GROUNDWATER RESOURCES
OF
NGALO (LOMLOM) ISLAND
REEF ISLANDS,
TEMOTU PROVINCE

by

R. J. CURRY

S. 123

MEMORANDUM

TO: Provincial Secretary,
Temotu Province.

Attn: Mr R Natowan

NO: Glld 1
DATE: 2/7/85
Tel. No.

Your ref: c.c. Permanent Secretary/MEP
Attn: Messrs Kitchener & Patterson, PDU.

c.c. Permanent Secretary/MHA&PG
c.c. High Commissioner, Australian High Commission
Attn: Mr G Brooke.

GROUNDWATER RESOURCES OF NGALO ISLAND

As promised,please find attached a copy of the report entitled 'Groundwater Resources of Ngalo (Lomlom) Island, Reef Islands, Temotu Province,as prepared by the undersigned.

The report details the study carried out on Ngalo Island from 5-9 June and considers the groundwater resource in relation to your proposed Water Supply Scheme requirements.

As can be seen from the report,sufficient groundwater exists on Ngalo Island to meet your Scheme requirements,although changes to the source of water for some villages are recommended.

Potential groundwater pollution problems have been identified and remedial or alternative actions are also outlined in the recommendations.

As mentioned in the acknowledgements,I would like to convey my thanks to the members of your Province involved in ensuring the smooth and well organised running of the entire trip.

Trusting this report now allows you proceed with the design of the scheme.

(R J CURRY)
Snr Water Resources Officer,
for Permanent Secretary/MNR
rr

att.

GROUNDWATER RESOURCES OF

NGALO (LOMLOM) ISLAND

REEF ISLANDS, TEMOTU PROVINCE

by

R J CURRY

Water Resources Section

Geology Division

Ministry of Natural Resources

GROUNDWATER RESOURCES

OF

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REEF ISLANDS

TEMOTU PROVINCE

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June 1985

Distribution: Provincial Secretary, Temotu Province
Permanent Secretary, Ministry of Economic Planning
Permanent Secretary, Ministry of Health & Medical Services
High Commissioner, Australian High Commission
High Commissioner, New Zealand High Commission

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REEF ISLANDS, TEMOTU PROVINCE

SOLOMON ISLANDS

R J Curry *

1. INTRODUCTION:

The Reef Islands are a small group of low-lying reefs and terraces located 48km north-east of Nendo, the main island of the Santa Cruz group. (Fig.1) The main islands are Ngalo (Lomlom), Ngawa and Fenualoa (Fig 2), the remaining islands consisting of smaller, outlying islands. In 1983 the total population for the Reef Islands was estimated at 4200 persons.

As with the other islands in the Reefs, Ngalo Island (14.02km^2) is devoid of any significant topography and so lacks natural surface water resources and scope for surface reservoir development (Fig 3b). Consequently water supplies are drawn by hand from several natural deep groundwater wells and a few shallow hand dug wells which are very sparsely located around the Island. More recently some villages have turned to roof catchment supplies for drinking water particularly where groundwater salinity is high, however these are both expensive and limited in capacity. As with many other islands Ngalo is experiencing an increase in population and a growing demand for water.

As part of the 1984 Provincial Rolling Plan, the Temotu Provincial Executive approved in principle the construction of a rural Water Supply project to serve 1600 persons on Ngalo Island. The project proposes that fresh water be pumped from natural wells at Nimoa (Balipa'a School) and Laro by solar power to elevated storage tanks and then distributed by gravity to surrounding villages (Fig. 4). Total project costs were estimated at $85,000 to be shared by the Province, local community, and a yet to be identified overseas aid source.

Before such a scheme can proceed an assessment of the extent of the groundwater resource must be undertaken in order to ensure that adequate water is available and that the extraction of same will not cause salt-water intrusion and thus contaminate the resource.

*Snr Water Resources Officer
Water Resources Section
Geology Division
Ministry of Natural Resources
Honiara.

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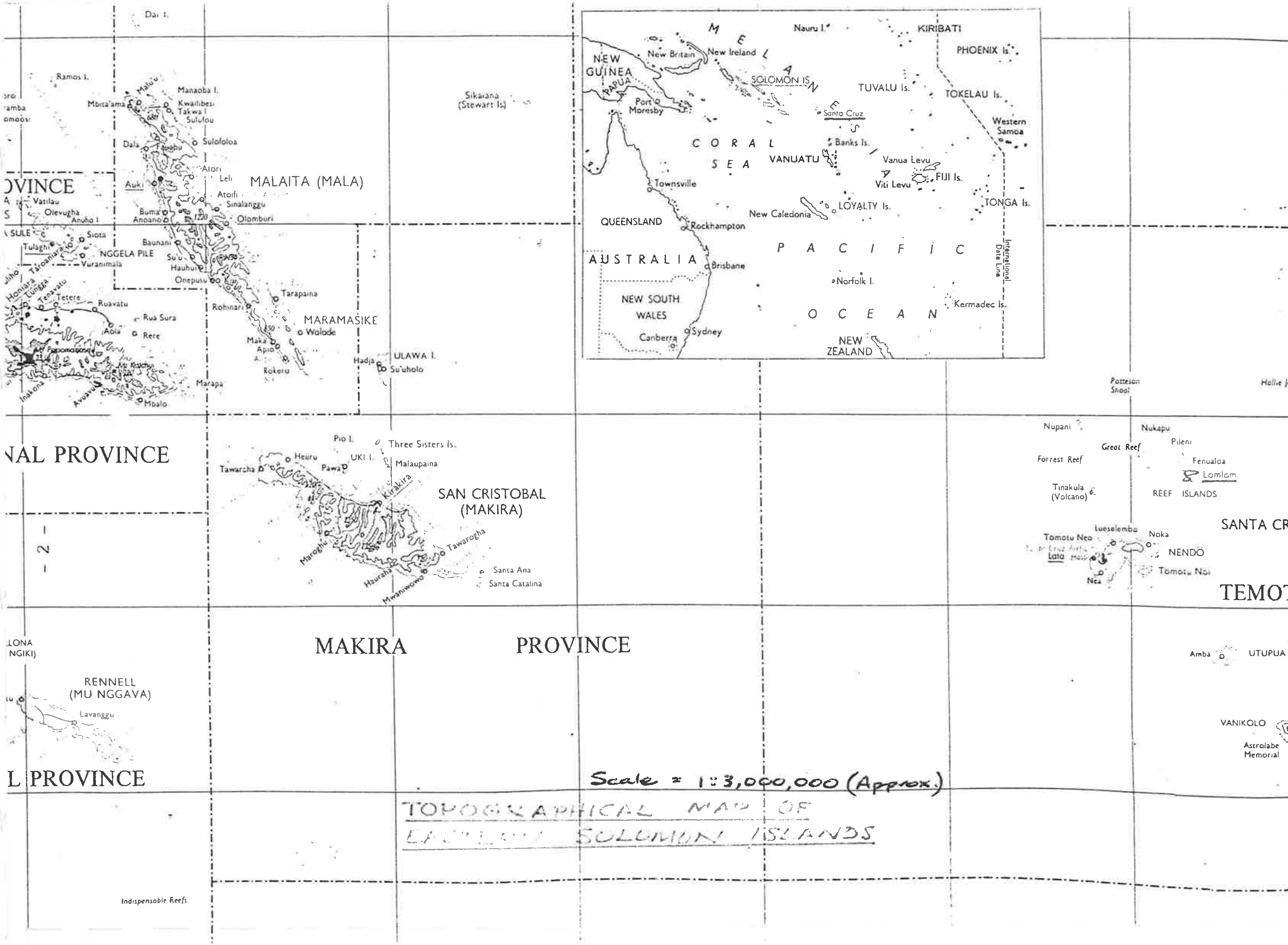
Dai I.
Ramos I.
Manaoba I.
Malu'u
Mbita'ama
Kwailibesi
Takwa I
Sulufou
Sulofoloa
Sikaiana
(Stewart Is)
Dala
Auki
Atori
Leli
Atoifi
MALAITA (MALA)
Sinalanggu
Buma
Anoano
Olomburi
Baunani
Su'u
Hauhui
Onepusu
Tarapaina
Rohinari
MARAMASIKE
Wolode
Maka
Apio
Rokera
Hadja
ULAWA I.
Su'uholo
Marapa
Mbalo
OVINCE
Vatilau
Olevugha
Anuha I
SULE
Siota
Tulaghi
NGGELA PILE
Yuranimala
Honiara
Tetere
Ruavatu
Rua Sura
Aola
Rere
Avuavu
Inakona
NAL PROVINCE
Pio I.
Three Sisters Is.
Heuru
UKI I.
Malaupaina
Tawarcha
Pawa
Kirakira
SAN CRISTOBAL
(MAKIRA)
Maroghu
Tawarogha
Santa Ana
Santa Catalina
Hauraha
Mwaniwowo
MAKIRA
PROVINCE
LONA
NGIKI)
RENNELL
(MU NGGAVA)
Lavanggu
L PROVINCE
Indispensable Reefs
Nauru I.
KIRIBATI
MELANESIA
NEW GUINEA
PAPUA
New Britain
New Ireland
SOLOMON IS
PHOENIX Is.
TUVALU Is.
TOKELAU Is.
Port Moresby
Santa Cruz
Western Samoa
CORAL SEA
Banks Is.
VANUATU
Vanua Levu
Viti Levu
FIJI Is.
Townsville
New Caledonia
LOYALTY Is.
TONGA Is.
QUEENSLAND
Rockhampton
PACIFIC OCEAN
International Date Line
AUSTRALIA
Brisbane
Norfolk I.
NEW SOUTH WALES
Kermadec Is.
Canberra
Sydney
NEW ZEALAND
Patteson Shoal
Hollie Jock
Nupani
Nukapu
Great Reef
Pileni
Forrest Reef
Fenualoa
Lomlom
Tinakula
(Volcano)
REEF ISLANDS
SANTA CRUZ
Tomotu Neo
Lueselemba
Noka
NENDO
Lata
Nea
Tomotu Noi
TEMOTU
Amba
UTUPUA
VANIKOLO
Astrolabe
Memorial
Scale = 1:3,000,000 (Approx.)
TOPOGRAPHICAL MAP OF
EASTERN SOLOMON ISLANDS

FIG. 1

- 2 -

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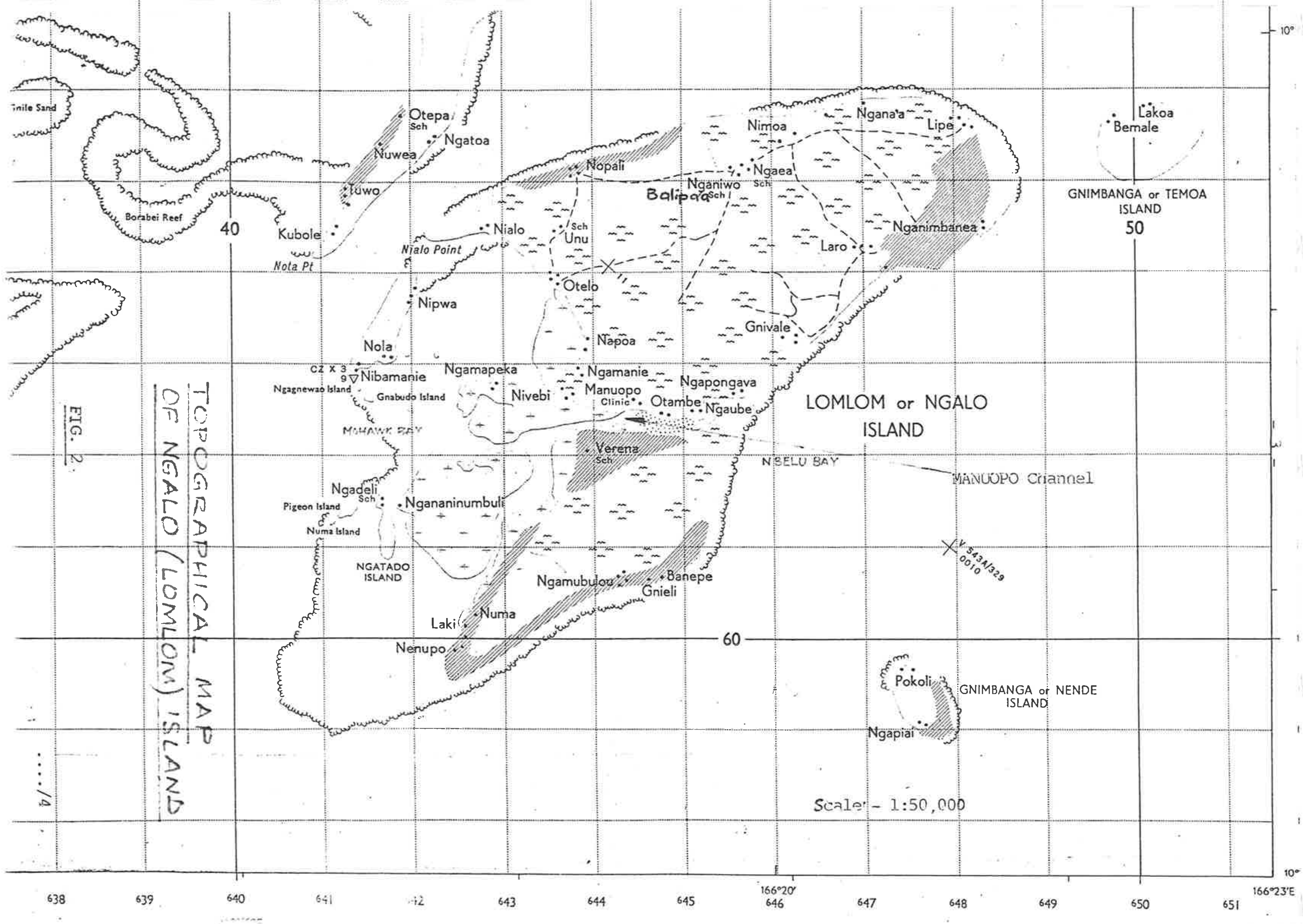

FIG. 2.

TOPOGRAPHICAL MAP OF NGALO (LOMLOM) ISLAND

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GEOLOGY MAP OF NGALO (LOMLOM) ISLAND.

FIG. 3

Fig. 3a

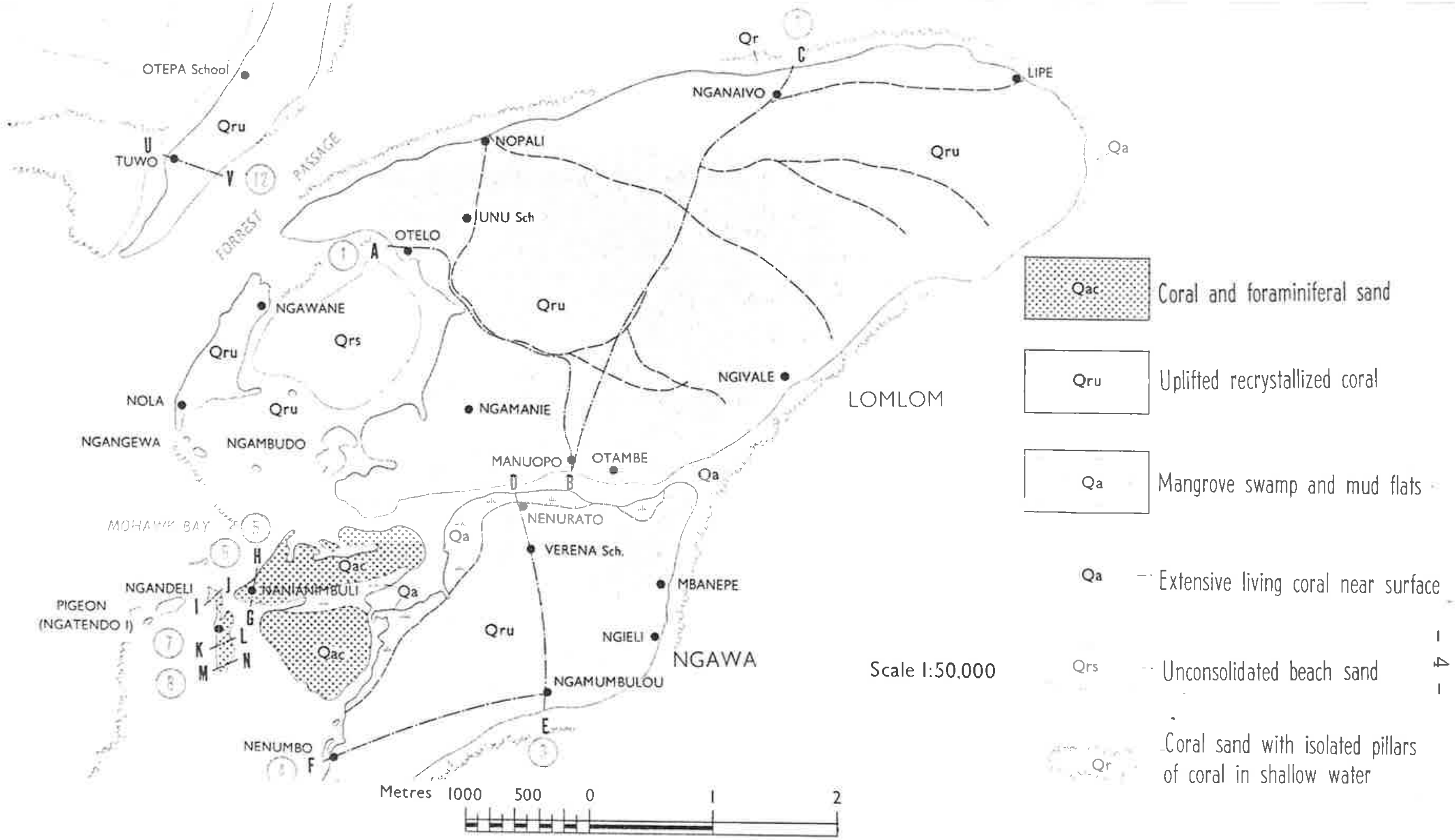


Fig. 3b

SECTIONS ACROSS NAMED ISLAND GROUP, OBTAINED FROM LEVELLING TRAVERSES. HORIZONTAL SCALE NOT CONSTANT, BUT APPROXIMATELY 6 INCHES TO 1 MILE.

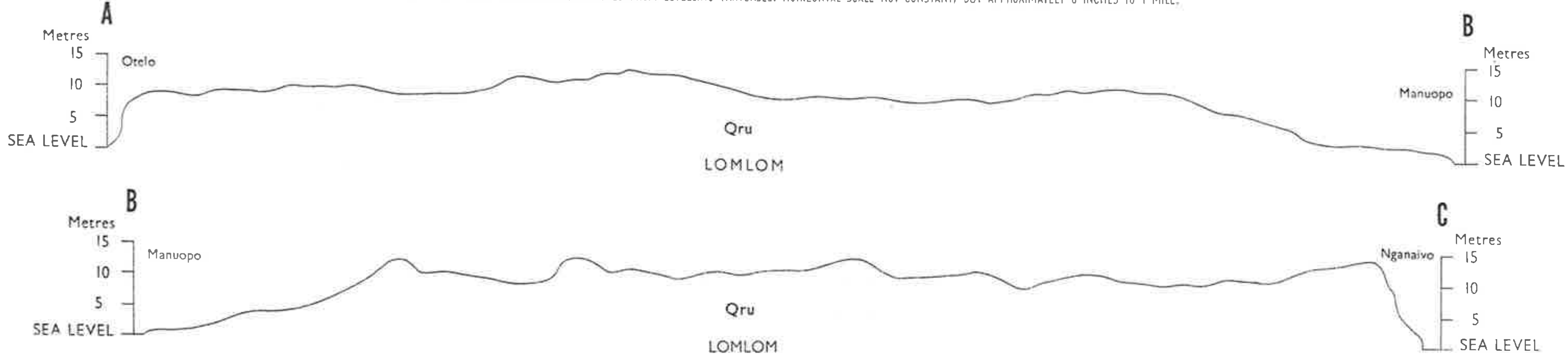
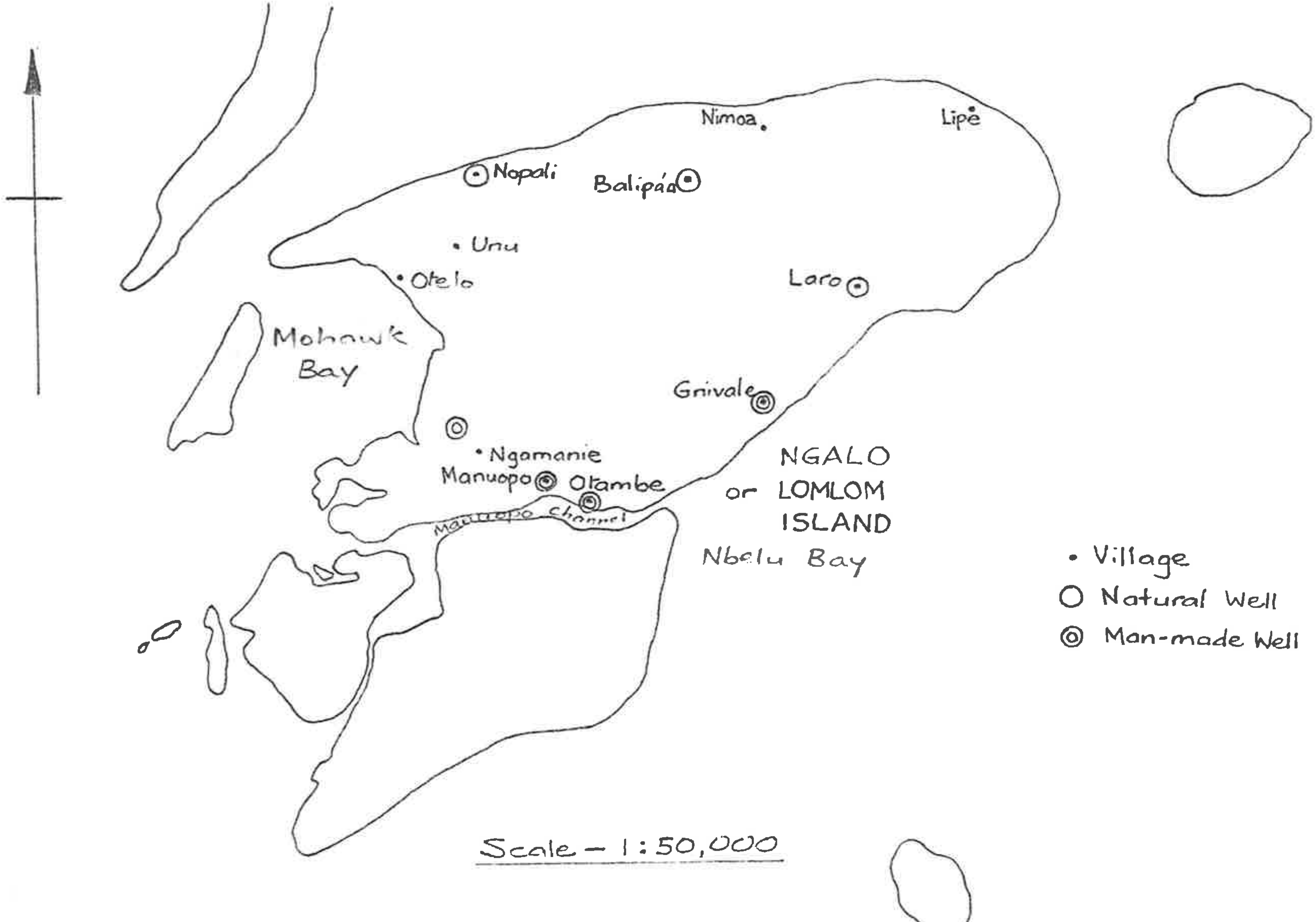


FIG. 4.



NGALO ISLAND, REEF ISLANDS

SHOWING VILLAGE AND WELL LOCATIONS.

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Considerable difficulties exist in assessing the groundwater on islands such as Ngalo ,with its comparitively small area and very low topographical relief (limiting groundwater lens development), together with the complete lack of hydro-geological data. In order to obtain a good understanding of the underground water resources of such an island, many months of well logging, levelling and geophysical testing would normally be necessary, however due to its extreme isolation neither time, nor manpower and financial resources were available for such a survey.

A water-resources survey team comprising Messrs Pule, Tickell and Curry spent 5 days on the island (5 - 9 June 1985) and during this time sufficient data were collected to allow predictions to be made on the maximum sustainable yields from the various wells studied.

2. GEOLOGY

A knowledge of the geology is essential to the understanding of the possible extent of the groundwater resource.

Ngalo Island is entirely composed of biogenic limestone and forms part of an extensive east-west aligned oval area based upon a discountinuous submarine ridge capped with living coral. The maximum altitude of the island is 31 metres above LWM, this being attained at the south-east end of the island. There is no surface drainage, the water supply being confined to several natural limestone solution channels and sinkholes, and coastal hand dug wells.

Ngalo Island consists entirely of uplifted recrystallised coralline limestone (Fig.3) bordered to the west by a deep steep sided linear passage (Forrest Passage) and to the east by steep cliffs and living coral platforms. The thickness of the coral reef limestone is unknown though it is believed to be exceedingly thick. Drilling on Bikini and Funafuti atolls indicate thicknesses of 760m and 335m respectively in similar limestones. (Kirk & Grundy 1961). Traverses and cliff height measurements indicate that the Ngalo Island surface dips towards the west and suggests that some regional tilting has occurred which may have been synchronous with the main period of uplift (Hughes et al 1981). Raised beaches, ranging from 2 - 4 metres above LWM surround the north and east of the island, provide evidence of regional physical instability and fresh water springs discharging water of varying salinities are common around the coast below HWM.

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The lower lying land to the south of the island, adjacent to the Manuopo Channel, is largely a mixture of fragmented coral and sands overlying the uplifted coralline limestone,however the depth of this pourous layer is not known.

Soils are generally shallow but do exhibit a three fold zonation viz dark brown humic top soil, a transition zone and a carbonate-sand layer.

3. GROUNDWATER POTENTIAL

The potential for there to be a groundwater resource on Ngalo Island is dependent on sufficient effective rainfall, adequate infiltration and a suitable degree of permeability within the underlying strata.

Adequate infiltration is evident with a thin soil layer overlying numerous cracks, and sinkholes synonymous with limestone strata. Permeability is likely to be highly variable, due to the fractured rock and solution tunnels, thus requiring site specific investigations to determine actual water yields.

Firstly, however there is a need to determine the amount of rainfall available for recharge in order to assess the groundwater resource potential.

3.1. Recharge Capability

The simple water balance equation used is as follows:

$$P = I + Ep + Re + RO + Qab + Qs + Si$$

where P = precipitation
I = intercepted rainfall
Ep = evapotranspiration
Re = recharge
RO = surface runoff
Qab = groundwater abstraction
Qs = groundwater flow to sea
& Si = incremental groundwater storage change

To determine recharge or the potential input to the system the above equation can read:

$$Re = P - I - Ep$$

Output parameters or losses RO, Qab and Si are insignificant compared with Qs which is unable to be quantified due to the number of sub marine and semi submarine outflows, only some of which were observed during low tide.

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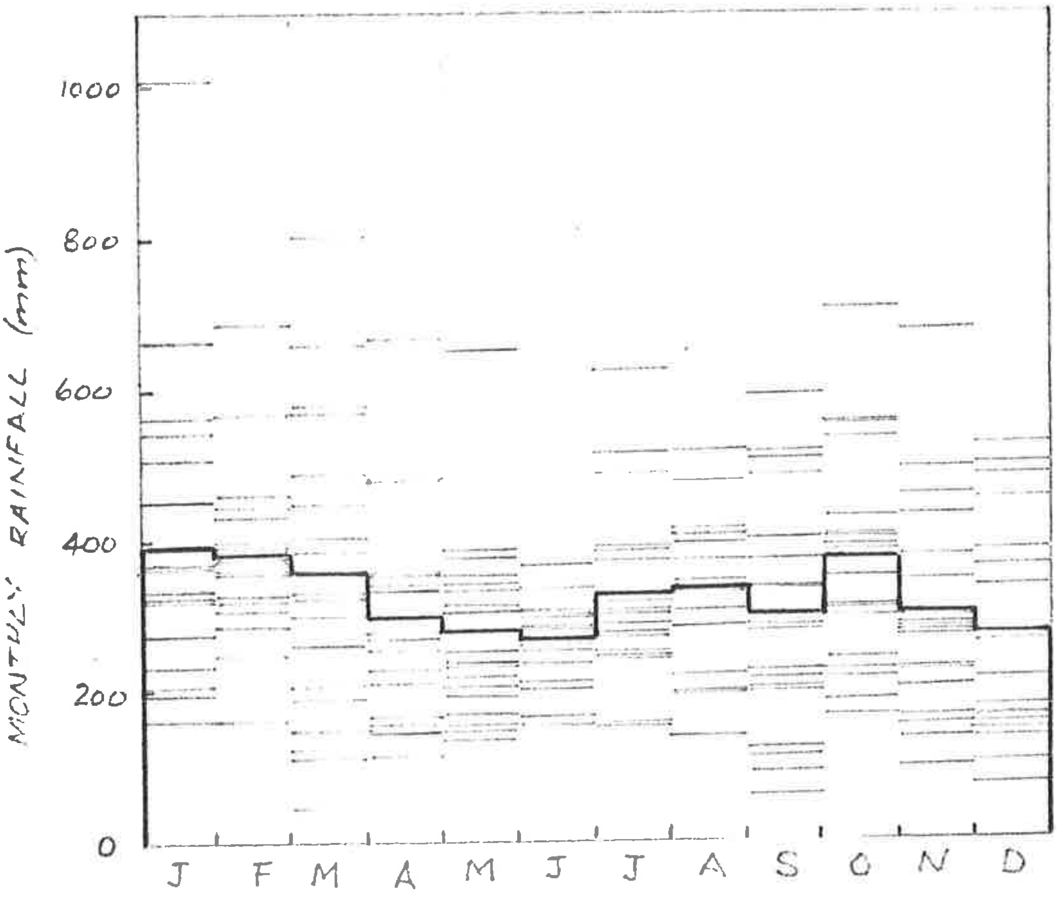
If the groundwater resource is assumed to be relatively stable from year to year then the recharge will approximately equal the flow to the sea and so an estimate of the magnitude of the throughput or water balance can be obtained.

Long term rainfall data for the period 1969 - 85 was available for Mohawk Bay (Fig.4), the monthly totals and long term monthly and annual falls being given in Table 1.



MONTHLY AND MEAN MONTHLY RAINFALL FOR MOHAWK BAY (REEF ISLANDS)

FIG. 5

TABLE 1

MOHAWK BAY (REEF ISLANDS)
RAINFALL RECORDS

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	TOT.
1967	451.9	689.4	404.6	481.3	387.4	369.1	278.6	518.9	280.2	404.6	279.7	179.3	4725
1968	368.3	353.3	260.9	255.3	170.4	169.4	513.8	395.5	508.3	704.6	379.0	499.1	4570.2
1969	281.2	372.4	111.0	666.0	204.0	284.7	627.1	n/a	92.5	551.2	136.4	524.3	–
1970	196.0	377.5	333.0	475.6	377.0	307.2	382.5	309.8	204.1	536.4	297.4	451.7	4002.5
1971	507.2	430.4	568.1	352.1	157.7	264.4	248.4	477.8	335.1	229.7	281.4	385.8	4223.5
1972	562.2	308.2	324.5	277.8	651.7	307.9	245.9	285.4	400.5	169.1	226.9	339.7	4107.2
1973	323.6	329.3	448.4	358.4	305.0	213.2	271.0	332.6	287.9	297.1	278.3	275.0	3719.1
1974	274.8	390.4	361.0	336.5	148.4	281.6	288.6	403.6	219.2	401.6	460.0	156.6	3722.2
1975	664.8	286.6	382.6	269.4	231.0	236.1	373.6	346.4	487.0	309.2	495.8	215.0	4297.5
1976	1008.2	569.6	656.6	340.8	218.6	269.0	390.4	332.6	333.6	350.8	431.4	484.4	5436.0
1977	540.0	396.0	801.6	207.2	333.4	337.2	487.4	406.8	373.4	429.2	168.2	163.4	4643.8
1978	233.8	460.0	300.6	324.0	235.0	153.5	150.5	199.0	123.5	189.0	156.5	165.0	2690
1979	326.0	162.0	149.0	228.0	252.0	202.0	253.5	197.0	197.5	219.0	238.0	265.0	2688
1980	203.5	249.5	577.5	114.0	138.0	255.5	309.0	221.0	593.0	242.0	678.0	73.0	3654
1981	366.0	370.0	48.0	351.5	191.0	266.0	319.0	374.0	115.0	313.5	273.0	364.5	3351
1982	372.5	389.2	124.2	145.0	322.0	295.5	300.5	414.0	228.0	383.0	99.0	104.0	3175
1983	323.6	387.5	184.0	150.2	342.1	300.2	169.0	137.0	519.0	392.1	204.2	136.2	3244
1984	329.7	398.2	204.5	158.2	352.6	306.9	301.0	337.5	61.5	552.5	345.5	147.5	3496
1985	156.0	322.0	488.5	167.5									
AVERAGE	394	381	354	298	279	268	328	334	298	371	302	274	3694

provided by: Meteorology Division,
Ministry of Transport & Communications

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Fig 5 shows the variability within each month and the relative uniformity of the average monthly falls throughout the year. The month of the survey (June) was noted as having the lowest long term average rainfall and the least variability and so was the best month to do the survey.

Normally potential evapotranspiration (Ep) is calculated using the Penman (1948) techniques but unfortunately adequate data are unavailable in Temotu even with the modifying corrections adopted for smaller islands by Lloyd, et al. (1977). As temperature is a standard measurement in any climate station irrespective of its function it would appear that the Thornthwaite (1948) evaporation estimation provides the only viable means of assessing this parameter despite its obvious shortcomings (Ward, 1971). In the Ngalo Is study this method was therefore used with temperature data for Lata. In view of the lack of data it is not possible to comment on the accuracy of evaporation calculated for Ngalo Is using Thornthwaite in comparison to the more sophisticated Penman method. However, where such work has been carried out elsewhere the Thornthwaite calculations have been found to be most in error where very variable climate conditions appertain so that gross errors would not appear to be likely in the calculations made for Ngalo Island.

Although precipitation is the controlling parameter for recharge input, on the Pacific atolls a significant proportion of the precipitation does not reach the ground and have the opportunity to support the vegetation cover through evapo-transpiration. Broad coconut fronds for example intercept precipitation which is subsequently evaporated; this loss is obviously important and may be considered to amount up to 15 percent of the total precipitation for islands such as Ngalo (Penman, 1963; West and Arnell, 1975).

To account for recharge reaching the water table the concept of a soil moisture balance as described by Penman (1950) and Lloyd, et al. (1966), was adopted using the effective precipitation as the total precipitation (P) minus the intercepted rainfall (I). The balance was established on a running monthly basis with the relationship between effective rainfall, evaporation and actual recharge to a lens subsequently controlled by two parameters 'C' and 'D'. Although it is appreciated that probably a daily balance (or at least a 10-day balance) may provide more accurate estimates (Howard and Lloyd, 1979) the accuracy of the rest of the ground water data on Ngalo does not justify such accuracy.

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The soil moisture parameter 'C' may be defined as the moisture level in the soil (in mm) which has to be satisfied before water can infiltrate as recharge below the root zone. The parameter is therefore a function of 'field capacity' and rooting depth. The parameter 'D' (mm) is the limiting moisture content in the root zone at which effective evapotranspiration ceases and plants start to wilt. In the balance evapotranspiration is considered to occur at the potential rate when soil moisture values are within the 'C' range. When values fall between the 'C' and 'D' limits the evapotranspiration is constrained and for Ngalo Is has been assessed to operate at 10 percent of the potential value (Penman and Schofield, 1964).

Values of 50mm and 120mm were adopted for "C" & "D" respectively. (Lloyd et al 1980).

In order to ascertain the magnitude of the annual average recharge, the water balance was calculated for the year 1984 (approximates mean annual rainfall and incorporates typical monthly variations). Monthly rainfall totals from the Mohawk Bay Station and mean monthly temperatures from the Lata climate station (Fig 1) for 1984 were used, the latter to calculate the monthly potential evapotranspiration (Table 2).

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CALCULATION OF POTENTIAL EVAPOTRANSPIRATION FOR REEF ISLANDS (SANTA CRUZ) USING THE THORNTHWAITE METHOD

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Mean* Monthly Temp. (°C)	28.4	28.6	27.8	28.4	28.5	27.6	27.2	27.8	27.9	28.2	28.4	29.1	28.2
Heat Index I	13.87	14.01	13.43	13.87	13.89	13.28	12.99	13.43	13.50	13.72	13.87	14.39	(Ia) 164.25
Uncorrec-ted PE (cm)	13.89	14.28	12.77	13.89	14.08	12.41	11.71	12.77	12.95	13.51	13.89	15.29	
PE correct-ions for 10°S (after Griddle)	1.06	1.08	1.07	1.02	1.02	0.98	0.99	1.00	0.91	1.03	1.03	1.08	
PE (mm)	147	154	137	142	144	122	116	128	118	139	143	165	1655

Heat Index I $= (t/5)^{1.514}$ where t is the mean monthly temp in °C.

e.g. For Jan. I $= \left(\frac{28.4}{5}\right)^{1.514} = 13.87$

Uncorrected PE (30days of 12 hrs) $= 1.6 \left(\frac{10\ t}{I\ a}\right)^{x}$

$$\text{where } x = 6.75 \times 10^{-7}(I_a)^3 - 7.71 \times 10^{-5}(I_a)^2 + 1.792 \times 10^{-2}\ Ia, + 4.9239 \times 10^{-1}$$

$= 2.9910 - 2.0800 + 2.9434 + 0.49239$

$= 3.9468$

e.g. For Jan U.P.E. $= 1.6 \left(\frac{10 \times 28.4}{164.25}\right)^{3.9468} = 13.89$ cm

* Provided by Meteorology Division, Ministry of Transport & Communications

TABLE 2

The potential recharge calculation for 1984 is given in Table 3 and shows that 1371 mm or 42% of the 1984 annual rainfall of 3244 mm is available for recharge.

As the areal extent of Ngalo Island is 14.02 km the average annual volume of water available for recharge is 1.9×10^7 m^3 which approximately equates to an average annual flow rate of 600 $l\ s^{-1}$. A flow rate of this magnitude can quite conceivably be accounted for from the numerous springs apparent around the coastline.

The water balance showed that adequate potential exists for there to be a good ground water system.

4. GROUNDWATER EVALUATION

As already noted the permeability in the limestone formations is likely to be highly variable and as such would not promote the Ghyben-Herzburg hydrostatic development and lens formation between fresh ground water and sea water as described by Wentworth C.K., 1947.

Nevertheless some local hydrostatic developments could exist within the highly permeable caverns and certainly in the pourous unconsolidated coastal coral and sand, accentuating the possibility of salt-water intrusion.

Prior to the Water Resources Teams visit to Ngalo Is., the Province was requested to take water samples from all the wells in use. Table 4 details the water quality analyses of these samples and the total dissolved solids (TDS) and chloride measurements made during the subsequent visit. The groundwater from all the wells tested was seen to be fit for human consumption, all being well within the World Health Organisation (WHO) maximum allowable standards. However, some parameters tested were a little over or very close to WHO maximum acceptable recommendations. These were Manuopo well with a high alkalime content (pH=8.6) and Ngivale with a TDS concentration of 500 $mg l^{-1}$.

Having recorded these baseline quality levels, detailed well testing was carried out on all the wells except Ngivale as it was assumed that, with pumping, the Ngivale TDS was likely to rise and become even less acceptable.

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TYPICAL SOIL MOISTURE - RECHARGE CALCULATION

FOR YEAR 1984

MONTH	MOHAWK BAY RAINFALL LESS INTERCEPTION (mm)	SANTA CRUZ POTENTIAL EVAPORATION (mm)	EFFECTIVE RAINFALL (mm)	SOIL MOISTURE DEFICIT (mm)	RECHARGE (mm)
Jan	280	147	133	0	133
Feb	338	154	184	0	184
March	174	137	37	0	37
April	134	142	-8	-8	0
May	300	144	156	0	148
June	261	122	139	0	139
July	256	116	140	0	140
Aug	287	128	159	0	159
Sept	52	118	-66	-51	0
Oct	470	139	331	0	280
Nov	294	143	151	0	151
Dec	125	165	-40	-40	0
					1371

Annual Recharge for 1984 = 1371 mm (42% of annual rainfall of 3244 mm)

Area of Lomlom Island = 14.02 km^2

Therefore total volume of water available for recharge
= 1.9×10^7 m^3 p.a. or 600 $l\ s^{-1}$.

TABLE 3

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WELL WATER QUALITY

Well	Dec 1984 pH	TDS	Tot Hard $CaCO_3$	$Ca.CaCO_3$	Mg $CaCO_3$	Na	K	JUNE 1985 TDS	Cl
Balipa'a	8.4	170	152	56	2.9	1.15	0.15	250/570	125
Laro	8.1	280	133	42.6	6.3	2.3	0.15	300/325	200
Manuopo	8.6	270	191	69	4.6	1.15	0.15	280	175
Ngamanie	8.2	310	211	77	4.6	1.8	0.15	320/320	
Otambie	7.8	450	281	76	118?	2.3	0.15	300/450	175
Ngivale	7.6	500	214	65	12.9	5.25	0.15	-	-
WHO Max Acceptable	7.0-8.5	500	365	190	175	-	-	500	250
WHO Max Allowable	6.5-9.2	1500	1030	500	530	-	-	1500	600

Samples collected by: M L Kevu ?
Samples analysed by: S. Veke 18.1.85

TABLE 4

4.1 Well Tests and Reistivity Surveys

This Section gives an account of the various investigations undertaken in and around each well and includes pump tests and water quality variations, earth resistivity results and water table levels in relation to sea level.

For water quality the total dissolved solids (TDS) and Chloride levels were measured using the pHox 52E portable conductivity meter, and Hach Test kit respectively, the former being checked with salt solutions of known concentrations under laboratory conditions (Scott & White 1984).

The earth resistivity survey was carried out as described in (White & Scott 1984) with an Abem Terrameter SAS 300 resistivity meter and a BGS -256 offset sounding cable system and results were reduced using the Altos Wenner programme..

4.1.1 Balipa'a School Well

The Balipa'a School well (Fig.4) is identified in the Water Supply Scheme proposal as the suggested source of water to be reticulated to the villages on the northern half of Ngalo Island. The villages to be served are Lipe with a population of 250, Nimoa with 215, Balipa'a with 5 plus the school, Napali with 165, Unu or Nila with 50 and Otelo with 190, a total population of 875 people.

4.1.1.1 Well Observations

The well is a natural cylindrical limestone solution vent perfectly symmetrical and approximately 1.2 metre in diameter. The depth to the water level varied from 11.0 to 11.3 metres below ground level and the depth to the bottom of the well was 17.45 metres giving a minimum depth of water of 6.1 metres. Water for the Balipa'a School and 6 permanent residence is extracted with a rope and a bucket.

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A large TDS profile variation was observed with depth of water, the TDS at the top being 250 - 260 whilst the TDS at the bottom was 570 - 660. This was the largest TDS vs depth variation observed in any well but the well had easily the greatest depth of water. A chloride concentration of 125 mgl^{-1} was recorded.

A continuous ripple was observed on the surface of the water which was too far down the hole to be effected by wind. A village elder believed the ripples to be caused by flow through the well but this could not be tested with the equipment available. The same man recalled that one person had been down the well and had said that the area of the well increased to several metres in diameter and was offset towards the sea.

Several sinkholes varying in size were observed within 500 metres of the Balipa'a well, one (200 metres further inland) was oval shape (the longest axis being approximately 10 metres) with steep sides and an overhanging lip. This hole adjacent to the Balipa'a School Playing Field, was currently being used as a rubbish tip but was once used as a source of water. Water was still visible in one low corner of the well and once access was gained several water level readings were taken and these tied into those at the main Balipa'a well. No flow was apparent.

The Balipa'a tip water level fluctuations were in syncronisation with those of at the main Balipa'a well but were 0.584 metres higher. Presuming that the two water levels were connected this is a large gradient over the approximate 200 metres between the two wells.

The potentiometric levels in the main well were read over parts of complete tide cycles and the results plotted as "+"'s against the Santa Cruz-Reef Island tide tables (Fig 6). Levels were seen to be sinoidal with the same frequency as the tide but with a 3 hour lag. The ratio of potentiometric level amplitude to tidal amplitude or tidal efficiency was 0.25.

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WATER WELL PIEZIOMETRIC LEVELS IN RELATION TO REEF IS. TIDE LEVELS.

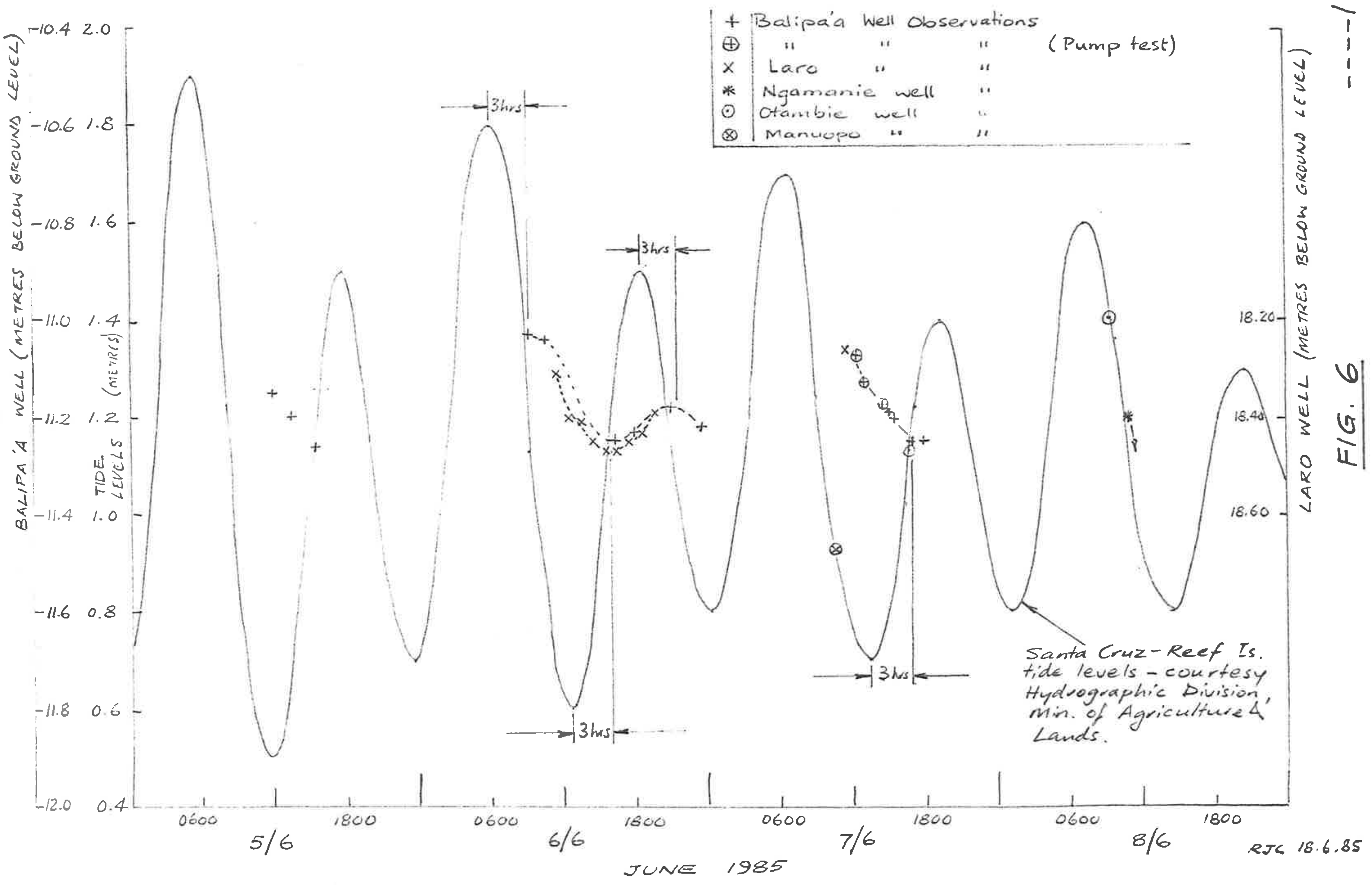

FIG. 6

RJC 18.6.85

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A levelling run was carried out over the 0.6 km between the Balipa'a well and the coast and levels tied into high tide observation from two cycles. Results showed the water levels in the main well to be 0.41 metres above estimated mean sea level and approx 0.6 metre above the sea level at the time.

Springs on the coast below HWM gave TDS and chloride levels of 2300 and 1700 mgl respectively.

4.1.1.2 Earth Resistivity Results

In view of the supposedly channelised underground streams through solution pipes in the limestones, two earth resistivity soundings were carried out (as show in Fig 7) in an effort to establish the possible areal extent of groundwater at Balipa'a.

Both soundings gave three layer geoelectric sections with a top soil layer of 850 and 890 m to 1.3 and 1.4 metres depth, a dry limestone layer of 2800 and 3400 m to 14 and 16 metres depth, followed by a third saturated layer of 26 and 170Ωm to an undefined depth (RMS errors of 2.6 and 3.5% respectively). As both sounding lines were 2-3 metre higher in elevation than the datum for the well measurements, the 14 and 16 metres to a saturated layer corresponds to within $\pm$1.0 metre of the observed water levels of 11.0 to 11.3 metres at the well. This variation in potentiometric levels could be real as a 0.6 metre difference was observed between the two Balipa'a wells. Results therefore confirmed an areally extensive resource albeit in fissure and solution channels.

The other main aim of the resistivity survey was the possible detection of a underlying layer of saline water however earth resistivity results neither confirmed or excluded the existance of such a layer.

4.1.1.3 Pump Test

The Balipa'a School main well was pump tested on 7 June (Fig 8) by lowering the Davey Model 8128 2" centrifugal pump by rope 7 metres down the well after having started it on the surface.

BALIPA'A SCHOOL EARTH RESISTIVITY SITE PLAN

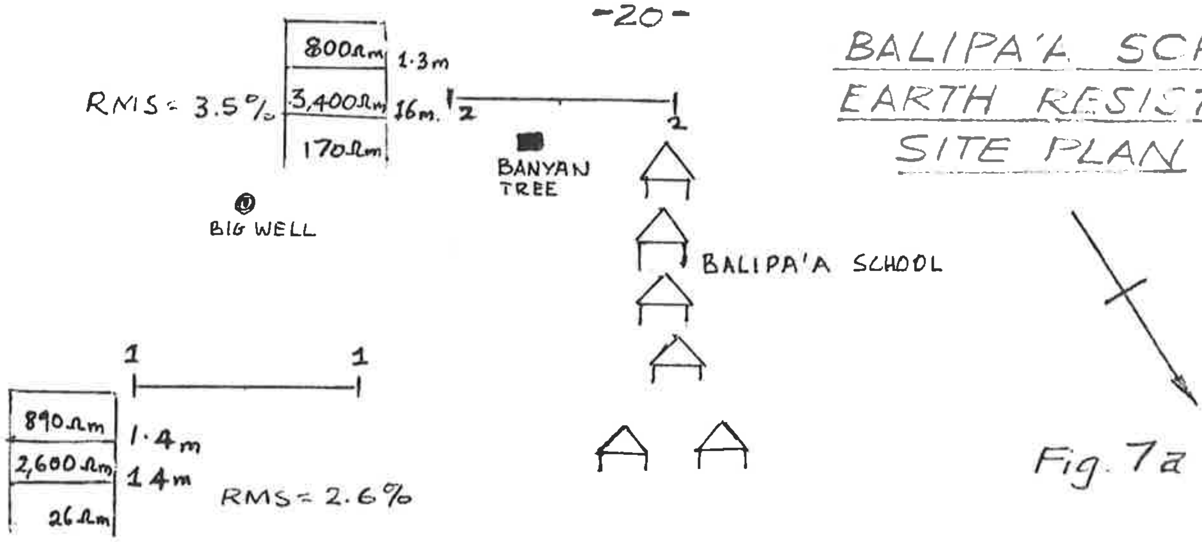

Fig. 7a

SCALE: APPROX 1:4000

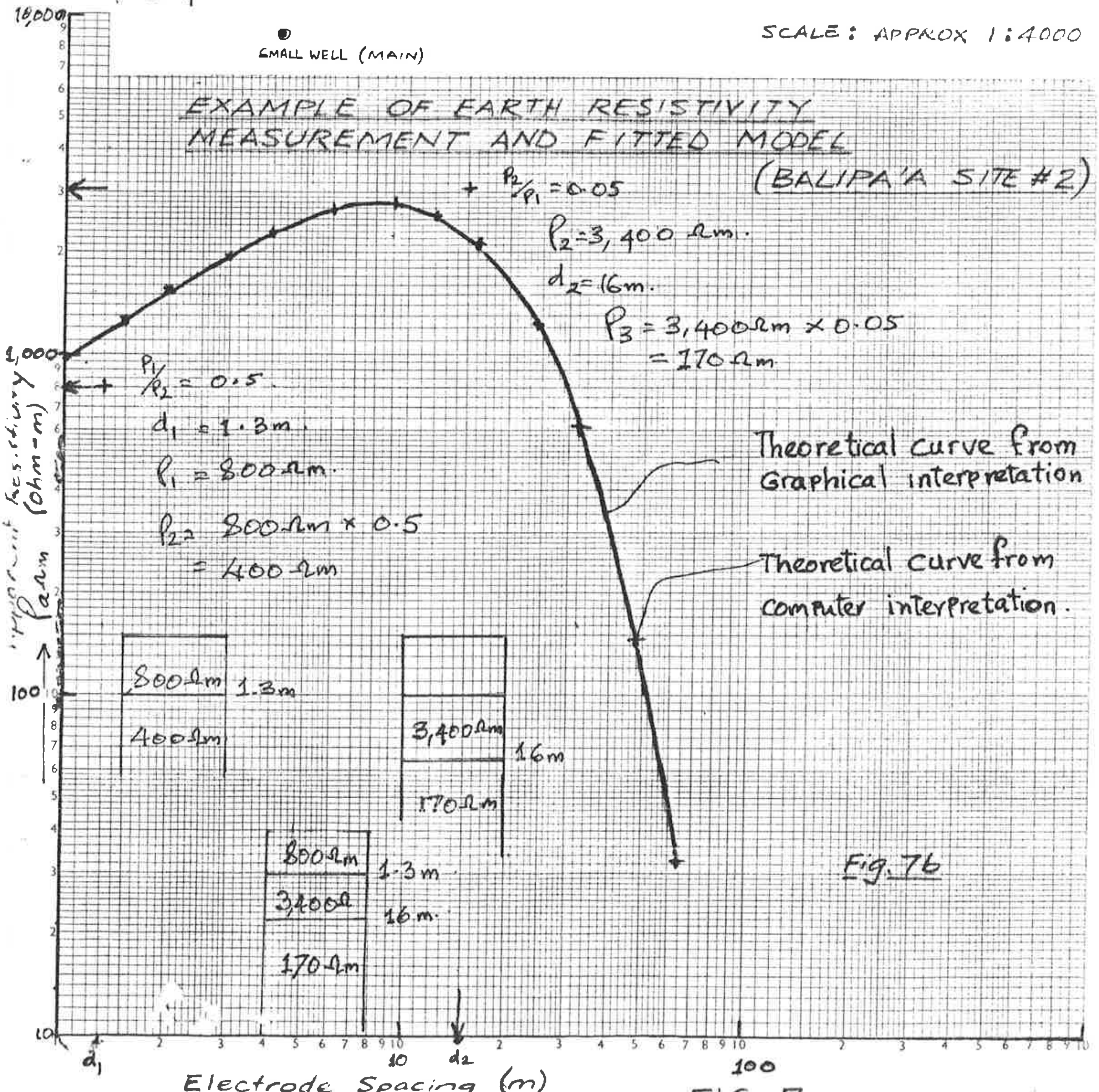

Fig. 7b

FIG. 7

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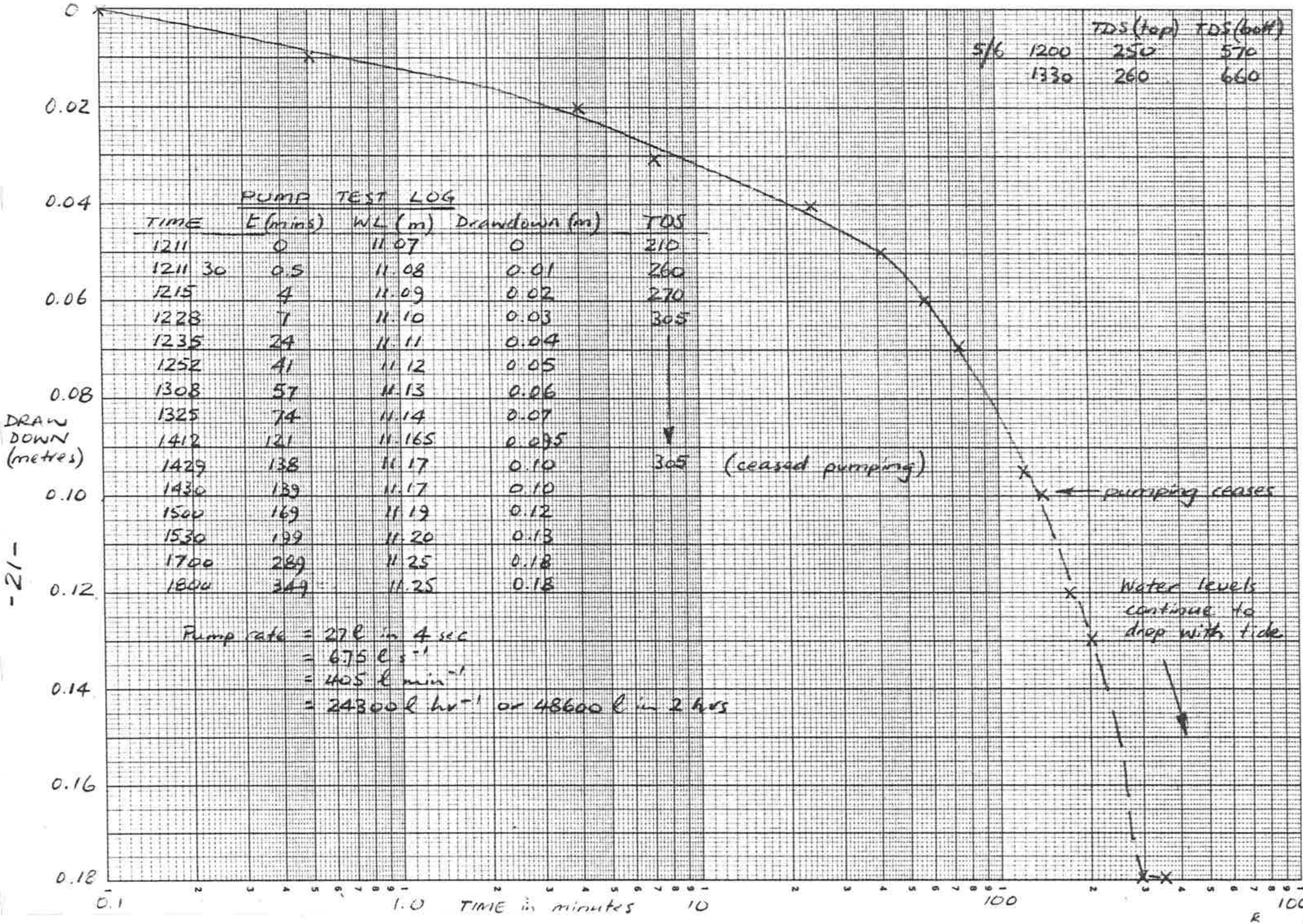
BALIPA'A WELL PUMP TEST



5/6	TDS (top)	TDS (bott)
1200	250	570
1330	260	660

PUMP TEST LOG

TIME	t (mins)	WL (m)	Drawdown (m)	TDS
1211	0	11.07	0	210
1211 30	0.5	11.08	0.01	260
1215	4	11.09	0.02	270
1228	7	11.10	0.03	305
1235	24	11.11	0.04	
1252	41	11.12	0.05	
1308	57	11.13	0.06	
1325	74	11.14	0.07	
1412	121	11.165	0.095	
1429	138	11.17	0.10	305 (ceased pumping)
1430	139	11.17	0.10	
1500	169	11.19	0.12	
1530	199	11.20	0.13	
1700	289	11.25	0.18	
1800	349	11.25	0.18	

Pump rate = 27 ℓ in 4 sec
= 6.75 ℓ s^{-1}
= 405 ℓ min^{-1}
= 24300 ℓ hr^{-1} or 48600 ℓ in 2 hrs

FIG. 8

Miraculously it pumped water at a rate of 24300 lhr^{-1} (5300 gph) for 2 hours 18 minutes until the tank run out of petrol, the outlet hose providing a high pressure 'swim' for the many spectators.

Water and TDS levels were monitored continuously throughout the test (Fig 8) giving a 0.10 metre drawdown and a rise to 305 mgl^{-1} at the end of the pumping, the latter presumably being due to the mixing of the top (250) and bottom (600)TDS levels during pumping.

Interestingly enough water levels in both the main well and the tip well continued to drop, the former to 0.18 metres after the pumping ceased where upon it began to rise in response to the 3 hour lag time behind the tide. The tidal influence was considered to be stronger than the extraction of 55,900 litres of water in 2.3 hours, thus rendering invalid any pump test analysis using the tip observation well or the pumped well data.

4.1.2 Laro Well

The Laro well (Fig 4) is identified in the Water Supply Scheme as the suggested source of water to be reticulated to villages on the southern half of Ngalo Island. The villages to be served were Laro with a population of 225, Ngivale with 190, Otambie with 150, Manuopo with 40 plus the Hospital and Ngamanie with 55, a total population of 660 people.

4.1.2.1 Well Observations

The well is a natural limestone solution vent in the form of an elongated crevasse with smooth, but irregularly, fluted sides. The water level fluctuations measured ranged from 18.25 to 18.50m below ground level and the depth to the bottom of the well was 20.9 metres.

Water for the adjacent Laro village population is drawn from this well although only small containers can be used due to large boulders obstructing the centre of the vent. Historians tell of a feud between the people of Laro and the nearby Ngivale village resulting in several large boulders being thrown down the vent to prevent the Laro people from using the well. Apparently when ever water is lifted from the well a chant is sung which curses the people of Ngivale, this ritual being continued even though relationships between the two villages are now good. These obstructions also prevented the lowering of a pump, down the well for a pump test.

TDS concentrations of 300 mgl^{-1} just below the surface and 325 mgl^{-1} at the bottom were measured and a chloride level of 200 mgl^{-1} was recorded. See also Table 4.

Well observations were taken from 1130 to 1930 hours on 6 June and the results plotted as "X"'s against the Santa Cruz - Reef Island tide tables (Fig 6). As with the Balipa'a fluctuations, potentiometric levels were seen to be sinoidal with the same frequency as the tide. Amplitude was also of a similar order with a tidal efficiency of approximately 0.25, however the time lag could be said to be 2½ hours which would account for Laro being 1-200m closer to the coast than Balipa'a.

A reconnaissance trip to the coast from Laro revealed the impracticalities of establishing and surveying a mean sea level with the rough seas pounding over a wide coral platform at the bottom of steep uplifted cliffs; so this was abandoned.

4.1.2.2. Earth Resistivity Results

Four earth resistivity surveys were carried out along the lines shown in Fig.9 with a view to establishing the areal extent of the water table around the Laro well, and to ascertain whether a salt water layer was present.

Particular difficulty was experienced in fitting theoretical curves to these both using graphical and computer interpretations, resulting in RMS errors higher than normally acceptable (7.3%-19.7%).

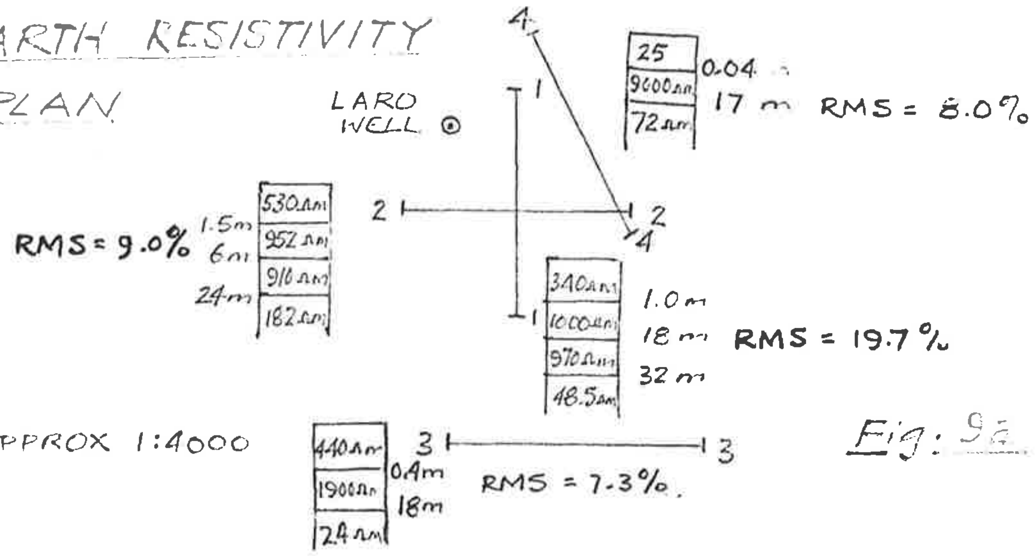
The soundings produced large variations in geoelectric sections even on lines 1 and 2 which were concentric but at right angles to eacher other. This indicates large variations in the strata through which the current is passed, confirming the existance of fissures and tunnels.

Sounding 3 and 4 gave three layer geoelectric sections and indicated water bearing strata of 24 and 72Ωm at 18 and 17 metres depth, which corresponds approximately to the measured potentiometric level in the Laro well. These soundings also had the smallest RMS errors of 7.3 and 8% respectively.

Soundings 1 and 2 gave best fits as four layer geoelectric sections and indicated water bearing strata of 48.5 and 182Ωm at 32 and 24 metres respectively. The RMS errors for these soundings were 19.7% and 9.0%.

LARO EARTH RESISTIVITY

SITE PLAN



SCALE: APPROX 1:4000

Fig: 9a

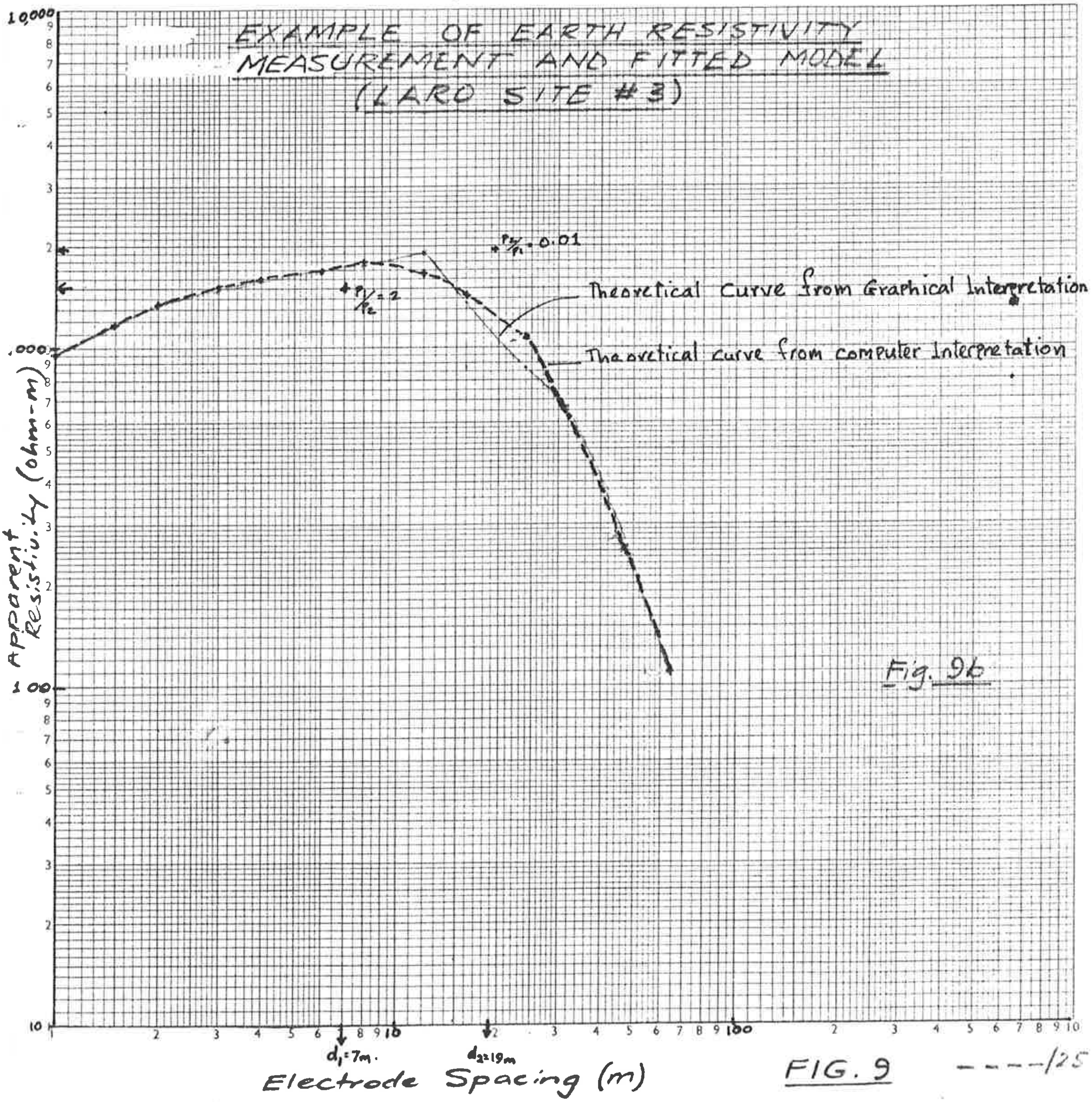


Fig. 9b

FIG. 9

This wide range of resistance in the bottom layer could be attributed to the sounding passing through sections of both dry coral and saturated fissures.

Neither of the four soundings detected a salt water layer, however the existance of such a layer could not be conclusively excluded when considering the RMS errors.

4.1.3 Manuopo Well

The Manuopo Well (Fig.4) is a shallow hand dug well at the south-western end of the sub-station and currently provides sufficient water for the 40 permanent residents together with the clinic/hospital. The well is situated approximately 100 metres from the Manuopo Channel connecting Nbelu Bay on the east coast with Mohawk Bay on the west. During low tide this channel is predominently mud flats and is not negotiable by canoe.

Water is pumped from the well to an elevated 1000 litre holding tank and is distributed throughout the village by hand. The village pump, however, was out of order and so the pump test carried out enabled a welcomed refilling of the holding tank.

4.1.3.1 Well Observations

Water levels were observed to fluctuate from 1.9 - 2.2 metres below the top of the concrete well wall (approx ground level) and the depth of the well was measured at 2.78 metres providing a water depth range of 0.6 to 0.9 metre.

The TDS and chloride levels were recorded as 280 mgl^{-1} and 175mgl^{-1} respectively and the water was noted to be highly alkaline with a pH of 8.6, 0.1 over the WHO maximum acceptable level but well within the WHO maximum allowable of 9.2.

A levelling run was carried out between the well and the sea level in the Manuopo Channel during a fast falling tide (See Fig.6) with the Channel level dropping 13 mm whilst levelling. Allowing for this change, the level in the well was calculated to be 0.090 m above the channel level. Presumably a tidal lag would be operating but time did not permit a more detailed study.

4.1.3.2 Pump Tests

A pump test was carried out for the time it took to fill the 1000 litre holding tank (2 minutes 34 seconds)

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and the water level was observed to drop from 1.96 metres to 2.47 metres below the top of the concrete wall, a drawdown of 0.51 metres. At the same time the TDS was seen to rise from 280-330 mgl^{-1}. Time to full recovery was 7 minutes.

Two further pump tests were undertaken for the same 2.5 minutes duration at 10 - 15 minute interval, and the drawdowns were seen to diminish to 0.39 metres and 0.24 metres respectively while the pumping rates during the latter two tests were estimated to be greater than during the first, due to a lesser pumping head (outlet at ground level instead of raised tank). As the water was discharged some distance away, the well was assumed to be still developing with each test (Fig 10) and not responding to infiltration of pumped water.

The TDS during the latter two tests was seen to rise to 350 mgl^{-1} during pumping and drop to 340 mgl^{-1} after pumping.

Variable results caused by the developing well rendered invalid any detailed pump test analysis.

4.1.4 Ngamanie Well

The Ngamnie Well is a shallow hand improved well situated several hundred metres towards Mohawk Bay from Ngamanie Village. (Fig 4) Water is drawn by hand and carried back to the 55 residents of Ngamanie Village.

4.1.4.1 Well Observations

Water levels were observed to fluctuate from 1.6 - 1.9 metres below the top of the well wall (approx. ground level) and the depth of the well was measured at 2.62 metres providing a water depth range of around 0.7 - 1.0 metre.

The TDS was recorded at the top and bottom of the well as 330 and 340 mgl^{-1} respectively.

A levelling run was carried out between the well and the heavily mangroved shoreline however as the tide was out, only the water level of a body of saline water believed to be connected to the sea could be levelled. The well level was found to be 27 mm above the saline water level however this could be attributed to a lag associated with the falling tide. (Fig 6)

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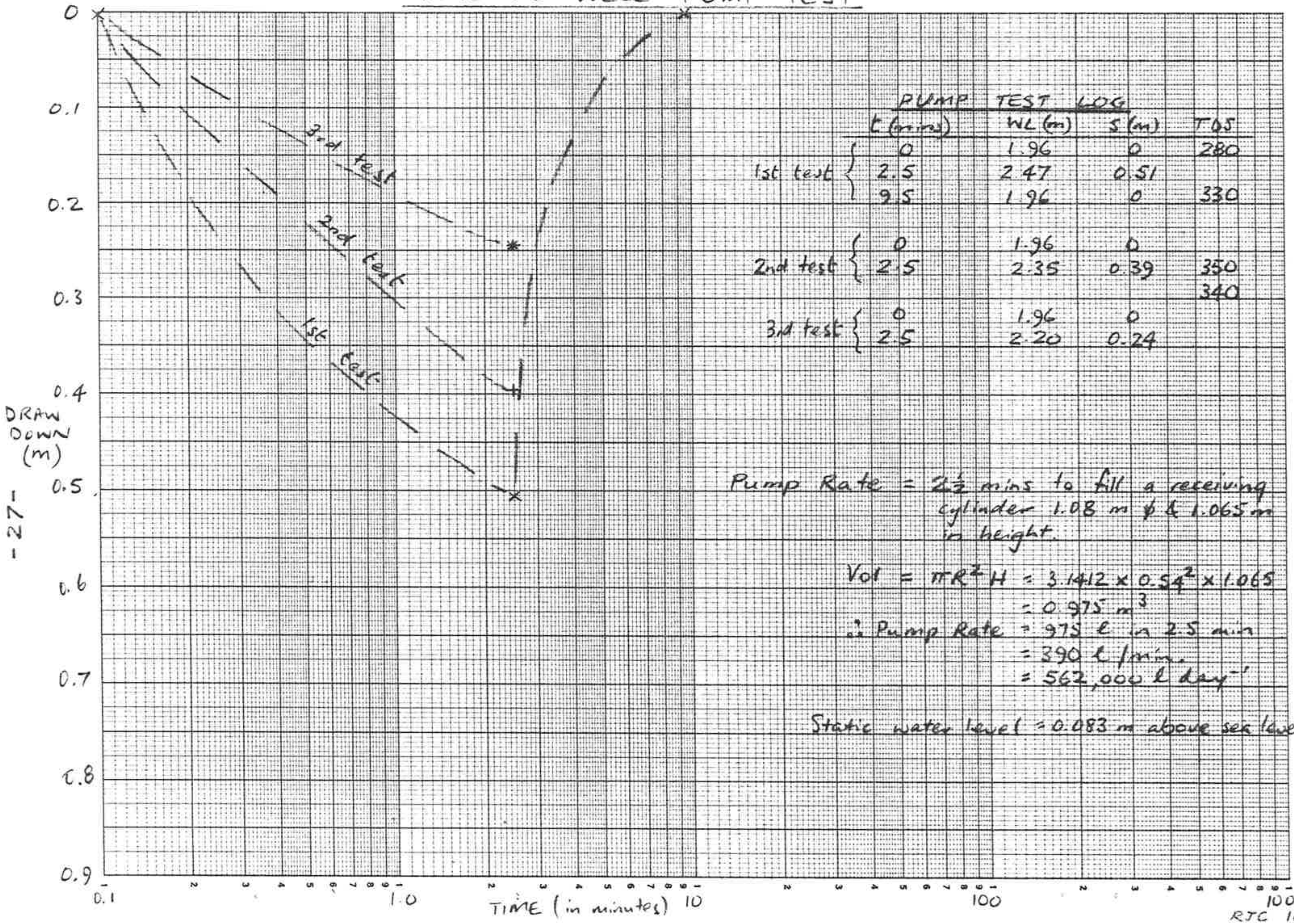
MANUOPO WELL PUMP TEST



PUMP TEST LOG

	t (mins)	WL (m)	S (m)	TDS
1st test	0	1.96	0	280
	2.5	2.47	0.51	
	9.5	1.96	0	330
2nd test	0	1.96	0	
	2.5	2.35	0.39	350
				340
3rd test	0	1.96	0	
	2.5	2.20	0.24	

Pump Rate = $2\frac{1}{2}$ mins to fill a receiving cylinder 1.08 m ϕ & 1.065 m in height.

$$Vol = \pi R^2 H = 3.1412 \times 0.54^2 \times 1.065$$
$$= 0.975 \, m^3$$
$$\therefore \text{Pump Rate} = 975 \, \ell \text{ in } 2.5 \text{ min}$$
$$= 390 \, \ell/min.$$
$$= 562,000 \, \ell \, day^{-1}$$

Static water level = 0.083 m above sea level

FIG. 10

RJC 18.6.85

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4.1.4.2 Pump Test

The Ngamanie well was pump tested from an initial level of 1.63 m below the top of the well for 10 minutes at 24300 lh^{-1} (5300 gph). (Fig 11) The drawdown of 0.175 m approximated steady state after 7 minutes of pumping and recovery to static water level took 3.5 minutes. Full recovery was not achieved due to a 13 mm difference caused by the falling tide (Figs 6 & 11).

TDS concentrations were monitored during the pump test and these were seen to rise from 340 mgl^{-1} whilst pumping, and continued to rise to 380 mgl^{-1} until substantial recovery was achieved. (Fig 11)

Such a rise in TDS after pumping ceased indicated that the pump rate was too excessive and could not be safely sustained for much longer than the test period.

4.1.5 Otambie Well

The Otambie Well is a shallow capped hand dug well situated in the middle of Otambie Village approximately 50 metres from the Manuopo saline Channel (Fig 4). Water for the 150 residents of Otambie is drawn by hand pump and carried to the houses by bucket.

4.1.5.1 Well Observations

Water levels in the well were observed to fluctuate with the tide and were about 1.7 - 1.9 metres below ground level. The depth of the well was 3.25 metres providing a water depth range of 1.3 - 1.5 metres.

A distinct TDS profile variation was recorded with depth of water, the TDS at the top ranging from 290 - 350 mgl^{-1} whilst the bottom was within the range of 440 - 500 mgl^{-1} after pumping. The chloride level before pumping was 175 mgl^{-1}.

Levelling was carried out between the well and the Manuopo Channel on the eve of 7 June with a mid rising tide, and the morning of 8 June with a higher but falling tide. (Fig 6) The evening levelling showed the well to be 190 mm above the Manuopo channel level whilst the morning levelling showed the Channel to be 120 mm

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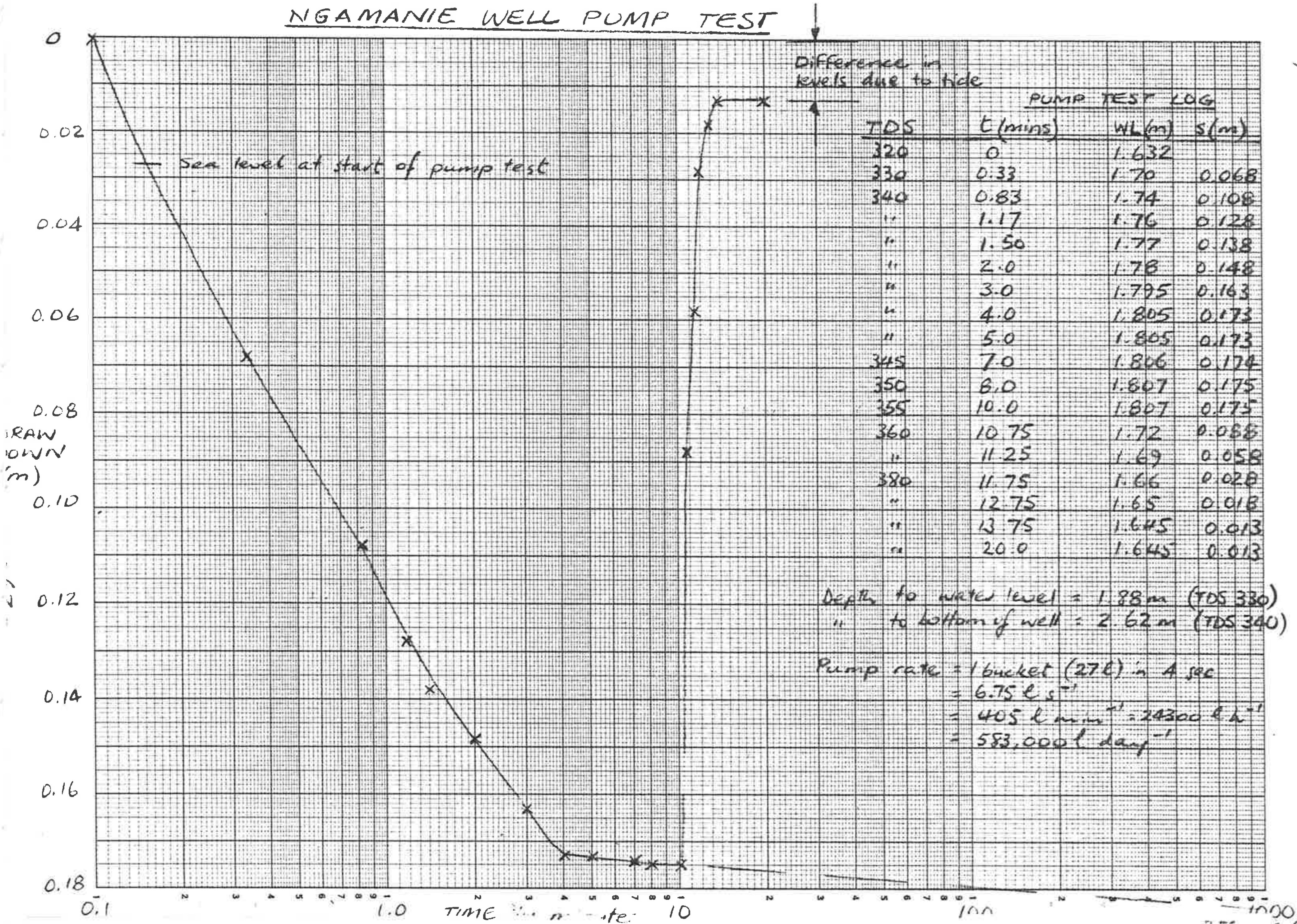
NGAMANIE WELL PUMP TEST



PUMP TEST LOG

TDS	t (mins)	WL (m)	s (m)
320	0	1.632	
330	0.33	1.70	0.068
340	0.83	1.74	0.108
"	1.17	1.76	0.128
"	1.50	1.77	0.138
"	2.0	1.78	0.148
"	3.0	1.795	0.163
"	4.0	1.805	0.173
"	5.0	1.805	0.173
345	7.0	1.806	0.174
350	8.0	1.807	0.175
355	10.0	1.807	0.175
360	10.75	1.72	0.088
"	11.25	1.69	0.058
380	11.75	1.66	0.028
"	12.75	1.65	0.018
"	13.75	1.645	0.013
"	20.0	1.645	0.013

Depth to water level = 1.88 m (TDS 330)
" to bottom of well = 2.62 m (TDS 340)

Pump rate = 1 bucket (27 ℓ) in 4 sec
= 6.75 ℓ s^{-1}
= 405 ℓ min^{-1} = 24300 ℓ h^{-1}
= 583,000 ℓ day^{-1}

FIG. 11

RJC 5.6.

higher than the well, exhibiting a lagged but strong tidal influence.

Springs were clearly visible along the Manuopo Channel at low tide and TDS readings of these ranged from 1000 through to 13,000 mgl^{-1}, the concentrations generally, rising, with the lower elevation and distance into the channel. The TDS of the channel was measured at 31,000 mgl^{-1}.

4.1.5.2 Pump Test

A pump test was carried out during the mornings higher tide as this was predicted to present a more critical salt water intrusion condition with the level in the channel being higher than that in the well.

Prior to pumping the well water level was 1.72 metres below ground level and immediately after pumping commenced the level dropped to 1.73 where it remained for the 8 minutes of pumping. Meanwhile the TDS levels steadily rose to 500 mgl^{-1} whereupon the pump was stopped to avoid contamination of the well. (Fig 12).

The water level immediately reverted to 1.72 m after pumping ceased indicating a high transmissivity.

4.1.6 Ngivale Well

The Ngivale well was not investigated further due to an already high TDS level of 500 mgl^{-1}, which would no doubt rise to unacceptable limits if the well was pumped.

4.1.7 Napali Well

This well was investigated as a possibility of supplying water to Napali Village. The well is a natural limestone cave which descends at an angle to approximately 20 metres which can be walked with a torch. It is situated approx 150 metres from the coast and appeared to have 4-5 metres depth of water.

4.1.7.1 Well Observations

TDS readings of 700 and 950 mgl^{-1} were observed

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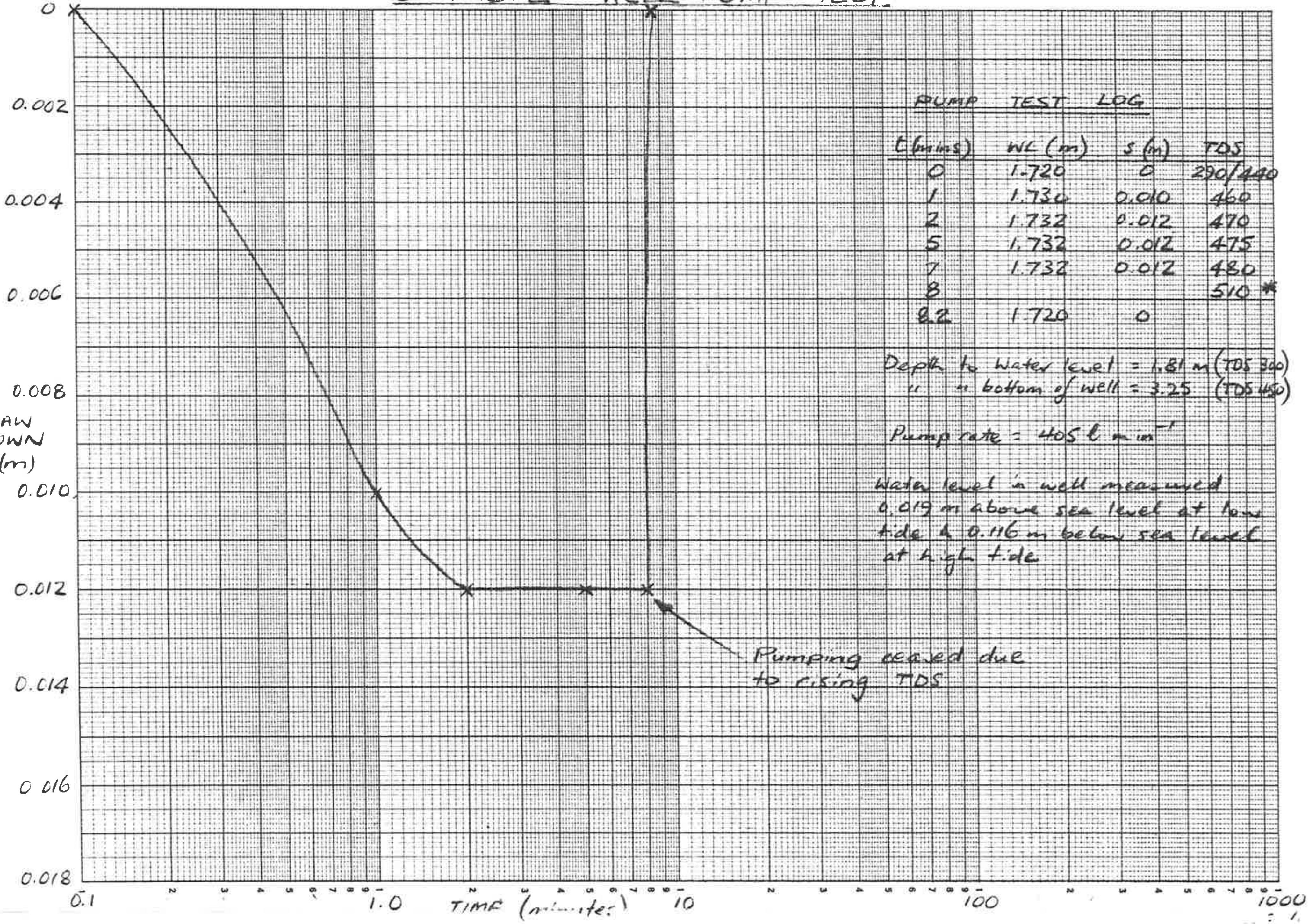
OTAMBIE WELL PUMP TEST



PUMP TEST LOG

t (mins)	WL (m)	s (m)	TDS
0	1.720	0	290/440
1	1.730	0.010	460
2	1.732	0.012	470
5	1.732	0.012	475
7	1.732	0.012	480
8			510 *
8.2	1.720	0	

Depth to water level = 1.81 m (TDS 300)
" " bottom of well = 3.25 (TDS 450)

Pump rate = 405 l min⁻¹

Water level in well measured 0.019 m above sea level at low tide & 0.116 m below sea level at high tide

FIG. 12

at the surface and bottom of the well respectively and the chloride level from a depth integrated sample was found to be 700 mgl^{-1}. Further investigations were abandoned due to these unacceptably high concentrations.

4.2 Interpretation of Results

From the well observations, the earth resistivity results and the pump tests undertaken, a clearer, but far from conclusive understanding of the groundwater system of Ngalo Island has been obtained.

Results showed that the water levels in all of the wells studied were responsive to tide levels which although not surprising in the shallow wells close to the coast, was somewhat unexpected in the deep natural wells up to 0.6 km inland. The time lags for both the Balipa'a and Laro wells were around 3 hours with a tidal efficiency of approx 0.25. This indicates a highly permeable connection with the sea which was further supported with the pump test at Balipa'a, where a pump rate of 24300 lh^{-1} had a lesser impact on well levels than that of the tide.

With this information in mind one conjures the notion of a maize of intereconnected fissures and solution tunnels running three dimensionally throughout the limestone. The resistivity soundings confirm this concept as the geoelectric sections (representing a considerable areal extent around the Balipa'a and Laro wells) show a large variation in strata; and where water was sounded water levels were seen to be at a similar depth to those measured in the wells. The large difference (0.58m) in the water table between the two Balipa'a wells is within the error of the resistivity soundings and the syncronous fluctuations in these two wells confirm vertical pressure connections.

The Balipa'a well results collectively suggest that salt water intrusion is most unlikely particularly as the water supply scheme pumping rates will be considerably less than the rate adopted during the pump test.

The mechanism operating in the vicinity of the shallow coastal wells adjacent to the Manuopo Channel is considerably different due to the material being an unconsolidated, pourous mixture of fragmented

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coral and sand, thus supporting a relatively permeable unconfined aquifer. Here a salt water tongue or localised Ghyben - Herzberg lens formation could be in operation thus accentuating the risks of salt water intrusion. The closer the well to the sea, both in distance and elevation, the greater the risk of contamination as is seen by the Otambie pump test.

However it is apparent that providing extraction rates are conservatively limited for each well, the integrity of the supply can be kept intact. This is witnessed by the successful hand drawn extractions from these coastal wells over the years.

4.3 Safe Well Yield Determination

Due to the brevity of this study and obvious limits on time and available 'hard data', the determination of safe well yields for each well was not possible. However as the likely demands on each well are known, then sufficient information is available to determine whether the well resource will be adequate or will likely to be under stress.

Each well will therefore be considered in terms of the likely population demand, allowing for the standard rural water supply consumption rate of 30 litres per head per day.

4.3.1 Balipa'a Well

As was evident in the pump test the Balipa'a well sustained an extraction of 24300 lh^{-1} for 2.5 hours without showing any stress, in fact tidal influences completely 'over-shadowed' the effects of pumping.

The Provincial Water Supply Scheme proposal suggests that the villages of Lipe, Nimoa, Balipa'a, Napali, Unu and Otelo be supplied from this well. Allowing 30 litres per head per day for the combined population of 875 people to be served, gives a daily demand of 26250 litres. This is only slightly in excess of the hourly pump test extraction and so can easily be met from the Balipa'a well.

4.3.2 Laro Well

Unfortunately the Laro Well could not be pump tested so an assessment of yield can only be determined from the well observations and resistivity results. The Laro well exhibits a similar frequency, amplitude and tidal lag time to the Balipa'a well (Fig 6) and the resistivity results suggest that, although the water table is further below ground level than Balipa'a, the surrounding strata is much the same. This being the case then the Laro well could be expected to produce a yield approaching that of the Balipa'a well, bearing in mind that it is approximately 200 metres closer to the coast.

The Provincial Water Supply Scheme Proposal suggested that the villages of Laro, Ngivale, Otambie, Manuopo and Ngamanie be supplied from this well. Allowing 30 litres per head per day for the combined population of 660 people to be served, gives a daily demand of 19800 litres. This daily rate is lower than the hourly test rate at Balipa'a and so assuming the Laro well to be of similar capacity, this extraction rate should not be excessive. As there is an element of prediction, it may well be prudent to supply all or some of the villages of Otambie, Manuopo and Ngamanie from their respective shallow wells, which may work out to be a more economical proposition when considering pumping and piping costs of the various alternatives.

4.3.3. Manuopo Well

An alternative to the proposed piping of Laro water to Manuopo is the use of the Manuopo Well to supply the sub-station. Water usage for the 40 residents and hospital/clinic is unlikely to exceed 2500 litres per day which is less than the 2900 litres collectively extracted during the three 2.5 minute pump tests.

In view of the developing well situation and stable TDS results the Manuopo well could sustain the daily demands of the sub-station.

4.3.4 Ngamanie Well

The pump test results approached a steady state condition at a pump rate of 24300 litres hr^{-1}, however the TDS concentration was rising and it was obvious that this level of pumping could, and should not be, sustained for longer than the test period. (Fig 11)

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From knowing the long term drawdown associated with the steady state pump rate the drawdown caused by the required extraction rate can be calculated by rearranging the following equation (Hazel 1975).

$$QL = QT \frac{Sw}{S_{10}4}$$

QL is the long term pumping rate
QT is the pump test rate
SW is the desirable working drawdown
& $S_{10}{}^{4}$ is the test drawdown (extrapolated) $S_{10}{}^{4}$ to 10^{4} minutes

$$\text{Rearranging} \quad SW = \frac{QT}{QL} \times S_{10}{}^{4}$$

$$= \frac{1650}{583000} \times 0.195 = 0.001 \text{ m}$$

As can be seen the Ngamanie Village requirement of 1650 litres per day will only cause a drawdown of 1 mm and even if a solar powered pump was used which had to pump the daily requirement in an average 6 hours per day the drawdown would only be 2 mm

$$\text{viz} \quad SW = \frac{1650 \times 24}{6 \times 583000} \times 0.195 = 0.002 \text{ m}$$

In view of this minute drawdown and the elevation of the well above sea level it was concluded that the well at Ngamanie can meet the requirements of Ngamanie village without the risk of salt water intrusion.

4.3.5 Otambie Well

The pump test clearly showed that the pump rate of 24300 lh^{-1} was excessive for the well as the TDS was rising rapidly with the incoming saline waters. (Fig 12).

Using the same equation as in Section 4.3.4, the drawdown to provide the Otambie Villages water requirement of 4500 l day over a 6 hour period would be

$$Sw = \frac{4500 \times 24 \times 0.012}{6 \times 58300} = 0.001 \text{ m}$$

It was therefore concluded that the Otambie well could supply Otambie Village but special care would need to be taken to avoid excessive use of the well as sea levels in the adjacent Manuopo

Channel (only 50 metres away) were noted to be higher than the water levels in the Otambie Well.

The safest long term plan would no doubt be to pipe the water from the Laro Well, although this would not appear to be the most economic.

5. RESOURCE CONTAMINATION

The bulk of this study has been centred around the ability of the various sources of underground water to meet the water supply scheme demands of 11 villages without becoming contaminated by salt water intrusion.

Saline mixing is not the only means of contamination, several other potential sources being noticed during the teams visit to Ngalo Island.

Village rubbish was seen to have been dumped in the large disused well at Balipa'a and as this well was found to be 'upstream' of the main well,very little filtering of leachates would occur before permeating the main well. A similar problem was noticed at Manuopo where the rubbish tip was seen to be in a hand dug depression only 30 metres from the well.

Several large shallow sinkholes, fenced with rocks, were pointed out as stock pens and one was seen to be holding a group of pigs. As these sinkholes are the natural inlets to the groundwater system any pollutants such as faecal pig wastes will be leached down into the groundwater.

One final threat is that of human wastes, as it is understood that the Province is proposing to site the sub-stations' toilet facilities within 100 metres of the Manuopo well. This is particularly serious as the water table is noted as being only 2.0 metres below average ground level.which is shallower than the depth the wastes would be released. Should such siting of the toilets be deemed absolutely necessary, then this may be a case for not using the Manuopo well in favour of the Laro piped water supply.

In all cases, wells should be covered to prevent contamination from the surface.

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6. CONCLUSIONS

As mentioned previously the 5 days spent on Ngalo Island was not sufficient to gain a thorough understanding of the total groundwater resource, as a comprehensive study for an island the size of Ngalo, would involve continuous recording of potentiometric levels in a number of well over a period of up to a year during which time several visits totalling 1-2 months would be necessary to carry out the required field measurements. A comprehensive earth resistivity of the whole island would alone take several weeks.

A gamut of logistical barriers, not the least being time, did not permit such a study, however sufficient data was obtained to be reasonably confident about the decisions made on whether the groundwater resource could or could not satisfy the expected demands of the proposed water supply scheme.

The following summarises these conclusions.

6.1 Recharge Capability

The water balance showed that adequate potential exists for there to be a groundwater system capable of meeting the domestic requirements of the people of Ngalo Island.

6.2 North Ngalo Village Water

From the tidal efficiency measured, the pump test and the earth resistivity results obtained in and around Balaipa'a, it was concluded that the Balipa'a main well as proposed, could adequately satisfy the water supply requirements of the villages of Lipe, Nimoa, Balipa'a, Napali, Unu and Otelo. Indications were that sufficient water was available in the Balipa'a main well to supply the needs of any future population projections for these villages.

6.3 South Ngalo Village Water

As the Laro well could not be pump tested with the equipment available, conclusions on well capacity have had to be assessed on the similarities in tidal efficiency and earth resistivity between the Balipa'a and Laro wells. It was therefore concluded that the Laro well could meet the water supply requirements of the villages

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of Laro and Ngivale.

The Otambie well was considered capable of meeting the present requirements of Otambie Village, however care would need to be taken that pumping rates were kept to an absolute minimum and that preferably pumping be carried out during low tides to minimize the risk of salt water intrusion.

One of the problems with automated pumping systems as opposed to the existing hand drawn bucket or hand pump systems is that it can encourage wastage, which in a situation where the demand is approaching the safe well yield, can lead to over exploitation of the resource. Care must be taken to ensure that if solar powered pumps are employed, these have a cut-off switch when the feeder tank is full and that individual water conservation habits are practised at all times.

The Manuopo Well was also considered capable of meeting the requirements of the sub station and hospital however care here is needed to prevent pollution of the groundwater resource from human wastes.

The supply of both Otambie's and Manuopo's water requirements from their respective wells is probably more economic and socially more acceptable, however if the risks of pollution at Manuopo can not be avoided then Laro water should be used. Such a pipeline could also supply Otambie village and would thus overcome the risk of salt water intrusion at the Otambie Well due to wastage and possible over exploitation at that point.

The well at Ngamanie was considered capable of meeting the requirements of Ngamanie Village but due to low potentiometric levels and close proximity to the high water coastline, was not considered capable of supplying the Manuopo Sub-Station. Here again conservation measures as for the Otambie Well would need to be practised to avoid over exploitation of this well.

In all cases the pump intakes should be set as high as possible in the well to avoid more saline water at depth. These depths

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should be determined from the natural fluctuations and/or the drawdown depths given.

7. RECOMMENDATIONS

The following recommendations arise from the conclusions of the Ground Water Resources investigation of Ngalo Island:

- that the Balipa'a well water be used to meet the requirements of the villages of Lipe, Nimoa, Balipa'a Napali, Unu and Otelo, and that the dumping of rubbish and holding of livestock in sinkholes be stopped.
- that the Laro well water be used to meet the requirements of the villages of Laro and Ngivale and if necessary Otambie and Manuopo, the latter being subject to planning and economic considerations associated with the prevention of pollution of the Manuopo Well Water.
- that the Otambie Well water be used to meet the requirements of Otambie but that steps be taken to prevent wastage and overexploitation.
- that the Manuopo Well be used to meet the requirements of the Manuopo sub-station but that steps be taken to guard against contamination by human wastes.
- that the Ngamanie well be used to meet the requirements of Ngamanie Village.
- that in view of the possibility of an underlying salt water layer being present:
  - . all pump intakes be set as high as practicable in each well
  - . all wells be pumped to a feeder tank of sufficient size to regulate withdrawls, rather than them being subject to direct demand.
  - . 'cut-off' switches be installed on all feeder tanks to avoid overfilling and wastage.
- that individual water conservation habits be taught and practised at all times.
- that all wells be covered with a suitable hatch which will allow easy removal for inspection purposes.

8. ACKNOWLEDGEMENTS

The author wishes to thank the Temotu Province for their role in finally arranging such a well orchestrated trip to the Reef Islands, despite numerous logistical odds, in particular the success of the trip was in no small way attributed to Sondra Rose (Planning Officer) and Alban Leaka (Public Health Inspector), whose vigilant organisation ensured the adequate provision of transport, guides, carriers and helpers during the course of the survey.

The co-operation and hospitality of the people of Ngalo Island was much appreciated as was the Australian High Commission's generous provision of a chartered aircraft which made the whole trip possible.

Special thanks must go to Narcily Pule for his untiring efforts on the earth resistivity surveys both in the field, and with office reductions, the Laro results giving particular problems with satisfactory curve fitting.

Last but not least was the assistance given by Steven Tickell both with the field survey and the helpful discussion and constructive comments made during the interpretation of results.

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