9	21.7	21.5	19.1	81	235.1
Feb	101	24.8	19.5	22.2	21.9	19.9	82	192.9
Mar	103	24.1	19.1	21.6	21.3	19.2	82	197.4
Apr	128	22.6	17.6	20.1	19.8	17.3	78	205.5
May	143	20.8	15.8	18.3	18.2	15.7	76	173.7
June	150	19.1	14.6	16.9	16.8	14.7	80	151.1
July	150	18.2	13.3	15.8	15.8	13.6	77	180.6
Aug	138	18.2	13.1	15.7	15.7	13.5	77	200.4
Sept	92	18.8	13.4	16.1	16.2	13.8	75	211.6
Oct	91	20.1	14.5	17.3	17.2	14.9	78	227.7
Nov	67	21.8	15.8	18.8	18.7	16.1	79	243.1
Dec.	84	23.2	17.5	20.4	20.1	17.7	80	239.1
Year	1335	21.3	16.1	18.7	18.6	16.3	79	2457.9
Length of Record	1890-1974	1939-1974			1957-1974		Calculated from wet and dry bulb data	1951-1974

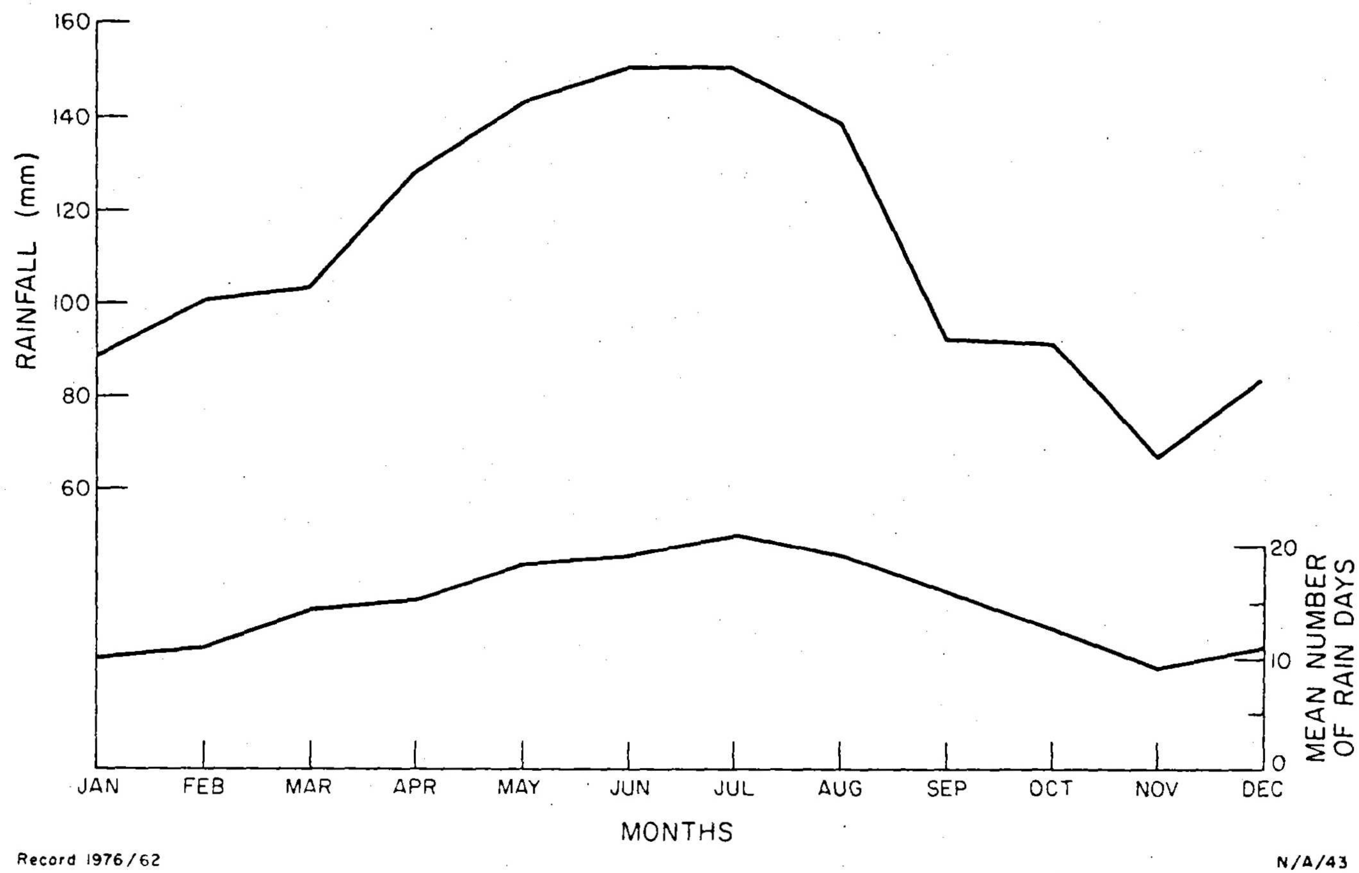

Fig. 2 Mean monthly rainfall (1890 - 1974)

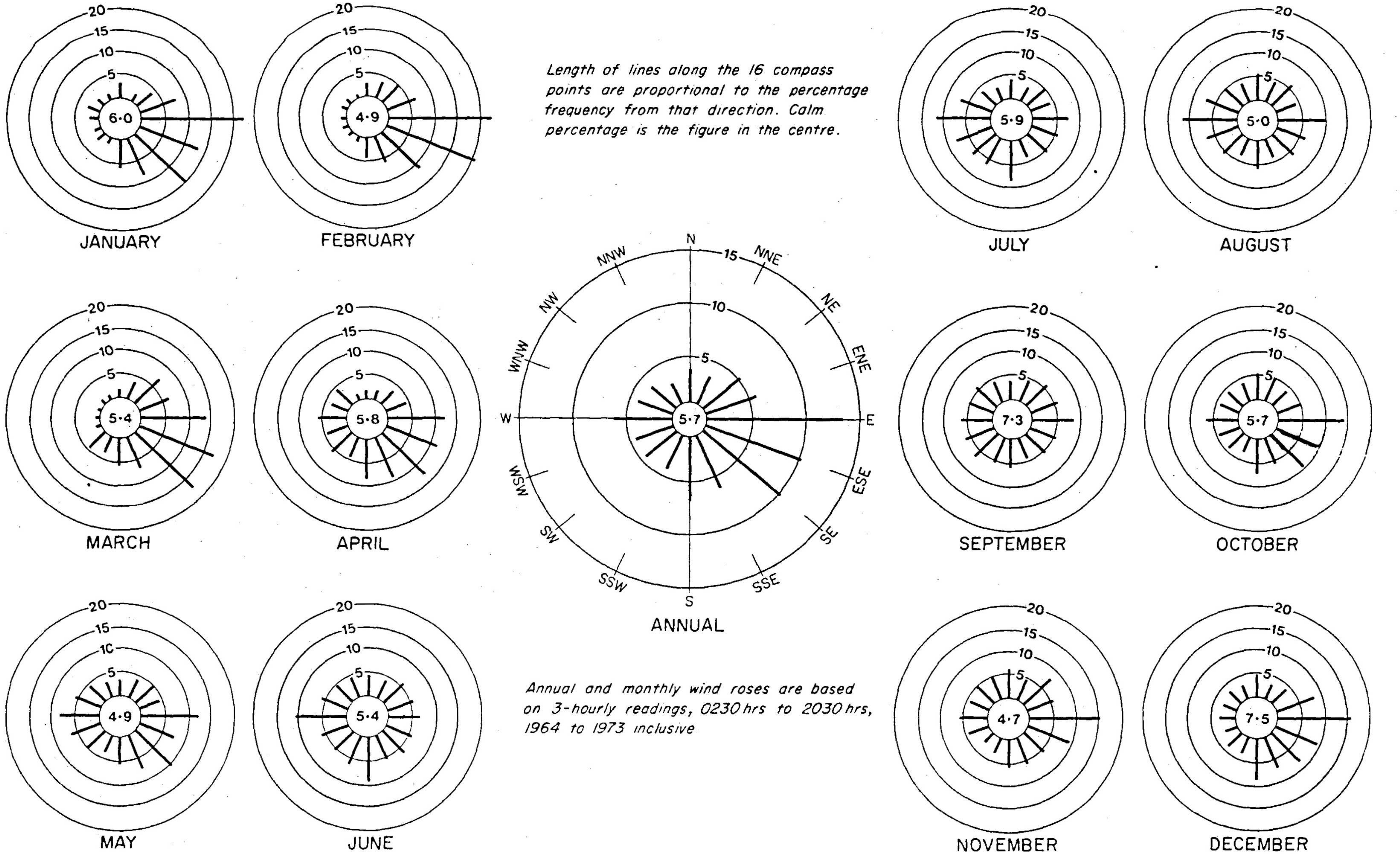

Fig. 3 Annual and monthly wind roses

The island is populated by 'Islanders' - descendants of the mutineers of HMS Bounty - and by 'Mainlanders' - later settlers, mostly from Australia, New Zealand, and the United Kingdom. In 1974 there were about 1600 permanent residents on the island, and - attracted by the remoteness, beauty, and restful appeal - more than 15 000 tourists visited Norfolk Island that year. Butland (1974) has detailed the economic and social factors affecting population growth on the island.

Vegetation and land use

Originally Norfolk Island was densely covered with a subtropical forest of palms, ferns, creepers, flax, and pines, of which a remnant has been preserved around the slopes of Mount Pitt and Mount Bates. Since the original settlement in 1788, extensive areas of forest have been cleared for cultivation and grazing. It is estimated that about half of the island remains forested (Fig. 4). The densely forested areas are associated with Mount Pitt Reserve and along some uninhabited valleys. Recent afforestation has been effected, particularly with eucalypts close to Anson Bay Road (on the western side of Mount Pitt Reserve), and Norfolk Island Pine has been planted to combat soil erosion in Watermill Creek. The open forest areas are mainly cleared land that has been taken over by a dense coverage of secondary growth which includes olives, guava, wild tobacco, and lantana thicket. About 15 percent of the island around Kingston, Cascade, and Headstone is pastoral, supporting coarse kikuyu grass; the remainder is cultivated land and urban development with some open woodland and secondary growth.

Agriculture is practised mainly at subsistence level. There are few large agricultural schemes owing to the fragmentary, and in places intensive, subdivision of land. Most people cultivate small tracts of land of only a few hectares and grow crops (mainly fruit, vegetables, and flowers) for their own and local needs. The most intensively used area for agriculture is between Stockyard Creek and Steels Point, where fertile arable soils occupy flat and unbroken country. There appears to be potential for agriculture but the greatest restrictions are transport and market limitations in neighbouring mainland areas.

A small local industry revolves around forestry, particularly timber for power and telephone poles, fencing posts, and other building needs. A tanalith plant operates for the treatment of wood products. A quarry at Cascade and a crushing plant provide aggregate for roads and other local needs. Concrete and cement products are manufactured on a small scale. As the island is bereft of natural mineral resources it is unlikely that any primary industry is likely to be established as a result of mining. Aeolianite makes a satisfactory building stone, and during the early settlements was quarried along the Kingston shoreline and from Nepean Island.

Much of the cleared land is used for grazing. Pastures around Kingston, Cascade, Headstone, and Anson Bay carry livestock, mainly cattle and horses. In 1974, 589 cattle and 34 horses were estimated by the Administration to have been granted pasturage on Kingstone Common, but, if private herds are taken into account, probably 1800 cattle, 400 horses, and smaller numbers of other types of livestock graze there. Cattle and horses are allowed to roam freely over the island, but their wanderings have led to overgrazing in some places, which has contributed to soil slumping and erosion. A pastoral industry based on dairying serves local needs.

Philip Island is a remarkable contrast to Norfolk Island, not only because of its rugged nature, but because it is almost devoid of vegetation (Plates 1 and 2). Philip Island lacks permanent water, except for a small seepage on the northwestern side. During the early settlements the island was stocked with domestic animals - including rabbits, which became responsible for the destruction of most of the vegetation cover. With the removal of the soil cover, erosion is now at an advanced stage, and the weathered volcanic rocks give the island an unusually barren but colourful appearance. The remaining vegetation consists of stunted trees and shrubs in the valleys and a few isolated Norfolk Island Pines; their roots are exposed by soil erosion.

GEOMORPHOLOGY

Norfolk Island is roughly pear-shaped in plan, with its long axis trending northwest for about 8 km. At a distance it gives a general appearance of subdued relief with a dense cover of vegetation contrasting with spectacular coastal scenery. In detail the geomorphology is dominated by elevated terrain in the northwest, rising to a semicircular ridge on which Mount Bates (318 m) and Mount Pitt (316 m) are the highest points. The remainder of the island consists of a deeply dissected southern plateau about 100 m high; a small remnant of the plateau occurs in the far northwest (Fig. 5). The high terrain reflects the remains of a volcanic vent that was largely responsible for the formation of the island.

Norfolk Island has a 32-km-long coastline with rugged coastal scenery (Plate 1). Along the northwest side of the island, the cliffs are up to 100 m high, but slope down to the southeast, where they are up to 50 m. At Kingston an ancient coastline modified by subaerial denudation marks the boundary between the southern plateau and coastal lowland. The coastal lowland, about 1.5 km long and 0.5 km wide, is less than 20 m above sea level. A line of surf between Point Hunter and

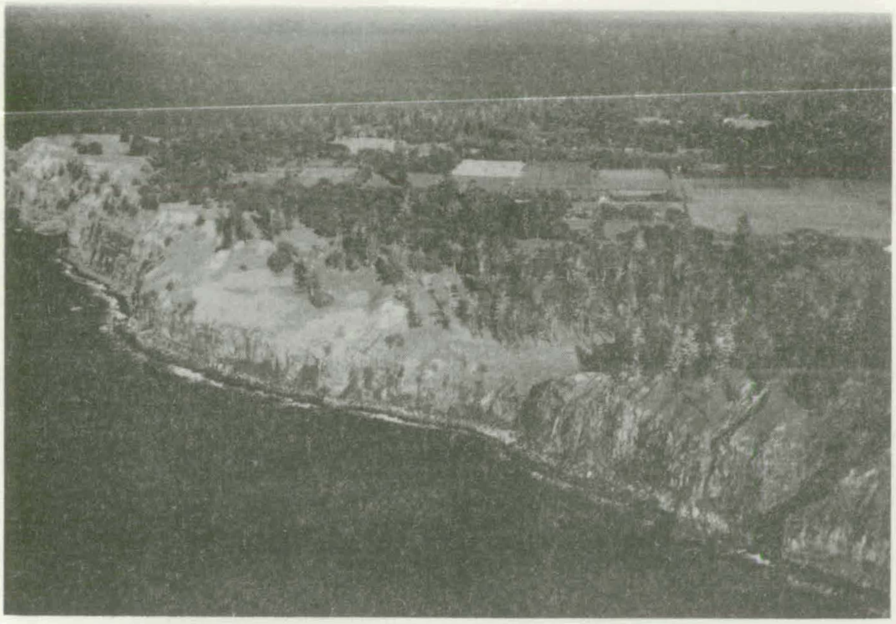

PLATE 1. Norfolk Inland from the air - looking southeast towards Steels Point.

PLATE 2. Philip Island, with its barren appearance, soil erosion, and lack of vegetation.

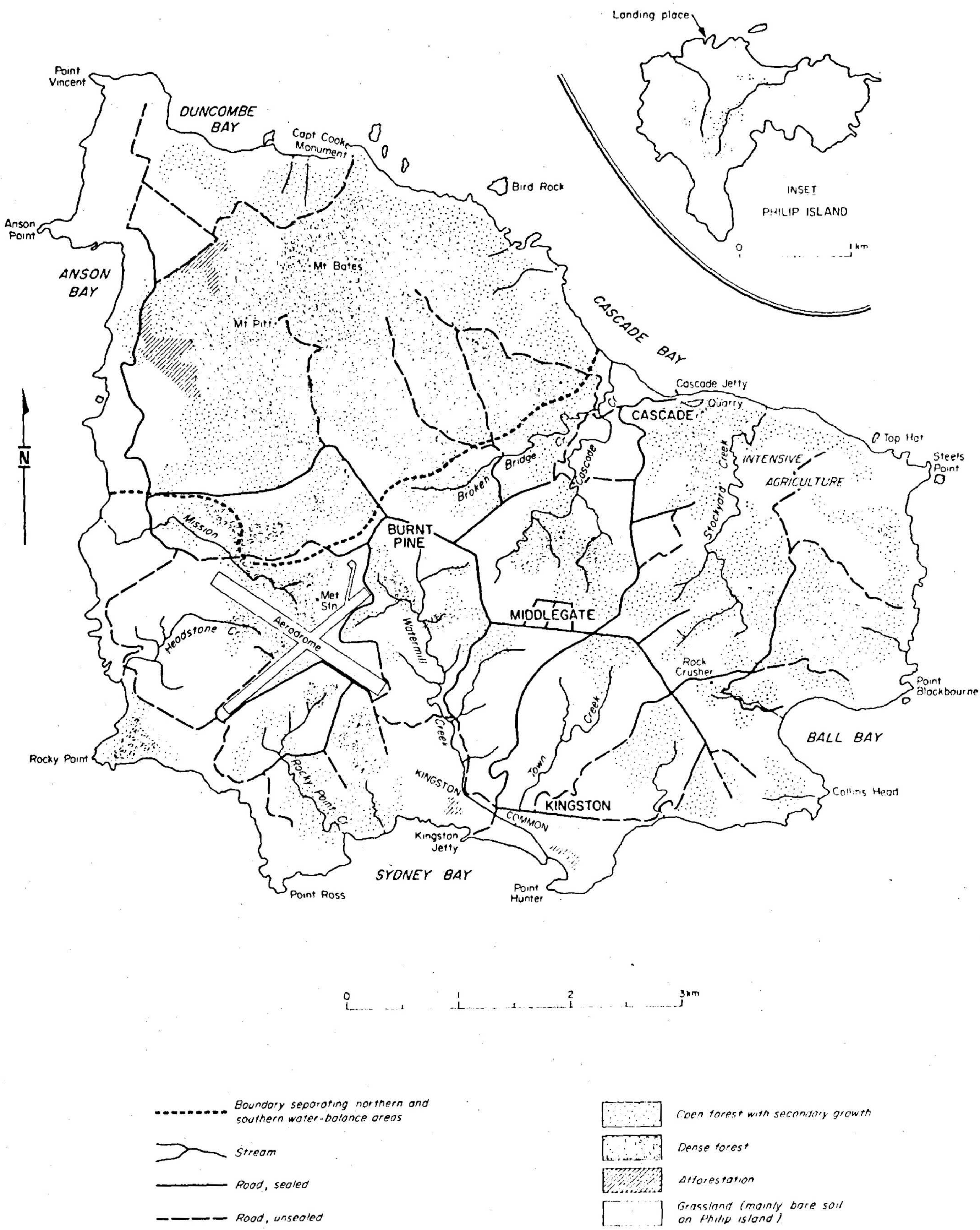

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Fig. 4 Land use

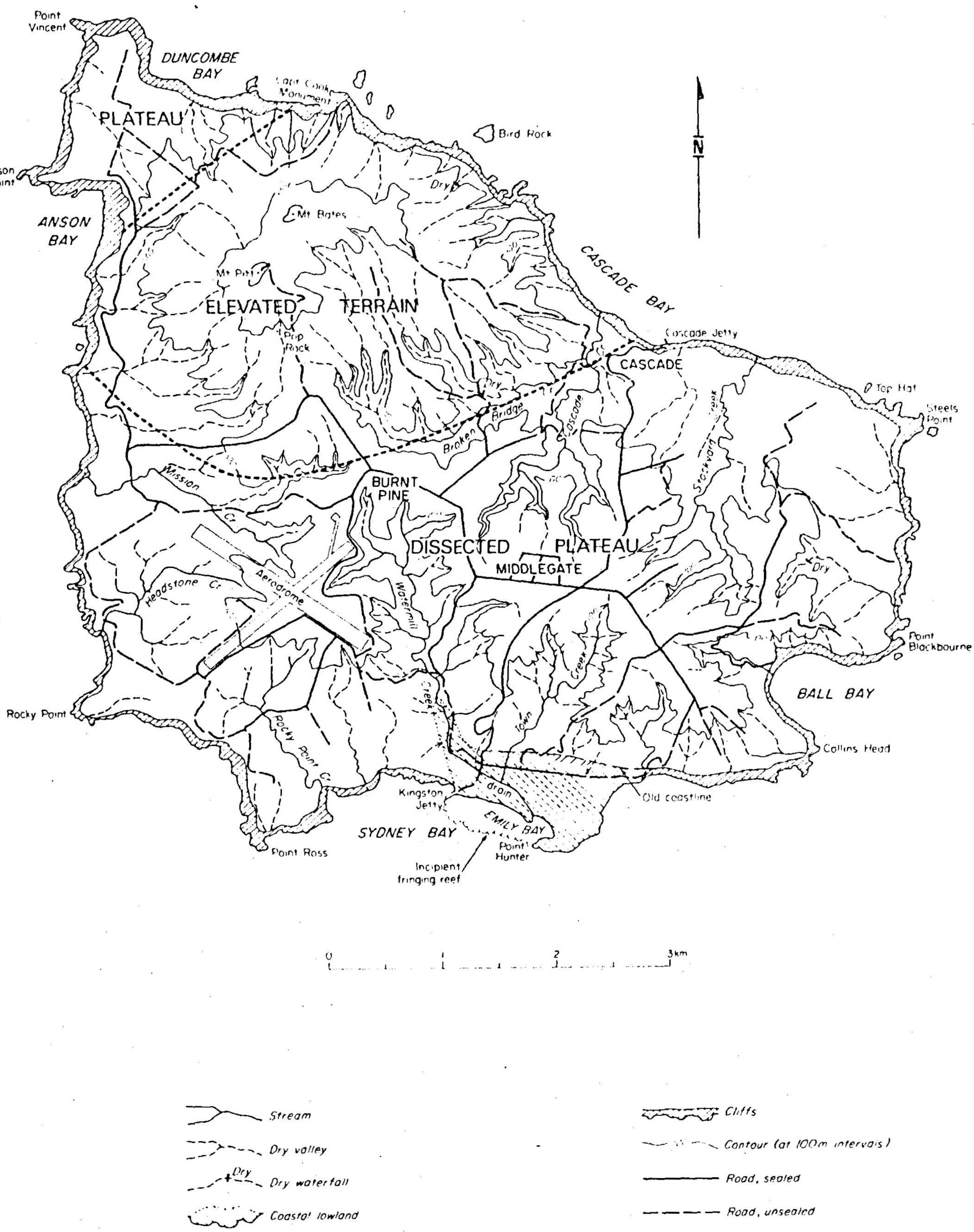

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Fig. 5 Geomorphology

PLATE 3. Typical coastal scenery in Duncombe Bay - looking west towards Point Howe.

PLATE 4. Ball Bay with hanging 'V'-notch valleys and mass movement in the weathered mantle.

Kingston Jetty indicates the position of a fringing coral reef.

Mass movement in the form of soil creep and landslips occur along the coastline and in some catchments that have been cleared. Such movement is also encouraged by steep slopes, ground saturation after heavy rain, and the grazing habits of cattle. Some control has been successfully practised by planting trees in the lower valley of Watermill Creek.

Marine erosion

The geomorphology of the coastline around Norfolk Island has evolved from the interaction of geological structure, lithology, marine and subaerial processes, and sea level changes associated with climate during and since the end of the Pleistocene.

The cliff profiles are controlled by a combination of subaerial and marine erosion processes. During periods of lower sea level and climatic change in the Pleistocene, cliff profiles were probably strongly influenced by subaerial processes rather than marine erosion. The recent rise in sea level since the end of the last glacial period has initiated a new cycle of marine erosion. The result is that cliff profiles tend towards the vertical in fresh rock, but are inclined at slopes of 45^{o} or more in weathered rock (Plate 3).

Evidence that marine processes are active is illustrated by linear sections of coastline on which the remains of promontories now form sea stacks, e.g., Bird Rock. Valley-mouth embayments which have been truncated by cliff recession have become hanging valleys that are dry or carry streams that cascade over cliffs as rapids or small waterfalls; clearly the present cycle of marine erosion is causing cliffs to recede quicker than streams can incise their course. The rugged and in some places angular shape of the present coastline results from wave action along vertical joints in basalt lava. At Point Ross, wave action causes undercutting along weathered contacts between lava flows, and, along other sections of the coastline, rockfalls and landslips occur where the weathered zone has been undercut by severe marine erosion (Noakes, 1957).

The smooth semicircular shape of Ball Bay is atypical of Norfolk Island's coastline. The bay may have resulted from a phreatic volcanic eruption (between ascending magma and groundwater) creating a maar or crater that may have been breached by the sea during the Holocene rise in sea level (J.G. Jones, pers. comm.). As this part of the coastline is relatively sheltered, the 'V' - shaped hanging valleys on the northern side of the bay may be due to mass movement in the weathered zone, with wave action removing the products of erosion (Plate 4).

Narrow wave-cut platforms at Steels Point and Rocky Point are related to cliff recession, and originate from a combination of stormwave abrasion and water-layer wetting (Bird, 1964). The action of surf and spray spheroidally weathers basalt above and within the intertidal zone. The chemical weathering process is aided by diurnal tides of low range, causing repeated wetting and drying of fresh rock in conditions of high temperature and evaporation. Wave action then operates to remove the products of decomposition and produce a platform.

Calcareous aeolianites along the coastal lowland at Kingston and on Nepean Island have a honeycomb appearance which results from the solution and removal of calcium carbonate by spray and wind action. Notch and vizor structures at the base of the cliffs suggest that undercutting is the main method of cliff recession.

Other typical marine erosional features - such as stacks, caves, and sea arches - commonly occur between Captain Cook Monument and Bird Rock, and also at Steels Point. These features afford evidence that the island had a greater areal extent in the past.

Drainage

Norfolk Island has developed a drainage system typical of that on volcanic terrain which has been deeply weathered in a subtropical climate. On the southern plateau the drainage system consists of a network of dry valleys leading into perennial and intermittent streams. The elevated terrain around Mount Pitt Reserve supports an extensive network of dry gullies.

The drainage pattern is radial to the main volcanic vent, except where the original crater was breached by lava flows that built the southern plateau. All that now remains of the original crater is a semicircular ridge at the head of a series of dry gullies forming the upper tributaries of Broken Bridge Creek.

Some structural control of drainage by joints and fractures is suggested by local development of straight reaches and sharp turns of eroding streams. In some places, tributaries join the main stream at right-angles. The effect of jointing has been to modify a dendritic drainage pattern that would otherwise have developed in the head tributaries of each catchment. These features can be observed from aerial photographs, particularly in cleared areas.

Drainage on the southern plateau is dominated by Watermill Creek, which drains one of the largest catchments on the island. The catchment is centrally placed and cuts back northwards for 2.5 km across the southern plateau from Kingston to Burnt Pine. On the plateau, streams are fed in their higher reaches by spring seepage, and to a large degree are maintained along their courses by groundwater runoff (baseflow). Most streams are active in the winter months, but in summer they dry out or are reduced to disconnected pools and swamps. Only Watermill, Cascade, Stockyard, and Headstone Creeks carry water in the dry periods. The upper tributaries of all catchments are dry (Plate 5).

Streams with interlocking spurs and steep narrow-sided valleys commonly 60 m or more deep are in a youthful stage of development. At present, most streams are 'underfit': they flow in valleys which are too large for them; they have little erosive power; and they reach solid rock only at the perimeter of the island, where they discharge over cliffs as waterfalls (up to 30 m high) or as a series of rapids. The only exception is Watermill Creek, which shows signs of early maturity in its lower course where it is a gently graded stream below Watermill Dam. The creek reaches base level on the Kingston lowland, and enters the sea at Emily Bay through an artifical drain cut into alluvium.

Stream profiles are generally irregular and typical of streams that are eroding or have done so in the past. Swampy reaches and dry waterfalls (Fig. 5) along the tracts of most valleys are probably due to rejuvenation during a period of lower sea level, and to streams impeded by vegetation and by silt released from breached surface storages. In Mission Creek, man-made alteration of stream channels has disrupted the natural flow pattern.

During Pleistocene pluvial periods, many of the streams were probably perennial, with much greater erosive power than at present. Dry valleys were cut originally by active streams which have since been lost because of a decrease in rainfall, a lowering of the water-table, and the development of a porous weathered mantle. The Pop Rock, at an elevation of 180 m, is a basalt outcrop with waterworn grooves and potholes on its surface; these suggest that a much greater volume of surface runoff occurred at higher elevations in the past.

GEOLOGY

Norfolk Island lies towards the eastern edge of the Australian lithospheric plate, and rises as a small landmass from the Norfolk Rise, a pronounced bathymetric feature between New Zealand and New Caledonia. The cliffs surrounding Norfolk Island provide a nearly continuous horizontal section of the geology (Fig. 6). Inland, outcrop is obscured by deep weathering and a thick vegetation cover - a contrast with Philip Island, which is stripped of vegetation and has a volcanic succession that is completely exposed.

The following account of the geology is taken largely from the work of Jones & McDougall (1973), and supplemented by my own observations. Norfolk Island is a deeply weathered erosional remnant of an extinct volcanic complex that evolved during a number of volcanic episodes between 3.05 and 2.3 m.y. ago. The volcanic sequence on Norfolk Island consists of lava flows and volcanoclastic rocks. A small area of calcareous aeolianite is exposed on the south side of the island.

Lavas

Basaltic sheet lavas are the commonest rock type on the island. They are generally flat-lying, although one at Anson Bay dips 30°S. Individual flows are up to 50 m thick, and exhibit a wide variety of joint patterns, of which columnar jointing is the most common. Some flows arenlenticular, with complex and irregular joint patterns. Most lava flows are vesicular and have fragmental or slaggy tops which weather to clay. Pillow lavas are locally developed near sea level.

The petrology and geochemistry of the basalts has been studied by Green (1973), who reports that they have affinities with basalts in eastern Australia and North Island, New Zealand.

Volcanoclastic rock

Yellow palagonitized tuffs are interbedded with and rest unconformably on the basalts; they range in thickness from a few metres up to 40 m. The most continuous exposures of tuff are along the northwest coast between Duncombe Bay and Cascade Bay. At Anson Bay, Rocky Point, and Steels Point, tuff is locally up to 40 m thick. This suggests that, as well as the main vent, other volcanic focii nearby may have been active during the island's history.

The tuffs record a new cycle of volcanic activity after a period of quiescence during which erosion had been active. The tops of the tuff sequences are normally conformable with overlying lava flows (Plate 6). At Steels Point, lavas lap onto the tuff.

The tuffs are composed of poorly sorted subangular basaltic fragments mostly less than 1 cm in size. The fragments consist of olivine and pyroxene crystals, and sideromelane (hydrated basaltic glass) containing microlites of plagioclase feldspar aligned as in flow texture. The formation of palagonite - an alteration product of sideromelane - has lithified the

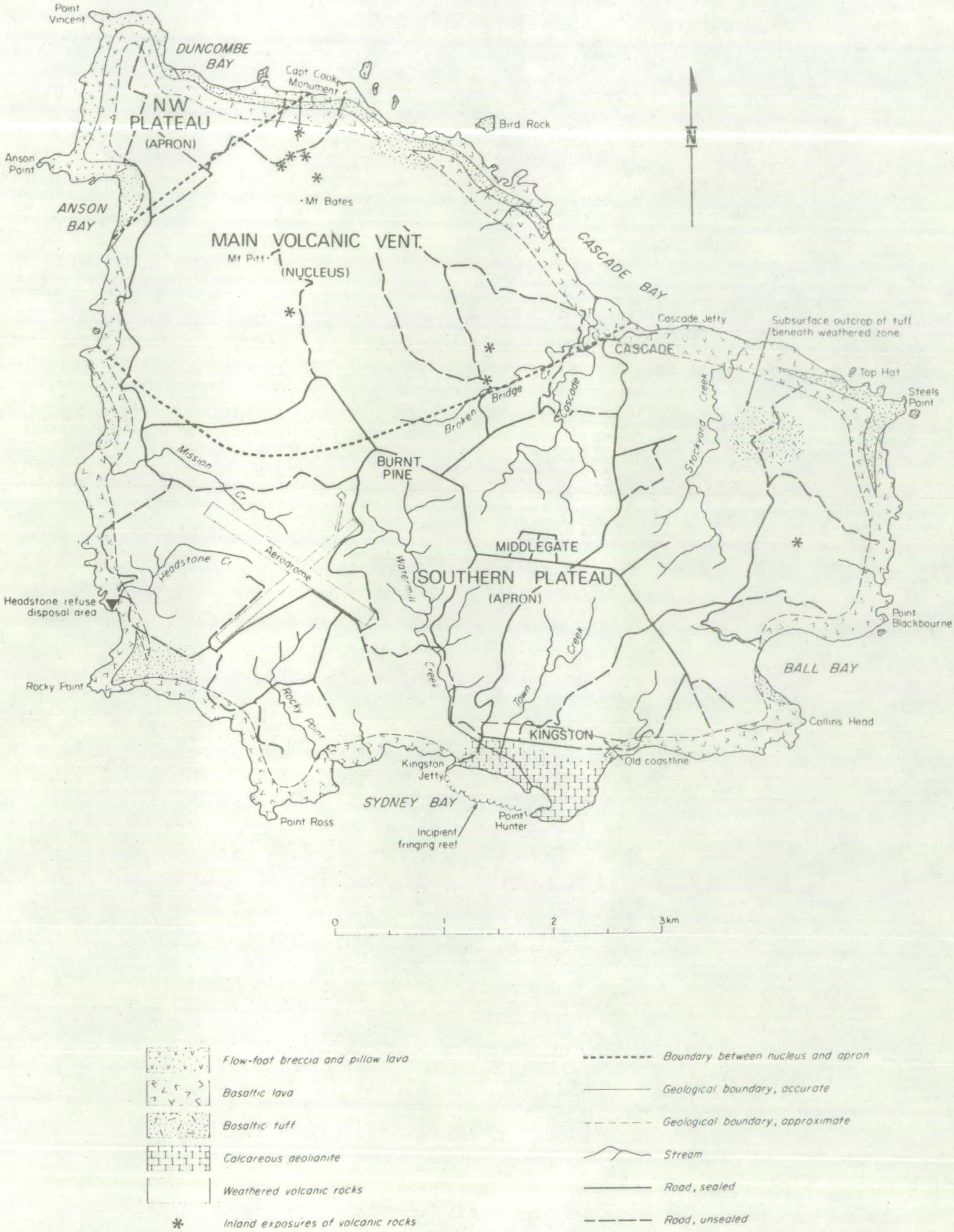

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Fig 6 Simplified geology of Norfolk Island (after Jones & McDougall, 1973)

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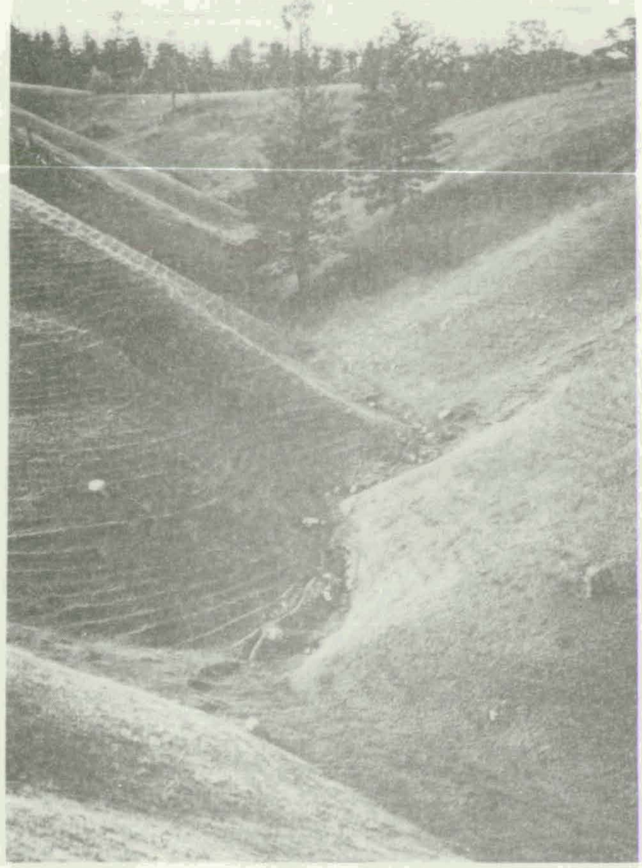

PLATE 5. Interlocking spurs of a dry upper tributary of Watermill Creek. The soil creep on steep slopes is aided by grazing animals.

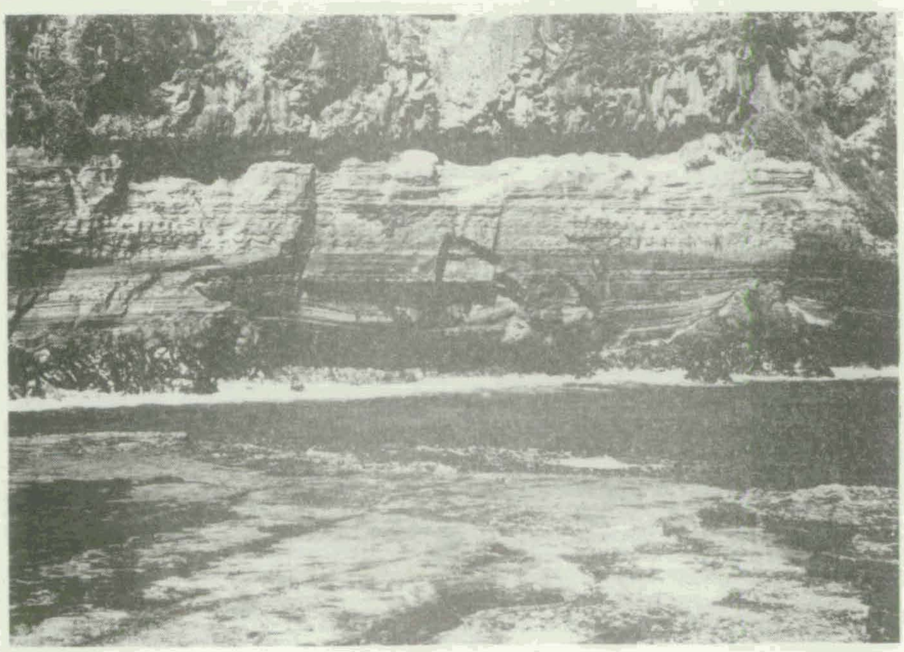

PLATE 6. Interbanded basalt and tuff at Steels Point. The tuff is shaped over an irregular surface in basalt, and is apparently conformable with the base of an overlying lava flow.

fragments. Palagonite imparts a deep yellow colour to the rocks in coastal exposures.

Bedding in the tuffs is generally horizontal, and is due to abrupt changes in grainsize where weathering has etched out the softer coarse-grained layers. Dune bedding, and ripple bedding (which usually has a smaller wavelength than the dune bedding), commonly occur with occasional scour and fill structures (Plate 7). These sedimentary structures suggest that water and wind have been active agencies in the formation of these rocks.

Other volcanoclastic rocks occur close to the summit area of Norfolk Island. Volcanic breccias exposed on Duncombe Road leading to Captain Cook Monument contain fossiliferous limestone clasts identified as bryozoan and calcareous algae fragments (D.J. Belford, pers. comm.). The occurrence of fossils in these breccias confirms similar findings by Coleman & Veevers (1971), who collected and examined inclusions of limestone in tuffs exposed at the landing place on Philip Island (Fig. 4). They suggested an early Miocene age for a fauna that lived in a shallow sea covering Norfolk Ridge before volcanic activity built Philip Island. A weathered volcanic agglomerate with rounded boulders of basalt is exposed along a ridge on the north side of Mount Bates.

Fossil soil profiles appear to be scarce in the volcanic sequence but, in a cliff section 30 m east of Headstone refuse disposal area, a thin lenticular exposure of red-brown clay 1 m thick contains carbonaceous matter and stringers of opaline silica. As the clay appears to pass laterally into unaltered tuff at Rocky Point, it probably represents hydrothermally altered tuff, the top 15 cm of which has been baked by heat from an overlying basalt flow. The base of the section is not exposed.

Flow-foot breccia

Along the north coast between Point Vincent and Steels Point, exposures of flow-foot breccia occur at the base of cliffs a few metres above sea level. These rocks are vitric breccias containing fragments of scoriaceous basalt in a yellow tuffaceous matrix (Plate 8). They are normally capped by hackly (close and irregular) jointed lavas, and in places are associated with pillow lavas. At Duncombe Bay, cross-bedding in these rocks dips to the northwest at up to 30^{o}. This lithofacies has been interpreted as the product of fragmentation of lava by a process of quenching as lava flows from air to water. The gradational contact between lava and breccia approximates to sea level at the time of eruption (Jones & McDougall, 1973).

Aeolianite

On the shore of the Kingston lowland, and also forming Nepean Island, is a sequence of cross-bedded and massive calcareous aeolianites with black carbonaceous clay. J.J. Veevers (Appendix 1) describes these rocks in detail and the relation between the different units.

The succession suggests that black muds were deposited in a quiet coastal lagoon behind a seaward barrier of calcareous dune sands that was breached from time to time by the sea. Later, an incursion of the sea caused the dune sands to transgress across the swamp, and to bank up against an old shoreline. The dip of the cross-bedding indicates that these sands were laid down by southerly winds and currents.

Thin sections suggest the aeolianite was originally unconsolidated shelly deposits laid down in shallow water; it is mainly composed of fragments of calcareous algae, foraminifera, and coral cemented by calcite.

A veneer of corals along the leading edge of a wave-cut platform between Point Hunter and Kingston Jetty simulates a fringing reef. Norfolk Island, at latitude 29^{o}S, is one of the most southerly islands with coral reef development in the Pacific Ocean. The reef can be traversed by foot on calm days at low tide.

Weathered mantle

Except for the coastal lowland the surface of Norfolk Island is deeply weathered. The weathering results from prolonged chemical breakdown of the volcanic succession in a humid subtropical environment. The weathering product is decomposed volcanic rock consisting of clay with iron and aluminium oxides released as end products of chemical weathering. The weathered mantle is well exposed in numerous road-cuttings around the island.

The main elements of the weathering profile are shown schematically in Figure 7. The soils have an average depth of 2 m, and have been described by Stephens & Hutton (1954) and Hutton & Stephens (1956) as mainly krasnozems. They are reddish brown friable open-structured clays, and coarse granular aggregations of clay minerals with coatings of iron oxide. Within the profile, basalt shows various degrees of spheroidal weathering. In most places, unweathered cores of basalt are surrounded by concentric layers of decomposed basalt. With advanced spheroidal weathering, cores of fresh basalt disappear. Zones of spheroidal basalt are present at different levels on the island, and represent the progressive weathering of more than one flow. In

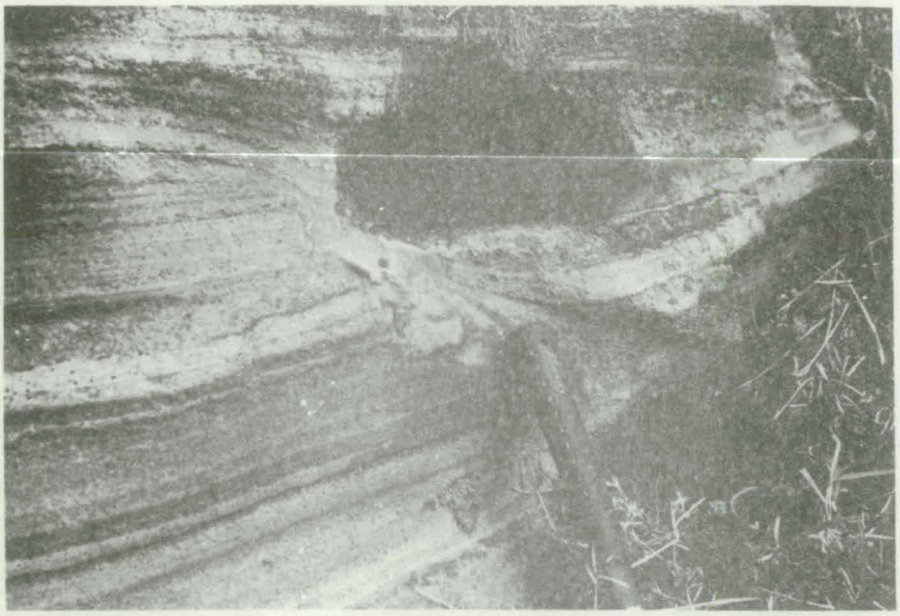

PLATE 7. Scour structure in basaltic tuff 200 m east of Captain Cook Monument.

PLATE 8. Coastal outcrop of flow-foot breccia at Point Vincent. (Courtesy J.G. Jones)

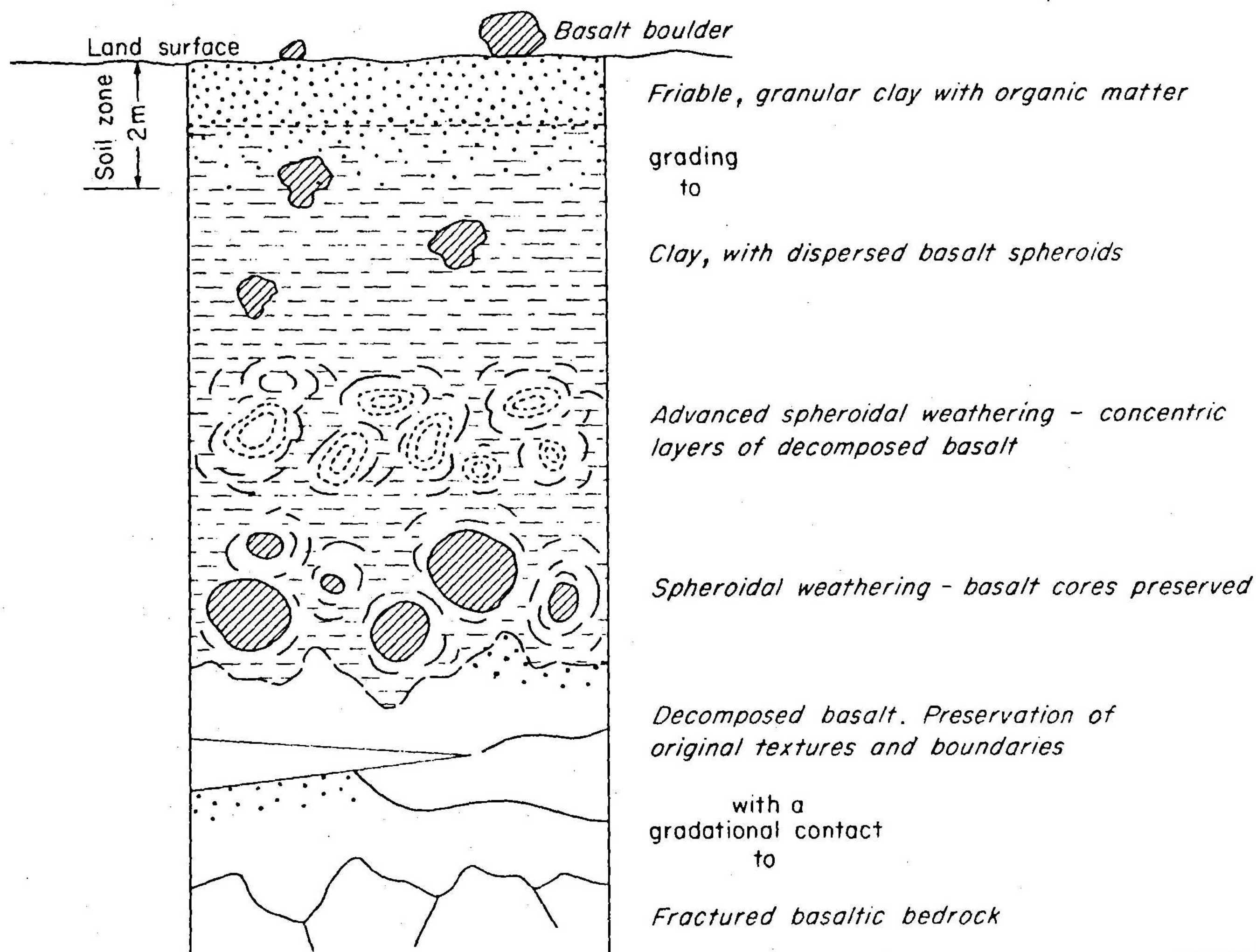

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Fig. 7 Schematic section of the main elements of the weathered mantle

PLATF 9. Basalt boulders as unweathered remnants from the weathered mantle, Town creek.

some places, rounded corestones of basalt (up to 2 m in diameter) are well exposed in eroding stream sections (Plate 9), or on interfluves where the ground has been cleared for pasture. The base of the weathered mantle comprises soft decomposed volcanic rock in which original textures and structures of the parent rock are preserved, e.g., vesicles and the outline of lava flows. This part of the sequence usually weathers to multicoloured clay, before grading to unweathered basalt.

It is assumed that basaltic tuff contributes to the weathered zone, but this is not clearly evident from an examination of roadside sections. However, cliff exposures at Rocky Point, Anson Bay, and between Captain Cook Monument and Bird Rock show fresh tuff grading directly up into the weathered mantle. According to Stephens & Hutton (1954), the soils near Steels Point have developed on subsurface exposures of tuff which constitute the main parent material of the profile.

The weathering profile has been able to develop slowly up to depths of 75 m without interruption since volcanism ceased in the late Pliocene. An early drainagennetwork carrying substantial quantities of surface runoff, a subtropical climate, and a water-table that fluctuated in response to seasonal changes in rainfall - all have contributed towards a gradual thickening of the profile. There is no strong evidence of erosion or a sudden change in lithology in the weathering profile that might suggest the island was submerged during the Pleistocene or at any other time. As the profile is without laterite or other forms of hardpan, the island cannot have experienced a climate with clearly demarcated wet and dry seasons.

STRUCTURE

The interpretation of the structural framework of Norfolk Island given here is based on a model of the evolution of a marine basaltic volcano, as proposed by Jones (1970). In this model the pedestal (submarine foundation) of an island grows originally as a mound by successive effusions of pillow lava on the sea floor. As the mound grows towards sea level, effusion gives way to explosive activity, and the volcano is established above sea level as a circular cone composed mainly of tuff and breccia. This is followed by the eruption of subaerial lava flows which spread out from the vent. As individual flows encounter water they are quenched or fragmented to form flow-foot breccia. With continued activity a basaltic lava apron develops outwards from the vent as a primary constructional feature overlying a pedestal of volcanoclastic rocks.

Based on this model Norfolk Island comprises two structural elements, a nucleus and an apron (Fig. 8). The nucleus corresponds to the main volcanic focus, and is composed mainly of volcanoclastic rocks and thin basalt lava flows. Cliffs on the western side of the southern peninsula of Phillip Island display a section through the main vent (Plate 10). On Norfolk Island the main vent may be similarly composed (Jones & McDougall, 1973). The apron, which is a remnant of a lava shield built up around the main centre of eruption, consists of basalt lava flows and thin layers of tuff.

The nucleus corresponds to the elevated terrain, and the apron to the plateau - the two main geomorphological zones on the island (Fig. 5). The boundary between the nucleus and the apron is probably a facies change marked by the interdigitation of lava flows and volcanoclastic rocks. It is expressed topographically by an abrupt break in slope and by a moat-like depression containing the headwaters of Mission Creek and Broken Bridge Creek; the latter flows in a deep valley trending north-east between Cascade and Burnt Pine.

The attitude of the top of the quench zone suggests that Norfolk Island has been tilted less than 1° to the south (Jones & McDougall, 1973).

Fractures

On aerial photographs, fracture traces appear as linear ground features defined by vegetation, topography, and soil tonal alignments. Fracture traces were identified and plotted on aerial photographs at nominal scales of 1:4000, 1:17 000 and 1:50 1:50 000. Care was taken to ignore man-made features such as fences and the margins of cleared land. The composite fracture map produced from this analysis, and a fracture map of Philip Island, were digitized by a Gradicon digital convertor connected to an HP 2100 computer. A computer program NORFRACTURE was developed that generated the data as a printout of fracture location, direction, and length. A simplified fracture map (Enclosure, Map 1) was produced by linking fractures along the same linear trend.

The fracture traces are probably an expression of joints, or zones of closely spaced joints at the surface. As most fracture traces remain straight over an irregular topographic surface they are probably steeply inclined. Some long fractures are curved, and others may be faults which are not obviously exposed in coastal sections. Columnar jointing in lava flows has probably assisted in providing lines of weakness along which major fractures have developed. However, the dense pattern associated with such joints not only creates a 'background' of minor fractures, but may obscure major fracture directions.

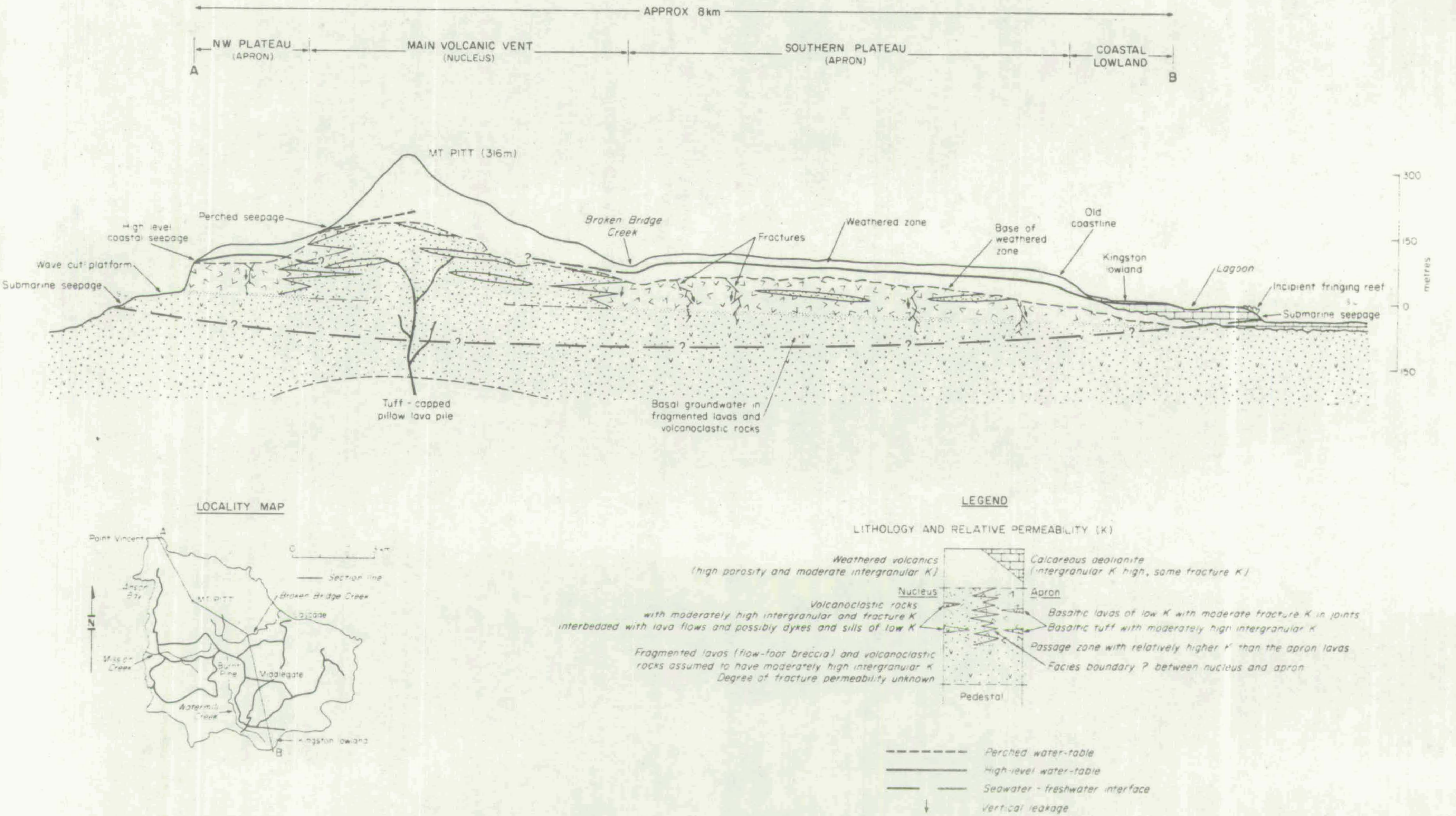

Fig 8 Simplified schematic hydrogeological section across Norfolk Island

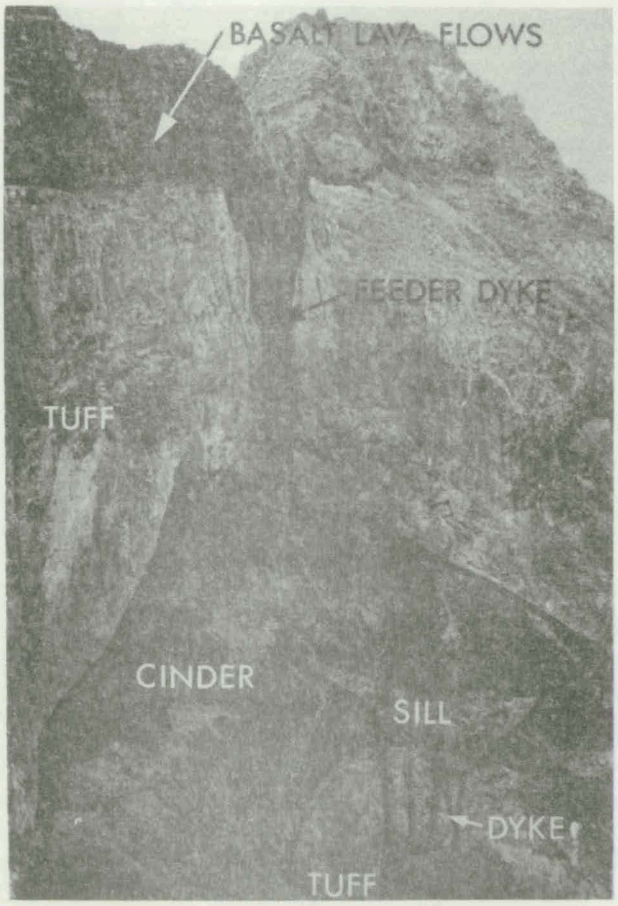

PLATE 10. Structure of the main volcanic vent on the southern peninsula of Philip Island - showing a thick pile of volcanoclastic rocks cut by dykes and sills. At left centre a dyke feeds a basalt lava flow.

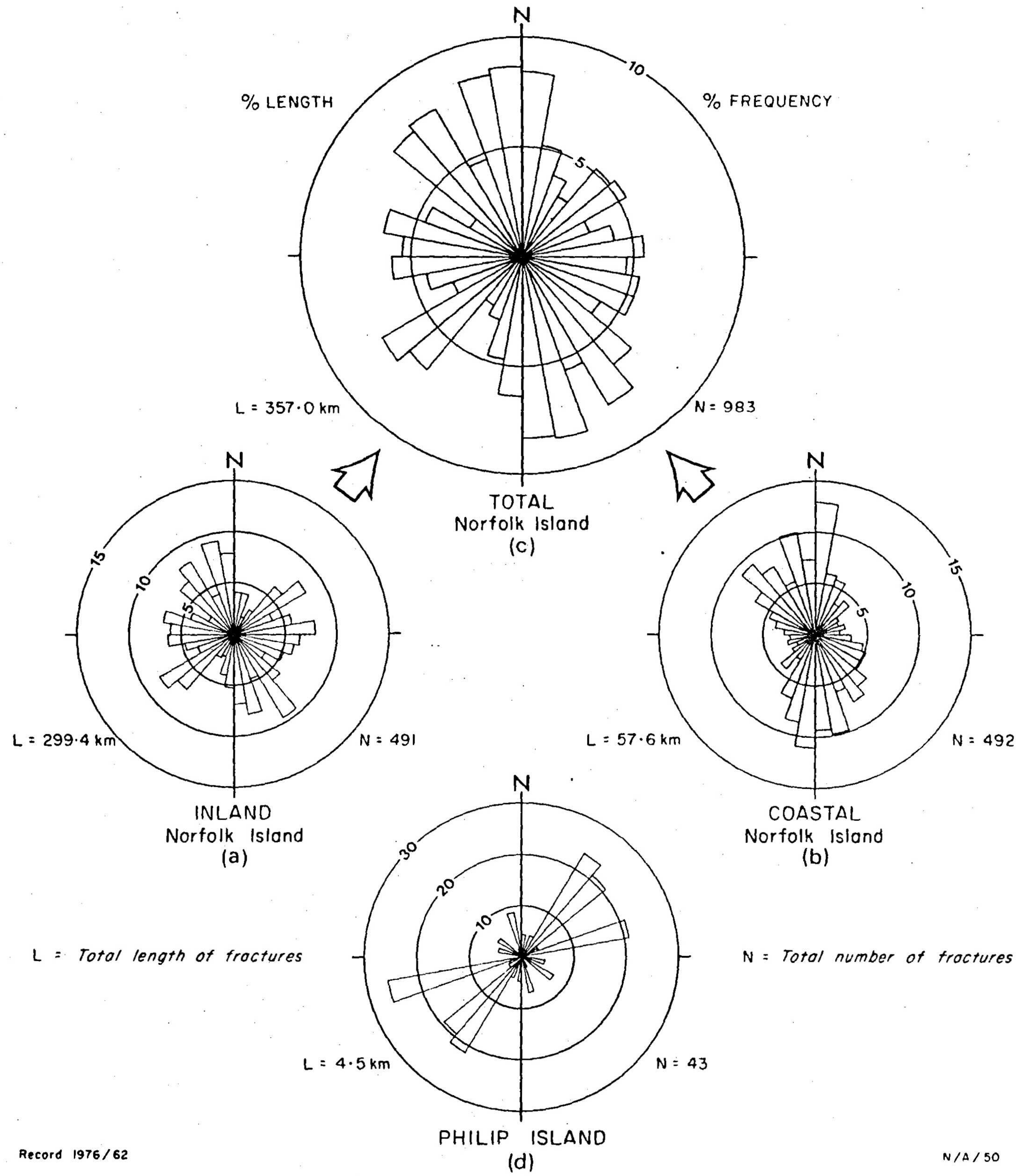

Fig. 9 Polar graphs showing percentage directional frequency and length of fractures

The fracture field is dominated by a set of long north-northwest fractures on the western side of the island and a similar set of northwest fractures on the northeastern side; the sets converge on the main volcanic focus centred around Mount Pitt. Where these two sets converge there is a dense network of fractures; their detection is accentuated by thick forest cover. A set of long northeast to east-northeast fractures crosses the island at evenly spaced intervals.

The printout data from program NORFRACTURE is presented as polar graphs (Fig. 9) which show that fracture trace trends are not random but exhibit a preferred orientation. A polar graph of fractures inland (Fig. 9a) shows that fracture directions fall into northwesterly, northeasterly, and easterly groups. Fractures detected around the perimeter of the island were based largely on coastline shape and master joints crossing wave-cut platforms; they show only a strong north-northwesterly trend (Fig. 9b). In both these polar graphs there is a strong correlation between percentage fracture frequency and length. When both graphs are combined to represent the total fracture system on the island (Fig. 9c), the north-northwesterly direction still predominates, but a large percentage of long fractures trends in an east-northeasterly direction.

Norfolk and Philip Islands may be too small for other than broad geological conclusions to be drawn from the fracture analysis. It seems that the main fracture directions on Norfolk Island are largely a complex response to stress relief resulting from seismic activity associated with deep-seated crustal movements. The main northwest-trending fracture zone on Norfolk Island follows the tectonic pattern along the Norfolk Ridge. According to Van der Linden (1968) and Jongsma (1976) the trend of magnetic anomalies is also in this direction. The northeasterly fracture trend is less easy to explain, but represents stress relief associated with and orthogonal to the main direction of fracturing. The main northeasterly fracture trend on Philip Island (Fig. 9d) is in broad agreement with the observations of Jones & McDougall (1973), who described a belt of fractures, faults, and dykes striking north-northeast across the island.

Seismic activity

Owing to the good preservation of the historical buildings at Kingston, which date back to the early 19th century, it is doubtful that Norfolk Island has been subjected to any severe seismicity during historical times. Early island records indicate that in 1793 two severe earthquakes were supposed to have widened the channel between Nepean and Norfolk Island. A number of tremors having Richter magnitudes of ML5.0 to ML7.0 and epicentres within 100 km of Norfolk Island were felt in 1959.

zn 1968, BMR set up the Norfolk Island seismic station (NIA). As a sample of seismic activity E.P. Paul (Toolangi Geophysical Observatory, Melbourne; pers. comm.) reports that during the 12 months to 30 April 1975, eight local earth tremors were recorded at this station: five had epicentres between 50 and 70 km away, and Richter magnitudes in the range ML2.0 to ML3.0; the other three had epicentres of 350 km (ML3.5), 180 km (ML3.5), and 20 km (ML1.8) from the station. No seismic activity originating from the Island has been recorded.

These data suggest that Norfolk Island occupies an area of low seismicity. This is consistent with its position some distance from the margin of the Australian and Pacific Plates.

WATER-SUPPLY DEVELOPMENT (1788-1974

Historical records indicate that early settlers found the island well watered. Settlers living in the lowland area at Kingston depended initially on surface water from Watermill Creek. Around 1793, an open channel (Watermill drain) was constructed to drain swampy lowland in the lower reaches of Watermill Creek, so that a more permanent settlement could be built at Kingston. Although the course of the channel has been altered several times, it can still be seen crossing the Kingston lowland, to enter the sea at Emily Bay (Plate 11). When the main administration buildings at Kingston were constructed, during the second settlement (1825-1847), a culvert was built to divert Town Creek into Watermill drain. This culvert remains in good repair where it opens into the Officers Bath, but between Quality Row and Watermill drain it is in need of repair, although the flow of water is not yet impeded.

Probably the first surface water storage constructed was Watermill Dam (its position is shown on old maps dated 1799), which was used principally to drive a watermill - but also to provide a local water supply. From the middle of the 19th century the dam gradually fell into disuse, but in 1969 it was emptied of soil and debris and recommissioned as a water storage. It now supplies water for stock, car-washing, fire-fighting, drill-rig tanker road-watering (in dry weather), and emergency water supplies in droughts.

Early groundwater extraction was from wells tapping a shallow water-table in the Watermill flood plain at Kingston. Many of the wells are 150 years old, dating from the early convict settlements. Some of these wells have caved in, but others, along Quality Row, are still in use and in good repair.

In 1856 the settlement of Norfolk Island by the Pitcairners gave increased stimulus to the division and clearing

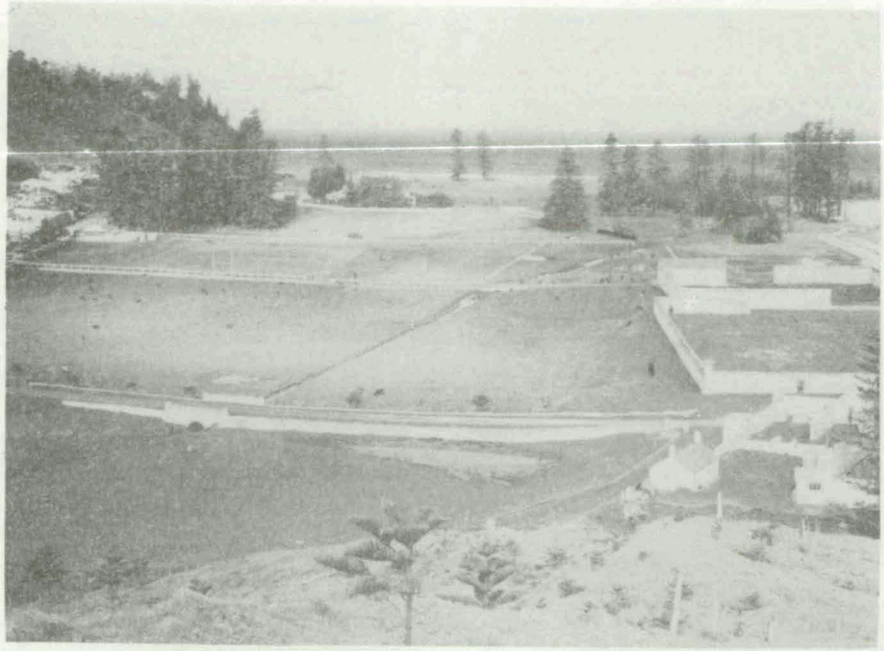

PLATE 11. Kingston lowland - looking east at artificial drainage channel and old coastline on the left.

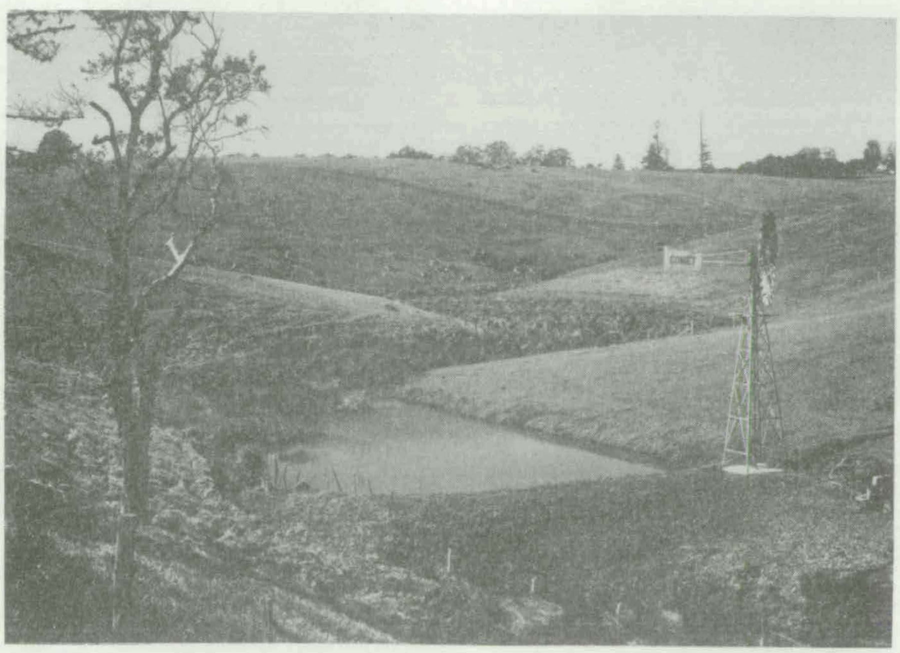

PLATE 12. Surface-water storage at Headstone Creek uses the only wind pump on the island.

of land on the plateau above Kingston. It was soon found that groundwater could be extracted from wells because the weathered volcanic rocks were not only soft and unusually thick but groundwater was mostly within 30 m of the surface. The ease with which groundwater could be obtained, coupled with the subdivision of land, meant that early island homes were able to have their wells sited conveniently close to the house rather than in the valleys below.

According to local information, some bores may have been drilled in the early 1950s, but no records are available. The first documented and properly constructed water-bore was drilled by R. Fitzgerald in 1966 at the old Kingfisher Hotel with a percussion rig brought from the Australian mainland. The bore still gives a consistent supply of 2150 l/h from a hole reported by the owner as being 50 m deep.

Rainwater from roofs has probably been collected and stored since the island was first settled. In the latter half of the 19th and early 20th centuries, corrugated galvanized iron sheets imported to replace the leaking bark roofs of homes probably improved the collection and storage of rainwater. At present, rainwater supplies are the most important source of water on the island, and it would be unusual if a householder did not use or have access to this form of supply. Surface water has always been exploited on a small scale, but is likely to retain only subsidiary importance to rain and groundwater development.

WATER CONSUMPTION

In the absence of records and a water reticulation system on the island, an estimate of water consumption was attempted by assuming that the average amount of domestic water consumed in 225 l/day/head - a typical quantity (including garden watering) in a rural environment. Domestic water consumption is based on a resident population (including temporary workers) of 1600. The number of tourists on the island averages 725 at any one time; this is based on a variation 350 tourists in winter and up to 1200 in summer. Total domestic water consumption for a total of 2325 people is estimated to be 1.9×10^5 m^3/annum. Water used for industrial and irrigation purposes is small compared with domestic consumption and is not included in the calculation.

Livestock water consumption (Table 2) is based on data (numbers of animals) supplied by the Department of the Capital Territory, Canberra; the daily livestock water consumption data taken from Hart (1974) is considered applicable to Norfolk Island.

TABLE 2. ESTIMATED LIVESTOCK WATER CONSUMPTION

Animal	Number	Water consumption (litres/day/head)	Total (litres/annum)
Cows	1800	60	3.9×10^7
Horses	400	60	8.7×10^6
Pigs	200	15	1.1×10^6
Sheep	50	10	1.8×10^5
Tablebirds (chickens, ducks, etc.)	3000	30/100 birds	3.3×10^5

From the figures in Table 2, total livestock water consumption is estimated to be 4.9×10^4 m^3/annum. Total water consumption (domestic and livestock) on Norfolk Island is estimated to be 2.4×10^5 m^3/annum.

The method adopted to estimate groundwater consumption was to measure or estimate a value for pump discharge, and the owner then supplied details of his pumping regime. It became apparent that few households relied entirely on groundwater, and some people used it only to supplement rainfall storage in summer months. The groundwater inventory (Appendix 2) indicates that up to 60 percent of the bores and wells recorded are used as groundwater extraction points.

Water-use statistics are available for 141 wells and bores. In 64 percent of wells and bores, groundwater is used intermittently all year; for the remaining 36 percent, groundwater is used only seasonally. In 25 percent of wells and bores there is wholly or almost complete dependance on this source as a main supply of water; the main users in this category are tourist accommodation, and others who are able to rely on a continuous supply of shallow groundwater in valleys. Most bores and wells have a multiple use: 70 percent of bores and wells are used partly for domestic purposes, 75 percent partly for gardening, and 20 percent partly for stock.

Total groundwater consumption is estimated at 1.0×10^5 m^3/annum, which accounts for about 40 percent of total water use on the island. It is worth noting that a large proportion of this quantity passes back to groundwater storage as sanitary waste. Groundwater consumed individually by large hotels catering for the tourist trade, and by some local residents practising irrigation, commonly exceeds 4.5×10^3 m^3/annum. Little groundwater is used for drinking.

The climate exerts a considerable influence on water demand. During periods of drought or below average rainfall, wells dry out and rainwater storages are depleted, causing severe personal hardship. Owners having a bore or well with a substantial yield often make water available to more than one user. A small number of water carriers operate on the island and deliver from anything up to eight truck loads/day in summer months. Suggestions have been made for communal watering points, carefully sited, that would alleviate water shortages during dry periods. Such watering points could be either bores supplying groundwater, or large concrete tanks set in the ground to store surface water pumped or gravity-fed from creeks.

RAINWATER STORAGE

The commonest and most important type of water supply on Norfolk Island is direct use of rainwater. Rainfall runoff from roofs has a number of advantages, among which are simplicity, relative safety from pollution, easy collection of water, and negligible operating costs. The main disadvantage is from overflow (wasted storage) after heavy rainfall.

Water collected from a roof catchment is fed by a system of drains or pipes to corrugated galvanized iron rainwater tanks mounted on a concrete base or perched on tank stands at the side of the house. In some of the older homes these installations are not well maintained. The capacity of the storage tanks usually ranges between 30 000-70 000 litres. In newer homes rainwater may be stored in large concrete tanks sunk into the ground. If properly constructed and sealed from the atmosphere they can store large quantities of water more efficiently than corrugated iron tanks over a longer period of time.

Rainwater storage is an effective water supply on Norfolk Island, since the distribution of rainfall is not markedly seasonal (Fig. 2). The average area of a roof on the island is 150 m^2; assuming a mean yearly rainfall of 1335 mm up to 1.5 x 10^2 m^3/annum of water can be collected (assuming a collection efficiency of 75%). As this would not satisfy the water demand of an average sized family of four (roughly 3.0 x 10^2 m^3/annum, rainwater storage needs to be supplemented by another source of supply such as groundwater.

Total dependence on this form of water supply must also take into account droughts and years of below average rainfall.

SURFACE WATER

Surface water is used by either pumping directly from streams or from small surface storages. The distribution of streams, catchment boundaries, and extraction points are shown in Figure 10. Table 3 shows that 1972 ha (or 57%) of the island is drained by only 10 creeks with significant stream-flow. There are 40 surface-water extraction points on the island, but probably no more than 30 are in use.

TABLE 3. SUMMARY OF SURFACE-WATER DATA

Creek	Catchment size (hectares)	Number of water extractions	Field conductivity expressed in micromhos/cm measured at the lowest point in the catchment
Broken Bridge	394	7	425
Watermill	309	7	450
Stockyard	254	1	475
Mission	240	2	425
Headstone	211	1	650
Cascade	206	8	375
Town	128	6	530
Rocky Point	122	5	840
Bloody Bridge	62	2	1100
Ball Bay	46	-	1400
Others	-	1	-
Total	1972	40	-

The largest surface-water storage on the island is Watermill dam, covering an area of about 5000 m^2. Other smaller storages include: on Headstone Creek, an earth dam (Plate 12); on Cascade Creek, a concrete weir (now disused) which was originally constructed to serve the old whaling station and subsequently the fish factory; and, on an upper tributary of

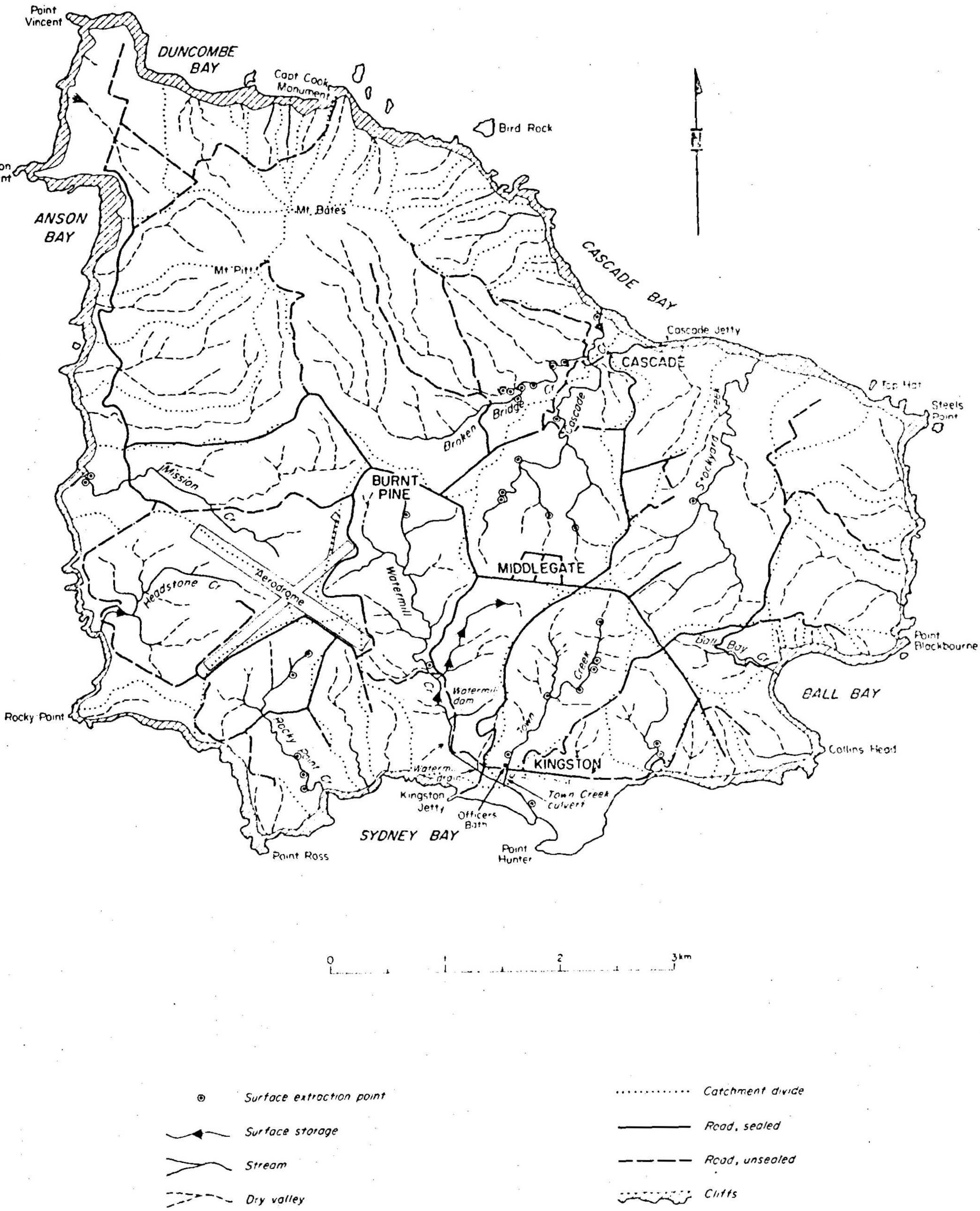

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Fig. 10 Surface water

Watermill Creek at map reference 877836, a small concrete dam that provides an emergency supply for Norfolk Hotel. Several other small storages exist on properties with access to Watermill, Cascade, and Mission Creeks. Attempts have been made to temporarily store surface water using butyl rubber sheets laid in a hollow scooped out of a dry drainage channel. The capacity of the hollow examined was estimated to be about 200 m^3; it would probably overflow three times in a year of normal rainfall. Cattle and rodents damage the sheets, and water leaks and vegetation grows through the resulting holes. This type of storage collects only stormwater runoff, and would appear to have only restricted use on the island.

The water-storage structures on some catchments are defective - particularly on Mission Creek, where the breaching of old earth dams has caused silting, vegetation growth, and the accumulation of stagnant water. Some natural meanders that have been cut off Mission Creek by stream straightening have been left as swamps and waterlogged areas. It is clear that the planning and construction of earth-dam storages has paid scant attention to the stream flow regime, the proper design of overflow structures, the use of chemical additives to strengthen earth walls and the maintenance of the structures after they have been completed. The general condition of Mission Creek is a clear example of what can happen if there is not sufficient legislative control of water-supply development.

An appraisal of large-scale surface-water development on Norfolk Island needs to take account of:

(1) The strongly dissected topography. Most creeks flow well below the average level of the southern plateau, and are not ideally positioned to provide a gravity supply to any inhabitated part of the island, except Kingston. The potential instability of valley sides, particularly in cleared areas, is evident from soil creep and landslips (Plate 5).

(2) The geology: the porous weathered volcanic rocks and the fractured underlying bedrock suggest that the storage area and damsite may lose water.

(3) The stream flow regime. A stream gauging program before the development of any surface storage is essential. Minimum flows (at the end of summer) must be known for perennial streams, so that limitations of the supply are fully appreciated. Maximum flows should be known, so that storage installations can be designed for appropriate levels of floods and stormwater runoff. All streams on Norfolk Island are presently ungauged, so that no reliable measurements of stream flow have been recorded except for Watermill and Broken Bridge Creeks between 1949 and

1950 - but these are not of sufficient duration to justify accurate long-term prediction for surface water.

(4) A number of other factors militate against the large-scale development of surface water; these include limited space, high evaporation losses, storage clogging with silt, vegetation growth on water surfaces, and pollution by cattle.

For continued small-scale development of surface water in the long term a network of stations needs to be established to monitor stream flow in perennial catchments. Most good stream-gauging sites are close to the coast, where the longer streams have eroded down to bedrock and flow over the cliff at a 'rock lip'; Cascade, Stockyard, Headstone, Ball Bay, Rocky Point, and Bloody Bridge Creeks, and Town Creek (in a culvert just above Officers Bath), all have obviously good stream-gauging sites, but Watermill and Mission Creeks do not. As all streams have low-flow characteristics, a 'V'-notch weir of simple design might provide an adequate stream-discharge record. A prefabricated weir structure of appropriate design mounted on a concrete base might be quick and easy to install to obtain stream flow records for up to a 10-year period.

FUTURE WATER DEMAND

The overall demand for water has increased considerably over the last 20 years. A rise in personal hygiene standards has followed the introduction of such appliances as washing-machines and fixed baths and showers in private homes. Garden watering is now more common since the introduction of sprayers. Studies on the Australian mainland suggest that seasonal variations in climate, in particular the number of raindays/month, determine garden watering use. The increased number of cars on the island (estimated at close to the residential population of 1600) has generated a substantial water demand for car washing. The agricultural and industrial demand for water on the island is comparatively small. The greatest demands on future groundwater use are likely to come from population growths resulting from immigration and an increased tourist trade.

Forecasting future demand is difficult and errors are inevitable, but Butland (1974) suggests that residential population growth should be limited to 2000 and the number of tourists visiting the island restricted to 20 000 per year by 1983. Using these figures - and assuming that only 1000 tourists would be on the island at any one time, and that the daily water demand increases (from 225 l/head) to 270 l/head - the estimated projected domestic water demand would be 2.9×10^5 m^3/ annum. If the forward estimate of water consumed by livestock is the same as the estimate already quoted (4.9×10^4 m^3/annum), then the estimated total water demand would be 3.4×10^5 m^3/annum. If groundwater dependence were to increase to say, 60 percent of total water use, demand from this source would be 2.0×10^5 m^3/annum.

GROUNDWATER OCCURRENCE

Groundwater on Norfolk Island functions as a dynamic system within the framework of the hydrological cycle (Fig. 11). Rainfall reaching the ground either returns to the atmosphere by evaporation from soil and plants, runs off the ground surface into streams and thence to the sea, or, because of the high porosity of the soil, infiltrates and moves downward under gravity past the root zone of plants to the saturated zone.

On the plateau, the top of the saturated zone is marked by a high-level water-table. Groundwater moving laterally in the direction of the water-table gradient emerges as coastal seepages near the base of the weathered mantle or in the floor of valleys where the ground surface intersects the water-table. If the water-table descends below the base of the valleys during dry periods, streams are reduced in flow or dry up.

At the base of the weathered mantle there is vertical leakage of groundwater through fractures in the unweathered volcanic sequence. Some groundwater moving through these fractures may be discharged as coastal seepages close to sea level, but the remainder may be dispersed in volcanic fragmental rocks underlying the island. The cycle is completed with groundwater discharge as submarine seepages at the margin of the island (Fig. 8).

Weathered mantle

Currently the most important underground water storage on the island is a high-level unconfined aquifer in the weathered mantle. The upper boundary of the aquifer is defined by a water-table and its base by an irregular surface of fresh volcanic rock. Its lateral boundary is at the margin of the island, where the weathered mantle is continuously exposed. High-level coastal seepages near the base of the weathered mantle are due to truncation of the water-table by marine erosion.

The contact between weathered and unweathered rock is gradational and irregular. A simplified structure contour map of the base of the weathered mantle (Fig. 12) was compiled from the depths at which fresh rock was known to have been struck during drilling, supplemented by bore depths as it is assumed that bores are normally completed in rock. The map shows an elevated ridge elongated northwest underlying the southern plateau. Other ridges trend east-northeast immediately north of the airport, and north-northeast north of Ball Bay. A depression trending northeast coincides with Broken Bridge and Mission Creeks, and a shallow trough is present in the Anson Bay area.

The depth of weathering ranges from 30-60 m, and in a few places exceeds 60 m. The irregular nature of the base of the weathered mantle is exphasized by abrupt changes of thickness over short distances. On block 49 (map reference 883 839) three bores drilled close to one another struck fresh rock at 20 m, 36 m, and 52 m within an area of a 100 m^2. Similar abrupt changes in thickness of the weathered mantle are known near Pine Valley flats and Valley View restaurant (approximate map reference 873 848).

The only known detailed lithological description of the weathered mantle was made from drill-cuttings collected from a water-bore on the Duvall property (NI 201). The log emphasizes the high percentage of clay in the profile. The sequence of the weathered mantle to solid rock has not been continuously cored.

The permeability distribution in the zone of weathering is difficult to assess from a visual examination of the profile in road-cuttings. The high percentage of clay and the sluggish spring seepage suggest that the weathered sequence has a high porosity but only poor permeability.

In the absence of pump tests the specific capacities of bores can be used as measures of the hydraulic properties of an aquifer - if the data collected relate to a common aquifer, and the bores are of similar construction and are pumped at about the same rate for about the same length of time.

The specific capacity data listed in Table 4 are less than ideal, as the pumping rates ranged from 0.20 to 1.24 l/s and the length of the tests varied from 3 to 12 hours. Nevertheless the data, ranging from .01 to 0.5 l/s/m, are broadly distributed across the island, and suggest the weathered mantle has generally low to moderate permeability.

At this stage, further data need to be collected for a more realistic assessment of permeability distribution in the weathered mantle. This could be accomplished by means of full-scale aquifer tests, laboratory determination of permeability from drill cores, and further specific capacity measurements on bores and wells.

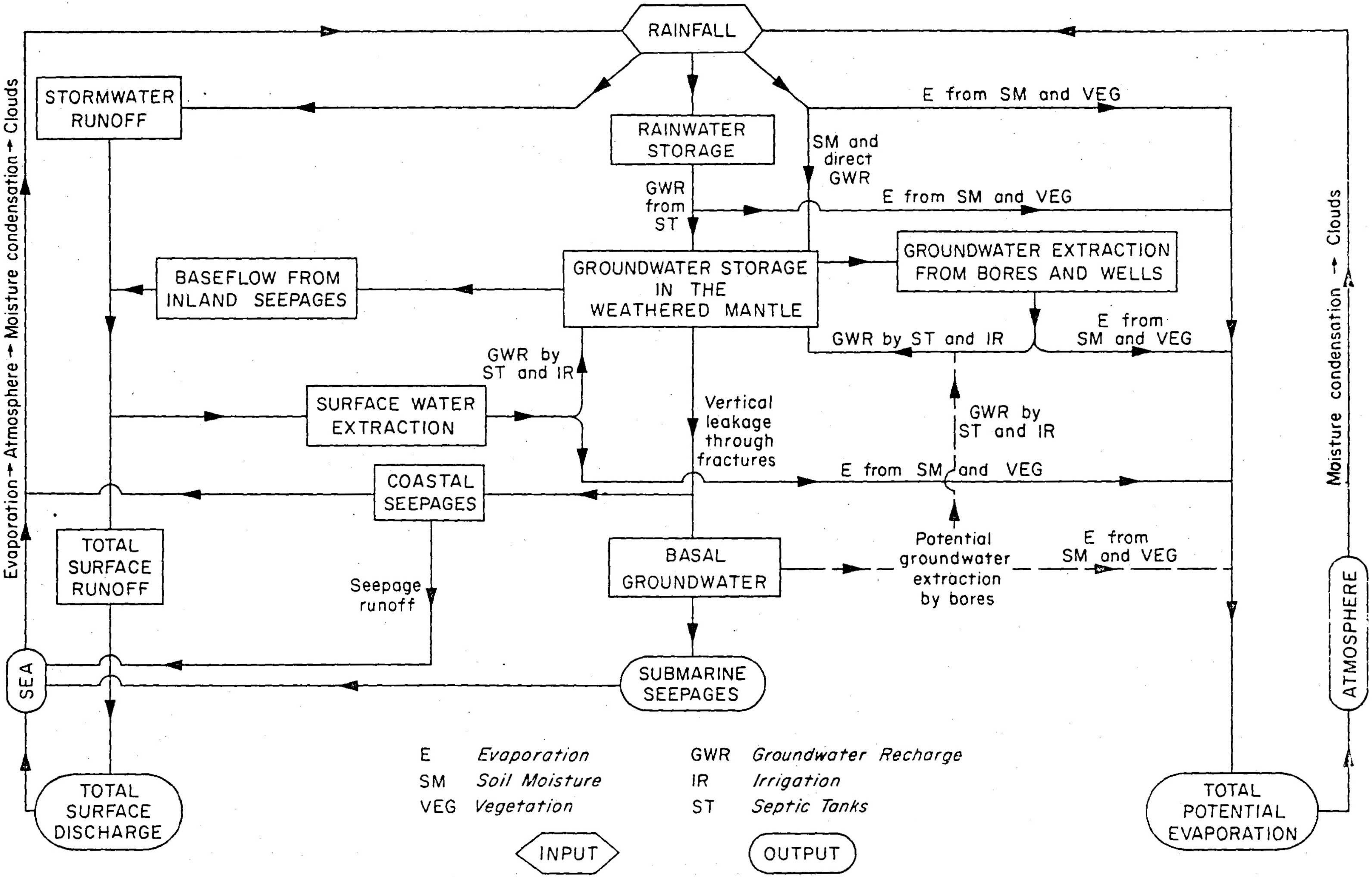

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Fig. 11 Hydrological cycle

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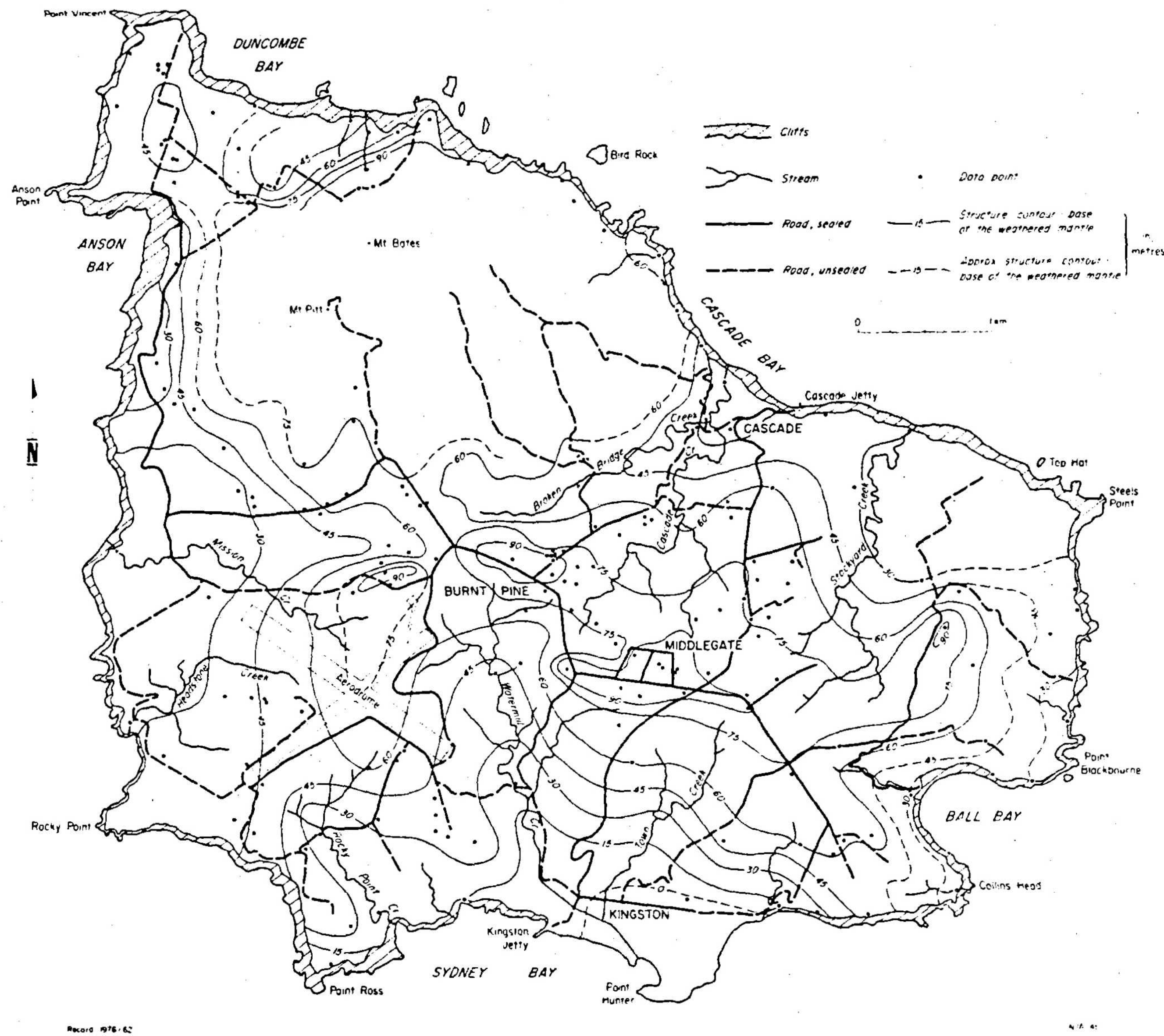

Fig. 12 Structure contours of the base of the weathered mantle

TABLE 4. SPECIFIC CAPACITIES OF BORES (BASED ON DRILLING DATA) IN THE WEATHERED MANTLE

Bore number	Duration of pumping (h)	Drawdown (m)	Discharge (l/s)	Specific capacity (l/s/m)
NI 17	5	15	0.20	0.01
NI 201	12	24	0.37	0.01
NI 209	3	6	0.22	0.03
NI 269	8½	6	0.37	0.06
NI 268	5	2	0.22	0.11
NI 293	4	2	0.21	0.11
NI 261	3	9	1.24	0.14
NI 130	3	1.5	0.24	0.16
NI 292	5	2	0.31	0.16
NI 296	4	2.4	0.50	0.21
NI 76	4	1.5	0.37	0.25
NI 295	5	1	0.37	0.37
NI 297	4	–	0.50	0.50

Lavas

Generally basalt lava flows are anisotropic water-bearing systems with the degree of permeability changing markedly in short distances. A visual examination of the basaltic sequences suggests that fracture permeability is associated with either long vertical fractures or variably spaced columnar joints. Vertical fractures act as important zones of permeability, probably extending to deep levels within the island. Evidence for these fractures comes from long joints cutting across polygonal shrinkage joints on wave-cut platforms and from linear features recognizable on aerial photographs.

Although the vertical component of permeability normally exceeds that in the horizontal direction, increased horizontal permeability occurs locally as irregular openings along subhorizontal joints and between lava flows. The fragmented or slaggy tops of the lava flows that have been weathered to clay may impede the vertical movement of groundwater and cause it to flow laterally to the coast, where it may emerge as seepages.

The basalts are not strongly vesicular, but, in some coastal exposures between Cresswell Bay and Kingston Jetty, flows contain small elongate pockets of vesicular basalt up to 30 cm across. In most places, vesicles are concentrated near the tops of lava flows, and may give basalts locally high porosity.

Hackly jointed lavas at the top of the quench zone may represent an important permeable zone up to 3 m thick distributed at about sea level, as shown in Figure 8.

Basaltic tuff

Basaltic tuff is exposed around the coast, but its lateral extent and thickness inland is unknown. Its occurrence on the southern side of the island is limited to thin lenticular beds, but close to the main vent it appears to be thickest.

That the tuff has a significant intergranular porosity and permeability is suggested by its poor consolidation and emphasized by changes in grainsize associated with normal bedding and cross-bedding. Unlike the lava flows with which it is interbedded, the basaltic tuff has a poorly developed fracture permeability through joints. Joints in basaltic tuff are generally spaced a few metres apart, and probably add little to the total permeability of the volcanic sequence.

Thin sections show that an original high primary porosity due to space between fragments of sideromelane has been reduced by the formation of palagonite, calcite, and possibly

TABLE 5. POROSITY AND PERMEABILITY DETERMINATIONS ON ROCK SAMPLES FROM NORFOLK ISLAND

Sample Number	Lithology	Porosity (Percent bulk volume) by water saturation	Porosity (Percent bulk volume) by mercury porosimeter	Permeability (Md) to nitrogen	Hydraulic conductivity (m/d) to nitrogen	Permeability (Md.) to freshwater	Hydraulic conductivity (m/d) to freshwater
1V	Basaltic tuff	22.6	36.8	<0.1	0.00008	<0.1	0.00008
1H		16.2	31.3	0.23	0.00016	<0.1	0.00008
2V	Basaltic tuff	20.2	13.2	0.43	0.00033	<0.1	0.00008
2H		17.8	12.7	0.20	0.00016	<0.1	0.00008
13AV	Basaltic tuff	32.0	27.6	53	0.041	169	0.14
13AH		34.2	34.7	1986	1.58	6172	5.1
13BV	Basaltic tuff	20.7	24.0	0.18	0.00016	<0.1	0.00008
13BH		21.3	25.2	300	0.25	252	0.21
19AV*	Basaltic tuff	31.2	-	149	0.12	45	0.03
19AH*		31.7	37.4	5249	4.3	6295	5.2
19BV*	Basaltic tuff	21.4	-	321	0.26	262	0.21
19BH		33.0	32.2	1858	1.5	1445	1.2
19CV	Basaltic tuff	33.5	36.4	371	0.31	63	0.05
19CH		32.4	33.7	7650	6.3	6790	5.7
19DV	Basaltic tuff	35.2	37.2	3332	2.7	2902	2.4
19DH		28.2	31.6	11707	9.7	7490	6.2
20AV*	Basaltic tuff	35.6	-	167	0.13	8.2	0.006
20AH*		31.0	37.1	5357	4.4	8699	7.3
20BV*	Basaltic tuff	42.5	-	4106	3.4	4187	3.5
20BH		47.0	40.5	7071	5.8	7719	6.4
20CV*	Basaltic tuff	33.3	-	1490	1.2	1429	1.2
20CH*		40.5	48.1	6634	5.5	7373	6.1
17V	Calcareous aeolianite	2.6	7.7	<0.1	0.00008	<0.1	0.00008

TABLE 5. (continued)

Sample Number	Lithology	Porosity (Percent bulk volume) by water saturation	Porosity (Percent bulk volume) by mercury porosimeter	Permeability (Md) to nitrogen	Hydraulic conductivity (m/d) to nitrogen	Permeability (Md.) to freshwater	Hydraulic conductivity (m/d) to freshwater
17H		2.2	6.9	0.12	0.00008	<0.1	0.00008
18V	Calcareous aeolianite	22.4	22.5	1543	1.2	1359	1.1
18H		23.2	22.5	478	0.40	36	0.025

V - Sample taken perpendicular to bedding plane

H - Sample taken parallel to bedding plane

* - Wax mounted samples

late zeolites precipitated by circulating groundwater. Some primary porosity in spherulitic structures lined with zeolites is still present.

The results of poroperm (porosity-permeability) determinations on samples of basaltic tuff in the Petroleum Technology Laboratory of the Bureau of Mineral Resources are given in Table 5. In general, specimens tested showed good storage capacity (20-40% porosity) and good hydraulic conductivity (up to 7.3 m/day) in both vertical and horizontal directions. For most samples, hydraulic conductivity in a horizontal direction exceeds that in the vertical owing to the effects of bedding. The samples measured were from coastal outcrops in which palagonite cement has been decomposed and removed by weathering. This effect might be responsible for some of the abnormally high hydraulic conductivity results in some samples.

Poroperm values suggest that basaltic tuffs may have potential for the storage of groundwater. Unfortunately their subsurface distribution and nature are little known, and would have to wait for exploratory drilling to provide fresh core samples for a more accurate determination of poroperm values.

Calcareous aeolianite

These rocks, with limited areal extent on the Kingston lowland, are not exploited to any large degree as an aquifer. Permeability is mainly intergranular, but some exposures show that fracture permeability exists along flaggy partings in cross-bedded sequences or along joints where the rock is massive.

Original primary porosity due to unconsolidated shell fragments has been reduced by the precipitation of calcite cement. There is a considerable range in porosity and permeability values (Table 5). In sample 17 the low values are typical of a massive aeolianite in which late calcite cement has reduced much of the primary void space, whereas in sample 18 some original porosity remains, with permeability being greater in the horizontal direction owing to the bedding.

The lateral extent and variation in thickness of the interbedded black clay is unknown. An examination of the clay in coastal section suggests it might behave as a thin confining layer holding groundwater under pressure beneath the coastal plain.

Poroperm values suggest that aeolianites are likely to function as useful aquifers, but would be liable to sea-water intrusion as they are exposed close to sea level. Before further groundwater development takes place, exploratory bores should be drilled, to confirm the distribution, thickness, and nature of the succession, and the hydrological properties of these rocks.

WATER-TABLE

A water-table in the weathered mantle is indicated by the levels at which groundwater stands in bores and wells. The water-table contour map (Enclosure, Map 2) shows a high-level water-table underlying the southern plateau, and a perched water-table over parts of the northern and eastern slopes of the main vent area. The high level water table is maintained to heights in excess of 100 m above sea level in the southern plateau by the low to moderate permeability of the weathered mantle.

Data

The most readily obtainable groundwater-level data are from wells, as access to most bores is restricted by pumps. Groundwater levels were measured using a locally made single-electrode water-level recorder based on the principle of the earth-return circuit. The data were measured over a six-week period from the middle of July to the end of August 1974, when water levels were beginning to rise as a response to seasonal recharge from winter rainfall. The data collected were corrected for bore and well elevations, and then plotted as water levels corrected to MSL (mean sea level) datum. Elevation error using the 1:10 000 topographic map is considered to be no more than $\pm$ 2 m.

Groundwater-level data are well distributed over the southern and northwestern parts of the plateau, but are scarce around the main volcanic vent, which is heavily forested and uninhabited. Data were supplemented with the depths of dry holes as an approximation of the minimum level below which the water-table occurs. In contouring the data it was assumed that since streams are fed and maintained largely by groundwater discharge, the water-table accords with stream level.

Field evidence

Apart from valley and high-level coastal seepages there is little field evidence for the water-table, except a circular pond 45 m west of Cascade Road at map reference 889 853; this is regarded as a high-level water-table window (Enclosure, Map 2; Plate 13).

The pond is mentioned in Governor Gidley King's early report of Norfolk Island. An old map dated 1794? shows the location of the pond as a small swamp which suggests that in the days of the first island settlement (1788-1814), the water level was higher than now. The pond is close to an early convict settlement, whose inhabitants might have formed its regular

PLATE 13. High-level water-table window at an elevation of about 100 m close to the western side of Old Cascade Road.

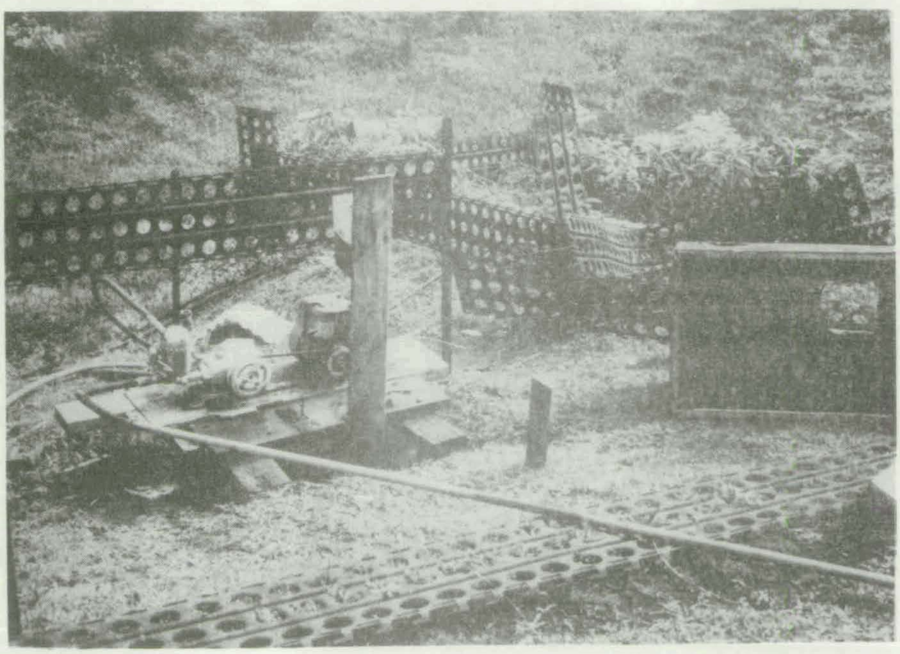

PLATE 14. Horizontal-displacement pump, Town Creek.

circular shape by clearing and deepening it for use as a water supply. Local people have talked of water-level fluctuations in the pond, and some have known it to overflow through a saddle on its northern side leading to a dry gulley which joins Cascade Creek below. Older residents have known the pond to go dry, and banana plants were planted in the bottom during a dry spell in the early 1920s.

The level of water in the pond is similar to that of a nearby well (NI 185), which suggests that both are related to the same water-table. Although the pond is close to the intersection of two minor fractures there is no evidence that it is related to a collapse structure at depth. A change of slope at about 2 m above water level (9.8.74) can be traced around the perimeter of the pond. This may represent the remains of an early excavation to deepen the pond during a dry period. Presently the pond is used as a watering point for stock.

Configuration and movement

Like the topography, the water-table is truncated at the margin of the island; otherwise, the contours roughly parallel the ground surface but with more subdued relief. Hydraulic gradients are generally steep on valley sides, but flatten out on the interfluves.

A trough-like depression in the water-table trending ENE reflects the boundary between the apron and nucleus. The westerly extension of this boundary is poorly defined mainly through lack of data. Near the junction of Two Chimneys and Stockyard Roads there is a local deepening of water-table.

Beneath the elevated terrain the configuration of the water-table is largely unknown. From the little data available there is the suggestion of an irregular groundwater mound influenced largely by the topography and permeability of the underlying rocks.

Groundwater movement in the weathered mantle is indicated on the water-table map by flow lines. These show that highlevel groundwater moves laterally under the influence of gravity from areas of high hydraulic potential (recharge areas), mainly on the central portion of the southern plateau, to areas of lower hydraulic potential (discharge areas), at the perimeter of the island. This general picture is complicated by groundwater movement towards valleys where contours and flow lines show that groundwater seepage feeds and maintains streams as base flow. Along the boundary between the upland and the southern plateau, groundwater movement is directed towards Broken Bridge Creek and then laterally to the margin of the island. Owing to the size of the island and the dissected nature of the plateau, flow paths are short. The distance between recharge and discharge areas is generally less than 3 km.

Groundwater-level fluctuations

Natural groundwater-level fluctuations depend on several factors, which include the topographic position of bores or wells, the proximity of recharge and discharge points, and the permeability of the weathered mantle.

Before the survey, the only measurements of groundwater levels were those recorded between 1970 and 1974 by M. Hoare from his well (NI 173) in Cascade Creek. Examination of his data showed that although measurements were at irregular intervals, groundwater levels only fluctuated over a range of about 2 m. This is typical of wells in valleys which have nearby streams maintained most of the year by base flow. A decline in water levels during 1973 and early 1974 was attributed to below average rainfall on the island in 1972-1973.

To obtain some impression of groundwater-level fluctuations a network of 14 observation wells and bores was established at locations shown in Enclosure, Map 3. The record spans the time between July 1974 and September 1975. By arrangement with the Norfolk Island Administration, groundwater levels were recorded fortnightly by J. Clapp and the data forwarded to BMR. The data is presented as a series of groundwater hydrographs with the appropriate rainfall record (Fig. 13).

Although the hydrographic records are probably too short for other than general conclusions to be drawn, there is a relation between groundwater-level movement and rainfall. The general rise in all hydrographs in August 1974 to January 1975 reflects a recovery of groundwater levels after a period of below average rainfall in 1972-73. After January 1975, groundwater levels responded to seasonal changes in rainfall, with levels rising in winter and declining in summer (NI 91, 162, 165). Seasonal fluctuations are normally within 3 m, although in an old well at the hospital (NI 70) they exceeded 7 m.

In some places the seasonal response to rainfall is not so obvious (NI 7, 11, 21, 52, 257, 263), and the hydrographs show a generally continuous rise in groundwater levels from August 1974 to June 1975. In these places, the observation bores and wells appear to have responded to long-term fluctuations in rainfall. This may explain why many local residents have commonly observed rising water levels in summer and falling water levels in winter. For observation bores and wells near the perimeter of the island, the effects of a seasonal recharge pulse will probably diminish with distance of the well from the recharge area; hence these bores and wells are more likely to reflect long-term changes in rainfall rather than seasonal changes.

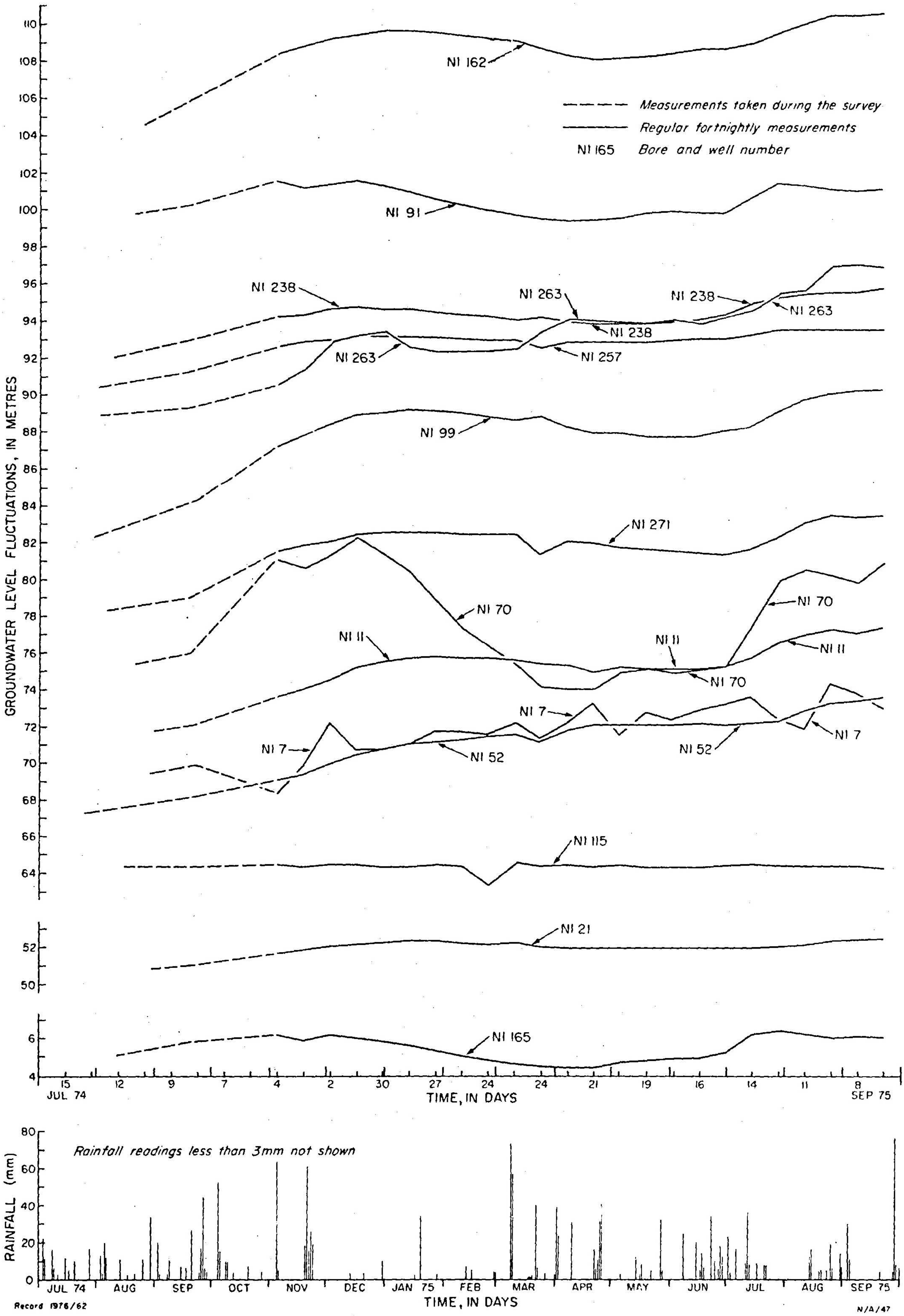

Fig. 13 Groundwater level fluctuations between August 1974 and September 1975

Generally, bores and wells in topographically high areas tend to exhibit larger fluctuations than those in valleys which are in zones of groundwater discharge (NI 115, 165). Where large fluctuations occur in topographically high areas, the waterlevel changes are assumed to be governed largely by the permeability of the weathered mantle (NI 70). In two places (NI 7, 263) local changes in groundwater levels due to pumping have been superimposed on a general groundwater-level rise.

GROUNDWATER DISCHARGE

Groundwater is naturally discharged as evaporation from plants and soil or as spring seepages on and around the island (Enclosure, Map 2). Most seepages have been mapped, although a few may have been missed in Mount Pitt Reserve. There are no records of attempts to measure or estimate seepage discharge. The location, size, and distribution of seepages reflects general hydrogeology on the island (Fig. 14).

Inland seepages

This group includes seepages formed where the ground surface intersects the water table or local bodies of perched water. They normally occur in valleys and are the main contributors towards base flow in all streams. With the seasonal fall in the water-table some seepages tend to become intermittent. Many seepages are associated with small 'nick-points' (small interruptions in the stream profile), usually marked by basalt boulders; the nick-points suggest that the stream has some erosive power and is cutting back into the valley at the point of seepage discharge. The diffuse and sluggish groundwater discharge high up in drainage lines suggests that the weathered mantle has only moderate permeability and behaves as an effective high-level groundwater storage.

A seepage with an abnormally high elevation 100 m north of Duncombe Road (map reference 860 877) is groundwater locally perched on layers of impermeable volcanic rock (basalt) at the base of the weathered mantle. Other evidence of perched groundwater is suggested from a water level measured in a well (NI 110) at map reference 879 864, and a perched seepage at map reference 877 869.

Further fieldwork in the valleys radiating from Mount Pitt should give more information on the occurrence and distribution of perched water.

Coastal seepages

Coastal seepages are poorly distributed around the margin of the island. They appear to be most numerous south of a line between Cascade and Headstone. Sections of the western and northwestern coastline appear to be barren of coastal seepages.

High-level coastal seepages occur just above the base of the weathered mantle, where the water-table is truncated at the margin of the island; some dry out in summer. Other high-level seepages are associated with vertical joints just below the base of the weathered mantle, where groundwater has moved from the zone of weathering into joints in unweathered rock before it discharges at the cliff face.

Low-level coastal seepages at Cascade and Ball Bay may be related to northeasterly and northwesterly trending fractures. At Steels Point, seepages suggest that the associated basaltic tuff has some degree of permeability if it is accessible to recharge. A seepage zone on the north side of Anson Bay is associated with vitric breccia and hackly jointed lava, and extends over a distance of about 30 m; this is probably the largest coastal seepage on the island and suggests that the quench zone may have a reasonably high permeability near sea level. Some seepages, particularly those near Collins Head and Cresswell Bay, produce a filmy white precipitate on the rock face. An attempt to identify the mineral by x-ray diffraction methods was inconclusive; it is thought to be an opaque form of silica. These seepages issue from a layer of clay formed by the weathering of fragmental and vesicular basalt between two lava flows.

'Offshore spring

Two offshore springs have been reported by local residents within 1 km of the shore: one between Point Vincent and Anson Point; the other close off Duncombe Bay (Enclosure, Map 1). Rising air bubbles and a muddy discolouration of the sea water after heavy rain has been observed at both places. Both springs are in line with a zone of northwest-trending fractures which cross the island. The sparsity of coastal seepages near sea level suggest that probably more offshore springs occur, but owing to a steeply shelving sea bed, strong winds, and heavy swells their location is difficult.

GROUNDWATER DEVELOPMENT

Early groundwater development on Norfolk Island began with wells which even until modern times were dug by two men using a pickaxe, shovel, and a bucket and hoist pulled by a horse to remove the spoil. Wells were excavated either to solid rock or more usually to a few metres below the water-table; hard layers were dynamited (Fig. 15a). The wells were lined from the top with

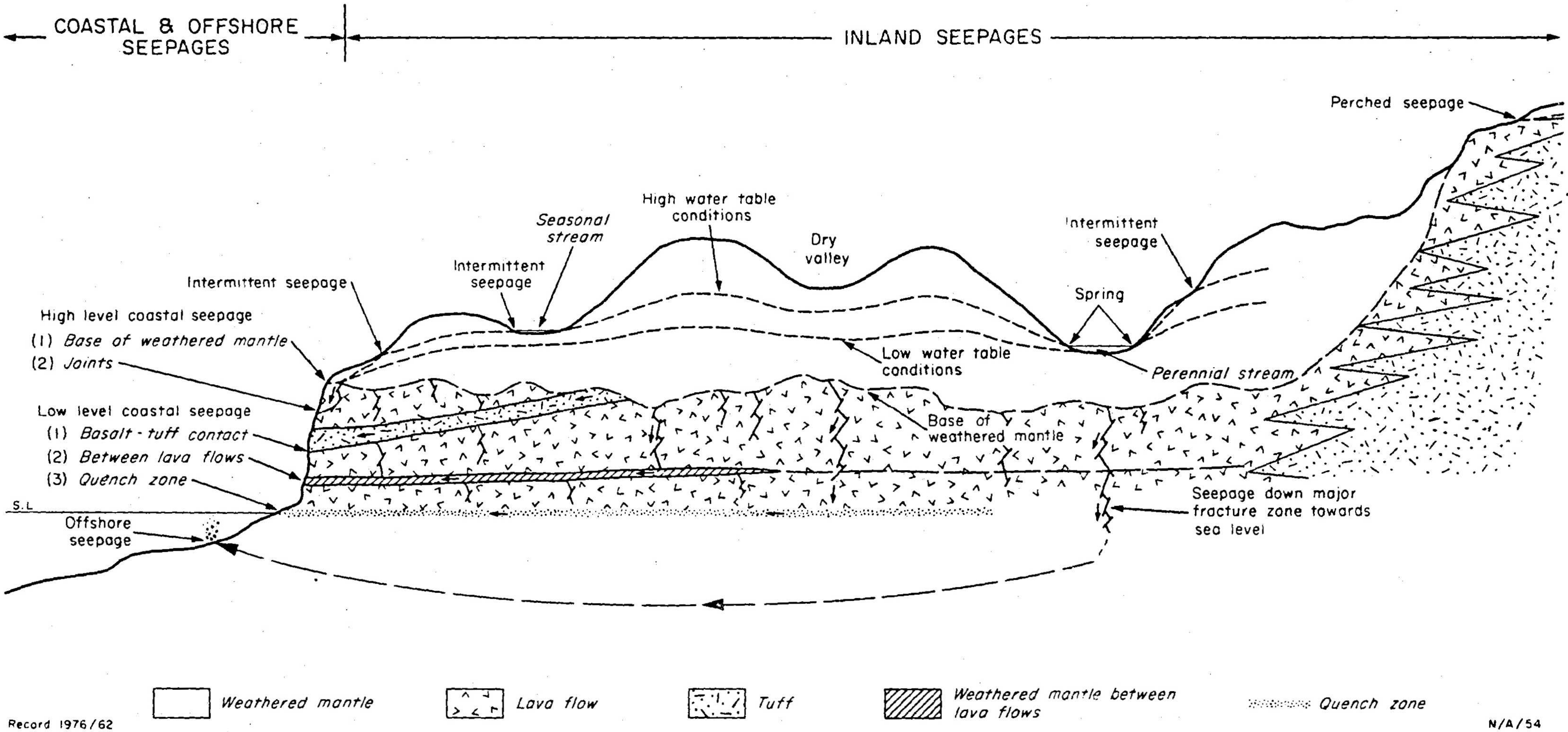

Fig. 14 Occurrence of spring seepages

up to 2 m of loosely cemented stone slabs quarried from calcareous aeolianite along the Kingston shoreline or from Nepean Island. The more recent wells are lined with concrete or galvanized iron. Many of the wells on Norfolk Island remain in good condition because the weathered volcanic rocks have a high clay content which rapidly hardens on exposure to air and allows the well sides to stand up without support. The mean depth of wells varies according to topographic position. On the interfluves they average 26 m; in valleys, 7 m. The deepest well measured during the survey was 60 m (NI 105). Most wells range from 1.2 to 1.5 m in diameter. Wells are an appropriate method for small-scale groundwater extraction from a weathered mantle of low to moderate permeability because - with a large surface area of aquifer exposed - there is maximum entry and storage of groundwater.

Groundwater development from bores did not significantly begin until 1970, when a Failing rotary drilling rig mounted on a truck arrived on the island from New Zealand. The rig has been able to drill effectively through the weathered mantle, but should it be required to investigate the possibilities of basal groundwater in much harder rock it would require a comprehensive overhaul: a number of working parts need to be replaced; a proper set of fishing tools is required; and larger-capacity pumps are needed in order to measure groundwater yield (the largest pump is capable of only 1800 l/hr). The present owner is G. Quintall, who was drilling about eight new holes per year during 1974 and 1975. In earlier times the rate has been quicker, but, recently, breakdowns and a shortage of spare parts have caused lengthy delays. The rig is not capable of percussion drilling.

The distribution of 297 bores and wells on the island is largely determined by the density of population in the Burnt Pine/Middlegate residential complex (Enclosure, Map 3). Bores and wells are locally concentrated at Kingston, on the northwest plateau, at Headstone, near Steels Point, and at the Melanesian mission. An inventory of bores and wells on the island (Appendix 2) was compiled from data collected during the survey and from subsequent information forwarded up to early 1976. Each bore and well in the inventory is identified by a number which has a prefix NI (Norfolk Island). Wells and bores are located by a six-figure grid reference based on a metric equivalent of the Australian map grid extending to Norfolk Island. The inventory shows that, out of a total of 297 groundwater extraction points, 175 are wells and 122 are bores. The inventory is set out under a number of headings with abbreviations and codes explained in a footnote. The data relating to bore and well depths, water use, and pumping regimes were obtained from discussions with well owners. The main deficiencies appear to be a lack of bore completion data - particularly water intersections, casing details, lithology, and pump test data.

Use

Groundwater is used mainly for domestic purposes (laundry and toilets) and gardening. Several hotels depend all year round on groundwater, but they use rainwater or surface water storage for emergency supplies. The South Pacific, Norfolk, Paradise, and Polynesian Hotels, and other tourist accommodation, use groundwater exclusively. Groundwater is also used for stock watering and irrigation. A few residents use spray irrigation on a small scale for growing fruit (citrus) and vegetables for the local market. Trickle irrigation is practised in an upper tributary of Watermill Creek catchment for watering young trees in an afforestation project. Groundwater supports local industries such as sawmills and the local concrete batch and tanalith plants. A bore at the South Pacific Hotel is used for the disposal of treated sewage effluent.

Yield

Most bores and wells have a measured yield of between 500 and 1500 l/h (Table 6). Yields of 13 500 l/h or more have been reported from five bores, three of which are in valleys and the other two on higher ground. Estimated yield values in the inventory were based on pump type or owners' estimates.

TABLE 6. YIELDS OF BORES AND WELLS ON NORFOLK ISLAND

Range of yield (litre/h)	Numbers of bores and wells
0-500	15
500-1000	66
1000-1500	42
1500-2000	12
2000-2500	12
2500-3000	3
3000-3500	5
3500-4000	0
4000-4500	1
4500-5000	1
5000	0

Where it was possible to start a pump, yields were measured using a bucket and watch. At many places, yields depend as much on the condition, type, setting, and placing of pumps as on the local groundwater conditions. There are many kinds of pump used on the island, but the basic reciprocating type is the most common. For wells and bores in valleys, horizontal-displacement piston pumps are usually used to 'push' the water up the hill to storage (Plate 14). On higher ground vertical-displacement pumps are more common; these 'lift' the water to storage (Plate 15). A type of pump commonly used is the ejecta pump, based on the Venturi principle, in which air is forced down one pipe so that water rises to the surface in the other. More recently mono and submersible pumps are becoming popular, as their rotary or screw action that forces water to the surface allows them to be used in almost any topographic situation.

Most pumps are powered by electric motors; others have petrol or diesel motors. Bucket and hoists are still used for drawing water in a few wells. Pumps may be operated automatically by time, float, or pressure switches, although it is usual for the owner to activate the prime mover. Groundwater is usually stored in corrugated iron storage tanks connected to the bore or well by PVC piping.

The standard of pump maintenance is only fair; many pumps have rusted parts. Some wells and bores are fitted with the wrong type of pump - particularly ejecta pumps, which are small but adequate only if they do not have to pump against severe topographic or hydraulic gradients. The maximum extraction of water from a bore or well depends on the type, setting, and suction depth (usually within 6 m of the bottom of the hole) of the pump.

An important control affecting yield is topography, which determines the large differences in available head of water between high and low areas. As most of the drainage lines are at least partly fracture-controlled, valleys are probably sites of higher permeability if bores can be completed to solid rock (NI 63, 114). The sluggish rate of natural seepage flow suggests that the low yield encountered in bores and wells is also a function of the moderate permeability of the weathered mantle. Yield will also be affected by the drilling method, which uses circulating mud, and by the standard of bore completion and development techniques.

Bore construction

Most bores are drilled to the base of the weathered mantle and up to 3 m into solid rock (Fig. 15b). Bore depths are greater than for wells, averaging 46 m on the interfluves and 34 m in valleys. The deepest known bore on the island is 106 m at the South Pacific Hotel. The depth of most of the bores could not be measured because they are covered by pump equipment and most depths are those reported by the driller on completion of drilling.

Full casing details are available for only 19 bores (Appendix 2). Apart from economy, the reason for the insertion of particular lengths of plain and slotted casing in bores has not been determined. Bores sited in valleys may not need plain casing, because the water-table is shallow and draw-downs are relatively small. As the amount of dewatered aquifer is small, slotted casing can be used to solid rock. For bores sited on interfluvial areas, drawdowns are larger and the amount of dewatered aquifer is correspondingly greater; hence, plain casing can be inserted if necessary to about pumping level. If adequate water supplies are being derived from below the weathered mantle, slotted casing should be inserted and the weathered mantle left plain cased. If bores are to function efficiently and give maximum yields, the driller is responsible for test-pumping bores at rates and overtime intervals that his client will need in practice, and also for accurately observing all water-levels, so that appropriate lengths of plain and slotted casing can be inserted into the hole.

The practice of drilling water-bores using circulating mud is not the ideal drilling practice in a weathered volcanic sequence that has a high proportion of clay. Drilling-mud clogs the pores of the aquifer and develops a filter cake on the wall of the borehole. This needs to be removed as far as possible during bore development. If the mud is not removed properly during test-pumping an inferior bore will result. If drilling-mud continues to be used it would be best to circulate a Revert or hydropol mud that produces as little invasion of the aquifer as possible.

Selection of bore sites

Underlying the southern plateau is a shallow water-table mound in the weathered mantle (Enclosure, Map 2). In droughts or when rainfall is below average, the water-table mound subsides as groundwater continues to move laterally and vertically to the margin and base of the island; thus water-levels will decline at a faster rate and to a greater degree on higher ground than at lower elevations.

For water-supply purposes, some knowledge of the depth to the water-table and its range of seasonal fluctuation is necessary for estimating a minimum drilling depth. In the past, the seasonal range of groundwater-level movements could not be predicted accurately. Groundwater-level data seems to suggest that over a period of below average rainfall (lasting, say 3 years) groundwater-levels would fall substantially, but then quickly recover in years of average or above average rainfall. Many of the older wells on the island have little water in summer or dry up completely in droughts, which suggests that at the time

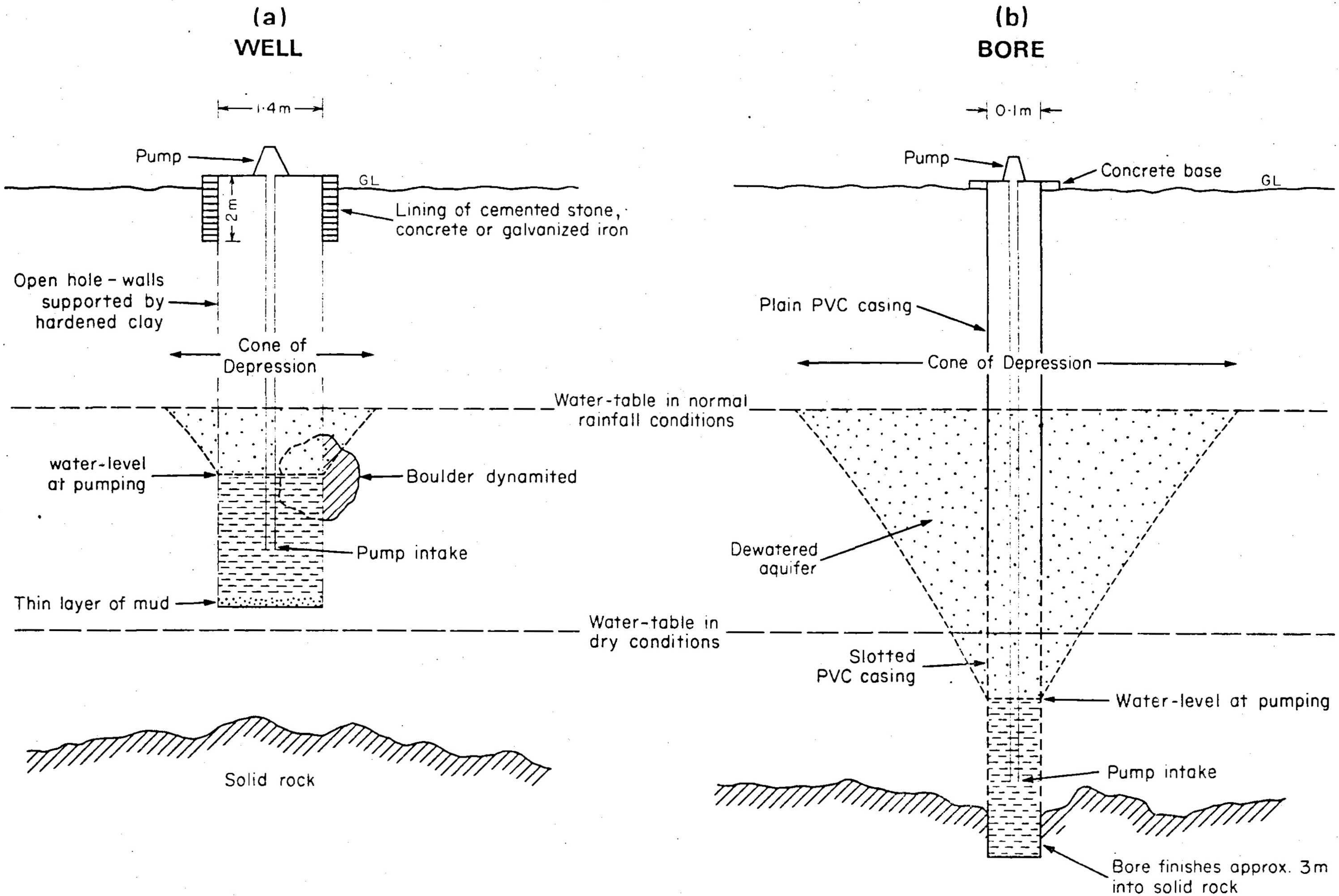

Fig. 15 Typical well and bore construction on Norfolk Island

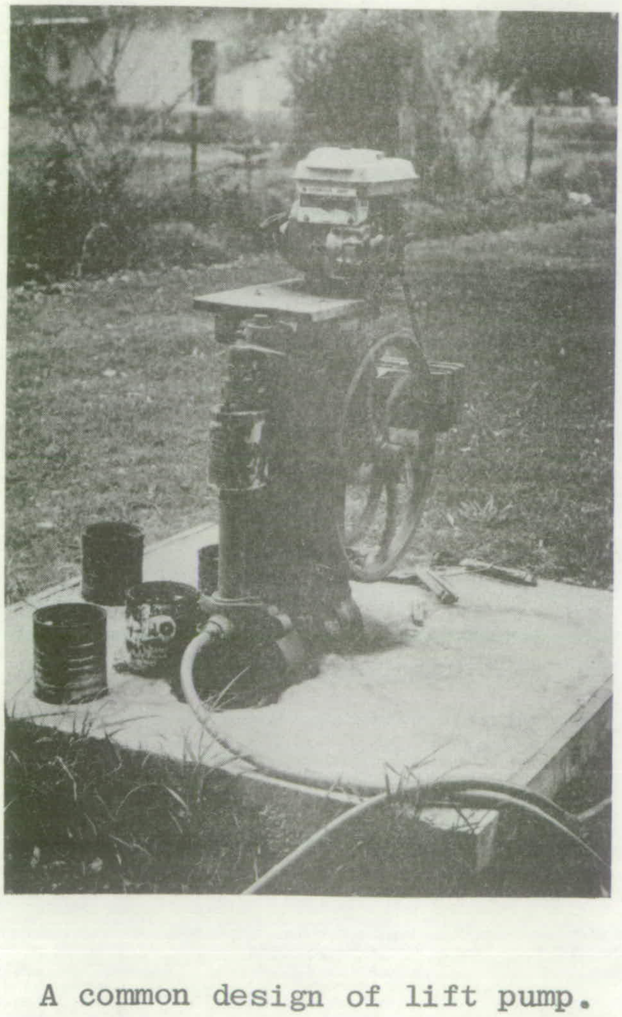

PLATE 15. A common design of lift pump.

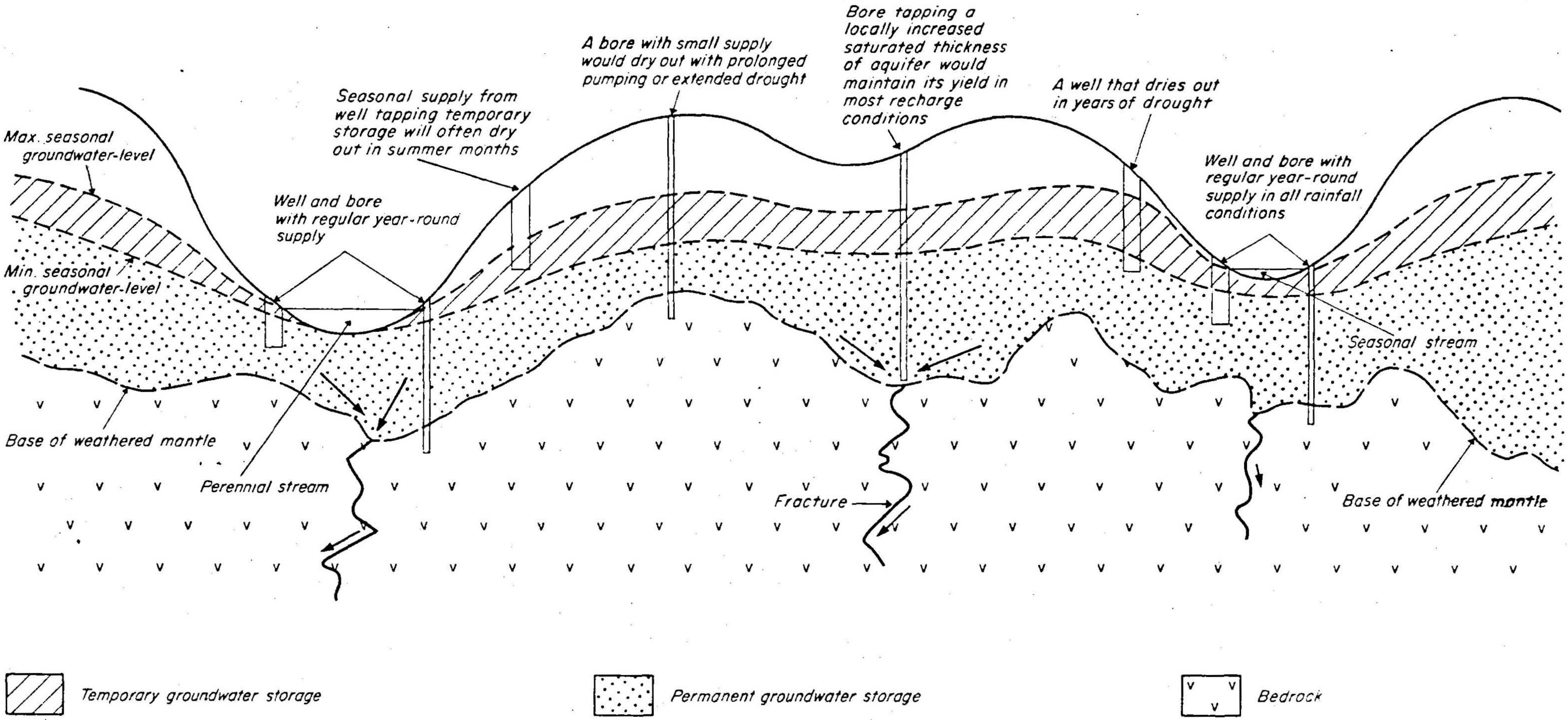

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Fig. 16 Groundwater development in the weathered mantle they were dug they did not allow for appropriate seasonal fluctuations in groundwater-level or that groundwater-levels were generally higher than at present.

Most wells derive their groundwater from temporary storage, which is the amount of water than can be made available to a well between minimum and maximum seasonal groundwater-levels. These are called replenishment resources as they depend only on changes in water-level due to rainfall recharge. Wells or bores sited in valleys carrying baseflow are probably almost exclusively tapping groundwater in permanent storage (Fig. 16).

To date on Norfolk Island, borehole siting has been rather haphazard. Most property owners require their water supply close to the house, and bore sites tend to be selected only with regard to the location of the septic tank system. This often limits the area available for prospecting. Most owners, if they do not use the services of diviners, take advice from the driller, or extract what groundwater information is available from adjacent property owners.

The present study suggests that property owners siting their own bores should find the lowest area on their block or, if it has a valley frontage, seek groundwater at the lowest point in the valley. Post-hole borers can be used quickly and effectively to prospect for water, and to determine the depth to the water-table. They are not recommended as a substitute method for drilling bores.

Advantages of low-level sites in valleys are shallow water-tables and small fluctuations in water-level. Such sites need only a shallow bore and will give continuously high yields ($>$ 4500 l/h) all year round. Disadvantages of a low site are the increased costs in bringing water to higher levels, and having a source distant from use.

Influence of fractures on yields

Generally where bores intersect fractures they should provide high groundwater yields. Although the importance of fractures in groundwater studies is well known there have been few detailed fracture-trace studies for groundwater development in volcanic rocks. However, Lattman & Parizek (1964) studied fracture traces in carbonate rocks and showed that specific capacities of wells drilled at the intersections of fractures are higher than those of wells drilled in interfracture zones or along a single fracture trace. Hine (1970), in an analysis of a limestone area in Kentucky, showed that a relation exists between fracture traces and joints, and that they are a potential source of water supply. Larsson (1972) indicated that tension faults and fractures in granites tend to remain open and are capable of high yields of groundwater.

On Norfolk Island most bores appear to have been sited between fracture zones (Enclosure, Map 1). The few that are sited within these zones give reasonably high yields of groundwater or are dry. Some bores sited on or close to fracture traces are able to maintain a moderate yield over long periods because they presumably tap a locally increased thickness of weathering in a fracture zone. However, lost circulation reported at drilling suggests that in some areas the permeability increases at the base of the weathered mantle; this may be associated with either interconnected fracture systems or long fractures crossing the island.

Near the junction between Two Chimneys and Stockyard Roads, three bores (NI 275, 279, 280; Enclosure Map 3) were abandoned with lost circulation or are dry at depths between 55-75 m. Some dry wells with depths in excess of 30 m in the same area may be affected by a local increase in permeability associated with subsurface tuff beds (NI 276, 277, 278). A bore with a depth of 106 m at the South Pacific Hotel (NI 138) lost circulation when it was drilled, and is now used for disposing sewage effluent; this bore appears to be associated with a strong north-northwest-trending fracture zone. High-yielding bores are sited in this zone at the Polynesian Motel (NI 123) and at Pine Valley Flats (NI 122). This suggests that only some sections of a fracture zone are active conduits for groundwater movement. In other areas of the island, people have experienced difficulty in obtaining water supplies, particularly near Bullock Hut Road, near the eastern side of Anson Bay Road, and near Mount Pitt Road. In these places the bores are not only close to fracture alignments, but they may be affected by a permeability change associated with the boundary separating the main vent from the northwestern and southern plateaux.

Available data correlating bore yield with fracture orientation is sparse and tends to be contradictory. Perhaps the permeability variation is related only to the degree of fracture closure with depth or the amount of clay formed by the locally increased depth of penetration of weathering in a fracture zone. As most bores have stopped at hard rock deepening might well improve their yield in some places. Offshore seepages seen by local residents off Point Vincent and close to Duncombe Bay are aligned with northwesterly and north-northwesterly fracture orientations; these directions may be significant for water-supply purposes.

If the success of bores were to depend on deriving water supplies from the intersection of fractures, favourable drilling sites would be where fractures can be related to visible zones of weakness such as joints and faults in coastal section. As the drainage network is partly fracture-controlled, fractures along valleys may be more concentrated and open beneath a superficial cover of alluvium.

To date, fractures have been studied only at a preliminary level. Only the broadest conclusions are offered; further investigations are required to fully assess what role fractures may have in the occurrence of groundwater on the island. In this respect, any drilling program should try to determine the relation between fracture traces and groundwater occurrence. Bores should be drilled in zones of high fracture-trace frequency or at fracture-trace intersections, and their water yields should be compared with those of bores drilled in areas of low fracturetrace frequency. Further studies should include a program of specific-capacity measurements on bores sited between and in fracture zones. If more groundwater were to be found in zones of high fracture-trace frequency than in interfracture zones, this would indicate that fractures aid the movement of groundwater to deeper levels; such sites would be suitable for water-supply purposes

Development of spring seepage

Seepages are not generally used as sources of water. The only one known to be in current use is 250 m north of the meteorological station on the headwaters of Mission Creek. At some stage a seepage close to Country Road at map reference 870 830 was used, as the remains of old equipment can still be seen. In some places soakage wells in valleys have been sited close to seepages.

Only one attempt has been made to use groundwater from a coastal seepage. At Anson Bay a collecting tank was lowered over the cliff below the Old Cable Station to collect seepage flow, which was then pumped to the top of the cliff. This supply is now disused, but the remains of the old tank and standpipe can still be seen.

The development of spring seepage is unlikely to be of little more than local significance for individual property owners. If a water supply is developed close to a seepage, care should be exercised not to excessively disturb the ground, so as not to locally alter the permeability and reduce discharge to a well or shallow bore.

Existence and development of basal groundwate

Normally the basic requirements for the accumulation of a groundwater lens below sea level depends on a suitable degree of permeability of the rocks that contain the water and control its movement, and on a sufficient amount of rainfall recharge to maintain a water-table above sea level. In small oceanic islands composed of unconsolidated sand and reefal limestone these conditions are usually fulfilled. Fresh water floats on sea water - which has the higher specific gravity - and thus displaces a volume of seawater equal to its own weight; this depresses the freshwater/saltwater interface below sea level. According to the GhybenHerzberg relation the saltwater/freshwater interface beneath islands of this type will extend about 40 times as far below sea level as the water-table is above sea level.

That groundwater occurs as a lens near sea level on Norfolk Island has been suggested by Jones & McDougall (1973). Field observations so far indicate that the geological succession appears to have mainly low to moderate permeability, and rainfall falling on the island is readily absorbed by the thick porous weathered mantle. Poor surface runoff and apparently small groundwater losses from high-level coastal seepages reflect in some measure the large storage capacity of the weathered mantle. The movement of groundwater through fresh volcanic rocks to sea level is largely through a system of fractures (Fig. 8).

According to a structural model of a marine basaltic volcano (Jones, 1970), a permeability contrast is likely to exist on Norfolk Island at about sea level. A passage zone about 3 m thick of hackly jointed and fragmented lava represents a zone where subaerial lava was shattered to flow-foot breccia as it flowed from air into water. These rocks in exposures between Anson Bay and Cascade appear to have a permeability greater than the subaerial lava sequence. Below the passage zone, flow-foot breccia extends to an unknown depth, but because of its fragmented nature it is assumed to have water-bearing properties similar to that of basaltic tuff. The permeability contrast is probably greatest beneath the plateau areas, as there is a succession of volcanoclastic rocks and minor lavas beneath the main vent.

For practical water-supply considerations the seasonal pattern of groundwater recharge that operates on Norfolk Island - although causing fluctuations in groundwater levels in the weathered mantle - is unlikely to have any appreciable effect other than to maintain a freshwater lens. The effects of tides on basal groundwater are unknown, as almost all bores are situated on the plateau and do not reach sea level. The only bores and wells that might be subjected to tidal influences are those closest to sea level where permeable calcareous aeolianite underlies the kingston lowland. The magnitude of normal tides is 1.6 m, which is large enough to cause some mixing of fresh water and sea water. The zone of mixing is greatest near the shore, and, although the effects of tidal fluctuations decrease with distance from the shore, their extent inland is unknown. Storm waves may cause locally higher fluctuations, particularly after cyclonic weather. The effect of tidal influences under the Kingston lowland could be studied by installing an automatic water-level recorder in a suitably positioned well or bore.

At present, basal groundwater on Norfolk Island is largely undeveloped and exists more or less in a condition of equilibrium with submarine seepage loss balanced by natural groundwater recharge. Only on the Kingston lowland is there a possibility that this equilibrium has been altered. A well at Government House (NI 224), a bore behind the Paradise Hotel (NI 226), and a recent bore drilled at the Golf Club (NI 297), with depths of 8, 12, and 10 m below sea level, may be drawing on brackish basal groundwater. The brackish water is probably caused by long-term tidal influences mixing seawater and groundwater rather than by overpumping in the short term. The pumping regimes at NI 224 and NI 226 are not heavy enough to cause a further deteriotion in water quality but restraint should be exercised to ensure against excessive use. Groundwater development in the Kingston lowland should take account of this problem, and be restricted to accurately levelled bores that do not extend far below sea level.

WATER QUALITY

Generally water quality is suitable for domestic use but may exceed salinity limits locally in the northwest plateau, Kingston lowland, and other coastal areas. Groundwater pollution due to seawater contamination, refuse disposal, and livestock and septic-tank waste is not presently a widespread problem.

The interpretation of hydrochemical data has been largely determined by the depth intervals of bores and wells in the weathered mantle. Water-quality data for Norfolk Island are given in Appendix 3; they include analysis by AMDEL (Australian Mineral Development Laboratories, Adelaide) of 25 groundwater samples collected during the survey. Seven analyses of groundwater samples collected by Eden (1965) are given for comparison. There is good agreement in both sets of analyses. A third group of incomplete analyses made by a selection of laboratories completes the total data. A list of water-quality data for surface water is also given in Appendix 3.

Chemical composition

The chemical analyses listed in Appendix 3 show that generally, sodium accounts for more than 60 percent of cations, and chloride 60 percent of anions. Ground and surface waters were classified by compiling a trilinear diagram using percentage of equivalents per million (% epm) of anions and cations (Fig. 17). All values plot in a sodium chloride field corresponding to a salinity similar to diluted seawater.

Sodium chloride in the groundwater is derived initially from salt spray from the ocean which becomes dissolved in rainfall; it does not originate from volcanic gases or hot springs. When rainfall strikes the surface it picks up additional ocean salts deposited by spray blown inland from continuous wave action around the island.

Rainwater samples were not collected during the survey, but analyses from Guam (Ward, Hoffard, & Davis, 1965) indicate that the salinity of rainwater contaminated by oceanic salts ranges from 20-30 mg/l of total dissolved solids (TDS) of which 8 mg/l is sodium and 14 mg/l is chloride. For the Hawaiian Islands Visher & Mink (1964) showed that the total dissolved solids in rainwater is about 24 mg/l of which 6 mg/l is sodium and 11 mg/l is chloride.

Groundwater quality is also determined by the composition of the volcanic succession. According to Green (1973) the most common minerals in Norfolk Island basalts are calcic plagioclase, olivine, pyroxene, accessory iron oxide, and apatite. Calcium and magnesium are released into the zone of weathering mainly from feldspars and ferromagnesian minerals. In the early formation of the weathered profile, far more calcium and magnesium were available than at present. As the profile has developed base exchange has operated with calcium and magnesium cations being replaced by sodium from cyclic salt dissolved in groundwater.

The high sodium chloride content suggests that groundwater is more or less in chemical equilibrium with the weathered zone. Where the profile remains chemically active, base exchange and other chemical processes may operate to promote local variation in the concentration of ions. Other changes in groundwater quality have been determined by man-made activities such as the disposal of waste in septic tanks and the introduction of livestock.

Standards of quality

The total dissolved solids (TDS) is a general indication of the salinity of a water sample, and is usually used as an indicator of water quality. However, the concentration of individual constituents must be taken into account when determining the suitability of water for specific purposes. A full explanation of water-quality standards for domestic, livestock, and irrigation use is given by Hart (1974).

In general terms, the maximum limit of TDS in groundwater suitable for domestic use on Norfolk Island is less than ($<$) 1000 mg/l TDS, and for livestock, $<$ 8000 mg/l TDS; the required upper limit for hardness is $<$ 500 mg/l $CaCO_3$ (Table 7). Water quality limits for livestock depend on the season, type of food, and the salinity to which they are

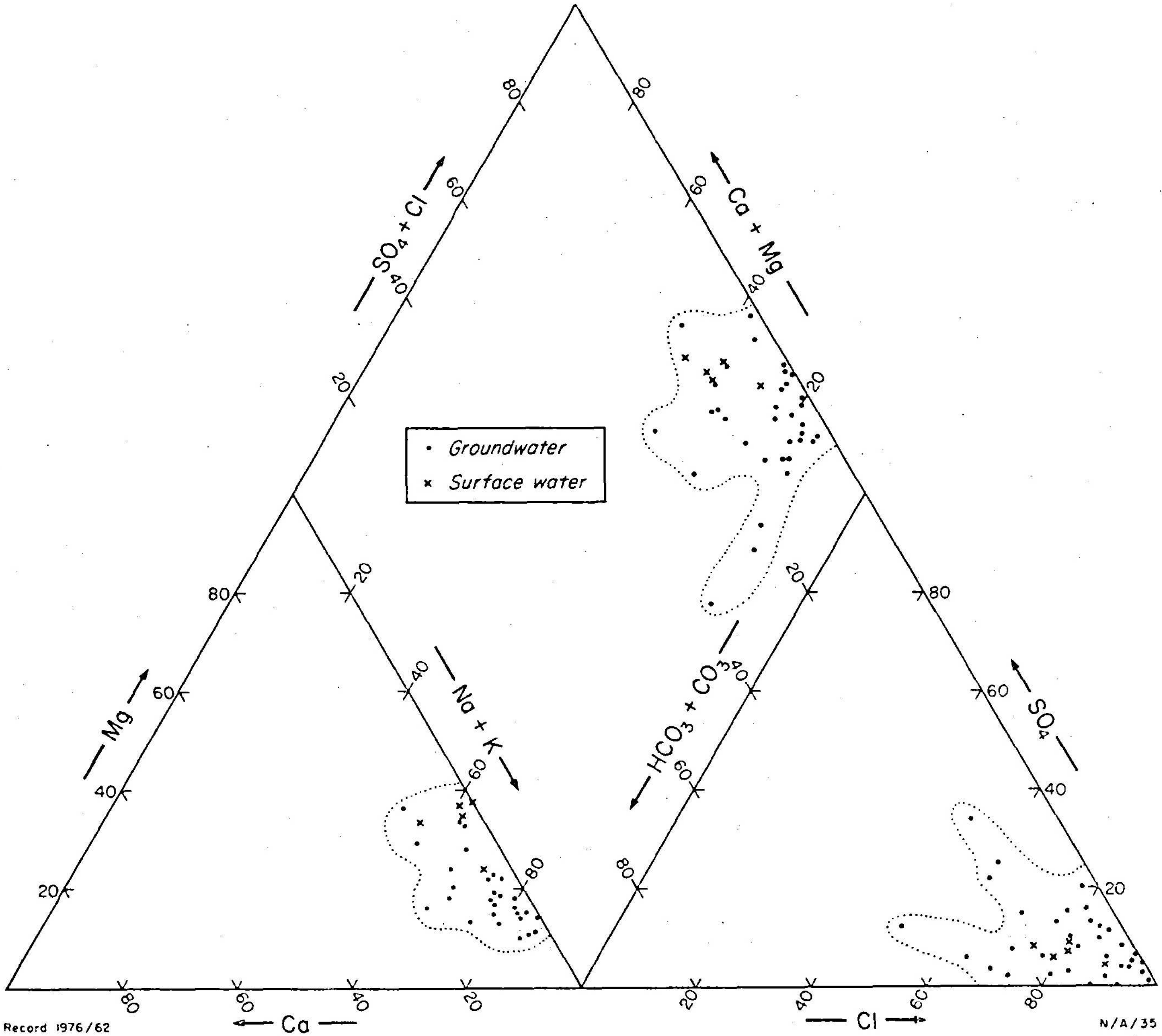

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Fig. 17 Chemical classification of groundwater expressed in percentages of major ions (% epm) accustomed. For domestic use, rainwater storage and surface water will provide on the whole better quality water than groundwater.

TABLE 7: SUGGESTED WATER-QUALITY LIMITS FOR DOMESTIC AND LIVESTOCK USE.*

Constituents	Domestic (mg/l)	Livestock (mg/l)
TDS	1000	8000
Hardness	500	-
Na	270	-
Mg	150	500
Ca	75	1000
Fe	0.3	10
Cl	200	Not more than 75% when total dissolved solids were limit,
SO_4	250	1000
NO_3	45	200
F	1.5	2.0
Mn	0.05	-
Cr	0.05	5
P	0.2	-
B	1.0	-
pH	6.5 - 9.0	6.5 - 9.0

*Source of information after Hart (1974), and Northern Territory Administration Water Resources Branch.

Salinity

As bores and wells are completed to depths of generally less than 75 m, groundwater analyses mainly represent the hydrochemistry of weathered mantle waters. A hydrochemical map (Enclosure, Map 4) shows salinity contours based on field and laboratory electrical conductivity data. Water samples from wells and unequipped bores were obtained from a small weighted can lowered on the end of a cable. From equipped bores samples were taken at the pump after it had been working for about 5-10 mins. Field salinity was measured using a 5-range portable

Dionic conductivity tester. The salinity values from both field and laboratory measurements were similar.

On the southern plateau, groundwater salinity generally increases from the centre to the margin of the island. This is complicated locally by high areas of saline groundwater around the eastern end of Two Chimneys Road and on the northwest plateau, where salinities exceed 1000 micromhos/cm. The high-level saline groundwater on the Burrell and Dale properties (NI 1, 3, 4) may be due to low permeability restricting groundwater movement near the base of the weathered mantle. Low salinity values ($<$ 500 micromhos/cm) centred on the main watershed crossing the southern plateau are correlated with areas of high hydraulic potential in recharge areas, as indicated by the water-table contours. At Kingston, salinity contours indicate a shallow saline wedge extending for a short distance inland; this suggests that Government House well (NI 224) and a bore behind the Paradise Hotel (NI 226) are drawing on brackish groundwater underlying the Kingston lowland.

There is only a poor relation between salinity (measured as field conductivity) and the depth of bores and wells (Fig. 18). The scatter of points outside the two main groupings is probably related to restricted flow systems at the base of the weathered mantle away from open fractures, the effects of septic-tank waste and contamination from seawater and dissolved solids from oceanic spray.

Acidity

Most groundwaters have pH values ranging from 4 to 7, so that many of them are acid and corrosive. Acidity means an excess of hydrogen ions arising through the hydrolysis of iron and aluminium, the hydration of iron in the weathered profile, and, to a lesser extent, the leaching of organic acids from decaying vegetation. Groundwaters on Norfolk Island are generally low in bicarbonate. The source of bicarbonate comes from the reaction of rainwater with carbon dioxide in the atmosphere and soil to form carbonic acid. If the acidic nature of the profile has an excess of hydrogen ions there is a tendency for any bicarbonate that forms to dissociate to further increase the concentration of hydrogen ions. Only when groundwater has a pH near to 7 is bicarbonate likely to occur in reasonable concentrations to react with any available calcium and sodium ions.

Minor ions

A few wells and bores contain excessive amounts of minor ions, among which the most important are iron and manganese.

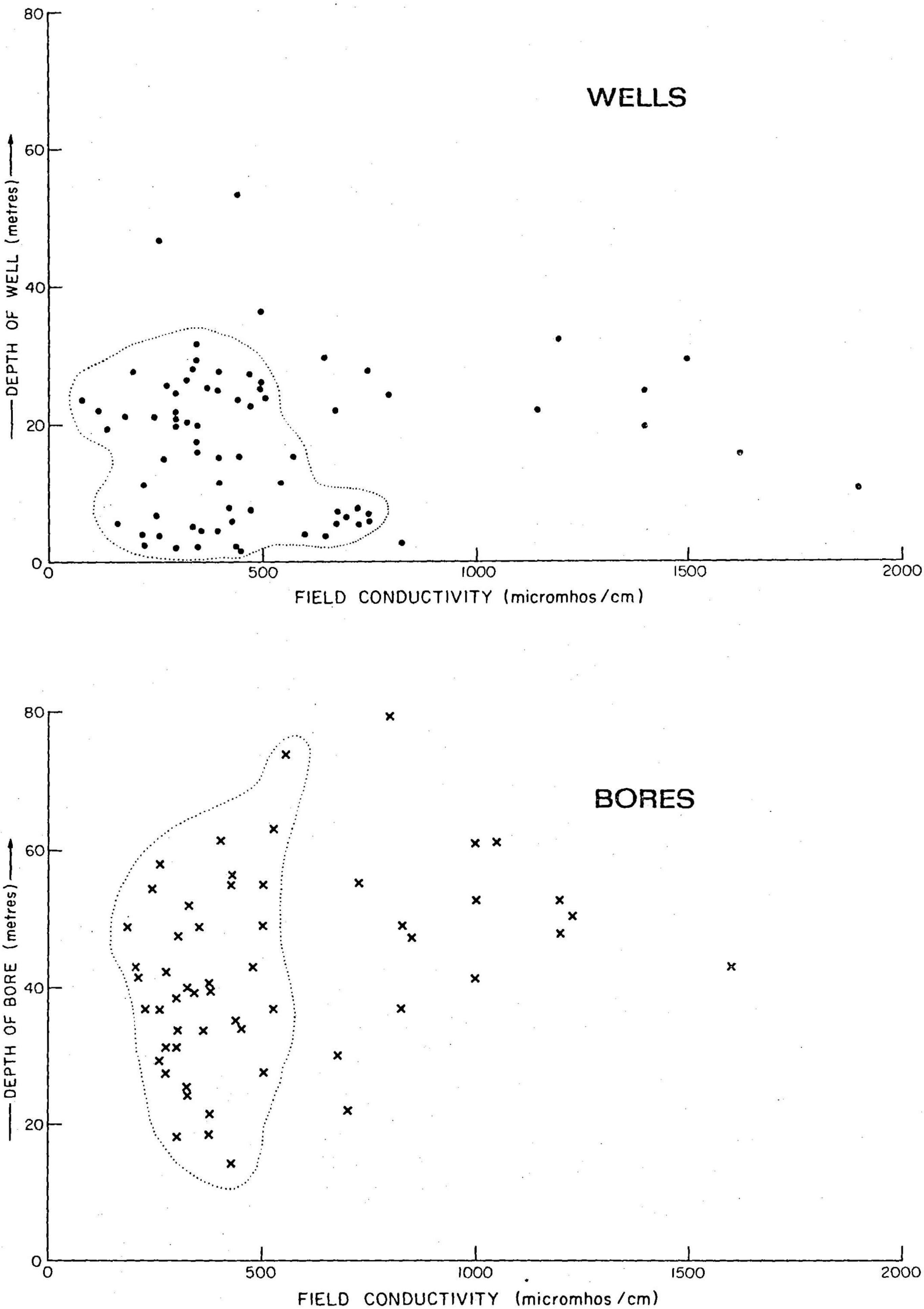

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Fig. 18 Groundwater salinity as a function of depth

Iron is widely distributed in the weathered mantle where it is released in the chemical breakdown of minerals in basalt, e.g., olivine, pyroxene, and iron oxides. Iron probably exists primarily in the ferrous state, but becomes oxidized to the ferric state in bores and wells when they are pumped. When water is left to stand in rising mains or in storage tanks, ferrous hydroxide is oxidized with the precipitation of iron oxide. In the swampy sections of streams where flow is restricted, local oxidization causes red-orange iron oxide to be precipitated on vegetation, and silvery iron oxide films on water surfaces. The iron content varies in groundwater: the limit of 0.3 mg/l iron (Table 7) being exceeded in 16 analyses (Appendix 3), with a highest value of 26.5 mg/l (NI 124). Some of the high values may be due to sampling error, if the pump had not operated long enough to remove all standing water from the rising main. Nevertheless the high iron content should be considered a constraint in groundwater used for domestic purposes, as it imparts a strong metallic taste and may cause red stains on laundered fabrics and plumbing fixtures. Some iron may be derived from pump parts and piping, but not from casing, which is appropriately made of PVC.

Concentrations of manganese are lower than those of iron, which manganese resembles in its chemical behaviour. In most bores and wells manganese exceeds the limit for domestic use, but only in one bore and one well (NI 1 and 14) does it exceed 1 mg/l. Manganese may cause dark brown or black stains on laundered fabrics, but concentrations are not high enough to be regarded as harmful. For other minor ions such as fluorine, boron, chromium, and phosphate, the limits set out in Table 7 are not exceeded. The low concentration of phosphate is probably due to the low level of fertilizer use.

Hardness

Hardness in groundwater is due to magnesium and calcium salts. The derived working level of hardness of domestic water supplies is 100 mg/l, but concentrations up to 500 mg/l are acceptable where no other water is available. On Norfolk Island, most hardness values are less than 100 mg/l. In general the hardness pattern (Enclosure, Map 4) follows the salinity pattern, with an increase towards the margin of the island. Rainfall containing sodium ions is a natural water softener and is partly responsible for the maintenance of low hardness values, but increased hardness concentrations near Two Chimneys Road and on the northwest plateau may be caused by calcic-rich clays or, on the Kingston lowland, by calcium and magnesium derived from calcareous aeolianite.

Irrigation

Factors which determine whether water can be used for irrigation are salinity and the concentration of sodium, boron, and bicarbonate ions. Other factors are climate, soil, position of the water-table, and crop type.

The chemical classification of irrigation water adopted is based on the relations between conductivity in micromhos and the sodium adsorption ratio (SAR). The conductivity indicates the degree of salinity of the water, and the sodium hazard is evaluated from the formula

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

where ion concentrations are expressed in epm. The SAR value for water indicates the extent to which a soil will adsorb sodium from groundwater, and the soil drainage characteristics. The basis on which the SAR ratio operates is base exchange.

Figure 19 shows a classification of irrigation waters for Norfolk Island based on SAR and salinity. The graph shows that most waters fall in the S_1 range, below a value of 10, which is a low-sodium water that can be used on most soils with little danger of harmful levels of exchangeable sodium. The remainder falls in the S_2-S_4 range which indicates a medium to high-sodium water with harmful levels of exchangeable sodium particularly in fine-textured soils. There is a wider dispersion of salinity, with most values falling within the C_2 range, corresponding to a medium salinity water that can be used on soils with a moderate amount of leaching. The graph shows that five of the water samples (NI 1, 11, 14, 64 and 284) have an appreciable amount of exchangeable sodium ions and high salinity. If such water were used it would cause a reduction in permeability and a hardening of soils. The effect of high salinity would cause an increase in osmotic pressure of the soil solution, resulting in reduced availability of water for consumption by plants.

The bicarbonate hazard is based on the concept of residual sodium carbonate (RSC), as shown by the formula RSC = $(HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$. As all the waters analysed have an RSC less than 66.2 mg/l they are safe for irrigation. Boron does not exist in high enough concentrations to be toxic.

Groundwaters on Norfolk Island are suitable for small-scale irrigation as they have low SAR ratios, salinities, bicarbonate, and boron. Although more data is required on the physical nature of the weathered zone, soils appear to be well drained and strongly leached in the upper portion of the profile. With deeper water-tables outside valleys, swampy and waterlogged

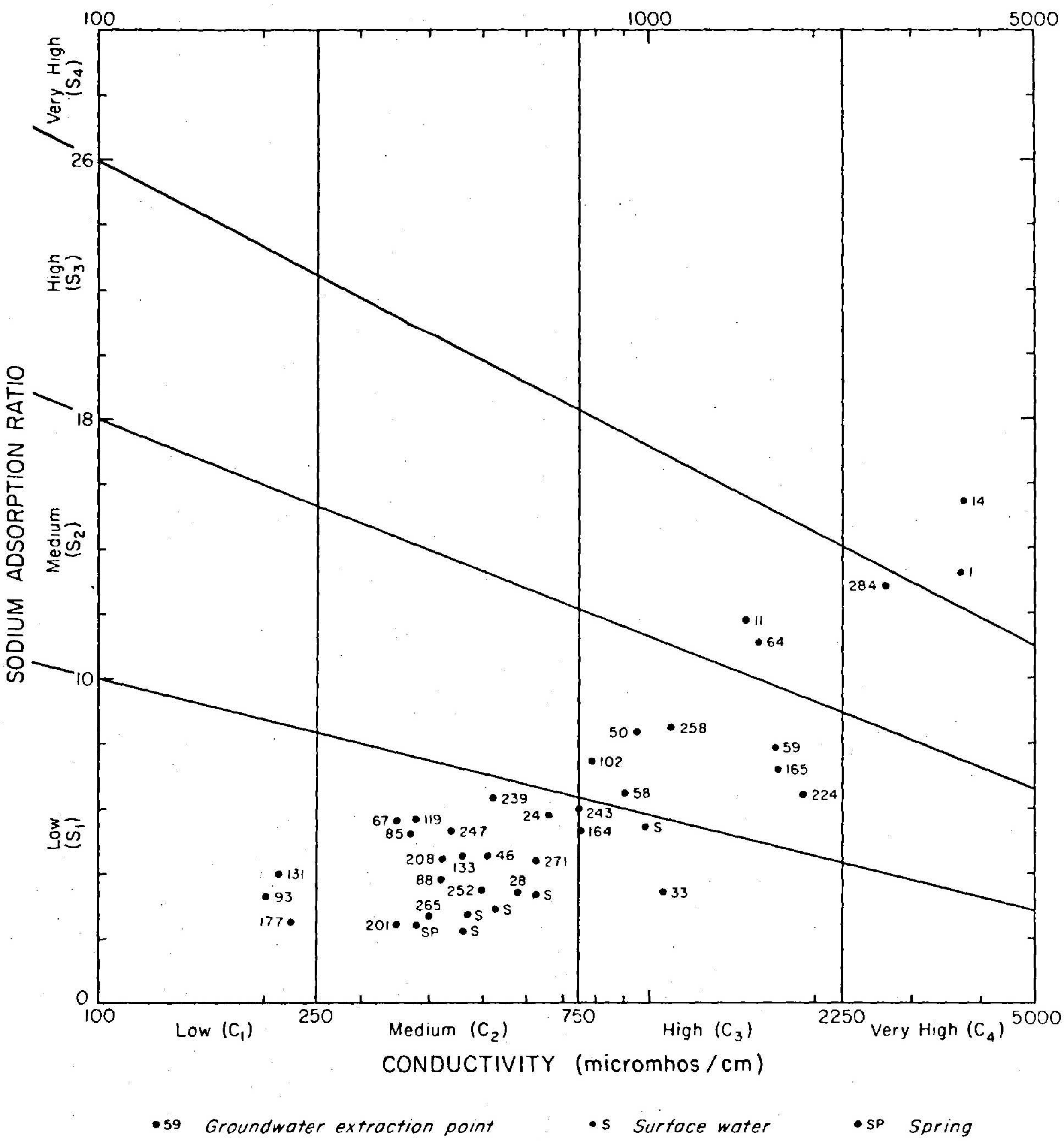

Fig. 19 Classification of irrigation waters

conditions are unlikely to occur. At present, only a few bores can maintain sufficiently high yields over considerable time intervals for irrigation schemes to be practicable. Provided that sufficient groundwater is available, that crops grown are of the right type, and that attention is paid to irrigation management techniques and to the method of application of water to the soil, then irrigation can be practised.

Surface water

Analyses of surface water are given in Appendix 3. The ratio of different ions in the analyses show that surface and groundwater are closely linked. Surface waters normally have close to neutral pH values, low salinities, and low nitrate values. The lower salinities encountered reflect a short retention time for groundwater constituting baseflow in streams. As might be expected salinity values increase downstream, with the lower-salinity surface waters associated with pereníally flowing streams. The most saline surface water measured in the field was in Ball Bay Creek where a field conductivity value reached 1400 micromhmos.

Generally the quality of surface water is very good in the larger catchments and is suitable for all uses. At present there is a danger of surface water pollution from free wandering livestock; the swamps in some stream sections have trapped livestock on occasions. To assist pollution control surface water extraction points should be protected by a shelter or fence.

POLLUTION

For groundwater that is being pumped from a bore or well and intended for human consumption, proper precautions should be taken to protect the purity of water. Matters relating to water pollution are covered by a Health Ordinance (1913-1969) under Health (general) Regulations as set out in the Government Gazette for May 1973.

Many of the older wells on the island are close to pit latrines or septic tanks, which pose a pollution threat to domestic water use. New bores should be located at least 30 m from and, where possible, on the uphill side of waste disposal structures.

Whenever a well is abandoned, for whatever reason, it should be sealed either by filling it in with earth or rubble or by constructing a concrete top if it is likely to be used again in the future. Even wells in use should be protected from surface contamination by being raised off the ground and having an appropriate board or seal across the top. Open abandoned wells are common on Norfolk Island, and poor sealing means that they are potential accident hazards. Many old wells are sealed or protected only by pierced steel planting (PSP), which is often rusted and unsafe.

At least four old abandoned wells are being used for dumping rubbish, such as bottles, tin cans, and household garbage. This is a deplorable practice, especially as a waste disposal area exists at Headstone. In an environment supporting a mean rainfall of 1335 mm/yr the weathered mantle holds enough moisture to dissolve or carry along metals, chemicals, and bacteria from any solid waste disposal in wells, pits, or natural gulleys. If such leachate is allowed to accumulate in large quantities, it poses a potential pollution threat, as many of the abandoned wells are in recharge areas where there is a dominantly vertical movement of groundwater.

All watering points should be adequately fenced or covered for protection from the weather, wandering livestock, rodents, and birds. Bores in use should be adequately sealed with a 1.5 m concrete plug, and the pump should be mounted on a properly constructed concrete base which is raised sufficiently to stop contamination from surface sources down the outside of the casing or through the top of the bore.

Bacteria

Pathogenic organisms such as bacteria and viruses are a potential pollution hazard. A program of water sampling for bacteriological analysis has been carried out on the island since 1970. According to D. Kruger (pers. comm.) samples collected to date have not shown any significant contamination of underground water supplies by pathogenic organisms. Analyses are available from the A.C.T. Health Services, Canberra.

Nitrate

Nitrate levels (Appendix 3) are related to high livestock densities in and around watering points or at diary farms. Additional nitrate comes from the disposal of domestic waste. The microbiological transformation of this waste oxidizes organic nitrogen through amino acids to ammonia and then to nitrites and finally nitrates, a process favoured by aerobic conditions (in the presence of oxygen). Some plants take up nitrate for protein use, but the remainder passes downwards towards the water-table. Where there is restricted groundwater in circulation near the base of the weathered mantle, nitrate may be reduced under anaerobic conditions (without oxygen) to nitrogen which can escape back into the atmosphere.

The distribution of nitrate-rich waters on Norfolk Island is uneven. All waters contain some nitrate, but only in one place is the limit for domestic use (Table 7) exceeded (NI 133). Out of a total of 34 water samples, 11 -all from wells rather than bores - have nitrate values exceeding 10 mg/l. As wells are open to the weathered mantle over much of their depth they are more susceptible to nitrate contamination than bores, which normally seal off with plain casing a large proportion of the weathered mantle below the water-table.

High nitrate concentrations may occur only in the upper portion of the saturated zone, where groundwater moves seasonally in aerobic conditions. In bores, which are usually completed to bedrock, anaerobic conditions are more likely to occur, except along active fracture zones when aerobic conditions may locally develop.

Sanitary waste

The sodium chloride content of groundwater is probably due in part to saline septic-tank waste moving to the water-table. Figure 11 shows that groundwater in the weathered mantle not lost as base flow or passing to deeper levels tends to circulate in a closed system. During the summer, when groundwater demand is high, the constant re-use of shallow groundwater increases salinity levels and reduces water quality. Current chloride levels over most of the island are still within reasonable limits (Appendix 3; Table 7) except where the groundwater is contaminated by sea water, dissolved salts from oceanic spray, and sanitary waste disposal. Samples were analysed for the presence of detergent, which however, was not detected and all values were within appropriate limits (< 0.2 mg/l Azure A).

The entry and movement of sanitary waste into the ground is subject to prevailing hydrogeological conditions. As the upper part of the weathered mantle is unconfined and porous, infiltrating rainfall can carry surface and sanitary waste material into the ground where there is no protection of the surface by buildings and roads. After the effects of evaporation, sanitary waste moves by gravity through the unsaturated zone to the water-table. The rate and direction of movement depends on the nature of the waste material, local hydraulic conditions in the weathered mantle, and any local pumping effects. As sanitary waste moves to the water-table it is attenuated by filtration, chemical alteration, dilution, and dispersion.

The physical properties of the unsaturated weathered mantle can effect considerable natural purification of sanitary waste before it reaches the water-table. The porous clay acts as a filtering agent to remove bacteria, undissolved solids, and some dissolved inorganic chemical contaminants; it will not, however, remove sodium chloride. The removal of bacteria and suspended solids is likely to clog the pores of clay immediately surrounding a septic tank or pit latrine, although fluids may still pass to deeper levels. Experiments show soils can remove bacteria from water. The removal process is mainly physical: by mechanical straining and settling in fine intergranular spaces. As bacteria move over grain surfaces, they can be killed by oxygen in contact with water in pore spaces. The rate of percolation in the unsaturated zone, and the life span of the organism, determine the distance the organism will travel. When introduced into a new environment of the unsaturated zone bacteria may die because temperature, food, moisture, and pH factors are not favourable to their growth.

To minimize the potential threat of pollution, septic tanks should be properly constructed, maintained in good repair, and emptied at frequent intervals. This would help to lessen the health risk of sanitary waste introduced into the ground. Only the South Pacific Hotel and Polynesian Motel operate sewage effluent plants for the disposal of waste.

The ratio of chloride to bicarbonate has been used in an attempt to delineate areas of the island where a pollution threat from sanitary waste may occur. Chloride-bicarbonate ratio contours (Enclosure, Map 4) show a narrow plume of moderately high values combined with high nitrate concentration stretching northeast across the Burnt Pine/Middlegate area and the head-waters of Watermill Creek. The locally high chloride values suggest that low-scale contamination of groundwater by sanitary waste is taking place. It is stressed that a much more stringent water sampling program would be needed to isolate in more detail the source, nature, and extent of the pollution. At this stage chloride and nitrate concentrations are not at harmful levels, but the Burnt Pine/Middlegate area, which supports a high density of population, needs to be closely monitored. At Kingston and other local areas at the perimeter of the island, the high chloridebicarbonate ratios are due to seawater or seaspray contamination.

A full-scale water quality sampling program should be undertaken to ascertain the sources and degree of groundwater pollution on Norfolk Island. In island environments, human waste disposal presents considerable problems. Although present dependence on groundwater on Norfolk Island is not high it will increase in future. In an environment where waste disposal is mainly through a septic-tank system the future possibility of polluted groundwater supplies must be considered. Measures to prevent pollution as far as possible should be implemented before costly remedies have to be considered to rehabilitate groundwater resources after pollution has occurred. As a general rule waste disposal should be directed to areas where pollution cannot harm groundwater. The possibilities of a reticulation scheme for the disposal of sewage effluent, with an outlet to the sea, should be seriously considered for the densely populated areas in the Burnt Pine/Middlegate complex.

WATER BALANCE

The components of the water balance and their interaction with one another is shown in Figure 11. The purpose of studying the water balance is to quantify as far as possible the factors affecting groundwater development. As there is a dearth of hydrogeological data, an estimate of the water balance for groundwater in the weathered mantle was undertaken to assess the availability of groundwater passing to deeper levels on the island. Any groundwater surplus obtained from the water balance equation would probably move from the weathered mantle towards sea level, where it might accumulate as basal groundwater before discharge as submarine seepages.

As Norfolk Island is small, has relatively low relief, and is isolated, a point water balance is probably satisfactory. A computer water-balance model WATBAL (Keig & McAlpine, 1974) was made available through CSIRO (Division of Land Use Research) by the co-operation of P.M. Fleming.

The equilibrium of the natural hydrological cycle has been altered progressively since the island was first settled in 1788. By 1810, a quarter of the land had been cleared of dense forest for agriculture. At present much more of the natural forest vegetation has been cleared (Fig. 4) or thinned to create pasture. The result of land clearing is evident from the annual water balance (Fig. 20), which shows different potential evaporation and groundwater recharge rates under pasture and forest.

The water balance estimate is based on the equation Rainfall (P) = Potential evaporation (PE) + Groundwater discharge (D) $\pm$ changes in groundwater storage (S).

Rainfall

Rainfall on Norfolk Island is the main agent of groundwater recharge. Figure 21 is a graph of total yearly rainfall between 1890 and 1974. The graph indicates that the rainfall has fluctuated considerably, even between successive years.

The size and subdued relief of the island suggest that the rainfall record of one station adequately reflects the rainfall regime. A comparison between the official rainfall record at the airport and data collected by G.C. Duvall at map reference 890 843 suggests that for the latter half of 1972, 1973, and early 1974 there was remarkably close agreement in the amount of rainfall recorded over the southern plateau. Both stations are on the south side of the island 3 km apart. Any differences in readings between the stations are probably due to measuring techniques and slight environment changes. Rainfall is unlikely to be greatly affected by altitude changes. The average height of the plateau is about 100 m, and the area above 200 m is small (Fig. 5). Only the Kingston lowland and lower reaches of Watermill Creek lie below 20 m. Rainfall on the forested hill slopes in the Mount Pitt reserve will perhaps be only slightly higher than at the airport.

An analysis of rainfall data was made to see if the record could be used as an indicator of drought. Rainfall can be expressed in terms of deciles, each of which is a tenth-part of the total number of annual rainfall records. The first decile range contains the lowest 10 percent of annual records. According to Gibbs & Maher (1967), annual rainfalls occurring below the first decile range constitute years of drought. For Norfolk Island, rainfalls of less than 1006 mm/annum would constitute drought years, with many wells and some bores drying out. Decile 5 is the median rainfall in which 50 percent of the annual records is either above or below 1320 mm, and decile 9 is the 90 percent decile in which 10 percent of the rainfall exceeds 1778 mm. Deciles 1, 5, and 9 as calculated from all available years of rainfall records by the Bureau of Meteorology, Melbourne, are shown on the yearly rainfall graph (Fig. 21). A serial correlation plot of successive years of annual rainfall (Fig. 22) shows a wide scatter of points, but suggests that wet years tend to occur singly and dry years in sequence.

<u>Potential evaporation</u>

Direct evaporation takes place from surface water storages and other forms of open water. At the time of the survey there were no pan evaporation records at the meteorological station, so that open water evaporation had to be estimated from climatic data*. Evaporation losses from open water are small compared with potential evaporation due to a thick vegetation cover on the island.

* Since the survey has been completed measurements of open water evaporation have been started at the meteorological station as from 1st November, 1975. This will enable more accurate estimates of potential evaporation to be made in the future.

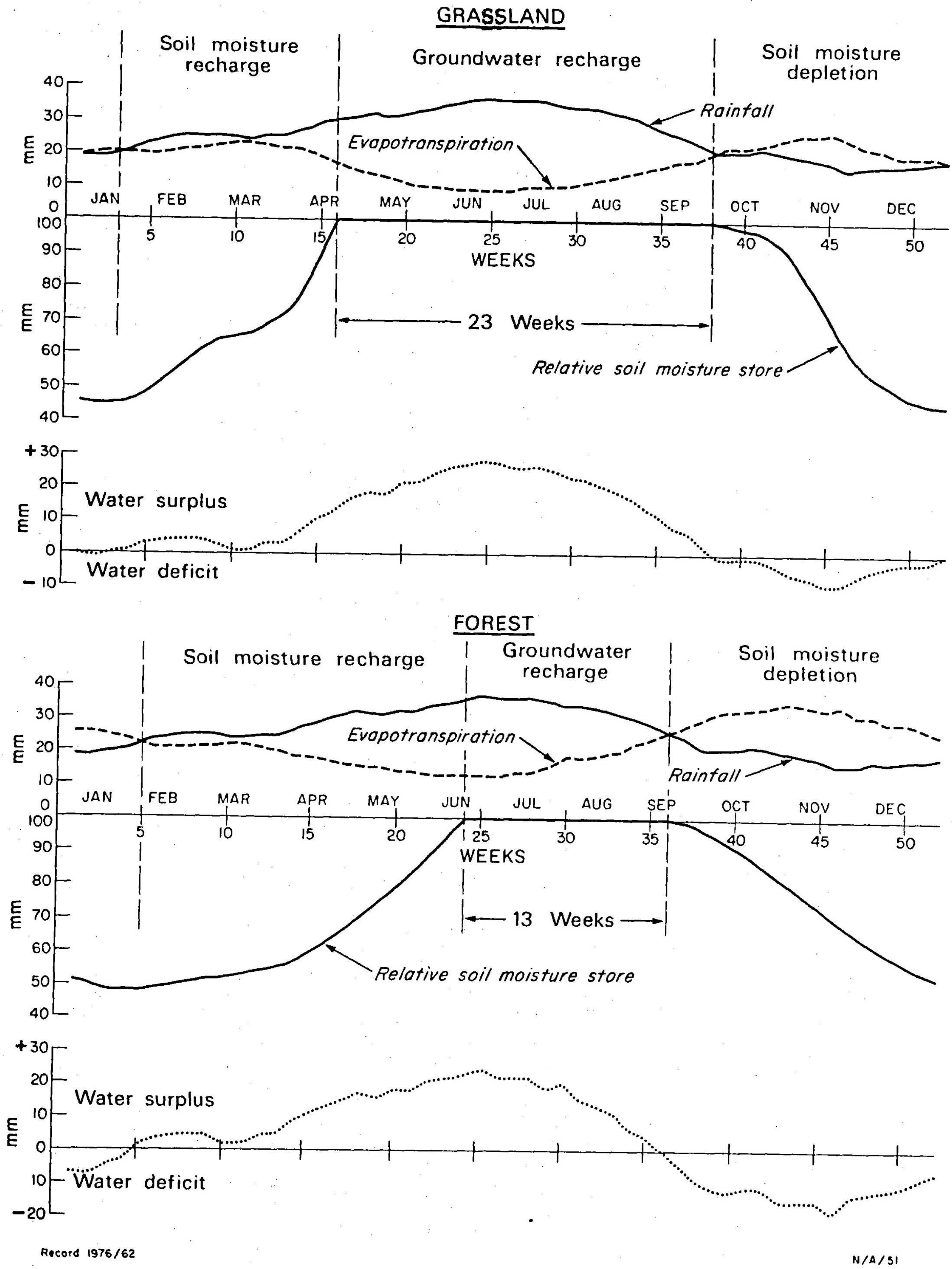

Fig. 20 Annual water balance

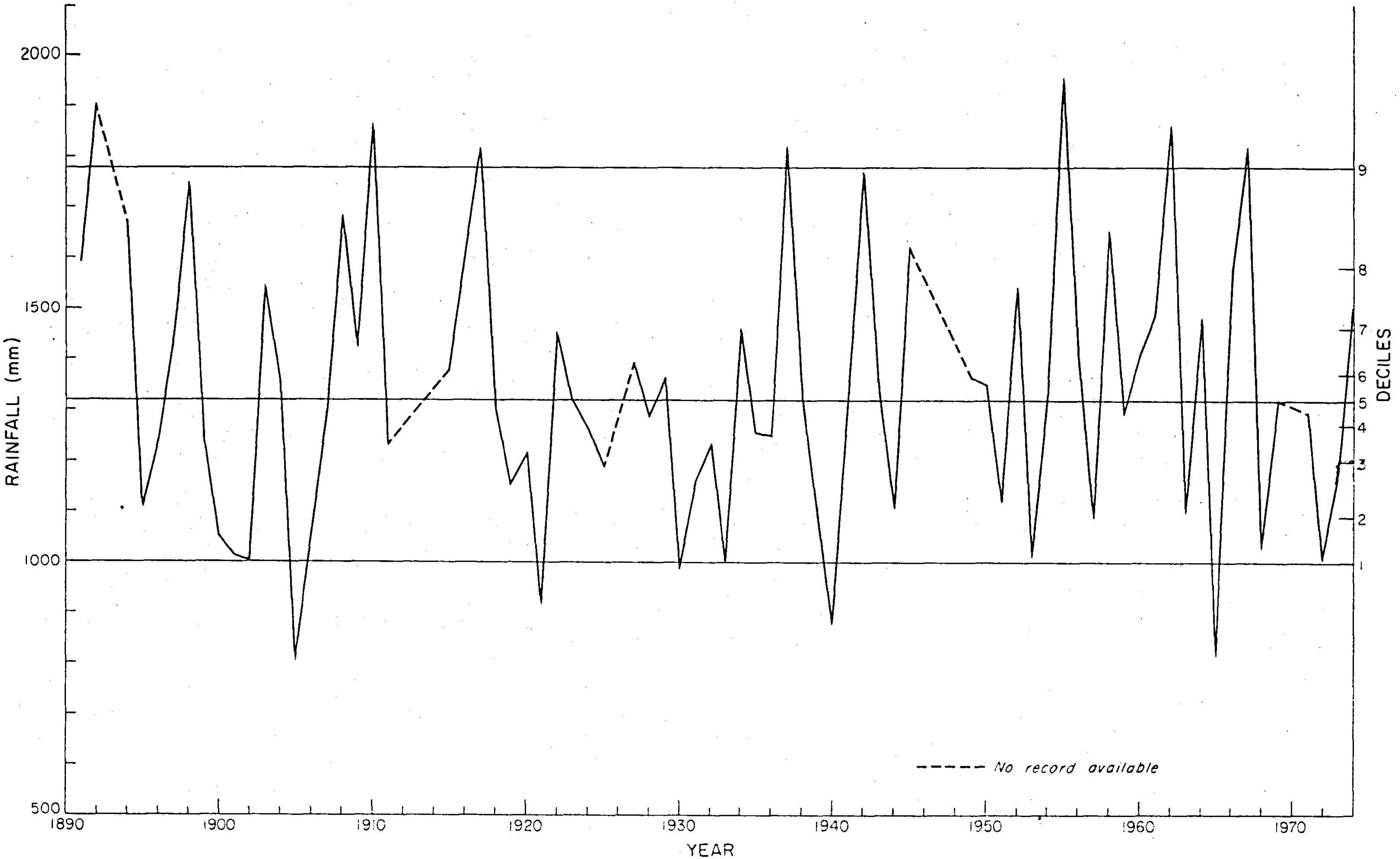

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Fig. 21 Total yearly rainfall, 1890 - 1974

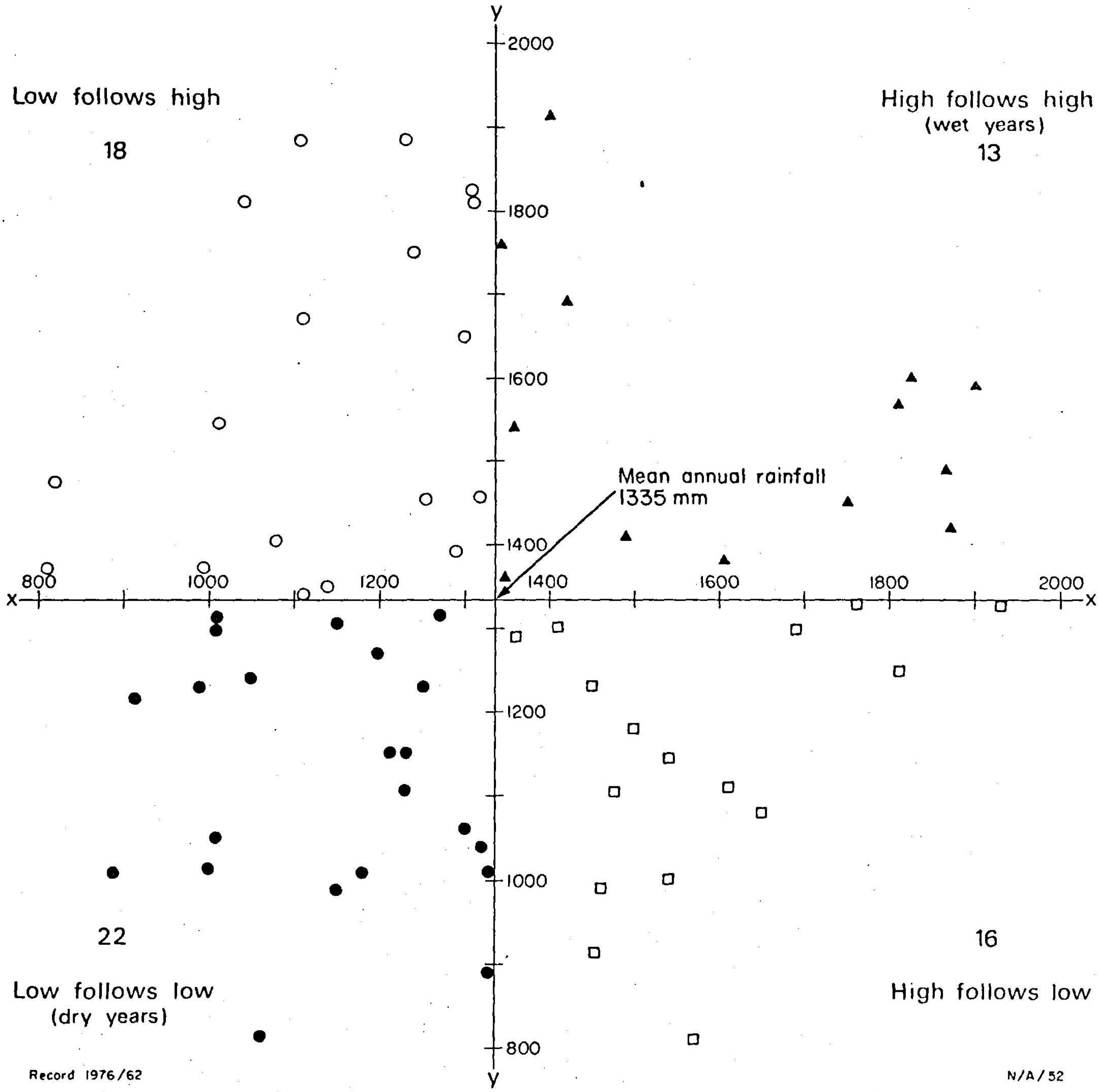

Fig. 22 Serial correlation of successive years of rainfall

The first attempt at estimating potential evaporation for the island was made by Stephens & Hutton (1954), and was based on a method developed by Prescott, Collins, & Shirpurkar (1952). They arrived at an annual potential evaporation value of 777 mm for grassland and 1037 mm for forest. The method was reapplied during this study using a further 20 years of climatic data and a more accurate assessment of relative humidity from wet and dry bulb temperature data. This gave an annual potential evaporation of 794 mm for grassland and 1058 mm for forest.

In the present study, potential evaporation estimates for the water balance are based on the Penman equation for open-water evaporation (Appendix 4). The data was processed by program WATBAL and printed out as weekly values of potential evaporation. The results show an annual potential evaporation of 925 mm for grassland and 1174 mm for forest, using a mean rainfall of 1324 mm. These higher values are considered to be a truer reflection of potential evaporation on the island than the values obtained from the Prescott method, which probably provide no more than a lower limit. The use of the Penman equation pays greater attention to the annual cycle in solar energy.

Runoff

The runoff data available for Watermill Creek between June 1949 and June 1950, is plotted as a hydrograph showing mean daily stream discharge data (Enclosure, Graph 1). The gauging location was a concrete weir at Watermill dam which measured discharge from a catchment area of 240 ha. The catchment is mainly grassed, except in its higher reaches where there is open forest.

Strong peaks on the runoff hydrograph are taken to be brief surface runoff events after intensive rainfall. A component analysis of the hydrograph indicates that more than 70 percent of stream discharge comes from groundwater. The stream discharge data responds to any lengthy period without rainfall, with a minimum being recorded in February-March 1950. Strong rainfall peaks that correspond with strong runoff peaks indicate intensive rainfall of short duration with high surface runoff.

There is a lack of runoff data on Norfolk Island, and, for a more accurate assessment of the water balance, a stream gauging network would have to be established on perennial and seasonal catchments on the island.

Groundwater recharge

A long-term mean water balance for forest and grassland for 1890-1974 (Fig. 20) was estimated using computer program WATBAL. These graphs, which show that a water deficit exists in summer and a water surplus in winter, are compatible with field observations and runoff data for 1949-50.

During summer there is soil moisture depletion as potential evaporation exceeds rainfall for both forest and grassland. Soil moisture recharge begins towards the end of summer, when rainfall exceeds potential evaporation. In forested areas, soil moisture recharge builds up more slowly than in grassland areas because WATBAL assumes that the root system in forest areas taps a greater depth of soil and therefore requires a greater soil moisture store.

When the relative soil moisture store is at 100, soils are at field capacity and cannot accept further increments of moisture. In these conditions, groundwater recharge occurs. Groundwater recharge usually takes place in winter months, although the time depends on the amount of rainfall and on the vegetation pattern. Cyclonic storms may cause water surpluses in summer. Figure 24 shows that the average length of recharge time to grassed areas of the weathered mantle is 23 weeks/year; for forest it is 13 weeks/year. Computer runs for a very wet year, as for example, 1955, show that, for grassland, recharge took place over 27 weeks in the winter and 2 weeks in December, but only 22 weeks in forested areas. In a very dry year, as for example 1965, groundwater recharge in grassland areas spanned only 10 weeks and in forest there was none at all.

Daily rainfall data relating to the observed runoff data (collected by the Commonwealth Department of Works (NSW Branch) between June 1949 and June 1950), and the long-term mean potential evaporation for a grassland catchment, which was obtained from program WATBAL using the same daily rainfall data converted to weekly data, were used to estimate a water balance for Watermill Creek (Enclosure, Graph 1). The water balance graph produced simulates extremely well the observed runoff data. The water surplus obtained was 495 mm, which is more than twice the measured discharge of 239 mm over the same period. Hence more than 50 percent of the water surplus is assumed to pass to groundwater storage. Watermill Creek is reasonably representative of perennial catchments on Norfolk Island, but, as most creeks tend to dry out in summer months, it is likely that much more than 50 percent of the water surplus could be apportioned to groundwater storage in non-perennial catchments on the southern plateau.

Norfolk Island has been divided into two water balance areas, as shown in Figure 4. The northern area includes the northwest plateau and elevated terrain around Mount Pitt and Mount Bates; it is characterized by forest and poor runoff. The southern area corresponding with the southern plateau and Kingston lowland is mainly grassland with moderate runoff. Losses due to groundwater extraction were ignored in the water-balance equation because most of the groundwater passes back into the ground as sanitary waste. Losses due to groundwater discharge from the weathered mantle amount to baseflow and high-level coastal spring discharge. Water balance calculations, for northern and southern areas of the island may not have a precise balance on both sides of the equation owing to soil moisture assumptions made in program WATBAL.

Water balance for the <u>northern area</u>

P (Rainfall) = PE (Potential Evaporation) + S (Groundwater storage).

1324 mm = 1174 mm + 184 mm

There is no appreciable baseflow, and losses due to high-level coastal seepage are assumed to be about 5 percent of groundwater storage, which is 9.2 mm. This makes 174.8 mm available for groundwater storage in the weathered mantle. The northern area has a size of 12.25 km^2 (1.2×10^7 m^2), so that the volume of groundwater recharge to the weathered mantle is 0.17 x $1.2 \times 10^7 = 2.0 \times 10^6$ m^3/annum.

Water balance for the <u>southern area:</u>

P = PE + D (Groundwater discharge) + S

1324 mm = 925 mm + 215 mm + 215 mm.

Water-balance studies in Watermill Creek suggest that about 50 percent of a water surplus of 430 mm is apportioned to baseflow, with the remainder passing to groundwater storage. Also, high-level coastal seepage is assumed to account for 10 percent of groundwater storage, which is 21.5 mm. This makes 193.5 mm available for groundwater storage in the weathered mantle. The southern area has a size of 22.75 km^2 (2.3×10^7 m^2), so that the volume of groundwater recharge is 0.19 x $2.3 \times 10^7 = 4.3 \times 10^6$ m^3/annum.

The total volume of groundwater recharge to the weathered mantle is $4.3 \times 10^6 + 2.0 \times 10^6 = 6.3 \times 10^6$ m^3/annum, which is equivalent to about 14 percent of the mean annual rainfall on the island. It is assumed that this quantity of groundwater is available to move from the weathered mantle to sea level. A small proportion of this amount (about 10%) is discharged through low-level coastal seepages, and the remainder, an estimated 5.7×10^6 m^3/annum, accumulates as basal groundwater. As groundwater recharge (6.3×10^6 m^3/annum) exceeds total water use on the island (2.4×10^5 m^3/annum) sufficient groundwater exists to satisfy normal water demands, even allowing for reasonable population and economy growth over the next few years. However, appropriate water resources management techniques should be applied.

CONCLUSIONS

1. The main aquifer presently exploited on the island is the porous weathered mantle, which has considerable groundwater storage capacity. A high water-table and sluggish seepage discharge suggest that the aquifer has only moderate permeability. A full assessment of the water-bearing properties of the weathered mantle has been hindered by the general lack and poor quality of hydrological data.

2. An estimate of the water balance using long-term hydrometeorological data suggests that - after the needs of stream flow, evapotranspiration, and coastal spring losses - about 14 percent of average annual rainfall is available for groundwater recharge. This suggests that enough groundwater exists within the weathered mantle to satisfy normal water demands over the next few years and that a surplus is available that could accumulate as a basal groundwater body.

3. Owing to the paucity of hydrogeological data the full extent of groundwater aquifer at and below sea level has yet to be assessed. Although basal groundwater in calcareous aeolianite may be tapped locally by a few wells and bores on the Kingston coastal plain, the exploitation of basal groundwater in the remainder of the island requires further exploration and ultimately careful development. The accumulation of basal groundwater below sea level is favoured by an apparent lack of coastal seepages near sea level, which suggests that groundwater movement beneath the weathered mantle has a strong vertical component. Volcanoclastic rocks and fractures in the fresh volcanic sequence may provide a permeability distribution capable of supporting a basal groundwater body.

4. Basal groundwater could be investigated by drilling in the following areas: near the northern and southern boundaries of the nucleus and apron; the main volcanic vent below Mount Pitt; the coastal lowland at Kingston; and near Steels Point. Apart from favourable hydrogeological conditions these locations are accessible to agricultural land and residential areas.

5. Groundwater from the weathered mantle is generally of good quality, and is suitable in most wells and bores for domestic use. Groundwater pollution due to seawater contamination and to the disposal of refuse and of sanitary and livestock waste is not yet a widespread problem.

6. Large-scale surface water-storage schemes cannot be seriously considered at this stage because the weathered mentle is porous and stream flow data is lacking. Perennial catchments would only appear to be able to support small-scale development of surface water either by direct pumping or from small properly constructed surfaces storages.

RECOMMENDATIONS

Owing to the paucity of groundwater data, only a preliminary appraisal of the island's groundwater resources is possible. Although a groundwater supply below sea level is likely, its development requires further hydrogeological investigations.

Exploration to determine groundwater potential of the island

To enable a comprehensive assessment of the island's groundwater potential to be made, the following information is required: (a) thickness variations in the weathered mantle; local thicknesses might be related to the interpretation of fracture zones (b) the thickness and extent of basaltic tuff beds (Fig. 8) that might store and provide supplies of groundwater (c) the nature and extent of a permeable breccia and its storage characteristics, and the depth to fresh water near sea level.

This information could be most economically acquired by a geophysical survey followed by a program of exploratory drilling. A geophysical survey should be directed to areas where hydrogeological evidence suggests that groundwater supplies are likely. The easiest and most practicable geophysical method that could be used on Norfolk Island would be resistivity traversing and depth probing. Resistivity surveys should be supplemented where necessary by gravity, seismic, and magnetic techniques, which would help to calibrate the resistivity data and confirm any findings made by this method. Geophysical bore-logging would be useful in the initial stages. A deep bore at the South Pacific Hotel (NI 138), and other bores, could be used to give control to the interpretation of geophysical data.

The evaluation of groundwater potential by locating off-shore seepages by thermal infrared imagery has doubtful value, largely because fairly strong year-round winds, heavy swells, and a steeply shelving shoreline mix sea water and fresh water, and thus probably mask the temperature and salinity contrasts between them.

The results of the geophysical surveys should indicate the most suitable sites for about 8 exploratory holes which might prove the existence and nature of an aquifer below sea level. The investigations should be supervised by appropriate professional staff, and the drilling and test pumping program should be undertaken by an experienced water-well drilling company.

The behaviour and potential for water-supply purposes of a basal groundwater aquifer would have to be examined under a carefully controlled test pumping program in which the changes in groundwater level at different pumping rates would be measured and analysed. Water quality should be monitored to assess appropriate pumping conditions whereby groundwater remains uncontaminated by seawater intrusion. At the completion of drilling, the bores could be used for either water supply or observation.

Control of bore siting and drilling procedure

An application for a permit to construct a bore or well should be lodged with the Administration. Although the present application form covers some of the necessary items such as a description of the property, it needs to be expanded to cover in more detail the proposed use, yield, depth, and construction material of the bore or well. At the completion of drilling, a bore completion form should record drilling technique, water intersections, casing, and pump test details. These forms should be completed on site by a competent person authorized by the Administration to undertake the task.

The modern water-bore drilling methods practised on the Australian and New Zealand mainlands are unfamiliar on Norfolk Island, where there is a lack of experienced drillers. Percussion drilling is recommended because this type of rig can be easily worked and maintained in the remote environment of Norfolk Island. It is suggested that the Administration ask for an experienced water well driller to visit the island to advise on present water-bore drilling methods. Special attention needs to be given to the drilling equipment in use, the most appropriate technique to suit the hydrogeological conditions on the island, and finally well development and completion techniques.

Introduction of groundwater legislation

Groundwater legislation is likely to become necessary in the future as an expanding population and greater numbers of tourists increase the demands on groundwater.

Apart from land held in leasehold tenure by the Crown, about 50 percent of the island is freehold property, which entitles a landowner to the ownership of the groundwater beneath his land. Similarly with surface water, if a landowner has access to a stream, he can exercise absolute water rights over the length of stream bordering his property.

At present there is inadequate legislation to protect the quality, quantity, and use of groundwater. For proper long-term management of Norfolk Island's water resources, the Administration should take a much larger share of the responsibility for the development of all water resources. In a report on a water-resources investigation of Norfolk Island Eden (1965) outlined basic proposals for legislation of water supplies.

Legislation does not have to mean that landowners lose their rights to groundwater and surface water, but rather it is a measure to protect the resource so that sufficient is available for all and its use is reasonably controlled. The purpose of legislation is to protect groundwater from depletion and to prevent and control any pollution.

If a deeper groundwater source is exploited in the future, the depth of drilling and the quantity of water pumped ought to be restricted. As part of the groundwater management techniques that will be necessary to protect groundwater from being overdeveloped and contaminated by seawater, some form of groundwater legislation will be necessary. Similarly, in drought conditions or other kinds of emergency, legislation could restrict pumping and make water available to those who cannot obtain it.

Owing to the severe fragmentation of land that has taken place since the island was settled, parts of the island now have a dense concentration of bores and wells, particularly the Burnt Pine/Middlegate area (Enclosure, Map 3). Legislation can have practical importance for the protection of individuals competing for groundwater where falling water-levels caused by overpumping may set up interference between closely spaced bores.

Most Australian States have adopted legislation that generally requires a property owner or occupier to obtain a licence or permit before he drills, alters, or deepens a bore or well. Some preliminary steps should be taken by the Administration to investigate what kind of legislation will best serve the needs of Norfolk Island.

Pollution control

A more extensive program of groundwater sampling is needed to study in more detail the chemical composition of groundwater on Norfolk Island. Rainwater samples should be collected and analysed to assess their initial cyclic salt concentration. This would help towards a better interpretation of the groundwater salinity pattern on the island.

As there is widespread disposal of sanitary waste through a septic-tank system, water quality should be monitored at frequent intervals to check the possible threat of groundwater pollution. A groundwater sampling program should be undertaken to study and report on a possible pollution threat to water supplies on Norfolk Island.

Surface water

Runoff is an important component in the water balance as it represents a water loss from the island. To quantify the volume of runoff would allow a more accurate estimate of groundwater in storage, as well as a better understanding of water-balance processes. For water-supply purposes, a stream gauging program over several years would be useful to assess what proportion of annual rainfall is lost by stream flow to the sea; this would include the regular gauging of all major streams, so that such data is available when needed for long-term water resource planning.

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The writer wishes to record his thanks to the Administrator Air Commodore E.T. Pickerd, officers of the Administration, and the people of Norfolk Island for their interest, co-operation, and assistance during the course of the survey.

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Professor J.J. Veevers and Dr J.G. Jones of Macquarie University, Sydney, gave advice and made available information on the geology of Norfolk Island. Mr P.M. Fleming of CSIRO processed climatic data for the water balance and helped interpret the results. Messrs I. Mason and K.E. Winters of the Commonwealth Bureau of Meteorology, Canberra, interpretated rainfall data and compiled wind roses.

The author is grateful to many colleagues at the Bureau of Mineral Resources for their helpful suggestions and advice.

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APPENDIX 1

The modern coastal sedimentary rock complex of Norfolk and Nepean Islands

By Professor J.J. Veevers, (Macquarie University, Sydney).

During the course of a general geological study of Norfolk Island and adjacent islands (Jones & McDougall, 1973; Coleman & Veevers, 1971), the modern complex of sediments outcropping along the coast of Norfolk Island near Kingston and on Nepean Island was examined (Fig. A).

Cross-bedded calcarenite, at least 35 m thick, makes up the entire emerged part of Nepean Island (Plate A), and is exposed near Kingston along the coast between the jetty and the cemetery and in a few disused quarries east of Government House. The calcarenite comprises fragments of shallow marine organic skeletons (corals, algae, *Halimeda*, bryozoa, foraminifera, and molluscs - see Stephens & Hutton, 1954, p. 6). Most of the exposed calcarenite is strongly cemented and leached, and some of it is dolomitized. The distinctive cross-bedding suggests that this calcarenite is an aeolianite. A radiocarbon age (GaK* - 3478) of 21 650 ± 700 years B.P. for a specimen of unleached and uncemented calcarenite (NV3B) implies that the aeolianite was deposited during the last low stand of the sea at the end of the Pleistocene (Curray, 1965). The intertidal platform shown in Figure 1 is probably aeolianite bevelled by the sea and subsequently veneered by living coral. Azimuths of cross-dips of the aeolianite suggest that the sand-depositing wind blew generally from the south. The interpretation differs from that of Hutton & Stephens (1956), who regarded this calcarenite as a makatea or a remnant of an uplifted probably Miocene fringing coral reef.

The aeolianite is overlain by a few metres of black organic clay and beachrock calcarenite. The black clay is best exposed between tide-marks on the beach in front of the cemetery (locality 5; Fig. A, Plate B). As shown by hand-drilling, it is at least 2.5 m thick and rests on basalt; whether the basalt is in place or is in the form of boulders was not ascertained. The clay contains hydrogen sulphide gas, and excellently preserved fossils of the Norfolk Pine (*Araucaria heterophylla*), or a closely related species, in the form of logs several metres long, leaves, and fruits. A radiocarbon age (GaK-34795) of 6870 ± 230 years B.P. was determined on a specimen of exposed wood

* Determination by Professor K. Kigoshi, Gakushuin University, Tokyo; based on radiocarbon half-life of 5570 years.

within 50 cm of the top of the clay. The occurrence in the clay of pieces of pumice up to 20 cm across suggests that the clay was deposited in a coastal lagoon that was occasionally open to the sea, and consequently crudely marks contemporary sea level. As the eustatic sea level at the time the clay was deposited (6870 ± 230 years B.P.) was within a few metres of its present level (Thom & Chappell, 1975), at least this part of Norfolk Island has been fairly stable since that time. The only other known localities of clay are about 400 m east of the jetty (localities 12 and 17; Fig. A). The clay is overlain by, and probably interfingers with, calcarenite, which because it dips seaward parallel to the surface of the sand beach along which it is exposed, is interpreted as beachrock.

Three beds are distinguishable in the beachrock complex near the cemetery (localities 4 and 15) and one south of Kingston (Fig. B). In descending stratigraphical order, they are:

C: brown massive calcarenite with fossils, rounded boulders of basalt, and angular blocks of aeolianite. A radio-carbon age (GaK - 3480) of 1450 ± 90 years B.P. for a well-preserved coral from locality 8 is consistent with the stratigraphic position of this bed above the clay. Another radiocarbon age (GaK - 3483), of 8130 ± 150 years B.P. for a specimen of calcarenite from locality 15, is interpreted as indicating that old material, derived probably from the aeolianite, was shed into carbonate sand provided by newly dead organisms;

B: grey-yellow thin-bedded calcarenite, which likewise has a high apparent age (GaK - 3482: locality 15: 15 800 ± 400 years B.P.); it disconformably overlies

A: massive calcarenite, whose radiocarbon age of 5460 ± 400 years B.P. (GaK - 3481; locality 15), while being consistent with stratigraphic superposition, is probably invalid for the same reasons as the high apparent ages of calcarenite samples from B and C.

This is a reconnaissance report of the modern coastal sediments. Further work should be done, particularly on the palynology of the black clay, in an attempt to cast light on the climatological history of Norfolk Island and the surrounding oceanic region for which Norfolk Island is the only accessible locality.

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I thank Mr. G.C. Duvall, for help and hospitality; Air-Commodore R.N. Dalkin, the then Administrator, for kindly arranging boat transport to and from Nepean Island; Dr J.G. Jones, for

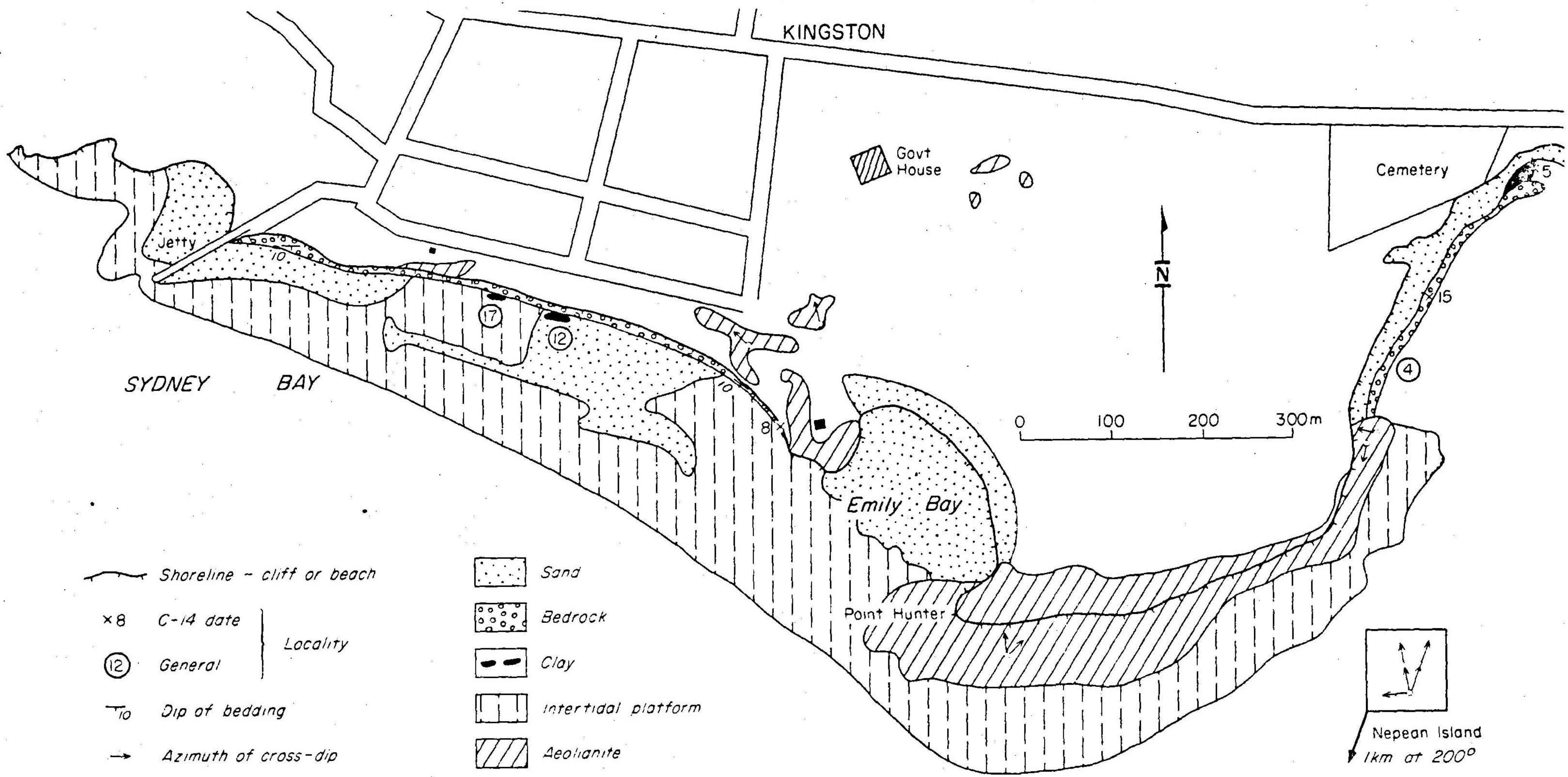

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Fig. A Kingston area of Norfolk Island showing distribution of modern coastal sediments. Unmarked areas covered by soil (Stephens & Hutton, 1954 ; Hutton & Stephens, 1956). The Steels Point Basalt (Jones & McDougall, 1973) crops out in the western and eastern edge of the mapped area.

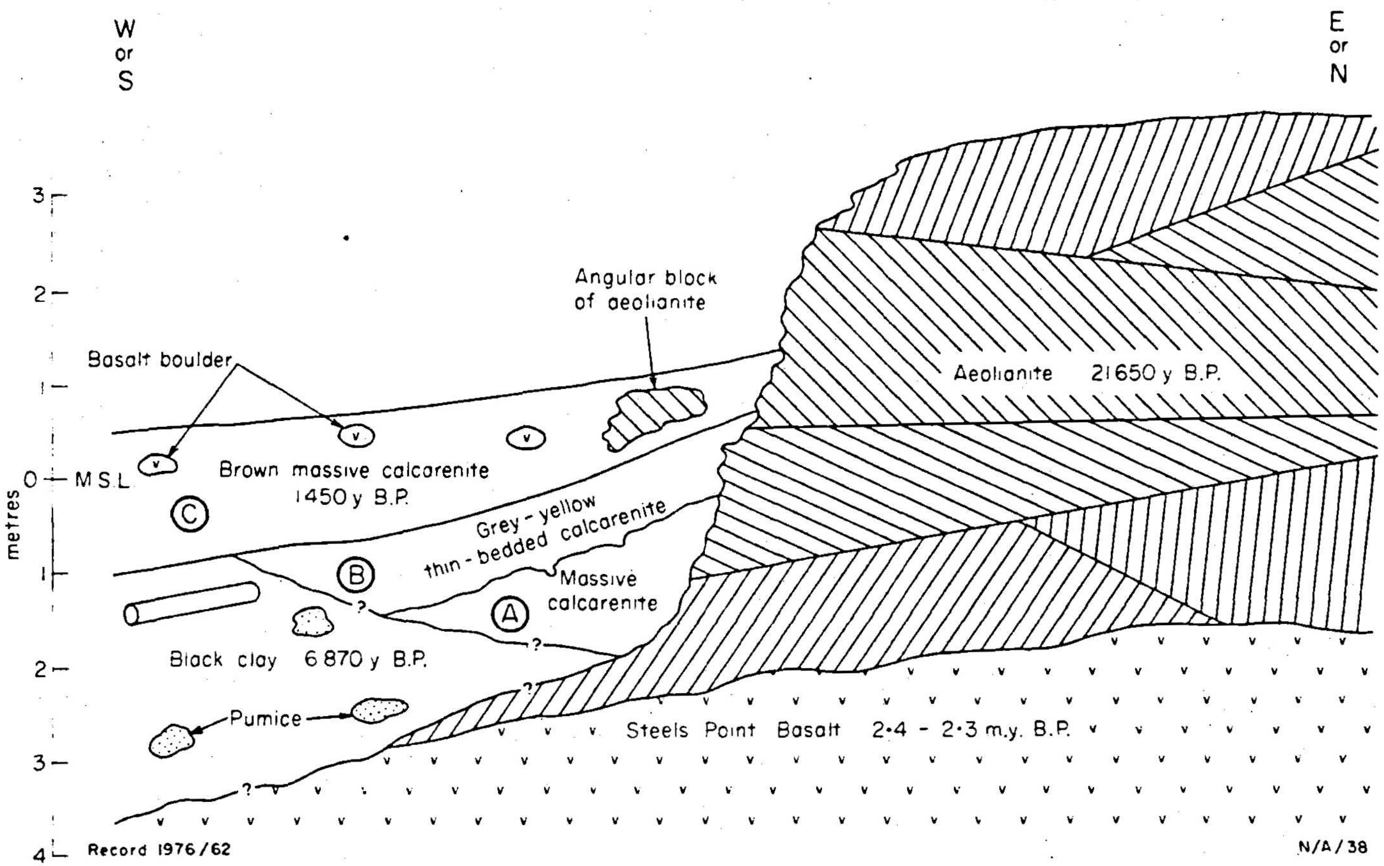

Fig. B Schematic stratigraphic section of the modern coastal sedimentary rocks. The Steels Point Basalt is described by Jones & McDougall (1973).

Appendix 1 - PLATES.

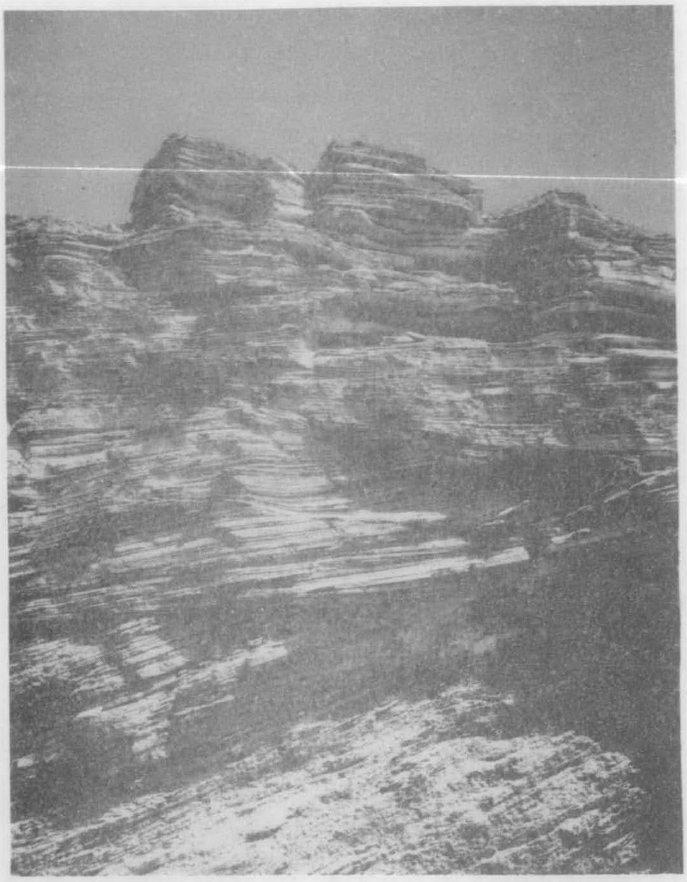

PLATE A - Cross-bedded aeolianite on Nepean Island. Field of view 10 m wide

PLATE B - Close up of log partly exhumed from black clay. Beach adjacent to the cemetery.

valuable discussion in the field and in the office, and Dr. R.J. Blorg for reviewing the manuscript. The work was supported by a Macquarie University research grant.

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APPENDIX 2

INVENTORY OF WELLS AND BORES ON NORFOLK ISLAND

NUMBER	OWNER	LOCATION	TYPE	ELEVATION ABOVE SEA LEVEL (metres)	DEPTH (metres)	WATER LEVEL BELOW SURFACE (metres)	DATE	YIELD (litres/hr)	PUMP TYPE	POWER	FIELD CONDUCTIVITY (micromhos)	STATUS	USE	TOPOGRAPHIC SETTING	CASING DIAMETER (metres)	CASING DEPTH FROM SURFACE (metres)	CASING TYPE	LITHOLOGY	REMARKS
NI 1	B.H. BURELL	844885	Well	88	43	32	19/7/74	1080	E	PE	4250*	0	D,S	I	1.4	2.3	CS	VB	
NI 2	J. DALE	844865	Bore	87	29	Dry	18/7/74	-	-	-	-	A	-	I	0.1	-	GI	VB	
NI 3	J. DALE	845885	Bore	88	40*	-	18/7/74	540	VD	PE	5500	0	D,S	I	0.1	-	PVC	VB	Pump Intake 37 m
NI 4	B.H. BURELL	843884	Well	85	34	25	19/7/74	2430	E	PE	8500*	0	D,S	I	1.4	1.8	CS	VB	
NI 5	J. RYVES	843881	Well	67	12	6	18/8/74	2430	HD	E	540	0	S	V	1.8	1.2	CS	VB	
NI 6	M. LAING	849881	Bore	94	29*	27	19/7/74	-	E	PE	-	(A)	D,S,G	I	.2	-	M	VB	Pump Intake 26 m
NI 7	J. CHRISTIAN	848879	Well	94	29	25	28/8/74	810	VD	E	1500	0	S	I	1.2	1.2	CS	VB	Observation well
NI 8	J. RYVES	845879	Bore	78	52*	10*	18/7/74	1125 (Est)	VD	E	1000	0	D,S,I	V	0.1	-	PVC	VB	
NI 9	P. EVANS	846878	Bore	87	52*	-	17/7/74	1350	M	E	1200	0	D	V	0.1	-	PVC	VB	
NI 10	R. FITZGERALD	846878	Bore	85	50*	-	30/8/74	2160	ES	E	1225	0	D,G	V	0.1	-	M	VB	Completed 1966
NI 11	R. FITZGERALD	845876	Well	94	25	23	30/8/74	-	-	-	1400*	A		I	-	-	S	VB	Site of old Kingfisher Hotel Observation Well
NI 12	F.E. CLARKSON	848875	Well	101	34	Dry	28/8/74	-	-	-	-	A	-	I	-	-	CS	VB	
NI 13	F.E. CLARKSON	849872	Well	110	32*	Dry	22/7/74	-	-	-	-	A	-	I	-	-	CS	VB	
NI 14	G. ADAMS	846870	Bore	94	53*	6	17/7/74	270	M	E	5000*	0	D,G	V	0.1	-	PVC	VB	
NI 15	G. QUINTALL	846869	Well	73	24	15	22/7/74	-	-	-	-	A	-	V	1.7	1.5	C	VB	
NI 16	G. QUINTALL	846864	Well	73	16	14	19/7/74	-	-	-	-	A	-	V	1.5	1.8	CS	VB	
NI 17	G. QUINTALL	844862	Bore	76	64*	28	19/7/74	720*	-	-	-	(A)	S	V	0.1	46(PL) 64(SL)	PVC	VB	Deepened 1975
NI 18	S. NAGLE	847859	Well	77	11	4	22/7/74	-	-	-	-	A	-	V	1.5	-	S	VB	Rock at 11 m
NI 19	B. CHAPMAN	849856	Well	72	41	Dry	22/7/74	-	-	-	-	A	-	V	-	-	S	VB	
NI 20	A.F. SUMMERSCALE	847854	Well	61	21	12	22/7/74	810	VD	PE	250	0	D,S	V	-	-	S	VB	
NI 21	MELANESIAN MISSION	848847	Well	72	31	20	28/8/74	-	-	-	-	A	-	I	1.4	1.5	CS	VB	
NI 22	MELANESIAN MISSION	849847	Well	73	23	23	28/8/74	-	-	-	-	A	-	I	1.4	1.2	CS	VB	
NI 23	MELANESIAN MISSION	846846	Well	69	20	19	28/8/74	-	-	-	-	A	-	I	1.4	0.9	CS	VB	Observation well
NI 24	MELANESIAN MISSION (Vicarage)	847846	Well	70	22	19	24/7/74	810	VD	PE	675*	0	D,G	I	1.5	1.6	CS	VB	

2.

NUMBER	OWNER	LOCATION	TYPE	ELEVATION ABOVE SEA LEVEL (metres)	DEPTH (metres)	WATER LEVEL BELOW SURFACE (metres)	DATE	YIELD (litres/hr)	PUMP TYPE	POWER	FIELD CONDUCTIVITY (micromhos)	STATUS	USE	TOPOGRAPHIC SETTING	CASING DIAMETER (metres)	CASING DEPTH FROM SURFACE (metres)	CASING TYPE	LITHOLOGY	REMARKS
NI 25	MELANESIAN MISSION (Vicarage)	847846	Well	72	22	21	24/7/74	-	-	-	-	A	-	I	1.5	-	S	VB	
NI 26	B. CREE	848845	Bore	78	55*	-	24/7/74	1350	VD	E	500	O	D,G	I	0.1	-	PVC	VB	
NI 27	DCA (Department of Civil Aviation)	849845	Well	82	31	29	14/7/74	-	-	-	-	A	-	I	1.8	-	S	VB	
NI 28	E.J. LLOYD	844842	Well	74	22	20	24/7/74	-	-	-	CA	(A)	S	I	1.5	1.5	GI	VB	
NI 29	P. CUSTANCE	843837	Bore	79	44	21	23/7/74	-	-	-	-	A	-	I	0.1	18 (PL) 42 (SL)	PVC	VB	Rock at 45 m
NI 30	P. CUSTANCE	845833	Bore	73	44	26	23/7/74	-	-	-	-	A	-	I	0.1	19 (PL) 31 (SL)	PVC	VB	Rock at 39 m
NI 31	V. GAVRILOFF	849830	Well	79	31	23	29/7/74	-	-	-	-	A	-	I	1.5	1.5	CS	VB	
NI 32	G. ADAMS	851879	Bore	94	41*	30	17/7/74	495	E	PE	1000*	O	S	I	0.1	-	PVC	VB	Pump intake 39 m Rock at 39 m
NI 33	J. HAYES	855879	Bore	136	79*	-	19/7/74	675	VD	E	800*	O	D,G	I	0.1	-	PVC	VB	Rock at 61 m
NI 34	D. KLASSEN	851875	Bore	107	29	Dry	16/7/74	-	-	-	-	A	-	I	-	-	UL	VB	
NI 35	D. KLASSEN	851875	Bore	107	27	13	19/7/74	-	-	-	-	A	-	I	-	-	UL	VB	
NI 36	D. KLASSEN	850876	Bore	105	42	Dry	16/7/74	-	-	-	-	A	-	I	-	-	UL	VB	
NI 37	D. KLASSEN	850876	Bore	107	40	37	19/7/74	-	-	-	-	A	-	I	-	-	UL	VB	
NI 38	D. KLASSEN	850875	Bore	155	34	Dry	19/7/74	-	-	-	-	A	-	I	-	-	UL	VB	Rock at 27 m
NI 39	J.W. FITZPATRICK	853876	Bore	98	39	20	13/7/74	-	-	-	-	A	-	V	-	-	UL	VB	
NI 40	V. ALSTON	859858	Bore	122	37	Dry	29/7/74	-	-	-	-	A	-	V	0.1	-	PVC	VB	
NI 41	F.H. RYAN	850853	Bore	61	30	Dry	29/7/74	-	-	-	-	A	-	V	-	-	UL	VB	
NI 42	F.H. RYAN	851852	Bore	67	49*	-	29/7/74	910	VD	E	350	O	G	V	-	-	S	VB	
NI 43	P. CUSTANCE	855851	Bore	110	59	44	23/7/74	-	-	-	-	A	-	I	0.1	33 (PL) 63 (SL)	PVC	VB	Rock at 62 m
NI 44	UNKNOWN	857851	Bore	113	61*	-	24/7/74	270	VD	E	1050	O	S	I	-	-	S	VB	
NI 45	D. SANDERSON	857852	Bore	119	56*	46*	23/7/74	810	M	E	430	C	D	I	0.1	37 (PL) 55 (SL)	PVC	VB	Pump intake 55 m
NI 46	D. DAVIDSON	859852	Bore	143	74*	46*	24/7/74	450	VD	E	550*	O	D,G	I	0.1	-	PVC	VB	Rock at 73 m
NI 47	D. SOUTH	861849	Well	69	5	3	15/8/74	3240	C	PE	- 340	O	G	V	-	-	UL	VB	

NUMBER	OWNER	LOCATION	TYPE	ELEVATION ABOVE SEA LEVEL (metres)	DEPTH (metres)	WATER LEVEL BELOW SURFACE (metres)	DATE	YIELD (litres/hr)	PUMP TYPE	POWER	FIELD CONDUCTIVITY (micromhos)	STATUS	USE	TOPOGRAPHIC SETTING	CASING DIAMETER (metres)	CASING DEPTH FROM SURFACE (metres)	CASING TYPE	LITHOLOGY	REMARKS
NI 48	T. DUFFET	859845	Bore	110	49*	-	15/6/74	270	VD	E	375	O	S,G	I	-	-	S	VB	Rock at 21 m
NI 49	F. COKER	851837	Bore	93	32	23	28/6/74	-	-	-	-	A	-	I	0.1	-	PVC	VB	
NI 50	D. BOOTH	852837	Bore	98	49*	27*	27/6/74	720	VD	E	825*	O	G	I	-	-	S	VB	
NI 51	K. BULL	854837	Well	102	30	24	26/7/74	1350	VD	PE	650	O	G	I	-	-	S	VB	
NI 52	P. CUSTANCE	851832	Bore	90	47	22	23/7/74	-	-	-	CA	A	-	I	0.1	30 (FL) 46 (SL)	PVC	VB	Rock at 47 m Observation bore
NI 53	J. BROWN	851830	Well	85	25	20	23/7/74	810	E	PE	500	O	D	I	1.5	-	S	VB	
NI 54	A. NOBBS	852831	Bore	90	30	21	25/7/74	-	-	-	-	A	-	I	-	-	UL	VB	Rock at 30 m
NI 55	W.H.F. EDWARDS	854832	Well	96	28	18	29/7/74	-	-	-	-	A	-	I	1.2	1.2	CS	VB	
NI 56	G. PLANT	855832	Well	98	26	21	26/7/74	1080	VD	E	275	O	G	I	1.5	-	GI	VB	
NI 57	Mr V.A. NOBBS Ms C.L. DONKIN	859834	Well	107	32	25	24/7/74	2970	VD	DE	-	O	D,G,S,	I	-	-	S	VB	
NI 58	B. BONIFACE	853825	Well	29	7	5	25/7/74	1350	E	E	750*	O	D,G	V	0.3	1.3	GI	VB	
NI 59	G. WOOLLEY	850828	Bore	87	43*	-	25/7/74	1080	VD	E	1600*	O	S	I	0.1	-	PVC	VB	
NI 60	J. NOBBS	851827	Bore	86	30	Dry	25/7/74	-	-	-	-	A	-	I	0.1	-	PVC	VB	Rock at 35 m
NI 61	A. NOBBS	855829	Well	50	6	1	25/7/74	1080	HD	DE	750	O	D,G	V	1.5	0.9	C	VB	
NI 62	G. RICHARDS	860832	Bore	76	14	1	25/7/74	1125	E	E	425	O	Ia	V	-	-	UL	VB	Rock at 15 m
NI 63	M. FOOTE	856827	Bore	43	30*	-	25/7/74	15750 (Est)	H	E	675	O	S,S	V	0.2	-	N	VB	Rock at 27 m
NI 64	H.D. BRUCE	855826	Bore	51	47*	-	25/7/74	810	VD	E	1200*	O	D,G	I	-	-	S	VB	Pump intake 43 m Completed 1972
NI 65	S. NOBBS	857822	Well	75	32	29	25/7/74	-	-	-	-	A	-	I	1.5	0.9	CS	VB	
NI 66	V. ALSTON	850857	Bore	160	76*	Dry	24/7/74	-	-	-	-	A	-	I	0.1	-	PVC	VB	
NI 67	[illegible] VINCENT	854852	Bore	120	52*	-	16/8/74	115	VD	E	325*	O	D	I	0.1	-	PVC	VB	Completed 1972
NI 68	J. RAWSON	854852	Bore	120	47*	-	16/8/74	540	VD	E	650	O	D	I	-	-	S	VB	
NI 69	A.H. PARTRIDGE	855850	Well	110	16	15	19/8/74	-	-	-	-	A	-	I	1.4	1.5	CS	VB	
NI 70	NORFOLK ISLAND HOSPITAL	858850	Well	111	47	36	19/8/74	-	-	-	260	A	-	I	-	-	S	VB	Observation well
NI 71	E.S. NOBBS	863852	Bore	117	49*	-	19/8/74	810 (Est)	VD	E	-	O	D	V	0.1	-	PVC	VB	Rock at 49 m
NI 72	E.S. NOBBS	862853	Bore	122	41	35	19/8/74	-	-	-	-	A	-	V	-	-	UL	VB	Rock at 49 m

NUMBER	OWNER	LOCATION	TYPE	ELEVATION ABOVE SEA LEVEL (metres)	DEPTH (metres)	WATER LEVEL BELOW SURFACE (metres)	DATE	YIELD (litres/hr)	PUMP TYPE	POWER	FIELD CONDUCTIVITY (micromhos)	STATUS	USE	TOPOGRAPHIC SETTING	CASING DIAMETER (metres)	CASING DEPTH FROM SURFACE (metres)	CASING TYPE	LITHOLOGY	REMARKS
NI 73	NORFOLK ISLAND HOSP.	869851	Well	73	2	S	19/8/74	350	HD	E	300	0	D	V	1.4	-	UL	VB	
NI 74	F.V. GIDLEY	860847	Well	111	27	18	15/8/74	540	VD	E	325	0	D	I	-	-	S	VB	
NI 75	V.W. SANDERS	861848	Bore	110	42	26	15/8/74	-	-	-	-	A	-	I	0.1	-	PVC	VB	
NI 76	V.W. SANDERS	861847	Bore	113	25*	13*	1/7/75	1350	-	-	-	0	S	I	0.1	19(PL)	PVC	VB	Rock at 19 m Deepened 1975
NI 77	V.W. SANDERS	861847	Well	111	19	14	15/8/74	540	E	E	1400	0	S	I	1.2	1.4	C	VB	
NI 78	K. BOWELL	861845	Bore	107	35*	-	15/8/74	945	VD	E	440	0	D	I	0.1	-	PVC	VB	Rock at 17 m
NI 79	D. SMITH	853853	Bore	83	35	24	19/8/74	-	-	-	-	A	-	V	0.1	-	PVC	VB	Rock at 37 m
NI 80	J.F. GORDON	853848	Bore	104	57	53	15/8/74	-	-	-	-	A	-	I	0.1	-	PVC	VB	Rock at 55 m
NI 81	J. FITZPATRICK	863847	Well	110	22	14	15/8/74	675 (Est)	C	E	-	0	D	I	1.2	1.2	CS	VB	
NI 82	W. BLUCHER	864848	Well	111	20	15	16/8/74	585	VD	E	325	0	D	I	1.2	1.2	C	VB	
NI 83	R. FARRELL	865848	Well	108	17	13	16/8/74	675 (Est)	VD	E	-	0	D,G	I	-	-	S	VB	
NI 84	G. RUTHERFORD	865848	Bore	113	41*	18*	16/8/74	295	VD	E	210	0	D,G,	I	0.1	-	PVC	VB	
NI 85	AIRPORT (DCA)	862843	Well	107	28	21	29/7/74	3375	VD	E	400*	0	G	I	1.4	-	S	VB	
NI 86	I. NOBBS	865844	Well	104	26	19	16/8/74	Small	BH	M	-	0	D,G	I	1	1.5	CS	VB	
NI 87	H. JACKSON	865844	Well	85	2	S	16/8/74	1125 (Est)	HD	E	-	0	D,G	V	-	-	UL	VB	
NI 88	B. CHRISTIAN	869843	Well	73	5	3	22/8/74	1620	VD	PE	360*	0	D,G	V	-	-	S	VB	
NI 89	R. SPREAG	867846	Well	111	24	16	16/8/74	585	VD	E	510	0	D,S,G	I	1.4	1.2	CS	VB	
NI 90	J. MAWSON	868849	Well	113	22	15	19/8/74	2700 (Est)	ES	E	-	0	D,G	I	1.4	1.5	CS	VB	
NI 91	D. ADAMS	869849	Well	113	16	14	19/8/74	-	-	-	-	A	-	I	-	-	S	VB	
NI 92	R.A. BATTAILLE	870847	Well	104	12	4	19/8/74	1125 (Est)	E	E	-	0	D,G	V	1.2	0.9	C	VB	
NI 93	K.J. MITCHELL	869846	Well	110	21*	13	20/8/74	1620	VD	E	300*	0	D	I	-	-	S	VB	
NI 94	K. NOBBS	853839	Well	91	5	3	15/8/74	1080 (Est)	HD	E	400	0	D	V	1.2	1.2	C	VB	
NI 95	E. CHRISTIAN	864840	Well	81	2	S	15/8/74	1080	HD	E	225	0	D	V	-	-	UL	VB	
NI 96	SOUTH PACIFIC HOTEL	869839	Bore	61	18*	-	27/8/74	4500	HD	E	300	0	D,S	V	-	-	S	VB	
NI 97	K.H. McINTYRE	869839	Bore	59	24*	-	28/8/74	15750 (Est)	M	E	325	0	I	V	0.1	-	PVC	VB	
NI 98	SOUTH PACIFIC HOTEL	869839	Bore	61	3	2	27/8/74	-	-	-	-	A	-	V	-	-	UL	VB	

MBER	OWNER	LOCATION	TYPE	ELEVATION ABOVE SEA LEVEL (metres)	DEPTH (metres)	WATER LEVEL BELOW SURFACE (metres)	DATE	YIELD (litres/hr)	PUMP TYPE	POWER	FIELD CONDUCTIVITY (micromhos)	STATUS	USE	TOPOGRAPHIC SETTING	CASING DIAMETER (metres)	CASING DEPTH FROM SURFACE (metres)	CASING TYPE	LITHOLOGY	REMARKS
NI 99	CONVICT STABLES	861833	Well	110	55	27	26/7/74	-	-		-	A	-	I	1.8	1.8	CS	WB	Observation well
I 100	J. MAWSON	862833	Bore	111	55*	-	24/7/74	1350	VD	E	725	0	D,G	I	0.2	-	PVC	WB	Completed 1973
I 101	R.D. DEADMAN	862832	Bore	110	55*	-	22/7/74	-	-	-	-	(A)	D,G	I	0.1	-	PVC	WB	Pump intake 46 m
I 102	L. COOPER	860828	Bore	94	63*	-	25/7/74	595	VD	PE	525*	0	D,G	I	0.1	-*	PVC	WB	Rock at 61 m
I 103	E.A. STARTIN-FIELD	862826	Well	88	43	38	26/7/74	-	-	-	-	A	-	I	1.5	1.5	CS	WB	
I 104	H. McCOY	863822	Well	72	51	35	26/7/74	Small	B/H	M	-	0	G	I	1.2	1.2	CS	WB	
I 105	I. BUFFETT	865830	Well	94	61	36	26/7/74	160 (Est)	E	PE	-	0	G	I	-	-	S	WB	
I 106	C.H. MENGHETTI	865828	Bore	93	49*	-	26/7/74	90*	VD	E	-	0	D,G	I	-	-	S	WB	
NI 107	A. ARDIMANNI	865827	Bore	91	55*	-	26/7/74	-	-	-	-	A	-	I	0.1	-	PVC	WB	Rock at 54 m
NI 108	R CAMPION	866827	Well	91	54	38	26/7/74	-	-	-	-	A	-	I	-	-	S	WB	
NI 109	G. HANDSCHIROW	868628	Well	88	20	Dry	26/7/74	-	-	-	-	A	-	I	-	-	UL	WB	
NI 110	D. HUDSON	879864	Well	116	8	16	22/9/74	-	-	-	-	A	-	V	-	-	UL	WB	
NI 111	S. QUINTALL	870857	Well	134	45	Dry	27/8/74	-	-	-	-	A	-	I	1.4	1.5	CS	WB	
NI 112	P. PATTERSON	874855	Well	85	18	Dry	28/8/74	-	-	-	-	A	-	V	1.5	1.5	C	WB	
NI 113	B. GRUBE	876855	Well	73	20	16	29/8/74	-	-	-	-	A	-	V	1.4	0.9	CS	WB	Rock at 18 m
NI 114	B. McKENZIE	676853	Bore	67	40*	-	14/8/74	540	M	DE	375	0	D,G,I	V	0.1	21 (PL) 18 (SL)	PVC	WB	Rock at 37 m Pump intake 38
NI 115	B. McKENZIE	876853	Well	67	8	3	14/8/74	-	-	-	-	A	-	V	-	-	UL	WB	Observation well
NI 116	R.G. REEVES	877850	Bore	111	39	16	13/8/74	-	-	-	-	A	-	I	0.1	-	PVC	WB	
NI 117	HIBISCUS FLATS	873851	Well	111	23	15	13/8/74	1125 (Est)	E	E	-	0	D	I	1.4	1.8	CS	WB	
NI 118	E. JUPP	874850	Well	111	21	14	14/8/74	-	-	-	-	A	-	I	1.2	1.2	CS	WB	
NI 119	D. EVANS	876850	Well	114	20	13	13/8/74	1080	C	E	300*	0	D,G	I	-	-	S	WB	
NI 120	E. F. YEAMAN	879750	Well	110	25*	22	13/8/74	1800 (Est)	HD	PE	-	0	D	I	1.4	1.2	C	WB	
NI 121	L.V. NOLA	877849	Well	116	24	16	14/8/74	1080	VD	E	80	0	D,G	I	-	-	S	WB	
NI 122	PINE VALLEY FLATS	874848	Bore	114	32*	13	14/8/74	13500 (Est)	ES	E	-	0	D	I	0.1	-	PVC	WB	Pump intake 25 m
NI 123	POLYNESIAN MOTEL	874848	Bore	110	43*	10	14/8/74	13500 (Est)	ES	E	200	0	D,G	I	0.1	-	PVC	WB	Pump intake 33 m Drilling completed 1970
NI 124	VALLEY VIEW RESTAURANT	873848	Bore	110	38*	-	15/8/74	180	VD	E	300	0	D,G	I	0.1	-	PVC	WB	
NI 125	POLYNESIAN MOTEL	873849	Well	101	8	4	14/8/74	-	-	-	-	A	-	V	1.2	-	UL	WB	

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NI 126	RAWSON HALL	870849	Well	113	18	13	19/8/74	-	-	-	-	A	-	I	-	-	S	VB	Observation well
NI 127	D GRAHAM	871848	Bore	113	20	12	19/8/74	-	-	-	-	A	-	I	0.1	8 (PL) 20 (SL)	PVC	VB	Rock at 17 m
NI 128	D GRAHAM	871848	Well	113	16	12	19/8/74	-	-	-	-	A	-	I	1.2	0.8	CS	VB	
NI 129	BOWLING CLUB	872847	Well	111	15	11	19/8/74	-	-	-	-	A	-	I	-	-	S	VB	
NI 130	T. MATHYS	874847	Bore	111	15*	10*	20/9/74	900*	VD	E	-	O	G	I	0.1	14 (SL)	PVC	VB	Rock at 12 m
NI 131	T.E. YAEGER	876847	Bore	117	49*	-	14/8/74	810	VD	E	180*	O	G	I	-	-	S	VB	Rock at 34 m
NI 132	E. CORBETT	872845	Well	111	21	12	20/8/74	540 (Est)	E	E	-	O	D	I	-	-	S	VB	
NI 133	C.J. CAMERON	871845	Well	111	24	13	19/8/74	1620	VD	E	450*	O	D,S,G	I	-	-	S	VB	
NI 134	K. PRENTICE	871844	Bore	82	24*	4*	26/8/74	2250	M	PE	325	O	D	V	0.1	-	PVC	VB	
NI 135	F. MENSHETTI	873845	Bore	111	27*	-	20/8/74	565	VD	E	500	O	D,S	I	-	-	S	VB	
NI 136	SOUTH PACIFIC HOTEL	874843	Well	113	19	13	20/8/74	-	-	-	-	A	-	I	-	-	S	VB	
NI 137	K. PRENTICE	872842	Well	113	24	23	26/8/74	-	-	-	-	A	-	I	1.4	1.5	CS	VB	
NI 138	SOUTH PACIFIC HOTEL	873841	Bore	119	103*	-	28/8/74	-	-	-	-	O	SE	I	0.1	-	PVC	VB	Lost circulation at drilling
NI 139	D. TANNER	875846	Bore	113	34*	-	20/8/74	610	VD	E	300	O	D	I	0.1	-	PVC	VB	*Ends in rock*
NI 140	R. BARRATT	875846	Bore	116	29*	-	20/8/74	1080	VD	E	260	O	D,G	I	-	-	S	VB	Ends in rock
NI 141	C.I. BUFFETT	875845	Well	113	25	15	20/8/74	810	E	E	300	O	D,G	I	1.2	1.9	CS	VB	
NI 142	M. DOURAN	875844	Well	111	18	15	20/8/74	-	-	-	-	A	-	I	1.4	1.8	C	VB	
NI 143	S. RAAM	875844	Well	110	15	15	20/8/74	-	-	-	-	A	-	I	1.2	1.5	C	VB	
NI 144	RSL CLUB	875844	Bore	111	37*	-	20/8/74	450	VD	E	260	O	D	I	-	-	S	VB	Rock at 33 m
NI 145	B CHRISTIAN-BAILEY	876842	Well	102	4	2	20/8/74	1620	HD	E	260	O	D,G	V	-	-	S	VB	
NI 146	M. BAILEY	877843	Bore	103	18*	-	22/8/74	1350	VD	E	375	O	D	V	-	-	S	VB	
NI 147	M. BAILEY	877843	Well	103	3	1	22/8/74	-	-	-	-	A	-	V	1.4	-	C	VB	
NI 148	M. BAILEY	877841	Well	119	21	16	22/8/74		VD	E	-	(A)	S G	I	1.2	1.2	CS	VB	
NI 149	J. MAWSON	879841	Bore	122	49*	17	22/8/74	1350 (Est)	VD	E	-	O	D	I	-	-	S	VB	Pump intake 46 m
NI 150	J. HILL	880840	Bore	126	31*	-	22/8/74	540	VD	E	275	O	G	I	0.1	-	PVC	VB	Rock at 30 m
NI 151	P. ANDERSON	871840	Bore	73	21*	1	21/8/74	13500 (Est)	M	DE	375	O	G	V	0.1	-	PVC	VB	
NI 152	G. PARK	875839	Well	119	22	19	21/8/74	1560	E	E	170	O	G	I	1.4	0.6	CS	VB	Rock at 15 m
NI 153	E. FRASER	879840	Bore	126	34*	-	22/8/74	540	VD	E	360	O	D,G	I	0.1	-	PVC	VB	Bore completed in 1970 Pump intake 30 m

NUMBER	OWNER	LOCATION	TYPE	ELEVATION ABOVE SEA LEVEL (metres)	DEPTH (metres)	WATER LEVEL BELOW SURFACE (metres)	DATE	YIELD (litres/hr)	PUMP TYPE	POWER	FIELD CONDUCTIVITY (micromhos)	STATUS	USE	TOPOGRAPHIC SETTING	CASING DIAMETER (metres)	CASING DEPTH FROM SURFACE (metres)	CASING TYPE	LITHOLOGY	REMARKS
I 154	CHERYL TRUST	879838	Bore	126	22	21	23/8/74	-	-	-	-	A	-	I	-	-	UL	WB	Rock at 24 m
I 155	G.R. FINDLEY	877838	Well	117	26	19	22/8/74	1620	VD	E	280	0	D	I	-	-	S	WB	
I 156	G. BAILEY	876836	Well	87	8	S	22/8/74	1125 (Est)	HD	E	475	0	D	V	-	-	S	WB	
NI 157	W. EDWARD	873838	Well	107	34	29	21/8/74	1125 (Est)	VD	PE		0	D,G	I	-	-	S	WB	
NI 158	B. WELLS	873836	Well	88	17	15	21/8/74	540	E	E	-	0	D	I	-	-	S	WB	
NI 159	D. BAILEY	877835	Well	120	33	26	23/8/74	-	-	-	-	A	-	I	1.2	1.2	CS	WB	
NI 160	M. BAILEY	876833	Well	116	32	25	23/8/74	-	-	-	-	A	-	I	1.4	1.5	CS	WB	
NI 161	E. JUPP	879835	Bore	125	58*	-	23/8/74	675 (Est)	VD	E	*	0	D,G	I	0.1	-	PVC	WB	
NI 162	R. BUFFETT	880833	Well	128	34	23	23/8/74	-	-	-	-	A	-	I	1.2	1.5	CS	WB	Observation well
NI 163	B. EVANS	880832	Bore	119	34	21	26/8/74	625 (Est)	VD	E	-	0	G	I	0.3	2.0	GI	WB	0.1 diameter bore originally drilled to 58 m Subsequently enlarged to 0.3 m diameter and drilled to 37 m.
NI 164	PANORAMA COURT	873824	Well	61	7	3	30/7/74	3240	M	DE	675*	0	D,G	V	1.4	0.9	C	WB/CA ?	
NI 165	LIONS CLUB	874821	Well	12	11	6	12/8/74	-	-	-	1900*	A	-	CP	-	-	S	CA	Observation well
NI 166	CROWN LAND	875822	Well	6	4	3	30/7/74	-	-	-	-	A	-	V	-	-	CS	WB/CA ?	
NI 167	B. EVANS	878823	Well	12	2	-	30/7/74	675 (Est)	HD	PE	440	0	D,G	V	-	-	UL	WB	
NI 168	R. A. BATTAILLE	879823	Well	18	6	3	30/7/74	675	E	E	625	0	D	V	1.2	1.1	C	WB	
NI 169	DEPT WORKS, KINGSTON	880821	Well	6	6	3	30/7/74	540 (Est)	E	E	675	0	D	CP	1.4	-	CS		
NI 170	10 QUALITY ROW, KINGSTON	890821	Well	9	8	3	30/7/74	540 (Est)	E	E	425	0	D	CP	-	-	CS	CA	
NI 171	C. KNIGHT	887857	Bore	49	27 *	10 *	12/8/74	1350 (Est)	VD	E	270	0	D,G	V	0.1	15 (FL) 27 (SL)	PVC	WB	Bore completed 1972 Pump intake 18 m
NI 172	E. QUINTALL	882853	Well	70	5	4	12/8/74	-	-	-	-	A	-	V	1.2	1.2	CS	WB	
NI 173	R. HOARE	883851	Well	73	8	4	12/8/74	1080	HD	PE	725	0	D,G	V	-	-	S	WB	Completed 1969
NI 174	W. EADES	881851	Bore	110	35	20	13/8/74	-	-	-	-	A	-	I	-	-	UL	WB	Rock at 37 m.
NI 175	J. CUTTING	881850	Bore	110	36 *	-	13/8/74	1080 (Est)	VD	E	-	0	D	I	0.1	-	PVC	WB	
NI 176	G. RYAN	881851	Bore	104	37*	-	13/8/74	-	-	-	-	(A)	D	I	-	-	S	WB	
NI 177	W. RANDALL	884850	Well	73	6	2	5/8/74	4000	HD	PE	160*	0	D,G	V	1.4	-	S	WB	

NUMBER	OWNER	LOCATION	TYPE	ELEVATION ABOVE SEA LEVEL (metres)	DEPTH (metres)	WATER LEVEL BELOW SURFACE (metres)	DATE	YIELD (litres/hr)	PUMP TYPE	POWER	FIELD CONDUCTIVITY (micromhos)	STATUS	USE	TOPOGRAPHIC SETTING	CASING			LITHOLOGY	REMARKS
															DIAMETER (metres)	DEPTH FROM SURFACE (metres)	TYPE		
NI 178	C. ADAMS	885852	Well	101	20	15	13/8/74	810	VD	E	350	0	D	I	-	-	S	VB	
NI 179	G.I. ADAMS	887852	Bore	101	39 *	-	13/8/74	810	VD	E	340	0	D	I	0.1	-	PVC	VB	
NI 180	W. RANDALL	887853	Well	85	4	2	9/8/74	-	S	P	225	(A)	S	V	-	-	S	VB	
NI 181	F.D. BURGESS	887852	Well	100	18	16	13/8/74	Small	BH	M	-	0	D	I	1.2	1.5	CS	VB	
NI 182	H. BUFFETT	887651	Well	105	21	16	13/8/74	3240	E	E	180	0	D,G	I	-	-	S	VB	
NI 183	B. BUFFETT	887851	Bore	104	37 *	12 *	13/8/74	810	VD	E	225*	0	D	I	0.1	-	PVC	VB	Pump intake 32 m Rock at 37 m
NI 184	J. OLSON	890850	Well	91	12	7	9/8/74	810 (Est)	VD	E	225	0	D,G	V	-	-	S	VB	
NI 185	G. CHRISTIAN	889851	Well	101	22	12	9/8/74	1620	E	E	300	0	S,G	I	1.2	1.2	CS	VB	
NI 186	W. RANDALL	888850	Well	104	15	15	9/8/74	-	-	-	-	A	-	I	1.4	1.2	C	VB	
NI 187	K.A. EVANS	888849	Well	107	18	17	9/8/74	675	E	E	-	0	D,G	I	1.4	1.5	CS	VB	
NI 188	G.A. EVANS	889849	Well	105	20	13	8/8/74	540	E	E	140	0	S,G	I	1.2	1.2	CS	VB	
NI 189	C. EVANS	886847	Well	111	27	25	8/8/74	1350	VD	PE	475	0	D	I	1.2	1.5	CS	VB	
NI 190	T. REYNOLDS	889847	Bore	109	42 *	-	8/8/74	540	VD	E	275	0	G	I	-	-	S	VB	
NI 191	A. ARDIMANNI	880843	Well	119	21	16	22/8/74	-	-	-	-	A	-	I	-	-	C	VB	
NI 192	TANNALYTH PLANT	884841	Well	110	7	5	23/8/74	1350	HD	E	250	0	In	V	-	-	-	VB	
NI 193	F. RANDALL	884843	Well	94	5	3	6/8/74	1350 (Est)	E	PE	-	0	G	V	-	-	S	VB	Rock at 5 m
NI 194	A.V.A. BATAILLE	886840	Well	134	33	32	6/8/74	-	-	-	-	A	-	I	1.2	1.5	CS	VB	
NI 195	B ADAMS	887842	Well	130	35	31	6/8/74	-	-	-	-	A	-	I	1.2	1.2	CS	VB	
NI 196	L. SULLIVAN	889843	Bore	129	41	34	6/8/74	-	-	-	-	A	-	I	0.1	-	PVC	VB	Ends in rock
NI 197	F. RANDALL	886844	Bore	125	40	28	6/8/74	-	-	-	-	A	-	I	0.1	-	PVC	VB	Rock at 33 m
NI 198	UNKNOWN	886843	Well	123	28	Dry	6/8/74	-	-	-	-	A	-	I	1.2	1.5	CS	VB	
NI 199	UNKNOWN	888841	Well	131	23	Dry	6/8/74	-	-	-	-	A	-	I	1.5	1.8	CS	VB	
NI 200	J. ANDERSON	889841	Bore	125	26	Dry	9/8/74	-	-	-	-	A	-	I	0.1	-	PVC	VB	
NI 201	G. DUVALL	890843	Bore	126	64 *	27 *	7/8/74	1350	M	E	400*	0	D,G	I	0.2	43 (PL) 18 (SL)	PVC	VB	Rock at 63 m. Drilling completed 1970. Pump intake
NI 202	P. CHRISTIAN	889844	Well	128	27	Dry	11/8/74	-	-	-	-	A	-	I	1.2	1.2	CS	VB	
NI 203	I. MILTON	889845	Bore	119	28	25	8/8/74	-	-	-	-	A	-	I	-	-	UL	VB	Rock at 43 m
NI 204	A. BUFFETT	888845	Well	116	29	26	8/8/74	-	-	-	-	A	-	I	1.4	1.2	CS	VB	
NI 205	J. McCOY	889845	Well	116	28	24	8/8/74	-	-	-	-	A	-	I	1.4	1.2	C	VB	

NUMBER	OWNER	LOCATION	TYPE	ELEVATION ABOVE SEA LEVEL (metres)	DEPTH (metres)	WATER LEVEL BELOW SURFACE (metres)	DATE	YIELD (litres/hr)	PUMP TYPE	POWER	FIELD CONDUCTIVITY (micromhos)	STATUS	USE	TOPOGRAPHIC SETTING	CASING DIAMETER (metres)	CASING DEPTH FROM SURFACE (metres)	CASING TYPE	LITHOLOGY	REMARKS
NI 206	C. STRAUSS	889846	Bore	114	40 *	-	8/8/74	540	VD	E	325	0	G	I	0.1	-	PVC	WB	
NI 207	L. ANDERSON	890847	Well	110	20	17	8/6/74	-	-	-	-	A	-	I	1.2	1.2	CS	WB	
NI 208	G. CLARKE	882840	Bore	134	55 *	-	23/8/74	585	VD	E	425 *	0	S,G	I	-	-	S	WB	
NI 209	G. RYAN	882839	Bore	135	37	20	31/8/74	810 (Est)	-	-	-	0	D,G	I	0.1	37 (SL)	PVC	WB	Rock at 32 m. Completed 1974
NI 210	G. RYAN	882939	Bore	136	32	21	22/8/74	-	-	-	-	A	-	I	0.1	-	PVC	WB	
NI 211	T. WOODS	883839	Bore	135	54 *	-	23/8/74	585	VD	E	240	0	S	I	0.1	-	PVC	WB	Ends in rock
NI 212	G.B. GREY	865939	Bore	136	58*	24 *	6/8/74	810	VD	E	260	0	D	I	0.1	-	PVC	WB	Pump intake 46 m
NI 213	J. HOOPER	884938	Well	141	41	31	23/8/74	-	-	-	-	A	-	I	1.4	0.9	C	WB	
NI 214	J.W. FITZPATRICK	883838	Bore	141	40	29	26/8/74	-	-	-	-	A	-	I	0.1	-	PVC	WB	Ends in rock
NI 215	J. OLSON	881835	Well	128	29	Dry	23/8/74	-	-	-	-	A	-	I	1.2	-	-	WB	
NI 216	UNKNOWN	885837	Well	142	37	Dry	6/9/74	-	-	-	-	A	-	I	1.2	1.2	CS	WB	
NI 217	P.M. IEVERS	899837	Well	133	31	29	6/8/74	540 (Est)	E	E	-	(A)	-	I	1.2	1.2	C	WB	
NI 218	R. DOURAN	888837	Bore	137	47 *	-	21/8/74	540	VD	E	300	0	G	I	0.1	-	PVC	WB	Ends in rock
NI 219	R. HUDSON	888836	Bore	135	43 *	-	5/8/74	110	VD	E	475	0	D,G	I	0.1	-	PVC	WB	
NI 220	H.E. QUINTALL	889829	Well	122	41	31	1/8/74	-	-	-	-	A	-	I	1.2	1.5	CS	WB	
NI 221	V. EVANS	885628	Well	107	33	Dry	1/8/74	-	-	-	-	A	-	I	1.4	1.8	CS	WB	
NI 222	G. AAFJES	856625	Well	109	54	47	1/8/74	450 (Est)	E	E	450	0	G	I	1.4	1.8	CS	WB	
NI 223	H.H. McINTYRE	980822	Well	12	12	8	30/7/74	2160	VD	E	400*	0	D,G	CP	-	-	CS	CA	
NI 224	GOVERNMENT HOUSE	880820	Well	8	16	12	30/7/74	2160	E	E	1625*	0	D,G	CP	1.8	1.8	CS	CA	
NI 225	7 QUALITY ROW, KINGSTON	981822	Well	21	23	18	31/7/74	1350	E	E	475	0	D	CP	1.2	1.8	CS	CA/WB	
NI 226	PARADISE HOTEL	884822	Bore	24	37 *	18	31/7/74	480	E	E	825*	0	D	V	0.2	-	PVC	WB	
NI 227	GOLF CLUB	883820	Well	12	10	Dry	12/8/74	-	-	-	-	A	-	CP	-	-	CS	CA	
NI 228	PARADISE HOTEL	885621	Well	11	16	9	31/7/74	-	-	-	575	A	-	CP	1.5	1.5	CS	CA	
NI 229	PARADISE HOTEL	890821	Well	18	1	S	31/7/74	2160	VD	DE	1100	0	D	V	-	-	UL	WB	
NI 230	L. YOUNG	891855	Well	93	14	Dry	12/8/74	-	-	-	-	A	-	I	1.2	0.9	CS	WB	
NI 231	H. CHRISTIAN	890854	Well	96	18	13	9/8/74	2700 (Est)	VD	PE	350	0	S	I	-	-	S	WB	
NI 232	H. CHRISTIAN	891852	Well	73	4	1	9/8/74	810 (Est)	VD	PE	-	0	G.I.	V	-	-	S	WB	
NI 233	A. BUFFETT	890853	Bore	94	34 *	-	9/8/74	2160	VD	E	300	0	D,G	I	0.1	-	PVC	WB	Ends in rock

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NI 234	V.M. BURGESS	896853	Bore	88	44	39	7/9/74	-	-	-	-	A	-	I	0.1	2.4	GI	WB	Ends in rock
NI 235	K. SALT	898854	Well	49	2	1	7/8/74	675 (Est)	HD	PE	450	(A)	D,G	V	-	-	UL	WB	
NI 236	B. BUFFETT	898853	Well	49	6	2	7/8/74	675 (Est)	HD	E	700	0	G,S	V	-	-	UL	WB	
NI 237	F. CHRISTIAN	893850	Well	85	21	5	12/8/74	1080	HD	PE	350	0	D,G	V	-	-	UL	WB	
NI 238	E. CHRISTIAN	890849	Well	105	18	12	8/8/74	-	-	-	-	A	-	I	1.4	0.9	CS	WB	Observation well
NI 239	E. CHRISTIAN	894850	Well	96	36	26	7/8/74	1125 (Est)	E	E	500*	0	G	I	1.5	2.4	CS	WB	
NI 240	R. EVANS	892848	Well	99	15	11	8/8/74	540 (Est)	E	E	-	0	D,G,	I	1.4	0.6	CS	WB	
NI 241	A. CARR	894849	Well	93	25	19	7/8/74	315	E	E	400	0	D,G	I	-	-	S	WB	
NI 242	L.R. ANDERSON	893849	Well	99	14	12	7/8/74	-	-	-	-	A	-	I	-	-	S	WB	
NI 243	T.L. TAVENER	899848	Well	64	4	1	5/8/74	2160	HD	PE	650*	0	S	V	-	-	UL	WB	
NI 244	K.D. FRIEND	893848	Well	99	15	12	7/8/74	540 (Est)	E	E	275	0	D,G	I	1.2	0.9	CS	WB	
NI 245	K.D. FRIEND	893847	Well	101	16	12	7/8/74	540	E	E	350	0	D	I	1.4	1.4	C	WB	
NI 248	K.D. FRIEND	892848	Well	102	15	13	8/8/74	-	-	-	-	A	-	I	1.2	0.9	C	WB	
NI 247	K. BUTTERFIELD	892847	Bore	105	37*	-	8/8/74	565	VD	E	525*	0	D,G	I	-	-	S	WB	
NI 248	C.PEDDLE	892847	Well	105	17	14	8/8/74	-	-	-	-	A	-	I	1.5	1.2	C	WB	
NI 249	S. BURNS	891846	Bore	110	37	16	8/8/74	-	-	-	-	(A)	-	I	0.1	-	PVC	WB	
NI 250	R. CHRISTIAN	892844	Well	113	26	27	7/8/74	810	HD	E	340	0	D,G	I	-	-	S	WB	
NI 251	A. PAYNE	897842	Well	73	6	5	1/8/74	1620 (Est)	HD	E	425	0	D	V	1.4	1.5	C	WB	
NI 252	G.R. QUINTALL	890838	Well	123	34	30	6/8/74	810	VD	E	450*	0	D,S	I	1.2	1.5	CS	WB	
NI 253	T. JACKSON	896839	Well	79	3	2	6/8/74	450 (Est)	HD	E	825	0	D	V	-	-	UL	WB	
NI 254	L. McCRAE	892834	Well	131	25	19	31/7/74	1080	E	E	375	0	D,G	I	1.2	1.4	CS	WB	
NI 255	G. QUINTALL	894834	Well	123	25	21	1/8/74	675 (Est)	VD	PE	-	0	D,G	I	1.4	1.5	CS	WB	
NI 256	A. ARDIMANNI	895833	Bore	116	56*	-	1/8/74	-	-	-	-	(A)	-	I	0.1	-	PVC	WB	
NI 257	G. CHRISTIAN	897835	Well	107	19	16	1/8/74	-	-	-	-	A	-	I	1.2	1.4	CS	WB	Observation well
NI 258	N. MENZIES	891831	Bore	131	61*	-	31/7/74	675	VD	E	1000*	0	G	I	0.1	-	PVC	WB	
NI 259	K. BAKER	894830	Well	122	32	31	31/7/74	-	-	-	-	A	-	I	1.4	0.9	CS	WB	
NI 260	S CHRISTIAN	892828	Well	81	2	1	27/8/74	-	-	-	-	A	-	V	1.2	0.9	C	WB	Originally 75 m deep. Lost circulation.
NI 261	L. CHRISTIAN-BAILEY	892826	Bore	82	22	5	13/8/74	2160	E	E	700	0	D	V	0.1	21 (SL)	PVC	WB	Rock at 21 m. Bore completed 1974.

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NUMBER	OWNER	LOCATION	TYPE	ELEVATION ABOVE SEA LEVEL (metres)	DEPTH (metres)	WATER LEVEL BELOW SURFACE (metres)	DATE	YIELD (litres/hr)	PUMP TYPE	POWER	FIELD CONDUCTIVITY (micromhos)	STATUS	USE	TOPOGRAPHIC SETTING	CASING DIAMETER (metres)	CASING DEPTH FROM SURFACE (metres)	CASING TYPE	LITHOLOGY	REMARKS
WI 262	L. EVANS	890823	Well	61	2	1	31/7/74	-	-	-	-	A	-	V	-	-	UL	WB	
WI 263	E.L. ADAMS	894827	Well	117	31	28	31/7/74	540	E	PE	350	O	G	I	1.4	0.9	CS	WB	Observation well
WI 264	E. ADAMS	895826	Bore	111	49 *	-	31/7/74	540	VD	E	500	O	S	I	0.1	-	PVC	WB	
WI 265	R. McCOY	898826	Well	104	29	22	31/7/74	675	E	E	350*	O	D,G	I	1.4	1.8	CS	WB	
WI 266	G.M. SHERIDEN	899825	Bore	99	20	Dry	31/7/74	-	-	-	-	A	-	I	0.1	-	PVC	WB	
WI 267	G. CHRISTIAN	899824	Well	94	28	24	31/7/74	1125 (Est)	E	E	-	O	D,G	I	1.2	1.8	CS	WB	
WI 268	A. McGUINESS	895825	Bore	108	76 *	34	23/10/74	810 *	-	-	-	O	D	I	0.1	58 (PL) 76 (SL)	PVC	WB	Bore completed 1974
WI 269	W. JUDD	898826	Bore	107	41 *	14	30/11/74	1350 *	-	-	-	O	S	I	0.1	23 (PL) 41 (SL)	PVC	WB	Bore completed 1974
WI 270	B. CHRISTIAN-BAILEY	904853	Well	91	25	16	5/8/74	1350	HD	PE	800	O	S	I	-	-	S	WB	
WI 271	T.L. TAVENER	901849	Well	99	25	20	5/8/74	1620 (Est)	HD	PE	500*	O	S	I	1.2	1.2	CS	WB	Observation well
WI 272	C. HUNT	902848	Well	99	28	23	5/8/74	1080	E	E	750	O	G	I	1.2	1.8	CS	WB	
WI 273	E.L. ADAMS	901847	Well	98	26	20	5/8/74	Small	BH	M	-	O	D,G	I	1.2	1.5	CS	WB	
WI 274	B. BUFFETT	901846	Well	101	22	17	5/8/74	-	BH	M	-	(A)	S	I	1.2	1.8	CS	WB	
WI 275	S. CHRISTIAN	901846	Bore	99	12	Dry	5/8/74	-	-	-	-	A	-	I	-	-	UL	WB	
WI 276	W.S. QUINTALL	902845	Well	98	40	Dry	2/8/74	-	-	-	-	A	-	I	1.4	-	S	WB	
WI 277	A. PAYNE	900842	Well	116	44	Dry	1/8/74	-	-	-	-	A	-	I	1.4	1.2	C	WB	
WI 278	W. CHRISTIAN	903844	Well	114	35	Dry	2/8/74	-	-	-	-	A	-	I	1.4	-	S	WB	
WI 279	R.B. WOTHERSPOON	903842	Bore	134	47	40	2/8/74	-	-	-	-	A	-	I	-	-	UL	WB	Rock at 41 m
WI 280	A. BIGGS	904845	Bore	108	3	Dry	2/8/74	-	-	-	-	A	-	I	-	-	UL	WB	Originally 55 m. Lost circulation at 49 m
WI 281	D. BUFFETT	905846	Well	93	27	Dry	2/8/74	-	-	-	-	A	-	I	-	-	UL	WB	
WI 282	J. KILBURN	907843	Well	91	16	7	2/8/74	1620	E	E	450	O	D,S	I	-	-	S	WB	
WI 283	H.E.J. BUFFETT	908844	Well	78	15	10	2/8/74	2160	VD	PE	400	O	S	V	1.2	1.5	CS	WB	
WI 284	S. MENZIES	908841	Well	88	29	26	2/8/74	Small	BH	M	2600*	O	S	I	1.4	1.8	CS	WB	
WI 285	F.S. BUFFETT	908840	Well	87	32	29	2/8/74	2160	VD	PE	1200	O	S,G	I	1.2	1.5	CS	WB	
WI 286	H.G. WALLACE	906833	Well	111	57	51	1/8/74	-	-	-	-	A	-	I	0.1	0.1	CS	WB	
WI 287	C. BUFFETT	910843	Well	75	22	18	2/8/74	-	-	-	1150	A	-	I	1.2	1.5	CS	WB	
WI 288	W.A. WISEMAN	911841	Well	70	8	Dry	2/8/74	-	-	-	-	A	-	V	1.4	1.7	C	WB	
WI 289	W.A. WISEMAN	911841	Bore	70	39	15	2/8/74	-	-	-	-	(A)	-	V	0.1	-	PVC	WB	Rock at 45 m
WI 290	W.F. REYNOLDS	871830	Bore	24	15 *	-	21/8/74	-	-	-	-	A	-	V	0.1	-	PVC	WB	Rock at 6 m
WI 291	J. HAYES	855878	Bore	105	79	26	26/2/75	-	-	-	-	O	S,I	I	0.2	46 (PL) 64 (SL)	PVC	WB	Bore completed 1975

NUMBER	OWNER	LOCATION	TYPE	ELEVATION ABOVE SEA LEVEL (metres)	DEPTH (metres)	WATER LEVEL BELOW SURFACE (metres)	DATE	YIELD (litres/hr)	PUMP TYPE	POWER	FIELD CONDUCTIVITY (micromhos)	STATUS	USE	TOPOGRAPHIC SETTING	CASING DIAMETER (metres)	CASING DEPTH FROM SURFACE (metres)	CASING TYPE	LITHOLOGY	REMARKS
NI 292	G. HANDSCHKOW	868826	Bore	61	22*	15	20/7/75	1125	-	E	-	O	D	V	0.1	14 (PL)	PVC	WB	Rock at 20 m Bore completed 1975
NI 293	SEVENTH DAY ADVENTIST CHURCH HALL	877847	Bore	114	38	29	18/5/75	765	M	E	-	O	D	I	0.1	19 (PL) 38 (SL)	PVC	WB	Rock at 38 m Bore completed 1975
NI 294	G. ADAMS	853879	Bore	98	24*	-	20/6/75	-	-	-	-	A	-	I	0.1	18 (PL)	M	WB	Lost circulation
NI 295	E. YAEGER	873648	Bore	107	12*	8	6/8/75	1350	- -	- -	- -	O	D	I	0.1	5 (PL 12 (SL)	PVC	WB	Rock at 12 m Bore completed 1975
NI 296	C.BARKMAN	855836	Bore	104	74	21	10/12/75	1800*	-	-	-	(A)	DI	1	0.1	56 (PL) 74 (SL)	PVC	WB	Rock at 53 m Bore completed 1975
NI 297	GOLF CLUB	853820	Bore	14	24*	3	12/12/75	1800*	-	-	-	(A)	DI	CP	0.1	12 (PL) 24 (SL)	PVC	WB/CA	Bore completed 1975

CODE FOR INVENTORY

Depth
50* - Reported by owner or other person

Water level
S - Water level at surface
50* - Reported at drilling, pump installation or by owner

Yield
50 (Est) - Estimated by pump type, head measurement, owner or other methods
50* - Data from test pumping at completion of drilling

Pump Type
HD - Horizontal displacement
VD - Vertical displacement
E - Ejecta
BH - Bucket and Hoist
C - Centrifical type
ES - Electric submersible
M - Monopump
S - Siphon

Power
E - Electric
PE - Petrol engine
DE - Diesel engine
M - Manual
P - Pressure

Field Conductivity
300* - Chemical analysis available
CA - Chemical analysis only

Status
O - Operating
A - Abandoned
(A) - Abandoned temporarily

Use
D - Domestic
G - Garden
S - Stock
I - Irrigation
SE - Sewage effluent disposal
In - Industry

Topographic Setting
I - Interfluve
V - Valley
CP - Coastal plain

Casing or lining type
PVC - Polyvinylchloride
GI - Galvanised iron
M - Metal -
CS - Cemented stone
C - Concrete
UN - Unlined
S - Sealed
PL - Plain
SL - Slotted

Lithology
WB - Weathered basalt
CA - Calcareous aeolianite

See text for description of well numbering system
Well locations are shown in Map 3.

Appendix 3 CHEMICAL ANALYSES OF WATER SAMPLES FROM NORFOLK ISLAND (expressed in mg/l except where stated)

GROUNDWATER

NUMBER	NAME	DATE	TYPE OF EXTRACTION	DEPTH (metres)	TOPO-GRAPHY	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	PO_4	F	B	Fe	Mn	Cr	SURFACTANTS as mg/l AZURE A	pH	TOTAL HARDNESS as mg/l	TDS	SAR (epm)	RATIO Cl/HCO_3	REMARKS
NI 243	T.L. TAVENER	23/9/74 (C)	W	4	V	10	10	110	1	20	40	174	1	0.03	< 0.05	0.12	0.15	0.04	< 0.05	0.03	5.5	66	356	6	16	
NI 284	S.MENZIES	" (C)	W	29	I	18	61	500	5	7	69	934	11	0.02	< 0.05	0.25	0.05	0.55	< 0.05	0.10	4.4*	296	1601	12.8	263	Collected by R.S. Abell during hydrogeological survey in 1974. Analyses by AMDEL (Australian Mineral Development Laboratories)
NI 256	N.MENZIES	" (C)	B	61	I	3	13	139	1	47	27	235	< 1	0.01	< 0.05	0.11	17	0.14	< 0.05	-	6.9	61	441	8.5	8	
NI 252	K.QUINTALL	" (C)	W	34	I	12	9	65	< 1	60	7	100	12	0.01	< 0.05	0.07	0.1	< 0.02	< 0.05	0.04	7.2	67	234	3.5	2.8	
NI 177	W.RANDALL(Spr)	" (C)	W	6	V	2	3	22	< 1	3	12	36	< 1	0.03	< 0.05	0.09	< 0.05	0.2	< 0.05	0.03	5.0*	17	77	2.5	10	
NI 239	E.CHRISTIAN	" (C)	W	38	I	3	9	68	1	13	18	128	38	0.01	< 0.05	0.12	< 0.05	0.12	< 0.05	0.04	4.9*	45	292	6.3	18	
NI 247	K.BUTTERFIELD	" (C)	B	37	I	2	7	74	< 1	13	8	126	7	0.02	< 0.05	0.06	4.25	0.28	< 0.05	0.02	5.8	34	230	5.3	18	
NI 208	G.CLARKE	" (C)	B	55	I	2	7	63	< 1	33	4	104	9	0.01	< 0.05	0.05	3.05	0.16	< 0.05	-	7.0	34	206	4.5	6	
NI 165	LIONS CLUB	" (C)	W	11	CP	50	50	300	22	207	13	556	26	0.01	< 0.05	0.2	0.3	0.09	< 0.05	0.13	7.5	331	1119	7.2	4.5	
NI 164	PANORAMA COURT	" (C)	W	7	V	18	11	112	4	67	50	164	1	0.03	0.05	0.09	< 0.05	< 0.02	< 0.05	0.06	8.8	90	393	5.4	4.4	
NI 119	O.EVANS	" (C)	W	20	I	2	4	53	< 1	7	5	74	26	0.01	< 0.05	0.11	< 0.05	0.08	< 0.05	0.03	4.9*	21	167	5.7	21	
NI 131	I.YAEGER	" (C)	B	49	I	1	2	28	< 1	20	4	35	1	0.01	< 0.05	0.04	8.9	0.2	< 0.05	-	6.4	11	81	4.0	3.3	
NI 133	C.J.CAMERON	" (C)	W	24	I	6	8	73	1	7	< 2	116	56	0.01	< 0.05	0.04	0.35	0.12	< 0.05	0.06	5.1	48	263	4.6	33	
NI 67	BLIGH COURT	" (C)	B	52	I	1	5	54	< 1	20	< 2	80	18	0.01	< 0.05	0.04	0.05	0.06	< 0.05	0.07	6.3	23	168	5.7	7.6	
NI 85	AIR PORT	" (C)	W	28	I	4	4	59	< 1	73	18	54	6	0.01	< 0.05	0.09	0.05	0.08	< 0.05	0.03	7.0	26	181	5.2	< 1	
NI 88	B. CHRISTIAN	" (C)	W	5	V	5	8	61	< 1	7	19	106	3	0.02	< 0.05	0.05	0.05	0.14	< 0.05	0.05	5.4	45	205	3.8	30	
NI 102	L.COOPER	" (C)	B	63	I	2	6	84	< 1	67	5	114	< 1	0.01	< 0.05	0.11	3.5	0.34	< 0.05	0.02	7.0	30	244	7.4	3	
NI 64	M.D.BRUCE	" (C)	B	47	I	9	28	285	3	93	77	433	8	0.02	< 0.05	0.10	0.05	0.14	< 0.05	-	7.1	138	894	11.2	10	
NI 58	B.BONIFACE	" (C)	W	7	V	6	14	136	2	7	30	231	7	0.02	< 0.05	0.10	0.01	0.22	< 0.05	0.05	5.1	73	430	6.5	65	
NI 50	O.BOOTH	" (C)	B	49	I	6	14	153	1	40	< 2	258	18	0.04	< 0.05	0.08	1.7	0.4	< 0.05	0.06	6.5	73	469	8.3	10	
NI 59	G.WOOLLEY	" (C)	B	43	I	12	40	255	5	13	15	514	1	0.01	0.10	0.15	0.6	0.92	< 0.05	0.07	6.5	195	848	7.9	70	
NI 24	VICARAGE - ST BARNABAS CHURCH	" (C)	W	22	I	5	8	95	1	13	37	144	< 1	0.01	< 0.05	0.10	26.5	0.52	< 0.05	0.04	6.6	45	297	5.8	20.5	
NI 14	G.ADAMS (Hse)	" (C)	B	53	I	38	146	925	11	20	161	1792	3	0.01	< 0.05	0.18	0.7	1.26	< 0.05	0.11	5.6	696	3096	15.4	168	
NI 1	B.H.BURRELL	" (C)	W	43	I	48	123	760	9	27	25	1590	1	0.02	0.2	0.14	2.2	1.12	< 0.05	0.10	5.9	626	2570	13.2	12	
NI 33	J.HAYES	" (C)	B	79	I	22	28	103	2	140	23	178	< 1	0.17	0.05	0.06	< 0.05	< 0.02	< 0.05	0.04	7.0	170	425	3.5	2	
NI 265	R. McCOY	14.12.65(A)	W	29	I	12	6	46	1.6	23	40	70	36.0	-	-	-	0.16	0.31	-	-	6.9	54	272	2.7	4.7	Collected by R.N. Eden during water resources survey in 1965. Analysis by Water Resources Branch, Northern Territory Administration. The analyses are held on the Norfolk Island administration files.
NI 224	GOVT. HOUSE	" (A)	W	18	CP	39	50	250	7	38	28	577	0.24	-	-	-	trace	-	-	-	8.3	312	1465	6.4	27.1	
NI 28	R.LLOYD	" (A)	W	22	I	4	20	72	2.5	39	35	130	34	-	-	-	-	-	-	-	6.9	92	408	3.4	6.1	
-	W.SANDERS	" (A)	Sp	s	V	2	12	42	1.6	33	36	73	-	-	-	-	0.23	-	-	-	6.4	58	258	2.4	4	
NI 11	KINGFISHER	" (A)	W	25	I	8	16	245	9	20	115	320	0.58	-	-	-	0.21	0.06	-	-	5.9	86	1028	11.8	30	
NI 4	B.H. BURRELL	" (A)	W	34	I	70	-	1720	18.0	6	160	4125	-	-	-	-	0.43	4.40	-	-	4.2*	1700	9096	15.9	1163	
NI 271	T.L.TAVENER	" (A)	W	25	I	6	9	71	3.1	11	35	158	45.0	-	-	-	0.11	0.45	-	-	5.6	60	399	4.4	22	
NI 183	B.BUFFETT	12.7.71 (A)	B	37	I	0.7	2.2	22.5	0.5	2.4	4	35.5		-	-	-	-	-	-	-	5.9	-	131	3.0	25	
NI 46	D.DAVIDSON	" (A)	B	74	I	4.5	10.4	73.0	1.8	10.4	4	144.5	-	-	-	-	-	-	-	-	7.2	-	357	4.6	20.5	

NUMBER	NAME	DATE	TYPE OF EXTRACTION	DEPTH (metres)	TOPO-GRAPHY	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	PO_4	F	B	Fe	Mn	Cr	SURFACTANTS as mg/l AZURE A	pH	TOTAL HARDNESS as mg/l Ca CO_3	TDS	(SAR) (epm)	RATIO Cl/HCO_3	REMARKS
NI 201	G.DUVALL	25/6/70 (C)	B	64	I	19	(29.2)	76	6.1	(64)	110	120	-	-	-	-	-	-	-	-	6.5	38	-	(2.5)	(3.4)	Other available analyses made by private laboratories, the Bureau of Mineral Resources, and the New South Wales Government analyst.
NI 223	N.H. McINTYRE	26/4/73 (C)	B	12	V	-	-	48	1.5	-	34	56.5	-	0.13	-	-	0.95	-	-	-	6.8	75	-	-	-	
NI 32	G.ADAMS	26/4/73 (C)	B	41	V	30	(3)	250	3	(60)	35	377.5	1.[illegible]	0.05	-	-	1.28	-	-	-	6.2	150	-	(12)	(8)	
NI 161	E.JUPP	13/4/72 (A)	B	56	I	-	-	-	-	-	43	185	0.15	-	-	-	0.1	-	-	-	6.5	109	-	-	-	
NI 226	PARADISE HOTEL	2/6/72 (A)	B	37	V	-	-	128	-	(47)	59	219	4.7	-	-	-	2.0	-	-	-	6.5	129	537	-	7.7	
NI 93	N.J.MITCHELL	26/4/73 (C)	W	21	I	5	12.5	54	1.3	(40)	12	97.5	0.2	0.05	-	-	0.33	-	-	-	5.8	40	-	3.3	6.5	
NI 52	P.CUSTANCE	25/6/70 (C)	B	47	I	93	-	148	10	(64)	152	619	-	-	-	-	-	-	-	-	6.4	200	-	-	-	

SURFACE WATER

NUMBER	NAME	DATE	TYPE OF EXTRACTION	DEPTH (metres)	TOPO-GRAPHY	Ca	Mg	Na	K	HCO_3	SO_4	Cl	NO_3	PO_4	F	B	Fe	Mn	Cr	SURFACTANTS as mg/l AZURE A	pH	TOTAL HARDNESS as mg/l Ca CO_3	TDS	(SAR) (epm)	RATIO Cl/HCO_3	REMARKS
	COCKPIT DAM (Cascade)	14/12/65 (A)				2	21	70	2.8	48	15	147	-	-	-	-	0.04	0.02	-	-	7.2	97	403	3.3	5	
	WATERMILL CREEK (near dam)	" (A)				8	15	47	0.3	46	15	103	-	-	-	-	0.02	0.02	-	-	7.5	80	290	2.2	4.1	Analysis by Water Resources Branch Northern Territory Administration and the New South Wales Government analyst.
	OFFICERS BATH (Town Creek)	" (A)				1	20	60	1.6	31	20	133	-	-	-	-	0.04	-	-	-	7.3	88	351	2.9	7.4	
	ELLIOTS CREEK	" (A)				2	17	52	0.7	32	15	121	-	-	-	-	0.02	0.02	-	-	7.7	79	321	2.7	6.8	
	HEADSTONE CREEK	" (A)				8	25	136	5.1	35	20	284	-	-	-	-	0.31	0.02	-	-	7.1	126	466	2.7	6.8	
	HEADSTONE CREEK	6/5/49 (A)				-	-	-	-	(50)	-	220	0.01	-	-	-	-	-	-	-	6.5	110	530	-	-	
	CASCADE CREEK	6/5/49 (A)				-	-	-	-	(40)	-	138	0.01	-	-	-	-	-	-	-	6.7	90	350	-	-	
	BROKEN BRIDGE CREEK	6/5/49 (A)				-	-	-	-	(40)	-	116	0.01	-	-	-	-	-	-	-	6.7	-	270	-	-	
	ELLIOTS CREEK	6/5/49 (A)				-	-	-	-	(20)	-	76	0.5	-	-	-	-	-	-	-	5.7	50	230	-	-	
	WATERMILL CREEK (Lower)	6/5/49 (A)				-	-	-	-	(50)	-	100	0.01	-	-	-	-	-	-	-	6.9	90	310	-	-	
	WATERMILL CREEK (Upper)	6/2/58 (C)				-	-	-	-	(47)	-	115	0.11	-	-	-	-	-	-	-	6.3	96	-	-	-	
	WATERMILL CREEK (Lower)	6/2/68 (C)				-	-	-	-	(54)	-	106	0.14	-	-	-	-	-	-	-	6.2	96	-	-	-	

Code
23/9/74 (A) - Date Sample Analysed
14/12/65 (C) - Date Sample Collected
V - Valley
I - Interfluve
Cp - Coastal Plain
Sp - Spring
B - Bore
W - Well
S - Surface
(64) - Estimated values
* - Chemical analyses with pH values of about 5 or less maybe suspect as they show a value for bicarbonate.

APPENDIX 4.

The Penman equation estimates for potential evaporation.

by P.M. Fleming (Division Land Use Research, CSIRO).

Data available

1) Sunshine hours
2) Three-hourly wet and dry bulb temperatures
3) Maximum and minimum temperatures
4) Wind speed and direction at 7 observations per day

Radiation estimates

Shortwave radiation (R_s) was estimated by:

$$R_s = R_x \, (0.27 + 0.5 \, {}^n/N)$$

where R_x is extraterrestrial radiation on a horizontal surface

n is actual sunshine hours

N is daylength

Longwave radiation (R_{Ln}) was estimated by:

$$R_{Ln} = R_{Lo} \quad (0.2 + 0.8 \, {}^n/N)$$

where $R_{Lo} = 5.96 - 0.2^6 \quad T^4$ mm of water

where T is the mean air temperature in degrees absolute 6 is Stefan's constant.

Long-term monthly means of n and T were used, and R_x was obtained from tables.

Vapour pressure, e_a

The wet and dry bulb monthly means at 0830 hours were used to calculate a value of air/stream vapour pressure, e_a, which was assumed to approximate the daily mean.

Temperature, (t_a)

Mean air temperature was taken as the average of the monthly means of maximum and minimum temperature.

<u>Saturation deficit,</u> (s.d)

The saturation deficit was estimated as the difference between saturation vapour pressure at mean air temperature e_s and e_a.

<u>Wind run at 2 metres elevation</u> (U_2)

The three-hourly observations and speed ranges were used to calculate a mean daily run of wind from July to December; the observation at 1730 hours approximated the mean daily run. Therefore observations at 1730 hours were adopted as mean daily wind speed and reduced from 10-m observation height to 2-m observation height using a factor 0.301.

<u>Mean monthly freewater evaporation</u> E_o was estimated from the following

equation $E_o = \frac{\Delta}{\Delta + \gamma} R_n + \frac{\gamma}{\Delta + \gamma} f(u) (e_s - e_a)$

where $\frac{\Delta}{\Delta + \gamma}$ and $\frac{\gamma}{\Delta + \gamma}$ are function of mean air temperature and read from tables

$$R_n = 0.95 \quad R_s - R_{Ln}$$

$$f(u) = 0.35 (1.0 + u_2/100)$$

Mean monthly otential evapotranspiration, (E_t) was obtained from the equation $E_t = PE_o$

the value of P is a function of the type of vegetation cover

Grass	P = 0.8 for all months
Forest	P = 1.0 for all months for closed forest
	P = 1.2 " " " open forest

The monthly values of E_o adopted are in mm day $^{-1}$

J	F	M	A	M	J	J	A	S	O	N	D
5.6	4.8	4.1	3.2	2.2	1.6	1.8	2.4	3.4	4.3	5.1	5.4

These values were converted by smoothed-curve fitting to weekly values for use in WATBAL.

APPENDIX 5

GLOSSARY OF GROUNDWATER TERMS

This glossary has been compiled to assist in the use of this Record. Most of the explanations of groundwater terms are based on Jones (1965) and the Department of the Environment and Conservation Australian Water Resources Council (1975).

AQUIFER: An aquifer is a body of rock or soil of which the saturated part contains a system of interconnected voids sufficient to yield significant quantities of water to bores, wells, or springs.

BASAL GROUNDWATER: Groundwater which occurs at the hydraulic base level for downward percolating water. On Norfolk Island this is at sea level.

BASEFLOW: The sustained natural flow of a stream maintained largely by groundwater discharge.

BORE: Any hole which is drilled, jetted, or augered to withdraw or replenish groundwater is regarded as a water-bore. Any hole large enough for a man to enter may be called a well.

CONE OF DEPRESSION: The cone of depression measures the extent and amount of lowering of the water-table by the withdrawal of water from a bore or well. It varies in size and shape with the rate and duration of withdrawal and the nature of the aquifer.

DRAWDOWN: The lowering of the water-table caused by the discharge of groundwater from a bore or well.

GROUNDWATER: Groundwater is the water in the saturated zone.

HYDRAULIC CONDUCTIVITY: Hydraulic conductivity is a measure of the ease with which water can flow through rock or soil. The term defines the rate of flow of groundwater through a given rock under unit potential gradient at field temperature. Hydraulic conductivity combines both rock and fluid properties (see permeability).

HYDRAULIC GRADIENT: The hydraulic gradient is the change in elevation of the water-table per unit of distance in a given direction.

INFILTRATION: Infiltration is the movement of water through the ground surface into small voids in either the saturated or unsaturated zone.

PERCHED GROUNDWATER. Perched groundwater is separated from the main underlying body of groundwater by an unsaturated zone which contains relatively impermeable material above the main water-table of the area.

PERMEABILITY: The permeability of a rock or soil is a measure of the ease with which fluids can flow through it. Where the term has been used in the text it is taken to mean intrinsic permeability, which is related only to the physical properties of the porous medium and does not take account of the properties of the fluid moving through the rock such as its density, viscosity, and temperature (see hydraulic conductivity).

POROSITY: The porosity of a rock or soil is its property of containing voids (spaces in the material not occupied by solid matter) and may be expressed quantitatively as the ratio of the volume of the voids to its total volume.

RECHARGE: Recharge of groundwater is the addition of water to the saturated zone, either directly from the surface or from the unsaturated zone.

SALINITY: The total content of dissolved solids in groundwater. The significance of salinity depends on the nature as well as the amount of the dissolved solids.

SATURATED ZONE: The saturated zone is that part of a body of permeable rock or soil in which all voids, large or small, are filled with water under pressure greater than atmospheric. Parts of the unsaturated zone, which typically overlies the saturated zone, may have all pores filled with water, but this water is at less than atmospheric pressure and cannot drain from the rock into a bore or well penetrating it.

SPECIFIC CAPACITY: The specific capacity of a bore is the rate of discharge of water from the bore divided by the drawdown within the bore.

UNCONFINED GROUNDWATER: The upper surface of unconfined groundwater is formed either by a body of surface water or by a water-table.

WATER BALANCE: In terms of the text the water balance is an accounting of the recharge to, discharge from, and storage of groundwater in a subsurface hydrological unit such as an aquifer.

WATER-TABLE: The water-table is that surface is an unconfined water body at which the pressure is atmospheric. It is indicated by the levels at which water stands in bores or wells that penetrate the water body just far enough to hold standing water.

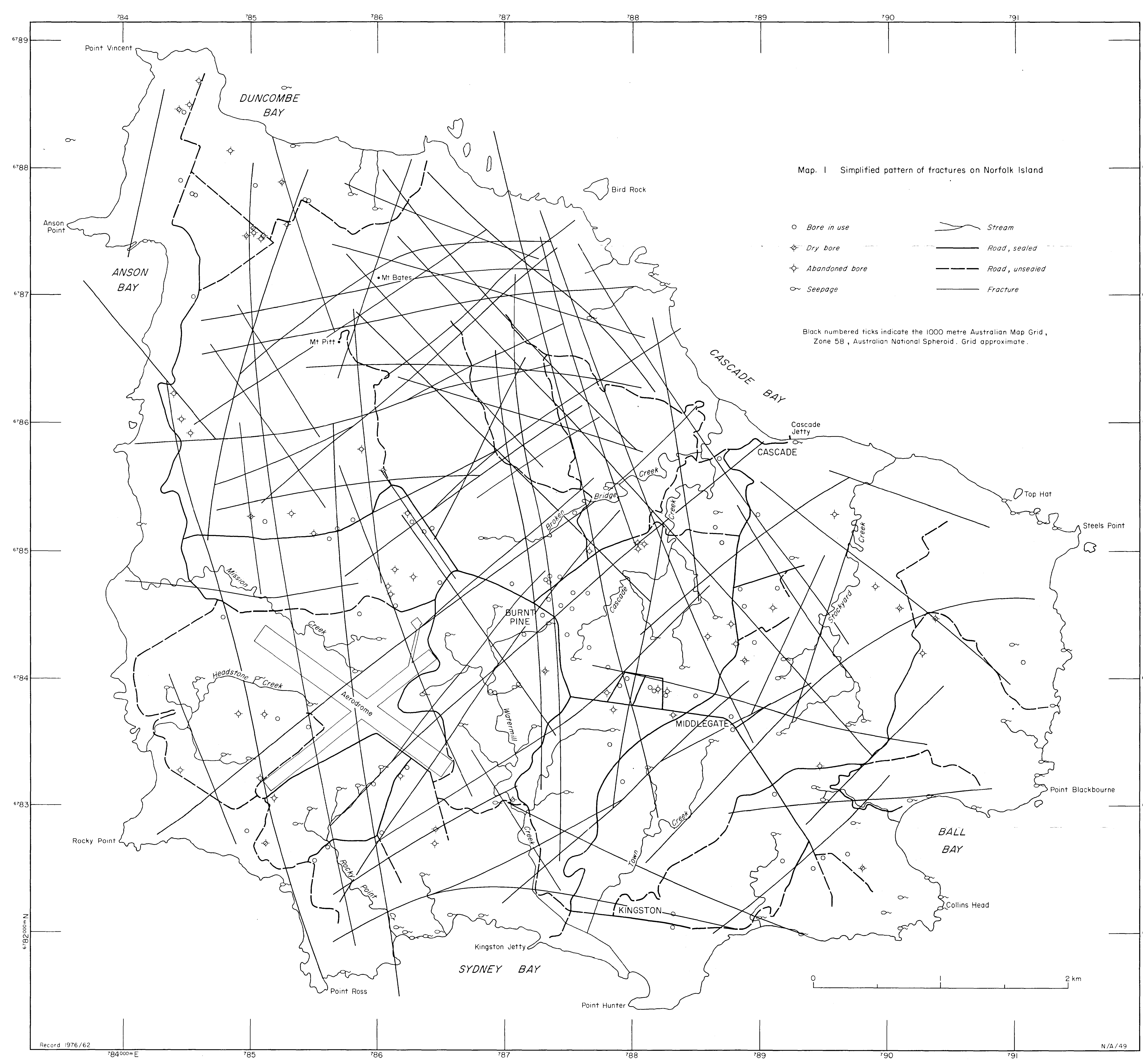
WELL: A water-well is any hole which is dug, manually or with excavating equipment, to withdraw or replenish groundwater. The distinction between water-bore and water-well usually includes both diameter of hole and method of construction.

YIELD: Yield refers to the rate at which water is withdrawn from a bore or well. The yield may decrease as the period of continuous pumping increases.

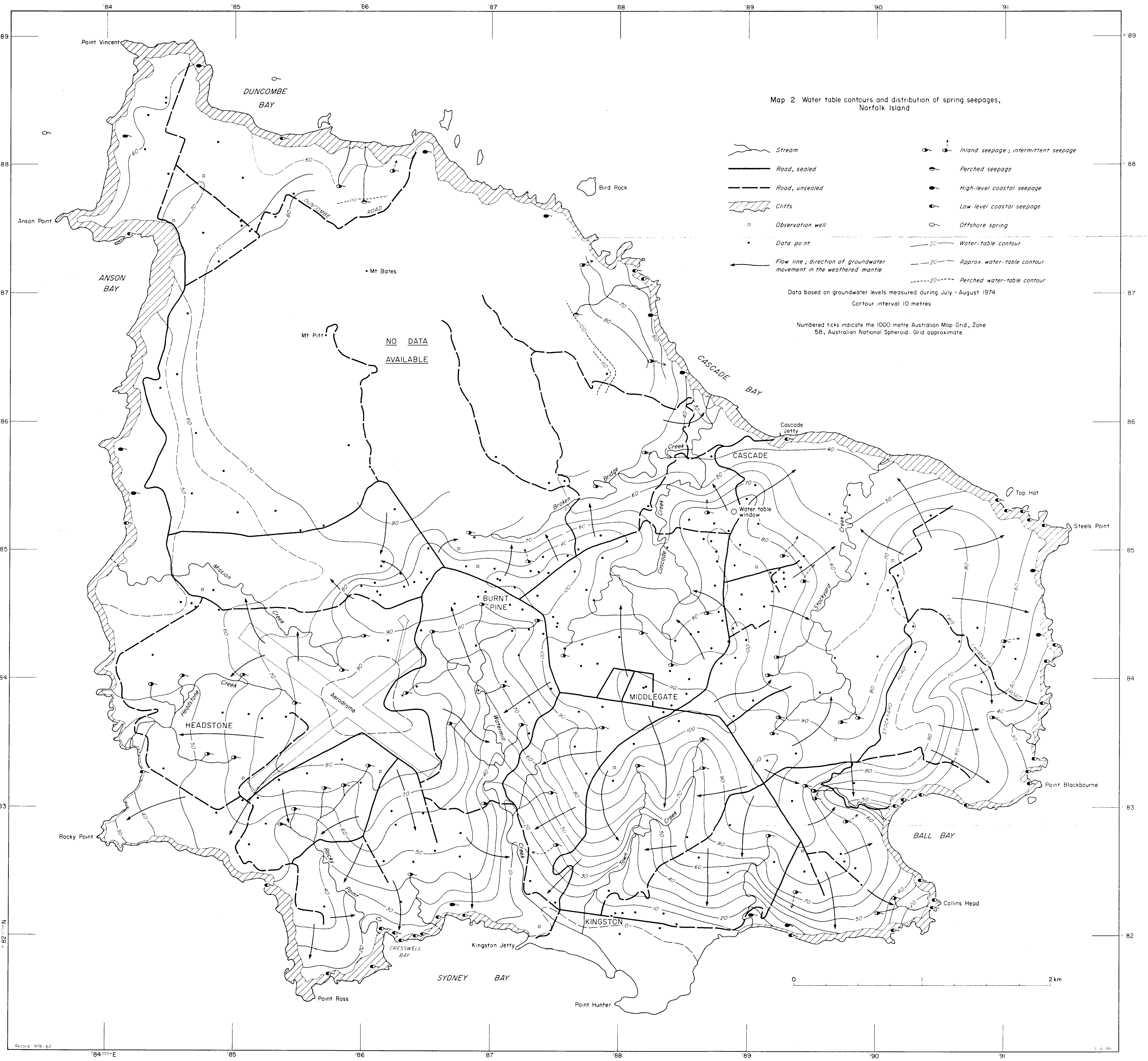
References

Jones, N.O., 1965 - Groundwater nomenclature in Australia. Bur. Miner. Resour. Aust. Rec. 1965/123 (unpubl.).

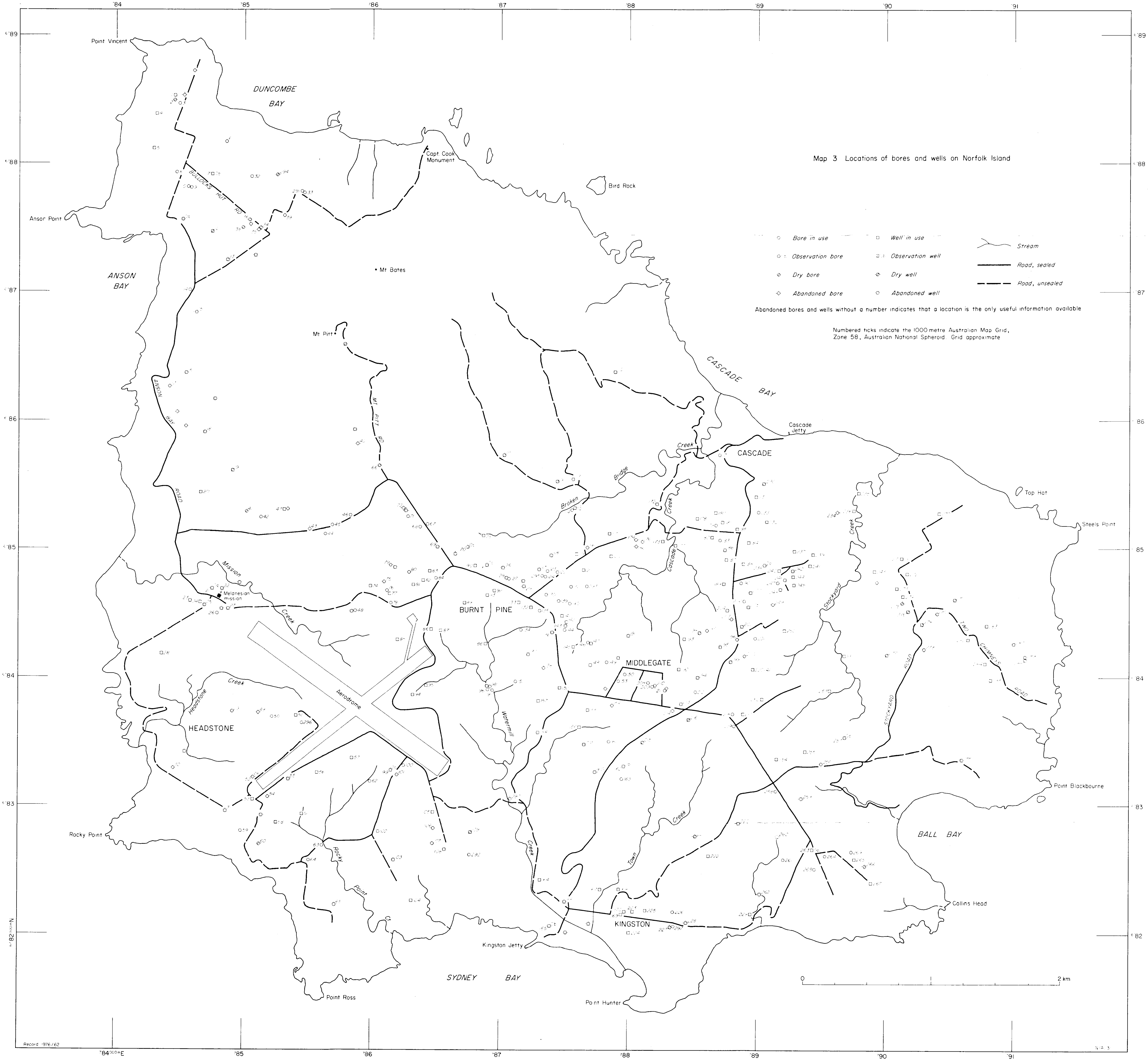
AWRC., 1975 - Groundwater resources of Australia. Canberra Australian Govt. Printing Service.



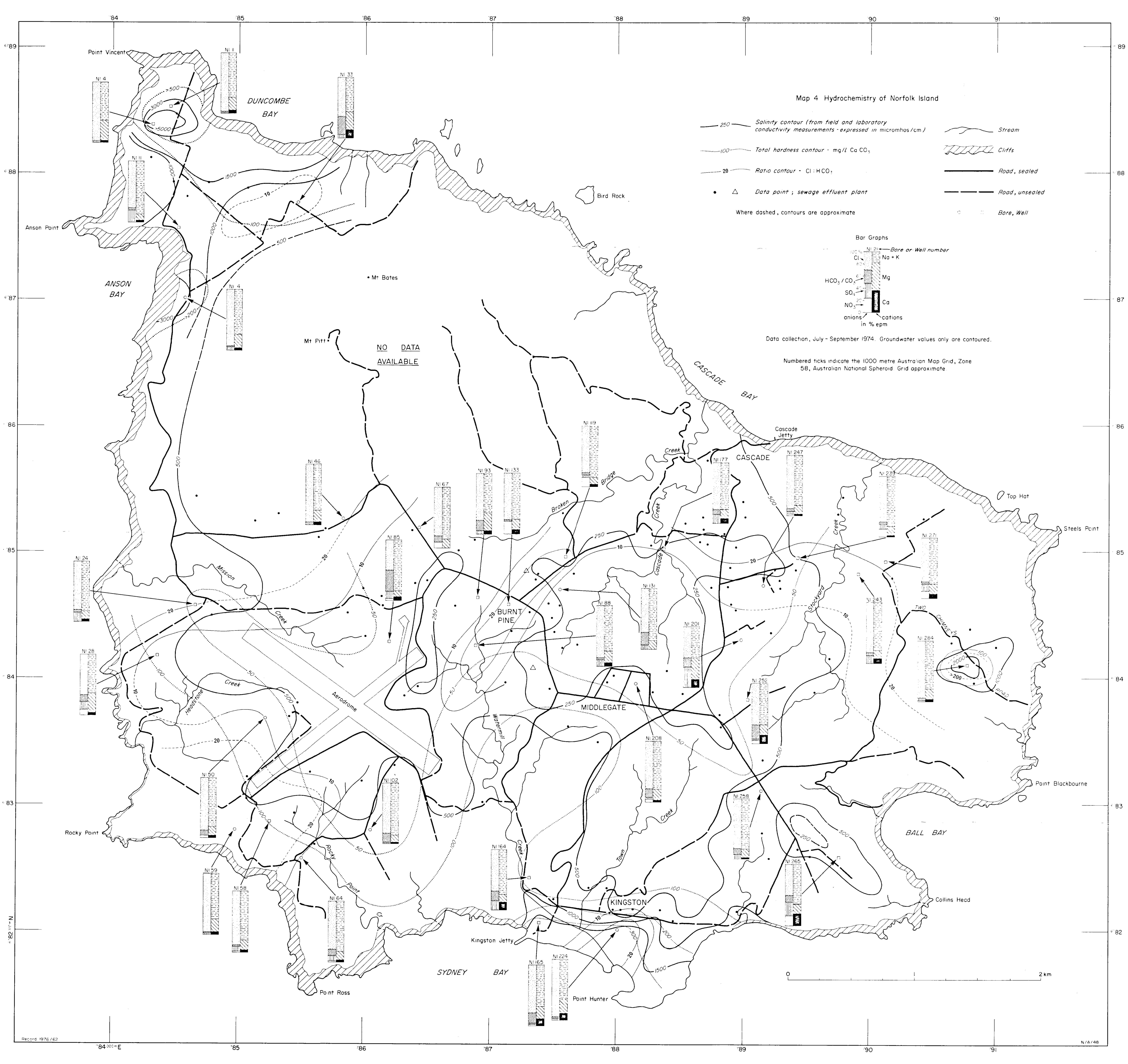
Map. I Simplified pattern of fractures on Norfolk Island
Bore in use
Dry bore
Abandoned bore
Seepage
Stream
Road, sealed
Road, unsealed
Fracture
Black numbered ticks indicate the 1000 metre Australian Map Grid, Zone 58, Australian National Spheroid. Grid approximate.
Point Vincent
DUNCOMBE BAY
Anson Point
ANSON BAY
Bird Rock
Mt Bates
Mt Pitt
CASCADE BAY
Cascade Jetty
CASCADE
Top Hat
Steels Point
Broken Bridge Creek
Mission Creek
Headstone Creek
Aerodrome
BURNT PINE
Cascade Creek
Stockyard Creek
MIDDLEGATE
Watermill Creek
Town Creek
Rocky Point Cr
Rocky Point
Point Blackbourne
BALL BAY
Collins Head
KINGSTON
Kingston Jetty
SYDNEY BAY
Point Ross
Point Hunter
0
1
2 km
Record 1976/62
N/A/49

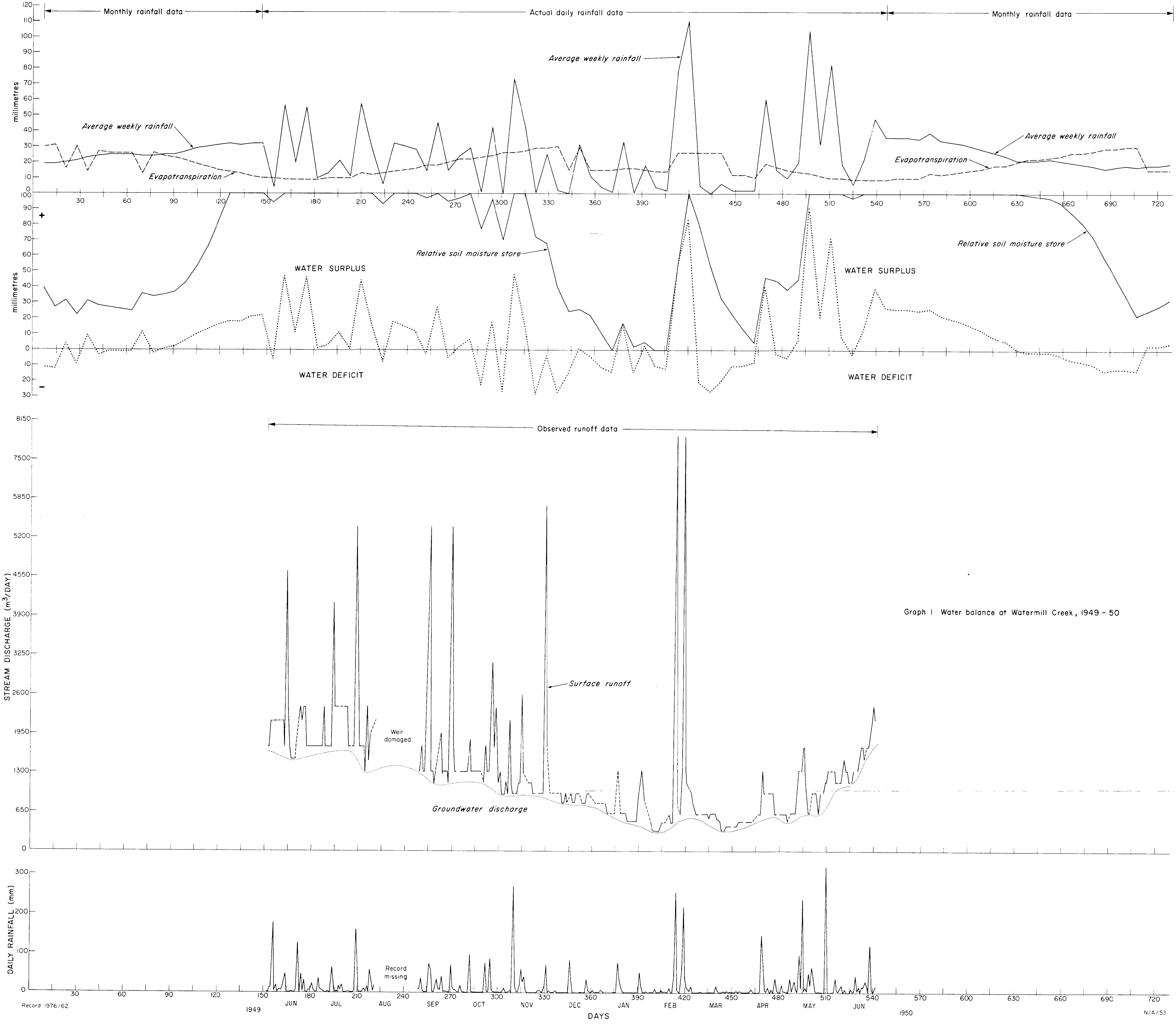


Map 2 Water table contours and distribution of spring seepages, Norfolk Island
Stream
Road, sealed
Road, unsealed
Cliffs
Observation well
Data point
Flow line; direction of groundwater movement in the weathered mantle
Inland seepage; intermittent seepage
Perched seepage
High-level coastal seepage
Low-level coastal seepage
Offshore spring
Water-table contour
Approx. water-table contour
Perched water-table contour
Data based on groundwater levels measured during July - August 1974
Contour interval 10 metres
Numbered ticks indicate the 1000 metre Australian Map Grid, Zone 58, Australian National Spheroid. Grid approximate.
Point Vincent
DUNCOMBE BAY
DUNCOMBE ROAD
Bird Rock
Anson Point
ANSON BAY
Mt Bates
Mt Pitt
NO DATA AVAILABLE
CASCADE BAY
Cascade Jetty
CASCADE
Water table window
Top Hat
Steels Point
Broken Bridge Creek
Cascade Creek
Stockyard Creek
Mission Creek
BURNT PINE
Headstone Creek
HEADSTONE
Aerodrome
Watermill Creek
MIDDLEGATE
STOCKYARD ROAD
TWO CHIMNEYS ROAD
Point Blackbourne
BALL BAY
Rocky Point
Rocky Point Ck
Town Creek
Collins Head
KINGSTON
Kingston Jetty
CRESSWELL BAY
SYDNEY BAY
Point Ross
Point Hunter
0 1 2 km
84000mE
82000mN
Record 1976/62



Map 3 Locations of bores and wells on Norfolk Island
Bore in use
Observation bore
Dry bore
Abandoned bore
Well in use
Observation well
Dry well
Abandoned well
Stream
Road, sealed
Road, unsealed
Abandoned bores and wells without a number indicates that a location is the only useful information available
Numbered ticks indicate the 1000 metre Australian Map Grid, Zone 58, Australian National Spheroid. Grid approximate
Point Vincent
DUNCOMBE BAY
Capt. Cook Monument
Bird Rock
Anson Point
ANSON BAY
Mt Bates
Mt Pitt
CASCADE BAY
Cascade Jetty
CASCADE
Top Hat
Steels Point
BURNT PINE
MIDDLEGATE
HEADSTONE
Aerodrome
Melanesian mission
Point Blackbourne
BALL BAY
Collins Head
KINGSTON
Kingston Jetty
SYDNEY BAY
Point Ross
Point Hunter
Rocky Point
BULLOCKS HUT RD
ANSON BAY ROAD
MT PITT RD
STOCKYARD ROAD
TWO CHIMNEYS ROAD
Mission Creek
Headstone Creek
Broken Bridge Creek
Cascade Creek
Stockyard Creek
Watermill Creek
Town Creek
Rocky Point Ck
0
1
2 km
'84
'85
'86
'87
'88
'89
'90
'91
'84⁰⁰⁰ᵐE
⁶'89
⁶'88
⁶'87
⁶'86
⁶'85
⁶'84
⁶'83
⁶'82⁰⁰⁰ᵐN
Record 1976/62
N/A 3


Map 4 Hydrochemistry of Norfolk Island
Salinity contour (from field and laboratory conductivity measurements - expressed in micromhos/cm)
Total hardness contour - mg/l CaCO3
Ratio contour - Cl : HCO3
Data point ; sewage effluent plant
Where dashed, contours are approximate
Stream
Cliffs
Road, sealed
Road, unsealed
Bore, Well
Bar Graphs
Bore or Well number
Na + K
Mg
Ca
cations
anions in % epm
Data collection, July - September 1974. Groundwater values only are contoured.
Numbered ticks indicate the 1000 metre Australian Map Grid, Zone 58, Australian National Spheroid Grid approximate
Point Vincent
DUNCOMBE BAY
Anson Point
ANSON BAY
Mt Bates
Mt Pitt
NO DATA AVAILABLE
Bird Rock
CASCADE BAY
Cascade Jetty
CASCADE
Top Hat
Steels Point
BURNT PINE
MIDDLEGATE
Aerodrome
Point Blackbourne
BALL BAY
Collins Head
KINGSTON
Kingston Jetty
Point Hunter
SYDNEY BAY
Point Ross
Rocky Point
Mission Creek
Headstone Creek
Watermill Creek
Town Creek
Stockyard Creek
Cascade Creek
Broken Bridge Creek
Rocky Point Ck
TWO CHIMNEYS
2 km
Record 1976/62
N/A/48



Graph I Water balance at Watermill Creek, 1949 - 50