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Water Resource Investigations on CICIA

by

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Abstract

The volcanic and limestone island Cicia was investigated in July 1994 by the Mineral Resources Department to assess its current freshwater resources and its groundwater potential. Village surveys and groundwater investigations, including geophysical investigations, were carried out for each of the island's five villages (Tarakua, Lomati, Natokalau, Naceva and Mabula). These villages currently rely on reticulated dam and spring water systems to meet their water needs. Water flow from these sources is reduced during times of drought, and at these times water rationing is practised in most of the villages. A large amount of the water available from these sources is wasted through leakage of pipes and tanks. In some villages storage capacity is low. Biological water quality is very poor, with high levels of faecal coliform bacteria being found in most of the surface water sources. The rainwater harvesting potential for the villages is poorly developed, as a result this viable water source is highly under-used .The potential for exploitable fresh groundwater exists in many places on the island. Recommendations have been made and options presented for improving village water supplies. These include the upgrading of existing water supply systems, the treatment of these supplies and the drilling of boreholes. The groundwater potential appears to be adequate for an islandwide reticulated water system.

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List of abbreviations

µS/cm	micro Siemens per centimetre (EC)
Ωm	Ohm-metre (Electrical resistivity sounding)
AE	Actual Evapotranspiration [mm]
AP	airport
ASL	above sea level
EC	electrical conductivity [µS/cm]
E-coli	Escheria *coli* bacteria (§ 3.3)
EM	electromagnetic profiling
l/s	litres per second
m/s	metres per second (Seismic sounding)
MRD	Mineral Resources Department
msl	mean sea level
PE	Potential Evapotranspiration [mm]
PWD	Public Works Department
P&T	Post and Telecommunications

List of Fijian[1] - English words

Dalo	Taro, a starchy root crop
Matanivanua	spokesman
Mataqali	clan
Sevusevu	traditional ceremony, in which amongst others permission is granted to enter the village lands
Soqosoqo vakamarama	women's group
Talatala	church minister
Tui	king (chief)
Turaga	chief
Turaganikoro	village headman

[1] Fijian words are printed in *italics* throughout the report

Conclusions and Recommendations

Summary of conclusions

The volcanic and limestone island Cicia was investigated in July 1994 by the Mineral Resources Department to assess its current freshwater resources and the groundwater potential. The villages for which the investigations were carried out are Tarakua, Lomati, Natokalau, Naceva and Mabula.

Existing water sources

1. Each of the villages on Cicia has a reticulated water supply with the source being 'open' dams and springs.
2. Water quantity from those sources is in most villages sufficient for present population needs.
3. The water supply systems are old, and many pipes, taps and tanks need repair or replacement. Water losses occur due to those defects.
4. The rainwater harvesting potential for each of the these villages is greatly under-used even though nearly all houses on the island have galvanised iron roofs.
5. Problems encountered with rainwater harvesting are: rusting of roofs, tanks and gutters, and the lack of maintenance.

Sanitation

6. Almost all households have water-sealed toilets. A few houses have flush toilets.

Water collection and use

7. Tap water is generally used for all purposes.
8. Where and when rainwater is available it is preferred for drinking and cooking.
9. Washing and bathing are often done at the standpipe. For other purposes the water is carried home.

Water quality

10. Two major problems with the open water catchments (dams and unprotected springs) are that surface contaminants enter the system during rains, and that the source is easy accessable to animals.
11. Biological quality of the reticulated water is generally very poor (especially with dammed streams and poorly protected springs).
12. Rainwater tanks are normally less contaminated than the village tap water and represent the village's cleanest and safest water source.

13. The chemical quality of the existing water sources are within the World Health Organisation's recommended limits for safe drinking water. Spring and creek water are low in magnesium and sulfates tend towards sodium bicarbonate type; those are soft and fresh. The Lomati dam water had elevated iron levels. The samples taken from two auger holes in the alluvial clays of valley AP3 had high iron and manganese levels. The chloride concentrations of the water from Natokalau cave and Dulo spring in Mabula indicate that there is a minor amount of saltwater mixing.

Operation and maintenance

14. The villagers generally assign a caretaker for their water supply.

15. In dry periods villages restrict water use by opening and closing the main valve in the mornings and afternoons.

16. Usually, maintenance and repairs are carried out only after serious breakdowns and when no other water sources are available.

17. Rainwater tanks are not periodically cleaned and disinfected.

Local organisation

18. Daily management of the village water supply is the responsibility of the *turaganikoro* and the caretaker.

19. Communally owned water systems are preferred above private systems. A government-managed water system is even more preferred by some.

Groundwater assessment

20. There is evidence that Cicia has a relatively abundant supply of fresh groundwater.

21. Potential groundwater sources have been identified for each of the five villages (see Table 11 for a summary).

22. Exploratory drilling will be needed to verify these groundwater potentials.

23. Borehole sites have been located in the following places: Valley AP2 (Tarakua and Tarakua Estate); Wailevu Creek valley (Lomati); Vakadranua(Natokalau); Vakadranu plateau (Naceva, more investigation required); and Mabula East Valley (Mabula).

24. Exploitable cave water has been noted for Natokalau and Naceva.

25. The possibility of a suitable freshwater lens within the coastal plains has been noted for valleys AP1 and AP4. Infiltration galleries will be needed for exploitation.

General Recommendations

Water source protection

1. Eventually all 'open' (unprotected) water sources should be properly protected against surface water contamination (where practical), be treated, or abandoned. This includes solutions such as enclosed intake structures at springs or infiltration galleries in seepage areas. This also includes the protection of the area around the source from human and animal activities.

Reticulation systems

2. Leaky pipes, tanks and taps should be repaired.

Water treatment

3. Further study into water treatment options, such as chlorination and slow sand filtration, for village water supplies is recommended; a pilot project could be set up.
4. All water tanks should be periodically cleaned and desinfected with bleach (chlorine).

Maintenance

5. Maintenance of the village reticulation systems as well as the communal and individual rainwater catchment systems should be encouraged, and maintenance should occur before breakdowns.
6. Water tanks, dams, gutters and so on should be periodically cleaned and inspected.

Rainwater harvesting

7. Rainwater harvesting should be encouraged to provide for safe and easily accesible drinking water

Training

8. A training at village level should include health and sanitation aspects for men, women and children
9. Other training needs include maintenance of reticulation- and rainwater catchment systems at village level.
10. PWD should consider a training programme for all rural water supply engineers and technical staff on aspects such as surveying, village water supply design, spring protection and cost effective technologies for rural water supply construction.

Groundwater development

11. Groundwater other than from springs, can be developed to supplement the present water sources (see recommendations for the individual villages).

12. Since borehole water is more expensive to use than rainwater or water from gravity fed systems, borehole water should be used only to supplement these other sources of water during times of low water flow and droughts

Further investigations

13. Further investigations on Cicia could consist of drilling a minimum of four exploration boreholes in order to provide confirmation of the islands groundwater resources. Two boreholes should be drilled on the alluvial plain; one at Lomati and the other within valley AP2. One borehole should be drilled on the Vakadranu plateau located midway between Natokalau and Naceva. Before this borehole is drilled, a more detailed geophysical investigation needs to be carried out for actual site selection. A fourth borehole could be drilled within the back part of the coastal plain at valley AP4 in order to assess the extent of the freshwater lens development. This borehole should be drilled in a controlled manner with the intention of obtaining a salinity profile, and a multi-level groundwater monitoring system, such as those used in Kiribati (Falkland, 1991), should be emplaced. Direct supervision of a hydrogeologist during all stages of this operation would be necessary.

See paragraphs 5.3, 6.3, 7.3, 8.3 and 9.3 for recommendations by village

1 Introduction

This report is the result of a water resources study on the volcanic and limestone island Cicia, from 20 to 30 July 1994. The study aims to provide detailed information on the existing water resources, their present use and their potential use on the island. The recommendations are meant to assist PWD, together with the people of Cicia, in further developing and managing the water resources. The report can be useful for any other person, department or agency involved in water issues and development on Cicia.

The report consists of a general chapter about Cicia (Chapter 2), a chapter about the geology and the hydrology of the island (Chapter 3), a chapter that explains the methodology used during the survey (Chapter 4), findings and results of the survey per village (Chapters 5 -9), and at the end a summary of the conclusions and recommendations (Chapter 10).

2 Setting

2.1 General

Cicia island is located within the central Lau Group about 240 km east of Suva. The island has five villages, two agricultural estates, a Public Works Department depot, a jetty and an airstrip. A road encircles the island connecting all the villages (Figures 1 and 2).

2.2 Demography

The island's population count made by the local health authorities in July 1994 totals 1197 people. This means that there was an average annual growth of 1.5% since the 1986 Census. The total number of people counted during this survey is generally lower than that of the health authorities. This could be due to the method of counting. However, these lower figures together with the population census of 1986 have been used in this report.

2.3 Health

Health statistics for the year 1993 indicate the prevalence of diarrhoea amongst children, skin infections (especially Dhani[1]), eye infections (especially during rainy days) and parasitic worms. No records are available on Typhoid, Weil's disease[2] or Dengue fever (information from Medical Attendant, Cicia Health Centre).

The Health Centre has been promoting the construction of water-sealed toilets. The department supplies the plastic pot for $25; every household has to buy 1½ to 2 bags of cement at $15 each, the mould is supplied by the Health Centre. Nearly every household at the island has a water-sealed toilet. Cicia's women's group has noticed that sanitation practices have degraded recently and therefore wants to start promoting proper sanitation practices and construction of water-sealed toilets for those who do not have one yet.

2.4 Water supply systems

All villages on Cicia have spring- or creek-fed village water supply systems built by Public Works Department (PWD). Some of these systems are over 20 years old and are in need of major replacement. The water usually drains into unprotected

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[1]Dhani is Hindi for *tinea versicolor*, a disease which causes decolouration of the skin

[2]Weil's disease, *leptospirosis*, is a hygiene-related disease. The disease organism is spread by way of the urine and faeces of infected humans and animals. The disease is contracted when open sores come into contact with contaminated water or soil.

Figure 1: Cicia location map

open dams in creek beds. This situation causes the biological water quality to be generally poor. Water from the dam is piped to a tank from which the village taps are fed. Pipes used are of galvanised iron, PVC and polythene. Village standpipes consist of a tap and shower above a cement slab, and the schools usually have only taps. Villagers often construct a shelter around the standpipe for privacy. Additional taps and in-house connections are occasionally added to extend the water supply system.

Most village water supplies have been constructed under a scheme from the Ministry of Regional Development. The village pays one third of the material costs and provides labour. The government pays the other two thirds and provides technical support through PWD. The system has a guarantee for the first six months, after which the village becomes responsible for maintenance. The village receives a toolbox and some spare parts. However, many villages remain dependent on PWD for repair of their water supplies.

Since 1993 PWD has started a training programme for villagers where a new supply is constructed. One or two men in each village are taught how to repair and maintain the village water supply. PWD expects this training to be economical as it should save the department from having to do most maintenance work. Training is, preferably, given to several villages at the same time. No training has been given on Cicia so far.

2.5 Local organisation

Fijian villages are headed by a chief (*turaga* or *tui*), assisted by his spokesman (*matanivanua*). Both, chief and spokesman, are inherited titles that belong to certain families. Women can also inherit the chiefly title, however since they usually marry outside the village or island and do not live in their own village the title is often given away or borrowed by another family. This is the case with the present chief of Tarakua. One of the villages on the island is paramount over the others and therefore more powerful and often wealthier. On Cicia the chiefly village is Tarakua. This village has its own chief with the paramount chief of Cicia Island living just outside the village.

Important decisions are normally made by a village committee. Members of the committee are usually men from the several clans (*mataqali*) that make up the village. Women do not directly contribute to the village committee but their influence might reach the committee through their husbands. A very respected and thus powerful person on the island is the Methodist Church minister (*talatala*). Whenever a village has to make a decision he will normally be included in the decision-making process.

Women are organised in women's groups (*soqosoqo vakamarama*). Their contribution to the village lies often in social activities. They work together with the health authorities, elect the village health workers, and go around the island to check on sanitation and hygiene practices. When the village has to raise money for specific purposes the women contribute through activities such as weaving mats and selling them to urban people or exchanging (*veisa*[1]) them for cash or cash items.

For the daily management of the village the committee assigns a *turaganikoro* (village headman). He will call the village together for activities such as cleaning the village or the water system and he assigns duties to certain villagers. The repair of water systems can be one of those. Water committees exist in certain villages, but are often not active. The village usually assigns one person (caretaker) the duty of looking after the water supply system. A common practice during dry periods is water rationing. This means the caretaker opens and closes the water system and water is allowed to run from the reservoir tank for only an hour in the morning and an hour in the afternoon. While the taps are closed the storage tank will fill again and by restricting the hours the total volume of water used will decrease and spillage minimised.

2.6 Economy

The island's economy depends mainly on copra. All villages, except Mabula, own the Cicia estate (Tabuta) and copra is sold through this estate. Lease money from the estate and the airstrip are paid to all the *mataqali* involved. The estate is one of the biggest share holders in Fijian Holdings, an major investment company in Suva. However, not much of its money seems to flow back into the island's development. Many people in the village do not think the village has money to invest in better water supplies, although they have raised money before to contribute to the existing systems. Whenever the church or the provincial council meeting asks for money the island is able to collect thousands of dollars through fund raising. This includes making mats and other crafts by the women of the island for sale or exchange (*veisa*[1]) to Suva.

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[1] *veisa* means literally *to have a partner*, in this case the partner from an urban area may give cash or cash items (eg food, lounge suite, cupboards etc.) in exchange for 6 or 7 mats of various sizes.

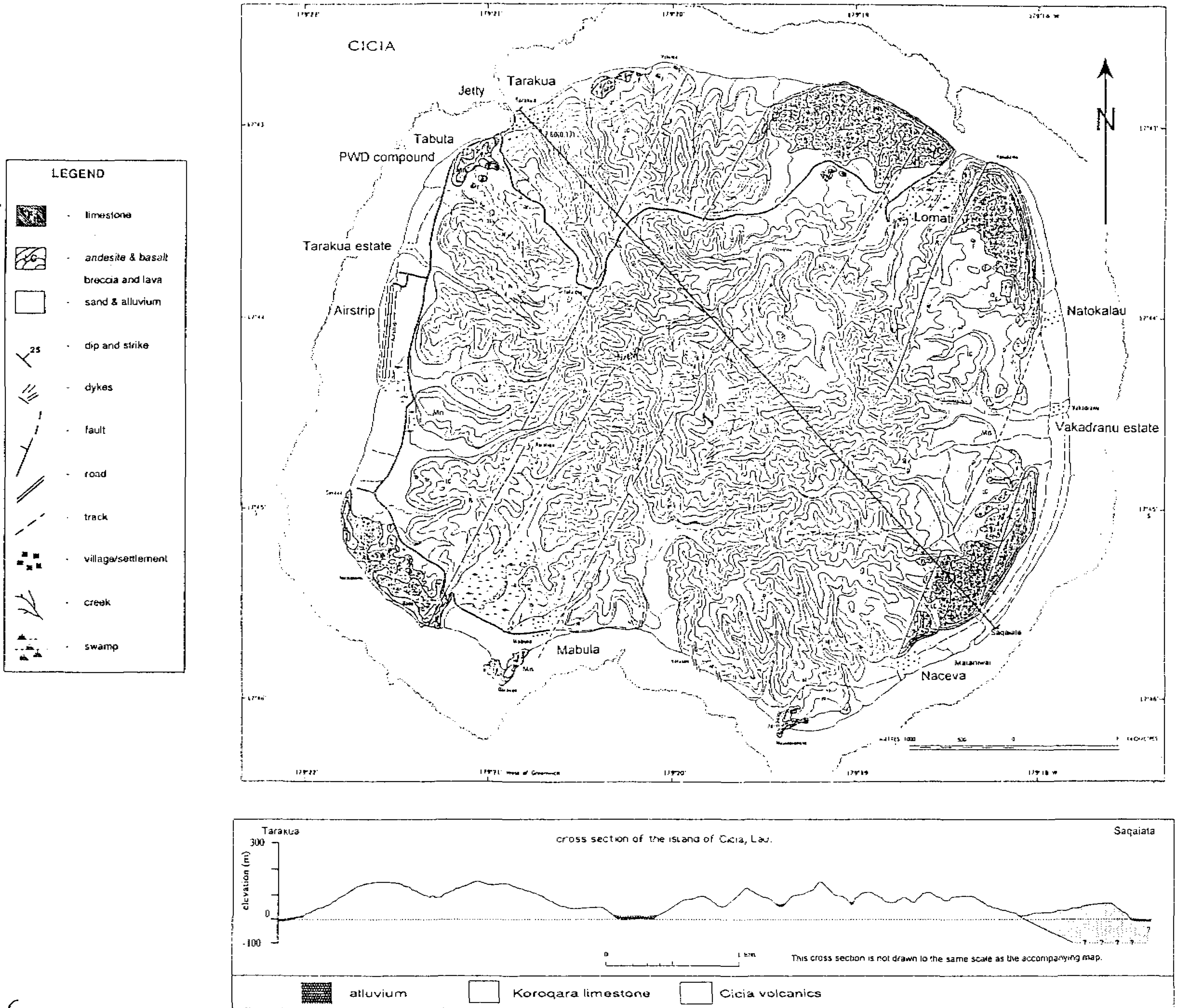

Figure 2: Cicia geology map

3 Geology and hydrology

Cicia island is located within the central Lau Group at 17°45'S and 179°20'W (Figure 1). It has a land area of 34.6 km^2 and a maximum elevation of 165 m ASL. The largest catchment area, which drains the central part of the island, is about 6 km^2. The next largest catchment has an area of 2.55 km^2. The island can be located on the Fiji Map Series 31, topographic map, sheet U27 and the Mineral Resources Department geological map LAU 1.

3.1 Geology

Cicia is a mixed volcanic and limestone island. It has a large central valley that appears to be the remnant of a breached crater. The volcanic terrain that makes up most of the island is dominated of deeply eroded valleys and ridges. The limestone is karstic and partially rings the island. Refer to Figure 2 for a geological map of the island, produced by Woodhall (1984).

A summarised geological description of Cicia after Rodda (1992):

Basaltic andesite to andesite occurring as flows, flow and pyroclastic breccias, and dykes (Cicia Volcanics, Lau VG), overlain by limestone of the Tokalau LG- reef with overlying volcanic/calcarenite conglomerate (Daliconi Limestone), then coralgal rudite (Koroqara Limestone). Surficial deposits: alluvial/colluvial clays, swamp deposits and carbonate sand and gravel. Radiometric date: 7.66 ±0.17 Ma (Cicia Volcanics). Submarine terraces occur at 8, 15 and 20 m below MSL, and notches at 25, 45 and 60 m below MSL. Caves occur in the limestone, for instance one at Naceva (Mataniqara) and another 1 km to the ENE (Saqaiata), the latter accessible for at least the lowest 20 m. Some manganese has been mined, at Vakadranu, and there are occurrences at Tarakua Estate.

3.2 Hydrogeological provinces

Coastal plains Carbonate sand and gravel coastal deposits ring most of the island to a width of up to 300 metres. These deposits are very permeable and would be intruded with saltwater for most of its width. There is a strong possibility that exploitable freshwater lenses or 'wedges' have formed within the inland portions of these deposits. Exploitation of this water would require infiltration galleries. This source has a

Limestone terraces The limestone terraces are karstic and contain a high degree of secondary porosity in the form of solution cavities and fissures. Several cave systems exist above and below the water table. Surface run-off from the catchment areas within the volcanic terrain behind the terraces drains into these cave systems. Most of this water exits the system from cave openings on the coastal plains. These caves can also serve as inlets for saltwater contamination. The coastal plain tends to form a permeable buffer between the ocean and the aquifer that exists within the terraces. The salinity of the water within this aquifer varies from fresh to saline and is dependent upon both location and season.

The freshwater-dominant sections of these aquifers should be able to make a contribution to the island's water needs. Caution must be taken when using this kind of water source since there is a high risk of saltwater contamination if over-utilised, and the water is prone to biological contamination. Treatment of this water (chlorination or slow sand filtration) is recommended if it were to be developed as a potable water source.

Limestone aquifers are prone to contamination since the large open channels do not allow for natural filtration of the water. This contamination is visually apparent during rain storms when surface run-off carries muddy water though the cave systems. These aquifers are also notorious for contamination caused by the decay of dead animals that occasionally get washed into the cave systems.

Alluvial plains The lower parts of the larger valleys contain relatively large alluvial plains. These low-elevation plains have three basic sediment types. Highly permeable coastal-plain deposits dominate the first few hundred metres from the coast. These coastal deposits grade into low-permeability silts and clays derived from brackish water swamps and overbank deposits. Brackish-water swamps still exist within some of these valleys, and in others the lower sections of the plains, though not swampy, still experience occasional saltwater inundations. Further inland from, and presumably underlying, these silts and clays are coarser and more-permeable colluvial/alluvial deposits. It is thought that the gravels associated with the creek beds above the alluvial plains extend beneath these plains within the paleo-drainage channels.

Colluvial plains Colluvial/alluvial plains have developed within the higher parts of the valleys. Geophysical investigations indicate that these deposits have a high clay content.

Volcanics The volcanic rocks that make up the bulk of the island consist of inter-layered lava flows and breccias. Many dykes have been found within valley channels. Several northeasterly trending faults have been inferred from topographical features by Woodhall. Spring flow appears to be mainly controlled by bedding.

3.3 Hydrology

To be able to estimate the amount of water one can safely extract from the aquifers (the sustainable yield), one has to understand the hydrology of the island. This includes knowledge of rainfall and evapotranspiration which helps when calculating the actual groundwater recharge.

3.3.1 Meteorology

The climate of Cicia is controlled by the SE Trade Winds which produce pronounced wet and dry seasons. The closest meteorological stations to Cicia are on Lakeba (18°13'S, 178°47'W), 75 km SE of Cicia, and at Lomaloma on Vanua Balavu (17°15'S, 178°58'W), 60 km NE of Cicia.

Rainfall At Lakeba daily rainfall records are available for the years 1955 to beginning of 1962, and for 1979 up to 1988. The average annual rainfall over these 17 years is 1944 mm, with the lowest 1357 mm and the highest 2946 mm. The average from 1979 to 1988 is 1750 mm (see Table 1).

The weather station at Lomaloma (Vanua Balavu) started operating in December 1985. Monthly rainfall data are available since then. The average annual rainfall from the years 1989 to 1993 (5 years) is 1824 mm (see Table 2).

Evapotranspiration An estimate of the potential evapotranspiration is needed for a water balance calculation. Potential evapotranspiration can be estimated from pan evaporation data or calculated from meteorological data. Neither the Lakeba station nor the Vanua Balavu station measures pan evaporation. Different methods are available to make these calculations. A commonly used method is the combination-method or the Penman equation. This method requires mean air temperature, mean vapour pressure, sunshine hours and mean wind speed (Shaw, 1988, p. 242-244). The method of Thornthwaite requires mean temperature and daylight hours (Shaw, 1988, p. 244-246). Priestley-Taylor formula uses temperature and radiation data (Falkland, 1991).

For Lakeba the Priestley-Taylor estimates are available from the Fiji Meteorological Service. Annual average potential evaporation over the years 1991 to 1994 (incomplete) is 1444 mm. Thornthwaite estimates over a longer period of data (36 years) gives an annual average PE of 1462 mm.

For Vanua Balavu the annual average potential evaporation using the Penman estimate is 1824 mm (five years of data) and the Thornthwaite estimate is 1577 mm. Because of the longer record of data and as it only requires temperature data, the Thornthwaite method is being used in the water balance calculations.

3.3.2 Water balance

Freshwater recharge to groundwater occurs as a result of rainfall. A water balance calculation is a useful technique for estimating the percentage of rainfall that actually recharges the aquifers.

A simple water balance equation is expressed as follows:

$$P = I + AE + Ro + Re + \Delta S$$

P	=	Precipitation (mm)
I	=	Interception by vegetation (mm)
AE	=	Actual Evapotranspiration (mm)
Ro	=	surface Runoff (mm)
Re	=	groundwater Recharge (mm)
ΔS	=	Soil moisture change (mm)

For Cicia island the Interception by vegetation is assumed to be negligible and therefore the I-term becomes nil. Potential Evapotranspiration (PE) is calculated using the Thornthwaite method. The Actual Evapotranspiration depends on the availability of soil moisture and plant conditions. The term 'Soil moisture change' provides for the water needed to bring the soil to field capacity. Since runoff and recharge are both unknown, these terms can be combined and called Available Water, which is to be calculated. Therefore the water balance equation becomes:

$$AW = P - AE - \Delta S$$

AW = Ro + Re = Available Water (mm)

Water balance model The available water calculation for Cicia takes into consideration the potential evaporation rate and the soil moisture status. This model has been used by Hallet and Keshwan (1991) for the Yasawa islands study and several subsequent groundwater studies in Fiji. The soil moisture balance was first described by Penman (1950). The model uses two parameters, C and D, to describe the soil moisture levels that control actual evapotranspiration and groundwater recharge. C is the soil moisture level that must be satisfied before runoff or groundwater recharge can occur. D is the soil moisture content at which evapotranspiration ceases and plants start to wilt (wilting point). In the water balance calculation, evapotranspiration is considered to occur at the potential rate when the soil moisture level is above the C limit. When soil moisture content falls between the C and D limits the evapotranspiration is constrained and is taken as 10% of the Potential Evapotranspiration. Below D the actual evapotranspiration becomes nil. The values used for C and D are those determined in a study carried out in Tarawa, Gilbert Islands (Kiribati) by Lloyd et al (1980) and are 50 mm and 120 mm respectively. The accuracy in using these values in Fiji has yet to be confirmed. They are being used here and have been used in most of the more recent Fiji groundwater studies as Fiji-specific values are not available.

Available Water A summary of the water balance calculations for Lakeba and for Vanua Balavu is presented in Tables 3 and 4. The yearly available water figure for Lakeba is 365 mm and that for Vanua Balavu is 235 mm. These two figures are significantly different due to the different range of years with meteorological data used for the two stations. The lowest number will be used to calculate the sustainable yield.

3.3.3 Sustainable yield

Major interest is given to determining the volume of water that can be abstracted without exhausting the aquifer (sustainable yield). In the case of the small islands, over-abstraction would lead to saltwater contamination of the water source. In this study, as in the study by Hallet and Keshwan (1991), the sustainable yield calculations are calculated on a yearly basis. For the Yasawa islands it was estimated that a volume equal to about 10% of the available water can be safely abstracted from the aquifer, this volume being the sustainable yield percentage. This estimation is a rule-of thumb approximation and not based on empirical observations (Bronders and Lewis, 1993). The necessary studies that would be needed for a more confident estimation have not been made for the conditions within Fiji. For the Cicia study 10% of the available water will also be used.

The sustainable yield of a borehole is calculated by multiplying the surface area of the catchment that lies uphill of the borehole site by the sustainable yield percentage of the available water. For the Cicia proposed borehole sites the sustainable yield will be calculated using 10% of the Vanua Balavu available water figure of 235 mm.

Sustainable Yield (SY) equation :

$$SY = CA \times AW \times 0.1 \qquad [m^3]$$

SY = Sustainable Yield (m^3)
AW = Available Water (mm)
CA = Catchment Area (km^2)

4 Methodology

The five villages of Cicia Island were visited from 20 to 30 July 1995. Every visit to a village started with a *sevusevu* to the chief or his representative. After the ceremony the team split up into two groups: one assessing the village and its water sources, the other conducting a hydrogeological survey outside the village.

4.1 Village survey

During the village survey an inventory of the existing water supply facilities was made. The various sources were visited and their present condition assessed. The village surveys were usually carried out within one day for each village.

A biological water quality test was performed on each water source, using the Oxfam Biokit. On 26/7/95 biological samples were taken from water sources in Tarakua and Natokalau and sent to the National Water Quality Laboratory at Kinoya to be analysed, as a cross check of the Biokit results (see also 4.3.1).

In the villages all roof sizes from buildings with rainwater harvesting potential were measured to calculate the potential roof catchment area and an inventory of the actual use of this source was made. The number of people living in each household was determined by asking those people present.

In all the villages, information on water use, attitudes and practices was gathered through informal interviews. Questions were also raised during lunch and at tea breaks, which gave additional information on the functioning of the village water supply. Only in Tarakua was a formal meeting organised in the evening where a discussion on water, organisation and responsibilities was held amongst a group of women and then a shorter interview on organisation and responsibilities was held with a group of men. During this second meeting the discussion was mainly between the *Tui Tarakua* and the divisional representative of PWD.

At Mabula village, a visit was paid to the primary school to teach the children about water resources, water quality and health. The water testing equipment was explained, a water sample taken and the results showed to them the next morning.

4.2 Groundwater Investigations

The rapid assessment approach used for the groundwater investigations on Cicia has been developed over the last few years of field investigations on the remote islands within Fiji. This investigative strategy is designed to provide the maximum amount of hydrogeological information in a short period of time with the available equipment.

On Cicia one or two valleys were investigated each day. The groundwater investigations were limited to catchment areas greater that 0.9 km^2. The alluvial plains associated with these catchment areas ranged in size from 0.1 to 0.5 km^2.

The approach entails the use of geophysics and geology to give an indication of the extent of the alluvial aquifers. The main factors affecting alluvial aquifer development that were investigated are the size of the catchment areas, size and shape of the alluvial plains, depth to bedrock and the extent of the saltwater intrusion. Catchment area size and the inland extent of the alluvial plains were the main criteria for site selection. Electrical resistivity soundings were used to measure the extent of saltwater intrusion and to give an indication of the nature of the subsurface soils. Seismic soundings were used to measure the depth to the water table and bedrock.

A spring survey was also conducted as part of this investigation. The main objectives of this survey were to note the positions of springs and seepages and to test the water quality.

4.2.1 Geophysical observations and limitations

Electrical resistivity depth soundings The electrical resistivity depth soundings were made using the Schlumberger electrode configuration with an ABEM Terrameter SAS 300 transmitter/receiver system. A curve matching program written by MRD staff using the methods of linear filtering described by Ghosh (1971) was used to aid interpretation. Resistivity surveys have been found useful in identifying saline groundwater, clay layers, and variations in sediment and rock depths.

The volcanic rocks on Cicia tend to weather to clays that have low resistivities. Three electrical resistivity depth soundings were carried out within the weathered volcanic bedrock and the high-elevation colluvial/alluvial plains, well away from the effects of saltwater intrusion. The sounding at site TAR1 was made on a road cut directly into weathered volcanics. This site is on the ridge behind Tarakua village at an elevation of about 150 m above msl. The soundings at site TAR2 (110 m above msl) and NAC1 (30 m above msl) are located on high-level colluvial/alluvial terrace deposits. These terrace deposits have resistivities ranging from 5 Ωm to 40 Ωm. The resistivity values for the weathered bedrock at these sites range from 4 Ωm to 35 Ωm, with deepest values, presumably the least-weathered rock, being around 20 Ωm (see Figures 3 and 13 for locations and Table 6 for summaries of the geophysics results). The very low resistivities for presumably non-salt-contaminated materials make it difficult to discriminate between salt-contaminated and uncontaminated sediments.

Several of the electrical soundings located on the alluvial plains produced erratic readings and non-interpretable curves. These results probably indicate inhomogeneities in the subsurface layering which in several cases can be attributed to varying groundwater salinities.

Seismic depth soundings Seismic depth soundings were made using a single channel Bison signal-enhancement seismograph, Model 1570c, with a sledge hammer and metal plate as an impact source. The soundings were made in one direction only. Interpretations were made using the critical distances and the slopes of the first negative of the signal to calculate velocities and layer thicknesses. The method assumes that all subsurface layers are horizontal. The seismic sounding was found to be most useful for identifying the depths to the water table and bedrock.

Throughout the period of these investigations the weather was very windy. These winds produced a large amount of seismic background noise, due to the swaying of the trees, which made the reading of the seismic signals problematic.

4.3 Water quality

4.3.1 Biological water quality

The Oxfam DelAgua Biokit uses the membrane-filter method to test presence of 'faecal' coliform bacteria. The 'faecal' coliform bacteria tested are thermo-tolerant coliform bacteria that grow at a temperature of 44°C and are able to metabolise lactose. Faecal-contaminated water sources can spread many kinds of waterborne diseases, such as typhoid and diarrhoeal diseases (see also Section 2.4). The Biokit can be taken into the field and sample results can be read the following day (Oxfam DelAgua, 1988).

The group of bacteria that make up the 'faecal' coliform bacteria comprises of several types of bacteria but it mainly contains *Escheria coli* (E-coli) bacteria[1]. Members of this group of bacteria can also originate from industrial effluent, decaying plant materials and soil. Therefore the term 'faecal' coliform is not precise, and a better term to use is 'thermo-tolerant coliform bacteria'. The concentration of thermo-tolerant bacteria is under most circumstances directly related to that of E-coli bacteria and is therefore accepted as an indicator of faecal contamination of water sources (WHO, 1993). Although not exactly correct, the report uses the terms 'faecal' coliform bacteria and E-coli for all thermo-tolerant coliform bacteria tested with the Biokit.

During this survey water samples of 10 ml, 50 ml and 100 ml were filtered through a membrane filter, incubated at 44° C for 12 to 14 hours, and the number of colonies of the thermo-tolerant coliform bacteria was counted. One set of samples was taken and tested at the National Water Quality Laboratory at Kinoya, Suva and

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[1] *Escheria coli* (E-coli) is a bacterium which can be found in abundance in human and animal faeces. It can be found in sewage and all natural waters and soils that are subjected to faecal contamination. Therefore E-coli is considered a good indicator of faecal contamination.

compared to the results from the Biokit. The method used at Kinoya is similar to the field kit method.

The results from Kinoya and the Biokit are not exactly the same (probably due to variations in sampling and delays in processing); however both results reflect the severeness of the faecal contamination for the several water sources. Therefore all the results presented in this report have been classified as follows:

0	E-coli /100 ml	: safe
0 - 10	E-coli /100 ml	: slightly contaminated
10 - 50	E-coli /100 ml	: contaminated
50 - 100	E-coli /100 ml	: heavily contaminated
above 100	E-coli /100 ml	: extremely contaminated

Results from Kinoya and the Biokit never differ more than one class. Refer to Table 5bfor exact counts.

4.3.2 Chemical water quality

Samples from most of the available water sources on the island were tested in the MRD laboratory in order to assess the chemical water quality. The chemical make-up of a water source can give clues to the origin and history of groundwater. The ions that were tested are Ca, Mg, Na, K, Mn, Fe, HCO_3, SO_4, and Cl. Other aspects tested for were total dissolved solids (TDS), hardness, and pH. The electrical conductivities of the samples were measured in the field.

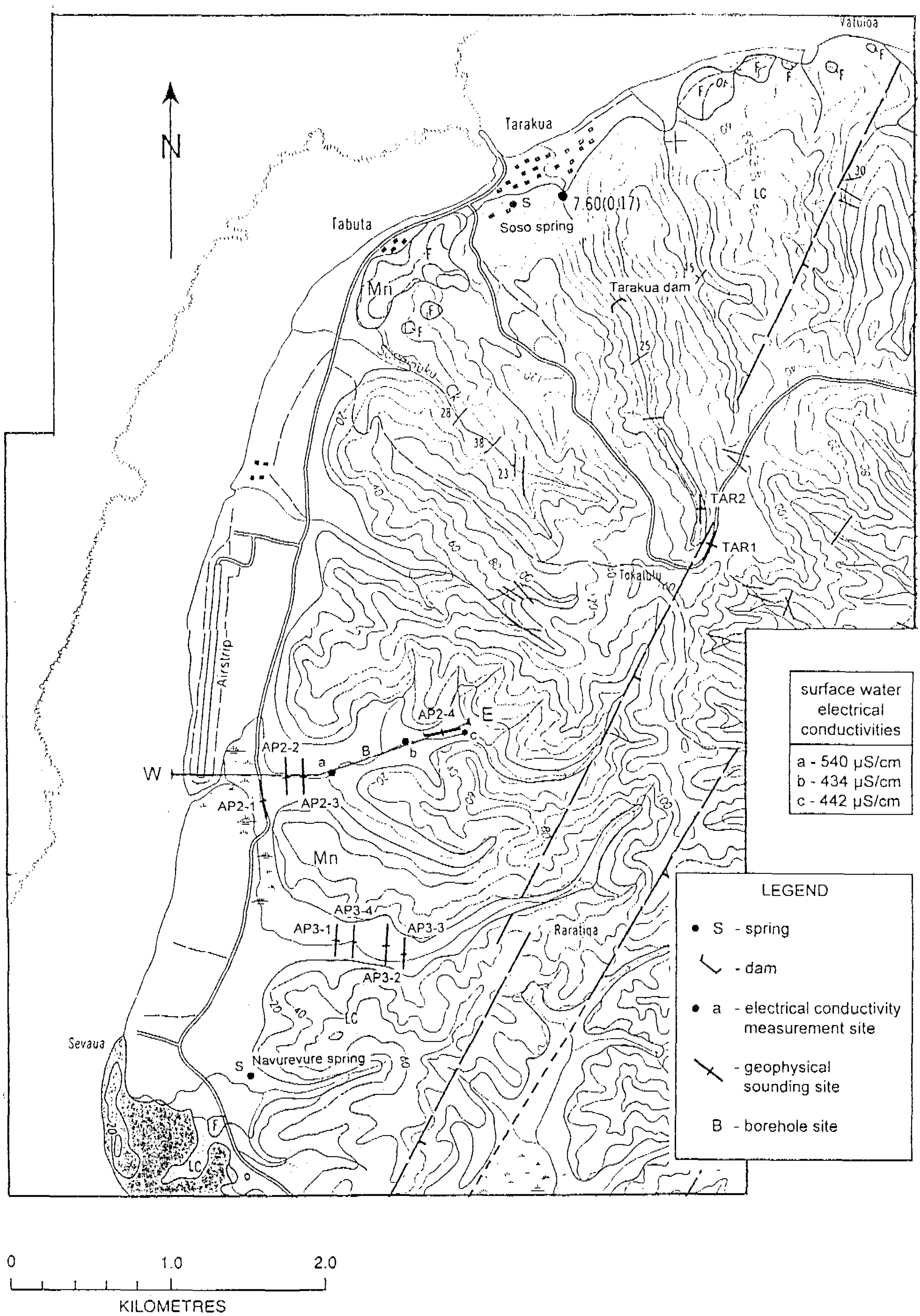

Figure 3 : Tarakua location map, Cicia

5 Tarakua

Tarakua is the chiefly village of Cicia. It is located on the coastal plain and the slopes of a hill on the northwestern side of the island. The village has a primary school and the Health Centre for Cicia. Tarakua had 204 inhabitants during the census in 1986, however during this survey only 133 were counted. The Cicia jetty, which is in a dilapidated state, is located in front of this village. Near Tarakua is the PWD compound at Tabuta and the Cicia (Tarakua) Estate. PWD previously reported that the village did not have a water problem, however during this visit the village was found to ration water. For locations refer to Figures 3 and 4.

5.1 Present water situation

5.1.1 Water sources

Tarakua dam Tarakua village has its water supplied from a dam in a creek in the valley behind the village. The dam is situated below a swampy area. Water comes from a spring higher up in the valley and from seepages at the sides of the creek above the dam. The dam water looks very dirty, and the screen only stops some of the larger debris.

At the time of survey, water flow was very low and most of it was captured by the dam. It is said that Tarakua has water shortages. However, this 'shortage' is also being contributed to by leaking tanks and pipes. The flow rate into the first tank was 0.3 l/s. This equals nearly 26000 litres (or 5700 UK gallons) per day, which can provide 200 people with 130 litres per day each. The electrical conductivity measured 242 µS/cm at the tank, and pH was 7.

Pipes and tanks The pipes and dam are over 20 years old. Pipes are rusting through and have many repaired parts. They are leaking at several places. The village has two tanks, an old 6500-gallon Humes tank from the 1970's and a 6600-gallon ferro-cement tank from the 1980's; both are leaking. Water in the tanks is dirty because dirt from the dam collects inside the tanks and the tanks are not periodically cleaned nor disinfected.

Taps Apart from the public standpipes, some households have made in-house connections. The houses on the hill south of the village do not get piped water due to low pressure, therefore the standpipes on the hill have fallen into disrepair. The elevation of the village tanks is not much higher than the village. It is said that before the tanks were leaking, water used to reach the hill.

Vede spring Vede spring is located on the slope of the hill south of the village. The spring is an open hole (1x0.7 m wide) filled with boulders, about 0.6 m deep. The spring is inadequately fenced with some corrugated iron sheets allowing surface

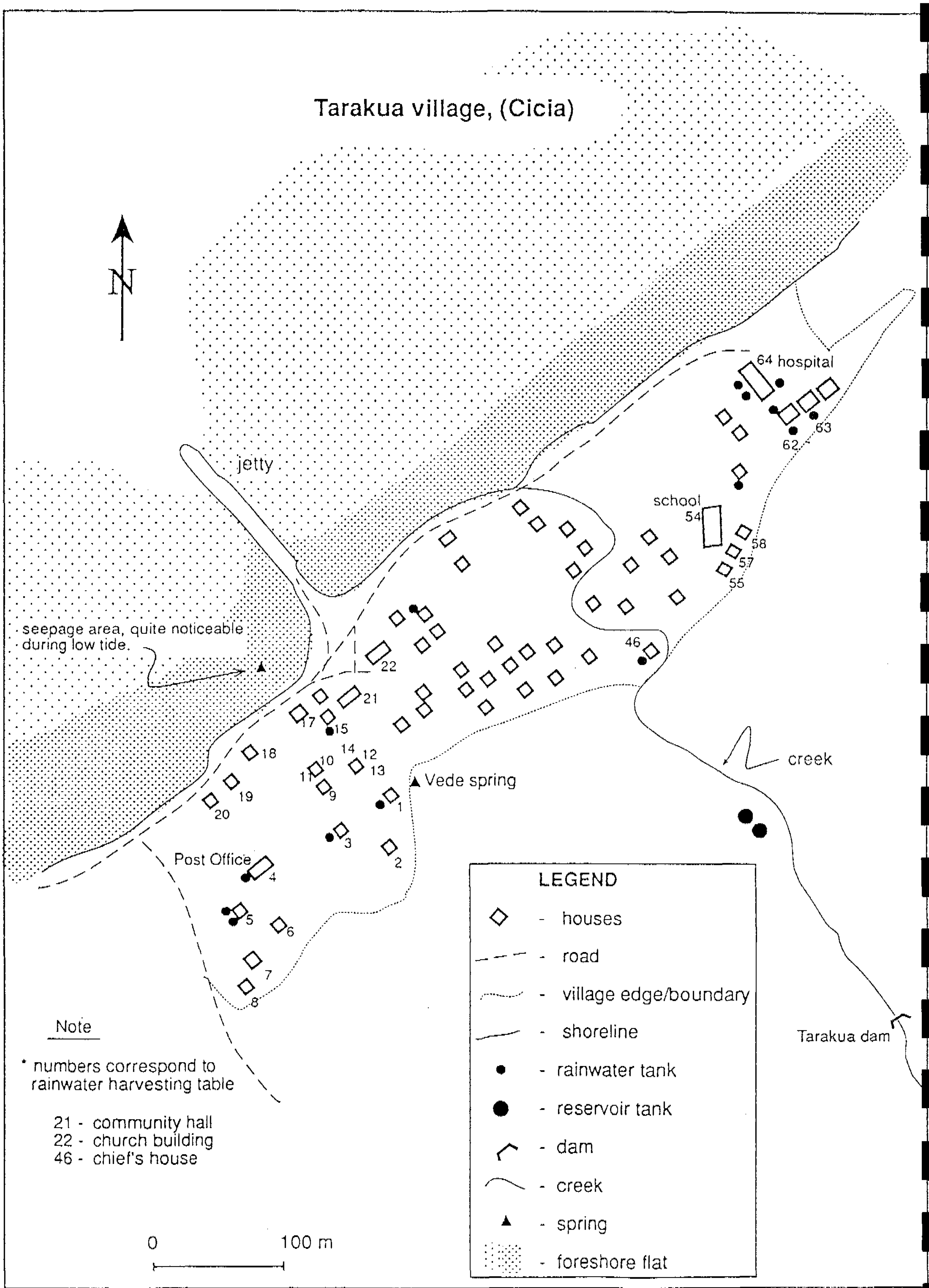

Figure 4: Tarakua village map, Cicia

runoff to enter the spring. Electrical conductivity was measured as 285 μS/cm; pH was 6.5.

Rainwater tanks The village has a number of rainwater tanks.

On the hill, where the piped water does not reach, eight rainwater tanks were found: four at individual households and four at the P&T station. The household tanks are all galvanised iron tanks, the four tanks at the post office and the house of the postmaster are made of galvanised iron (2), cement and fibreglass. The water in the fibreglass tank is slightly acidic with the pH in the range of 5 to 6 (universal indicator paper). The P&T house has a small rooftop tank which provides the pressure for the taps inside the house.

In other sections of the village five individual households with rainwater tanks (made of ferro-cement and galvanised iron) were found .

The church has an empty tank which has never been used so far, due to poor or unfinished construction.

The health centre with four buildings is fully equipped for rainwater harvesting with full gutters and seven galvanised iron tanks. The doctor's and nurse's houses each have a small roof tank for the in-house water supply needs which include a flush toilet.

The school water tank and gutters have fallen apart.

Rainwater is also collected in all kinds of containers from small gutters throughout the village.

Rainwater harvesting Currently only 28.6% of the suitable roof area is being used for rainwater harvesting. The total rainwater storage capacity is 80.7 m^3 (17 750 UK gallons) - refer to Table 10a.

Sanitation Most households have water-sealed toilets. Some households have flush toilets inside the house, but since there is insufficient water from the village supply those toilets are not being used or are flushed with bucket water. Since the village is built against the hill it has several open drainage gutters towards the sea, and a creek bed runs through the village.

5.1.2 Water collection and use

Tap water is used for all purposes. Water is carried to the houses in buckets or used at the standpipes. Several people mentioned they boil the water before drinking.

Vede spring is mainly used by the eight houses on the hill slope, since the spring is nearer than the tap. The spring water is predominantly used for bathing and washing clothes and dishes. Most of these houses use rainwater for cooking and drinking, and when there is not enough they use the tap water from a tap down hill. When the village taps are closed other villagers often come and use the spring.

Many women mentioned they like to use rainwater and they use it whenever available, especially when the tap water is dirty. They do not have enough rainwater storage to use this source as much as they would like.

The hospital and two accompanying houses are nearly self sufficient in rainwater, but for washing and bathing they also use village tap water.

5.1.3 Biological water quality

The water becomes very dirty, especially during rainy season due to surface runoff entering the dam reservoir and consequently the tanks and taps. Some women mentioned that "the tap water is sometimes so dirty that small eels (worms?) appear from the taps". Since the dam is open and difficult to protect, all types of pollution can be expected in the water. Biological contamination was confirmed by tests with the Biokit and from the National Water Quality laboratory (Tables 5a and 5b). Tarakua dam water was extremely contaminated, with over 200 E-coli bacteria per 100 ml. The same water coming from the taps contains about 100 E-coli bacteria per 100 ml.

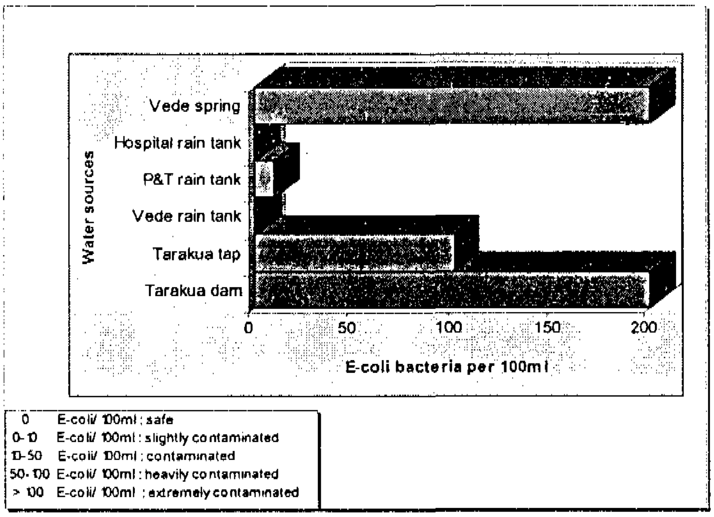

Figure 5: Biological water quality, Tarakua

Vede spring was also extremely contaminated with over 200 E-coli bacteria per 100 ml. The rainwater tanks were much better, with 0 E-coli bacteria per 100 ml in the hospital tank, 1 E-coli bacterium per 100 ml in the household tank near Vede and 10 E-coli bacteria per 100 ml in one of the rainwater tanks from the P&T station. This last tank needs to be cleaned as well as the gutters and roof.

The difference between the quality of rainwater and dam water shows that for Tarakua village rainwater tanks are a good option for safe water supply for human consumption and should be considered seriously.

5.1.4 Chemical water quality

Water samples were tak en from Tarakua dam, the reservoir tank fed from Tarakua dam, Vede spring, and the health centre rainwater tank for the chemical analysis for major ions (Table 6). Each of these sources contained potable water (chemical quality only) with ion concentrations within the WHO guidelines for safe drinking water. There are no significant differences between the Tarakua dam and the reservoir samples that could indicate in-line contamination of the water source.

5.1.5 Operation and maintenance

At the time of the survey (21/7/94), water was being rationed, with the taps being open for approximately 1 hour in the morning and 1 hour in the afternoon. This happens every dry season and can last for 4 to 6 months. In the wet season the taps are opened for 24 hours a day. One of the men in the village is responsible for opening and closing the taps.

The *turaganikoro* is responsible for initiating repairs, and some men in the village have the skills to work with concrete and other materials. However, nobody was ever trained by PWD for the water supply maintenance. Still they have been trying to repair leaks but the system is very old, rusted and decayed beyond effective repair. Some men were thinking that a trained person would help a lot. Some women mentioned that it might be a good idea to train the women as well.

5.1.6 Local organisation

Tarakua was said to have a committee for water. The committee was selected in a village meeting. The *Tui Tarakua* is the head of the committee; no one recalled who were the other members. The committee does not seem to be very active. A group of women thought that it would be a good idea to have also a woman in this committee as women are generally more concerned about water than men.

The village had set up a fund where every household was to pay 20 cents per month for water. This fund has however not been raising any money for a while. (It is said to have 20 dollars in cash). The women were of the opinion that the village does not have enough money to construct more gutters and tanks.

Ownership The piped supply is owned by the village. The women in Tarakua thought a community-owned system works better than private systems, also for rainwater collection. This is because even private water has to be shared with others anyway.

The *Tui Tarakua* suggested that a metered system would be better, and then the government would be responsible for the system. The PWD representative however mentioned that the village would still be responsible for pipes from the meter to the houses, and taps.

5.2 Groundwater investigation

The Tarakua investigations were carried out in three of the four valleys situated on the western side of the island near the landing strip, on the high-elevation colluvial/alluvial plain behind the village and on the ridge above these deposits.

5.2.1 Site observations

Valleys AP2 and AP3 These are the two largest of the four large valleys on the western side of Cicia (Figure 3). AP2 has a catchment area of 1.29 km^2 and AP3 has a catchment area of 0.9 km^2. Both have large alluvial plains that are composed of carbonate sands and gravels near the coast and carbonaceous clays within the interior sections. Brackish-water swamps exist in the lower parts of these two valleys, extending inland 300 metres in valley AP2 and 500 metres in valley AP3.

In valley AP2, at the time of the survey, the surface water closest to the coast appeared as small pools in the main drainage channel at about 600 metres inland, with a conductivity of 540 µS/cm (fresh water). At 900 metres the water was flowing as a trickle and had conductivities of about 440 µS/cm (fresh water).

In valley AP3, three shallow auger holes were dug and the electrical conductivities were recorded for the water table at these places (Table 9). All three sites contain carbonaceous clays. The hole at site AP3-1 (700 m inland) went to a depth of 4.2 metres. Water was struck at 0.67 metres and had an electrical conductivity of 1325 µS/cm. At 1.1 metres the conductivity was 1480 µS/cm. No further testing was carried out in this hole due to the limited length of the conductivity probe cord. The auger hole at site AP3-4 (950 metres inland) went to the depth of two metres into brown clays. The water table was struck at 0.8 metres and the water had an electrical conductivity of 738 µS/cm. Site AP3-2 (1000 m inland) went to the depth of two metres. The top 1.7 metres consists of colluvium. Beneath this is a blue/black clay. The water table was at about 1.5 metres below the surface and the conductivity of the water was 650 µS/cm. Ponded creek water adjacent to the auger sites had conductivities around 600 µS/cm.

Valley AP4 This valley, Navurevure[1], has a catchment area of 0.2 km^2 and contains a small marshy area within an otherwise dry alluvial plain. This marshy area is about 10 m square and has a deep open pool about two metres in diameter. It is located about 600 m inland from the coast and about 50 metres from the base of the northern side of the valley. The electrical conductivity of the water was measured at 420 µS/cm.

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[1]Water source/spring

Tarakua upper valley and ridge In the upper part of the valley behind Tarakua village is a high-elevation alluvial/colluvial plain (110 m above msl). On the ridge above this plain is a road cut within the weathered volcanics. These two areas were investigated in order to obtain geophysics results for ground conditions well away from the effects of saltwater intrusion. These results are discussed in section 4.2.

5.2.2 Geophysical observations

Valley AP2 In valley AP2 four electrical resistivity soundings and four seismic soundings were carried out. Refer to Figure 6 for the geophysical profile for this valley and Tables 7 and 8 for a summary of the geophysical interpretations.

The electrical resistivity sounding at site AP2-1 was located on the road 300 metres inland. This sounding indicated that there was about 2.75 metres of dry carbonate sands and gravel (480 Ωm) overlying about 7 metres of the same material saturated with fresh to brackish water (60 Ωm). At about 10 metres depth is the top of the saltwater intrusion (3 Ωm). The seismic sounding at this site indicates that the water table begins at two metres below the surface where the seismic velocities change from 287 m/s to 1260 m/s. Another change in velocities, 1260 m/s to 1783 m/s, occurs at six metres below the surface. The nature of this second change in bedding is not readily apparent. Neither the electrical nor the seismic soundings were able to detect the depth to bedrock.

Site AP2-2 is located about 420 m inland from the coasts. The electrical resistivity sounding indicates that about the first metre of soil is composed of alluvial clay (7 Ωm), the next 20 metres is a 400-Ωm material that is probably freshwater saturated carbonate coastal deposits. From about 21 metres below the surface is a material with resistivity of 10 to 40 Ωm, bedrock. The seismic sounding indicates that the top of the water table begins at about 4.6 metres below the surface and that the bedrock is deeper than 18 metres below the surface.

Site AP2-3 is located about 520 metres inland from the coast. The data from the electrical resistivity soundings at site AP2-3 were not interpretable. This result can be attributed to inhomogeneities in the subsurface layering caused by the transition between coastal and alluvial deposits. The alluvial deposits in this area probably contain some degree of residual salinity as found by augering in valley AP3. The seismic sounding indicates that the top of the water table was at 4.6 metres and bedrock at 19.6 m below the surface.

Site AP2-4 is located about 930 metres inland from the coast. The electrical resistivity sounding indicates about 10 metres of 6-Ωm alluvial/colluvial clays overlying 15-Ωm weathered bedrock. The seismic sounding indicates that the top of the water table was at 2.7 m below the surface and weathered bedrock at 9.6 m.

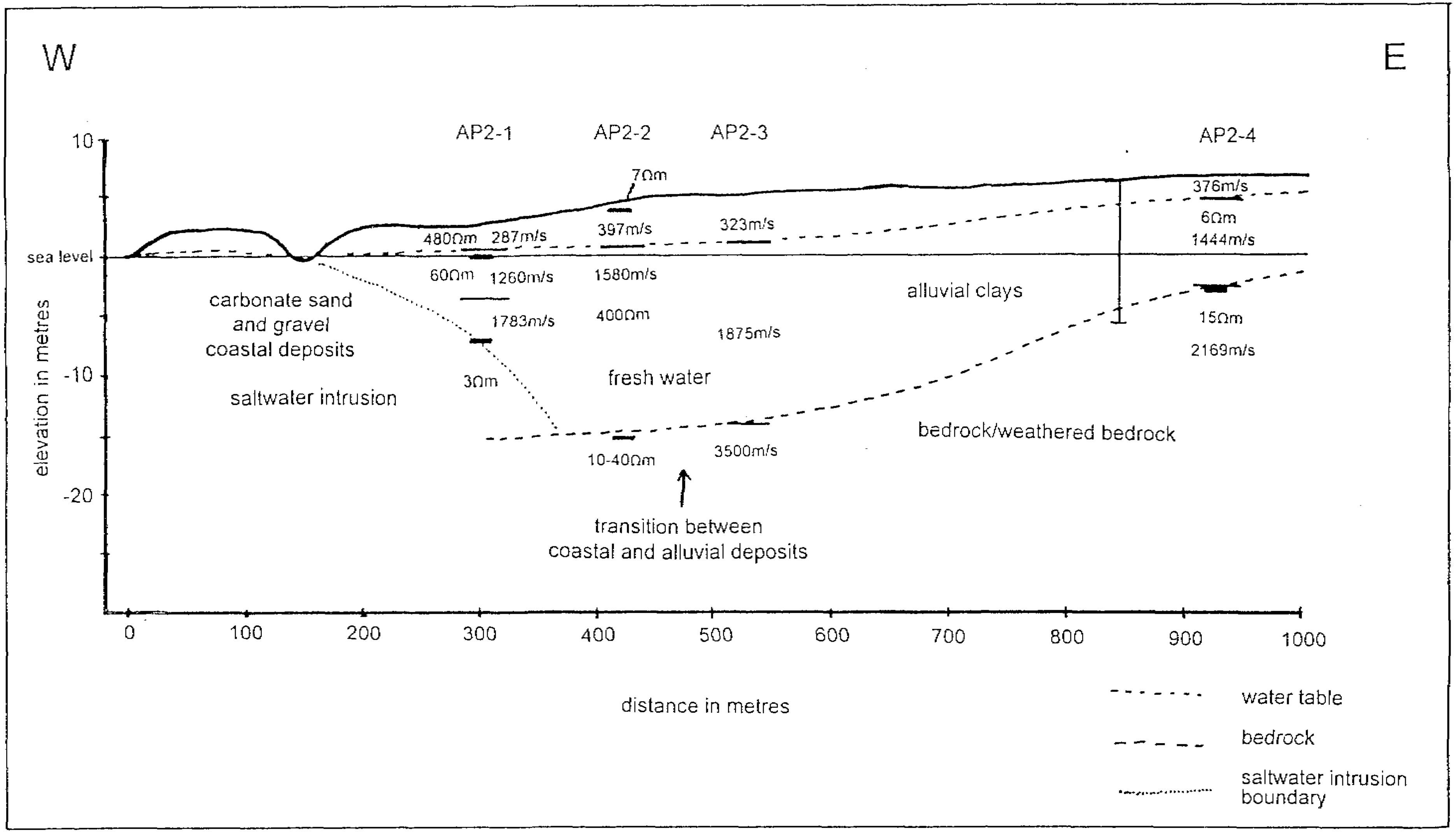

Figure 6: Geophysical profile, Valley AP2, Cicia

Valley AP3 Four electrical resistivity soundings were carried out in Valley AP2. No seismic soundings were performed in this valley. Refer to Table 7 for a summary of the geophysical interpretations.

The soundings AP3-1 and AP3-4, located 700 and 800 metres from the coast respectively, produced non-interpretable results similar to sounding AP2-3. The sounding at site AP3-2 indicates that there is about one metre of 8-Ωm dry colluvium overlying a three-metre layer of 3.1-Ωm alluvial clays. Beneath this is 20-Ωm colluvium/alluvium. The resistivity readings obtained at site AP3-3 were not very stable and are difficult to interpret. The sounding does, however, indicate material of 25 to 35 Ωm deeper than five metres below the surface. The actual depth to bedrock was not apparent in any of these soundings.

5.2.3 Hydrogeology

The coastal-plain deposits of carbonate sands and gravel extend inland about 500 metres. These deposits tend to be very permeable. The saltwater intrusion extends inland about 300 to 400 metres at valleys AP2 and AP3 and probably less for valleys AP1 and AP4. The lower drainage channels of valleys AP1 and AP4 are not as prone to saltwater flushing as is the case in the shared lower channel of valleys AP2 and AP3.

The carbonaceous alluvial clays that lie inland from the coastal deposits are of low permeability and most likely form an aquiclude. They tend to contain varying amounts of residual saltwater.

A freshwater wedge appears to exist between the front of the saltwater intrusion and the alluvial clays. This freshwater source has a high risk of saltwater contamination and would need to be developed and managed very carefully.

A freshwater aquifer should exist within the weathered bedrock and lower alluvial/colluvial deposits near the back of the alluvial plain. The base of this aquifer would be the impermeable bedrock. This is considered the safer of the two possible freshwater aquifers for exploitation.

There is some evidence that the basal aquifer becomes confined beneath the carbonaceous alluvial clays and is then released within the coastal plain deposits. The seepage area described for valley AP4, as well as a similar seepage in the Mabula West valley, may be due to such a phenomenon.

5.2.4 Groundwater potential and borehole recommendations

There are two main approaches for groundwater in these valleys. The first is boreholes in the back part of the valleys extending down into the basal aquifer. The second is to have infiltration galleries within the coastal deposits.

A borehole site has been chosen in valley AP2 and is indicated in Figure 3. It is located within the northern splay of the valley about 800 metres inland from the coast. Based on the electrical resistivity and seismic soundings the weathered bedrock should begin at about ten metres below ground level. The borehole should be drilled to bedrock or no more than about 15 metres below ground level and finished to an 8-inch diameter (6-inch minimum). The catchment above this site has an area of about 0.85 km^2. The sustainable yield for a borehole at this site has been calculated to be about 0.63 l/s, which is 268 l/p/d for the Tarakua population in 1986 (Census). There is easy access to this site for a drill rig.

Before development of a gallery system within the coastal deposits, an exploration borehole should be drilled near site AP2-2, with special attention given to the measurement of the changes of groundwater salinity with depth. A salinity monitoring system could be put into place, similar to those used in the Republic of Kiribati (Falkland, 1991), to keep track of seasonal changes of the thickness of the freshwater 'wedge', and allow sustainable yield estimates to be made.

The spring seepage area in valley AP4 can be developed as one would a hand dug well. To develop this as a pumped water source the nature of this seepage should be investigated (perhaps pump tested), and the area should be investigated for the potential for infiltration galleries. With minor improvements this water source could be capped and pumped for the nearby houses and used for the watering of cattle. It is located 4.4 km from Tarakua village and 2.5 km by road from Mabula village.

5.3 Conclusions and recommendations

5.3.1 Conclusions

At the time of the survey the villagers reported that due to the low yield from the Tarakua dam they had to ration water. The actual yield from the dam was measured at the tank inlet and was found to be 0.3 litres per second (25 920 litres per day). A quick calculation shows that at this flow rate, each of the 133 people that were currently occupying the village should have 195 litres of water available each day. This amount is significantly greater than the 115 litres per person per day PWD takes as standard for public standpipes for general use (Cooper, 1984). Having to ration the water indicates that there is a large amount of leakage from the system. The first two recommendations, below, should provide the village with a sufficient water supply.

The most cost effective solution to Tarakua's current water problem would be to replace the existing, worn out, reticulated water supply system and improve the intake structure. The advantage of developing the groundwater potential of the airport valleys for the village water supply is that it would provide a safe source of drinking water. This potential source can also be used in the redevelopment of the

Cicia (Tabuta) Estate, provide an emergency water supply or in the development of tourism on the island.

5.3.2 Recommendations

1. Leaks within the two main water tanks need to be repaired.
2. Since the existing piping is in very poor condition, replacement of the 20 year old system is needed.
3. The village needs to better use their rainwater-catchment potential, for water quality reasons as well as to supplement their reticulated stream water. Currently only 28.6% of the available roof area is being used and current rainwater storage capacity is 80.7 m^3.
4. Water treatment of the reticulated water is recommended.
5. A borehole has been sited in one of the valleys adjacent to the airport. This source is expected to have a maximum potential yield of 0.63 l/s (268 l/p/d).
6. Additional groundwater can be abstracted from the shallow coastal aquifer near the airport. This water source could be used for cattle production on the Tabuta Estate.

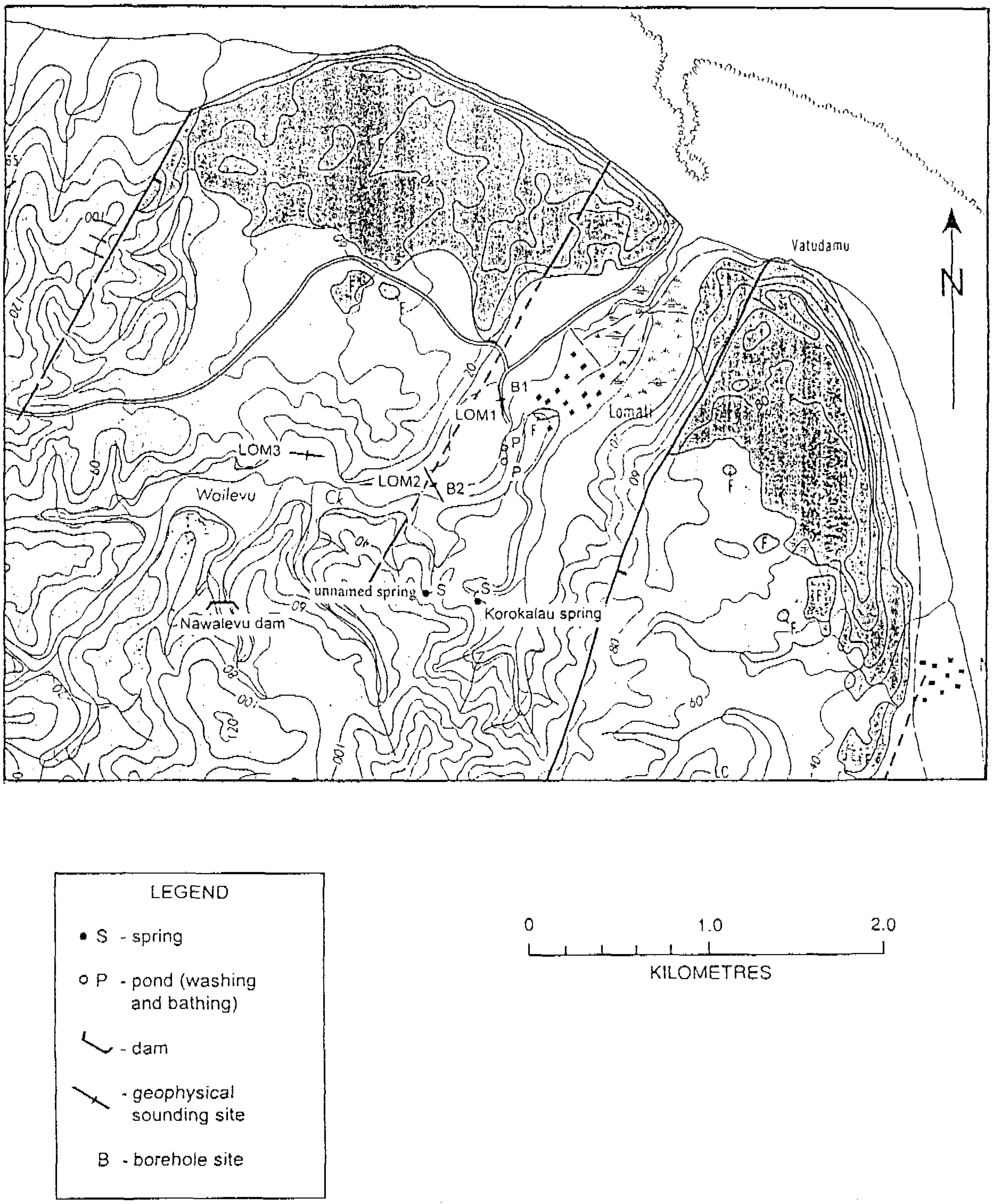

Figure 7 : Lomati location map, Cicia

6 Lomati

Lomati is one of the larger villages on Cicia. It is located on an alluvial plain about 500 to 1000 m from the sea on the northeastern side of the island. Most of the village is on flat land. The village has a primary school. Lomati is the only village on Cicia with a village power supply (diesel). The village had 252 inhabitants during the census of 1986 and 279 during this survey (22/7/94). PWD reported that the village did not presently have a water supply problem but that the village would have one with future growth. For locations refer to Figures 7 and 8.

6.1 Present water situation

6.1.1 Water sources and sanitation

Nawalevu dam Nawalevu dam is located in a tributary of the Wailevu[1] Creek about two kilometres from the village. Water from the dam is piped to the village as the main water supply. Before entering the pipes the water flows through a screen; there is no storage tank. The area above the dam is used for growing *dalo*, and pollution from this area is likely to enter the dam. The flow rate into the dam was 0.5 l/s (22/7/94); this can provide 279 persons with 155 litres per person per day. The electrical conductivity was measured at 152 µS/cm. According to the villagers there is no water quantity problem at the moment.

In another tributary of Wailevu Creek, at approximately one kilometre from the village, is another spring which is surrounded by *dalo* patches. This source is not used, discharge being very small. Electrical conductivity was 270 µS/cm.

Korokalou spring Korokalou spring lies about 1 kilometre from the village in the large valley southeast of the Wailevu Creek valley and is used as an emergency water supply. It is a dug pit within a seepage area near a creek bed on a tributary to the main part of the valley. The area is fenced off and is used for *dalo* plantation. This spring is used when the main water supply from the dam is reduced. It was used last in December 1993. The electrical conductivity of the spring water was 252 µS/cm.

Wailevu Creek Wailevu Creek is the main water course at Lomati village. At the southern edge of the village is a ford[2] within the creek, and several tens of metres upstream are ponds used for washing, bathing and swimming. The creek appears to be dirty near the village, rubbish being dumped in the creek.

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[1]big water

[2]shallow place in the creek where one can walk across

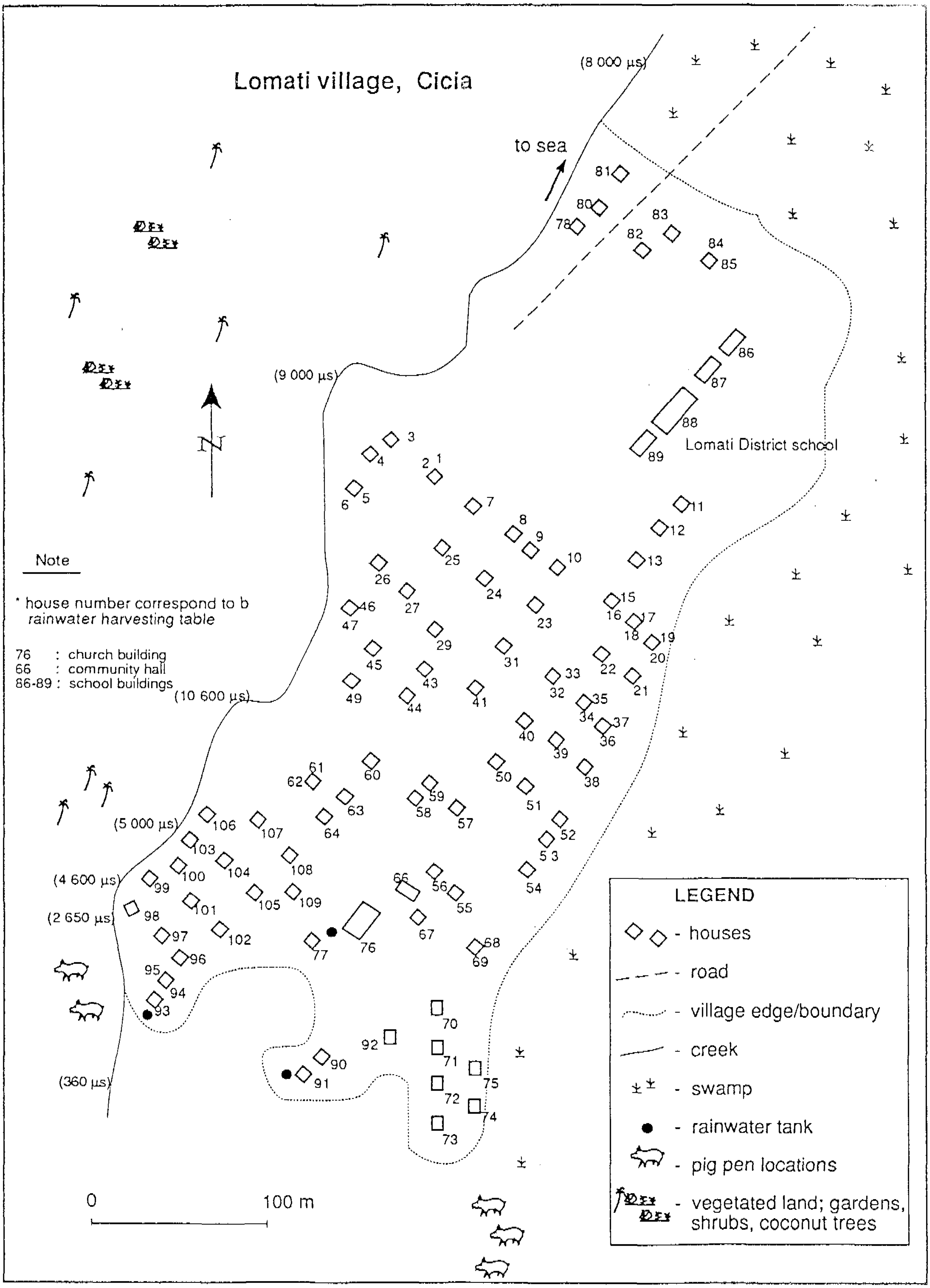


Figure 8: Lomati village map, Cicia

Taps The village has a piped water supply with taps in the village. There is about one tap per six households, which is not enough according to the women in the village. It means they have to wait at the standpipes. There are five standpipes at the school compound.

Rainwater tanks There are three rainwater tanks in Lomati: one community tank and two private tanks. The private tanks are galvanised-iron tanks and both are located at houses in the most southern part of the village. The community rainwater tank is a concrete underground tank near the church. Although the church still has the gutters the tank is not being used. It is cracked and leaking. It was built by the villagers in 1961 and has also been used for storage of creek water.

Rainwater harvesting Currently only 10.5% of the suitable roof area is being used for rainwater harvesting. The total rainwater storage capacity is 6.6 m^3 (1450 UK gallons) - refer to Table 10b.

Sanitation The village suffers from poor drainage. Most of the village is flat, and waste water from standpipes does not flow away. This results in muddy and swampy spots in the middle of the village where pigs have a pleasant time playing around. Attempts have been made by the villagers to provide drainage. However, some of the cement drains have collapsed and the other drains need to be dug out again. People living near one of those drains agreed that it needed to be cleaned but explained they wait for the *turaganikoro* to organise this.

6.1.2 Water collection and use

Tap water is used for all purposes, including drinking. The taste is good according to those who drink it. Only a few people boil the water before drinking. Other sources used for consumption are the springs in the bush and green coconuts.

Except for the two galvanised iron tanks in the village the only use of rainwater is of rain collected in buckets, tubs or other containers from a few small gutters or directly from the roof. When rainwater is available it is used for drinking and cooking.

The creek is used for bathing, washing clothes and fishing. Creek water is brackish alongside the village, but the actual washing pond (upstream from the village) has fresh water. Washing of clothes is also done at the tap stands with a tub and 'running' water.

Water is carried home in any container available. During droughts water from Korokalou spring is carted in 44-gallon drums using horses, and is carried by hand in buckets and other containers.

6.1.3 Biological water quality

One water quality problem mentioned by all the villagers was that mud and dirt gets into their tap water during rains. Women in the village agreed that therefore it would be a good idea to have more rainwater tanks to be used for consumption only. When tap water is dirty more people use water from the two existing rainwater tanks.

All the sources in Lomati were found to be heavily contaminated. Bacteriological tests revealed over 100 E-coli bacteria in 100 ml water at Nawalevu dam, and even more in the tap water at the village. Thus water becomes contaminated either from inside the system or from water with a greater degree of contamination entering the system during the previous rainfall.

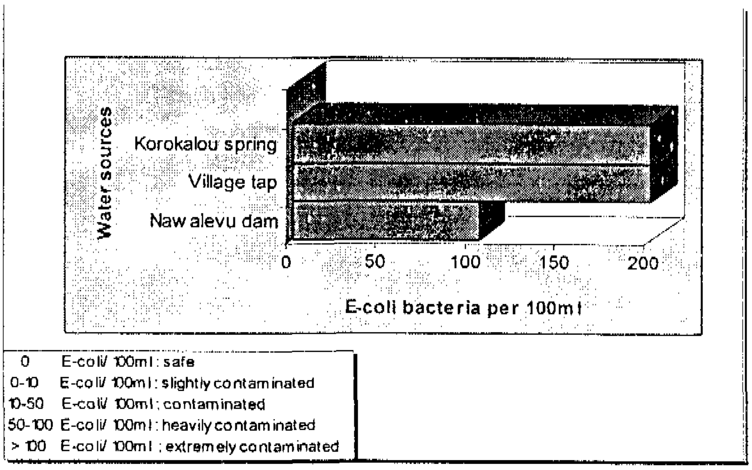


Figure 9: Biological water analysis, Lomati

Korokalou spring was found to be extremely contaminated as well.

6.1.4 Chemical water quality

Water samples were taken from Nawalevu dam and Korokalou for the chemical analysis for major ions (Table 6). Each of these sources contained potable water with major ion concentrations within the WHO guidelines for safe drinking water. The sample from Nawalevu dam had an iron concentration of 0.88 mg/l which may be enough to cause staining in laundry. The iron concentration of the sample from Korokalou spring was slightly elevated at 0.12 mg/l. In both cases the manganese concentrations were below 0.02 mg/l.

6.1.5 Operation and maintenance

As the village owns the water supply it is responsible for maintenance and repairs. Only the rainwater tanks are privately owned. Some of the men in the village can repair taps, etc. The women said they do not make repairs but just use the taps "as much as we can".

6.1.6 Local organisation

The *turaganikoro* organises village-wide jobs and projects, and is overall responsible for village maintenance. These responsibilities include repairing taps and pipes, and cleaning sources and drains.

Income The only regular income in the village is from copra. When money is needed for repairs and so on, the *turaganikoro* will call a meeting and ask an amount per household. No money is collected regularly and no water fund exists.

6.2 Groundwater investigation

6.2.1 Site observations

Lomati village sits near the back of an alluvial plain that extends inland about 900 metres before forking into two valleys. The southwestern fork contains Wailevu Creek and is the island's largest catchment area at 6 km^2. The southern fork has a catchment area of about 0.6 km^2.

The surface water within the main valley is tidal for 900 metres along the main drainage channel. Conductivities in this channel varied from 10 600 µS, in the ponded channel behind the beach berm, to 2650 µS/cm, just below the fall line at about 900 metres inland. Water flowing, from above the fall line, into the channel has an electrical conductivity of about 330 µS/cm.

6.2.2 Geophysical observations

Three electrical resistivity and seismic soundings were carried out within Wailevu Creek valley. Sites LOM1 and LOM2 are located within the back part of the alluvial plain at about 1000 and 1400 metres from the coast. Site LOM3 is situated on an alluvial terrace about 1800 metres from the coast. Electrical resistivity sounding at site LOM1 indicates a 2-Ωm layer extending to a depth of about 22 metres, which is interpreted as marine clays with a high residual salinity. Below this depth is 200-Ωm material that may be sand and gravel saturated with fresh water. The seismic sounding at this site shows 15 metres of clays which have low velocities, up to 716 m/s, overlying a material with a seismic velocity of about 1050 m/s which is probably a more compact clayey material. Bedrock was not reached in this sounding.

Site LOM2 is situated about 400 metres inland from site LOM1, and has about 9 m of 1.8-Ωm saline alluvial clays overlaying 10-Ωm material which probably contains fresher water. The seismic sounding at this site is similar to that of LOM1 in having a thick deposit of low-velocity material. In this case there is about 19 metres of clays, with velocities up to 621 m/s, overlying 2821-m/s material that is probably weathered bedrock.

Site LOM3 is located about 1800 m inland from the coast within the Wailevu Creek valley. The electrical sounding was carried out on an alluvial terrace 6.5 metres above creek level, and the seismic sounding was carried out on a lower adjacent terrace 3.5 metres above creek level. The electrical sounding indicated a 1.4-metre layer of 30-Ωm soil, then 25 to 35 metres of 12-Ωm material both alluvium/colluvium and weathered bedrock. Beneath these two layers is the bedrock of 30 Ωm. The seismic sounding indicates that there is 0.6 metres of loose soil and 11.2 metres of alluvium/colluvium overlying weathered bedrock. The depth to the water table is not apparent in either sounding, but should correspond to the creek bed, which contained a small amount of flowing water at the time of the survey.

6.2.3 Hydrogeology

At present there is a brackish-water swamp that extends about 700 metres inland on the northeastern side of the village. The main drainage channel of the valley is tidal to about 900 metres from the coast, and contains brackish water throughout this distance.

The alluvial plain consists of thick deposits of marine clays that still retain a high salinity. These clays are expected to have a very low permeability, and to extend to a depth of about 22 metres at site LOM1 as indicated in the electrical sounding. Under these clays is a layer of high-resistivity material that appears to be freshwater-bearing sand and gravel (which would be good water producing strata). It is likely that this layer extends under the clay deposits to crop out as the coastal deposits. This layer was not seen at sounding LOM2 about 400 metres inland.

The bed of Wailevu Creek above the fall line contains volcanic sands and gravel, as do the recent alluvial deposits observed in the cut banks of the creek. It is likely that these deposits overlie the bedrock beneath the alluvial plains and would be reasonably permeable.

At site LOM2 there is about 19 metres of clay overlying weathered bedrock. There is a possibility of basal gravels sitting on the weathered bedrock. A borehole at this site should produce an adequate amount of water for the village.

6.2.4 Groundwater potential and borehole recommendations

Two borehole sites have been chosen for this village: a primary and an alternate. The primary site is located at site LOM1. The planned depth of a borehole at this site should be about 30 metres, with solid casing from the surface, through the clay, down to the water-bearing stratum at about 22 metres (according to the geophysics). This site was chosen as the primary borehole site on its potential for having high yields.

The alternate borehole site is located at site LOM2. The depth of a borehole at this site should be 25 metres. The water-bearing strata are expected to be the weathered bedrock and the overlying gravels. This site has less risk for saltwater intrusion than site LOM1, but the potential yield is not as high.

The catchment area above site LOM1 has an area of 5.8 km^2. The sustainable yield of a borehole at this site, as calculated from the Vanua Balavu meteorological data, is 4.3 l/s. The sustainable yield of a borehole at site LOM2 would be slightly less. The actual yield from these boreholes will depend upon the properties of the aquifer material and borehole design. There is easy access to both sites for a drill rig.

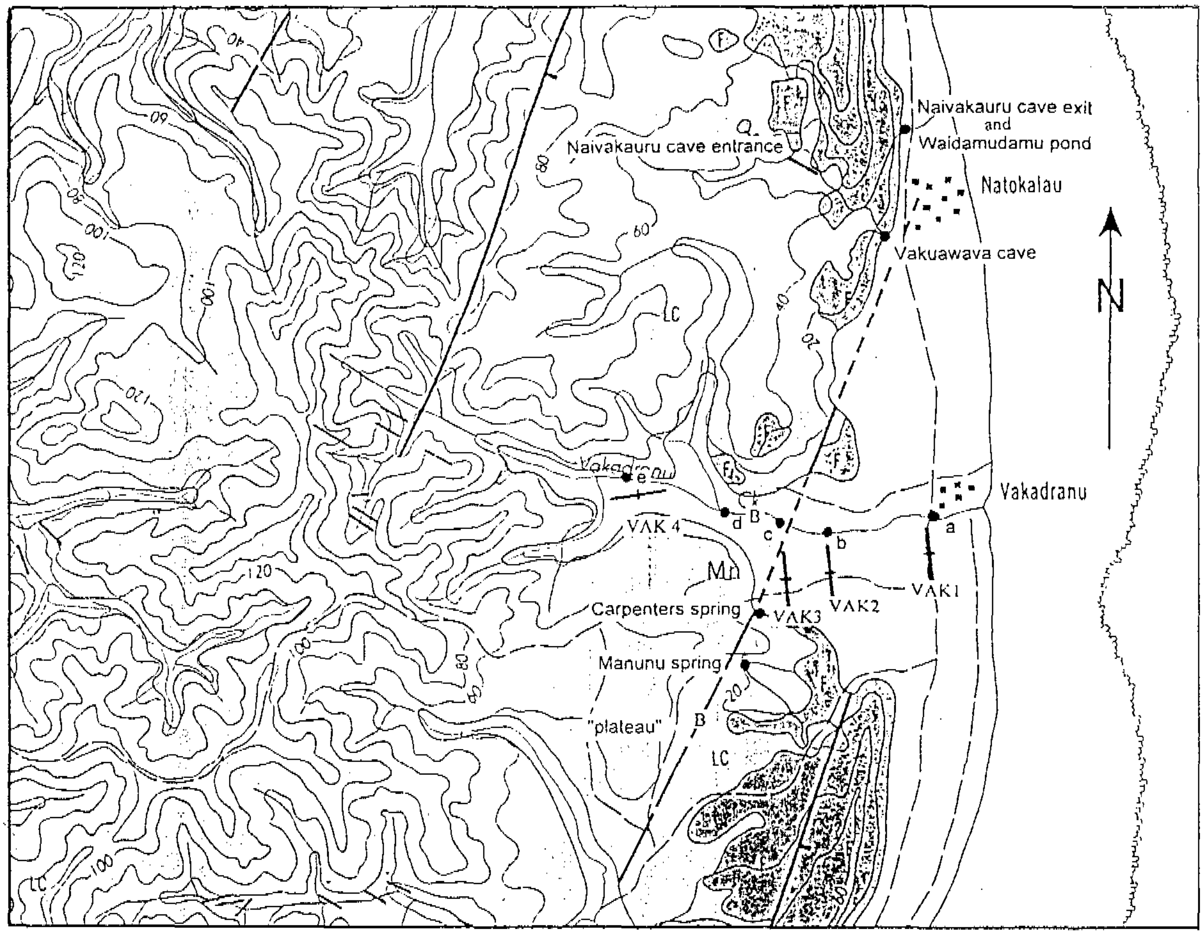
6.3 Conclusions and recommendations

6.3.1 Conclusions

Lomati village has a water supply that is normally adequate for their needs; however, the source is a dammed stream and is prone to contamination. There have been times in the past when this supply had to be supplemented with water from other sources. Building storage into the existing system could help the village during times of low dam output and help in meeting the needs of an expanding population. Implementing rainwater harvesting would improve the quality of village drinking water. Providing water treatment, such as slow sand filtration or chlorination, would also improve the water quality situation. A borehole would be a viable option if the village were to need additional water. If the proposed borehole were to produce at the expected rate it could be used as a basis for an island-wide water reticulation scheme, to supplement current sources of water during times of low water flow and droughts.

6.3.2 Recommendations

1. The existing pipes need to be inspected and repaired as needed.
2. When water demand increases, water storage can be introduced into the existing reticulation system.
3. The village can better use their rainwater harvesting potential for water quality reasons. Currently only 10.5% of the available roof area is being used and current rainwater storage capacity is 6.6 m^3.
4. Treatment of the reticulated water is recommended.
5. Additional protection of the spring sources is recommended. A proper design has to be sought.
6. The groundwater potential for this village is the best of the island. The proposed borehole is expected to have a maximum potential yield of 4.3 l/s (more than sufficient for the villager's present needs). However, actual yields can be less.



0 — 1.0 — 2.0
KILOMETRES

LEGEND

- • S - spring
- ● P - pond (washing and bathing)
- • a - electrical conductivity measurement site
- ╲ - geophysical sounding site
- B - borehole site

surface water electrical conductivities
a - 15 000 µS/cm
b - 1962 µS/cm
c - 771 µS/cm
d - 653 µS/cm
e - 466 µS/cm

Figure 10 : Natokalau location map, Cicia

7 Natokalau

Natokalau is situated on a narrow stretch of coastal plain, at the base of high limestone cliffs. The village is surrounded by coconut palms and bushy vegetation. Goats and pigs walk freely through the village and into the hills. The village had 27 households with 179 inhabitants during the census in 1986. During this survey 148 people were counted. Near Natokalau is the Vakadranu Estate where nobody is living at the moment. The village has a primary school. PWD reported that this village had problems with their water supply. For locations refer to Figures 10 and 11.

7.1 Present water situation

7.1.1 Water sources

Vakauwava cave The village has a freshwater cave within the limestone directly behind the village. The cave is protected from free-roaming animals and surface water flow from the village by a low concrete wall (0.8 m high) about 15 m from the cave entrance. The electrical conductivity of the water in the cave was 690 µS/cm, indicating fresh water. The water level in the cave is subject to tides. There is a proposal with PWD to install a solar pump and construct a new 2400-gallon tank on the hill near the cave opening. It was reported that this source was "salty" in the past.

Manunu spring At a distance of 2.5 km southwest of the village is Manunu spring. This spring is developed and feeds the village tap system. The spring is located above a wet area with *dalo* plantations. The area around the spring is fenced and overgrown by vegetation. The drainage ditch dug behind the spring was in need of cleaning out. The actual spring is a hole of 2 m diameter and an estimated 2 m depth, filled with limestone boulders. The intake structure is a concrete box (1x1x1 metres) which only partly covers the hole. Water from the spring box goes through a screen and through pipes to a tank 100 m away. Only in very dry periods does the spring dry up. The electrical conductivity was 358 µS/cm and the pH was 6.5.

Tank and pipes The village water tank (4200 UK gallons, 19 m^3) was repaired by adding a new cement layer (inside and outside) in November 1993. The inflow from the spring was 0.23 l/s (25/7/94); this equals nearly 20 m^3 per day, which can supply 150 persons with 130 litres each. Pipes were found leaking at several places, resulting in water losses and the possible contamination of the water.

Waidamudamu pond Waidamudamu[1] pond is located 100 m north of the school at the foot of the limestone cliff where Mataniwai Creek emerges from Naivakauru cave. During rains, fresh water flows out of the cave, and the pond is then used for washing and bathing. During this visit the pond water was dirty brown and fairly

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[1]brown water

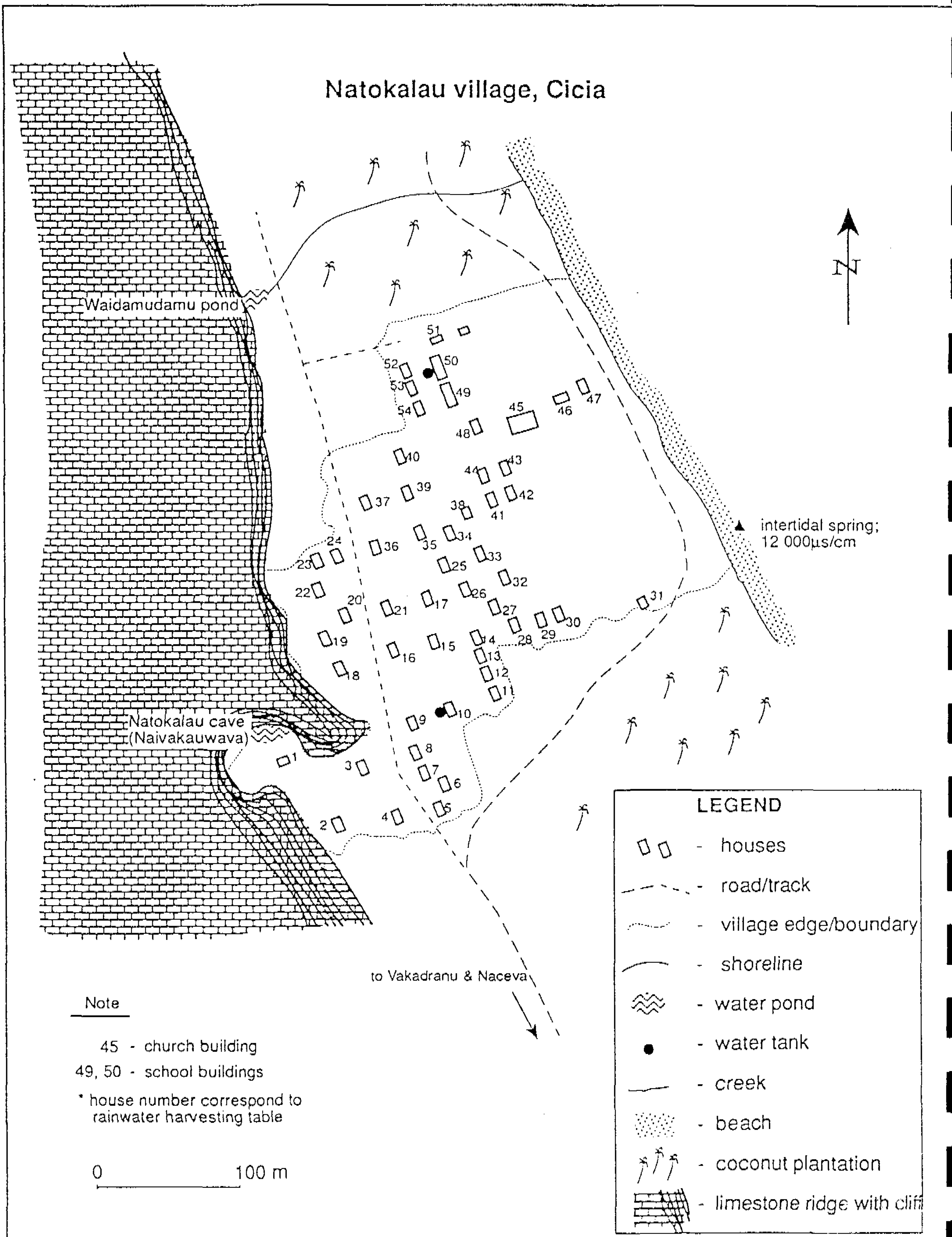

Figure 11: Natokalau village map, Cicia

salty (3500 µS/cm).

Rainwater tanks In Natokalau village only three rainwater tanks were found. The school has a new 1000-gallon fibreglass tank. One household has a tank made of two 44-gallon drums welded on each other. The third tank (galvanised iron) is not yet being used. It is a donation of the Poverty Alleviation Fund to set up a goat farm outside the village. Apart from the rainwater tanks, 'Bombay' pots, buckets and other containers are used to collect rainwater.

Rainwater harvesting Currently only 14.4% of the suitable roof area is being used for rainwater harvesting. The total rainwater storage capacity is 5 m^3 (1100 UK gallons) - refer to Table 10c.

7.1.2 Water collection and use

Tap water is used for all purposes. People say the taste is good.

The cave is used for bathing, mainly by people living nearby. During droughts, use of the cave is restricted, and no water use inside the cave is allowed. Normally cave water is not used for consumption, but during droughts it is used for drinking and cooking as well. However, some people prefer to transport water from other villages instead of drinking the cave water.

Rainwater is used for cooking and drinking, rainwater from the drum tank is used to wash clothes. Rainwater was said to taste good as well.

Waidamudamu pond is used for washing and bathing after rains when fresh water flows through.

7.1.3 Biological water quality

Manunu spring has the lowest E-coli count of all the springs on Cicia (1 E-coli bacteria in 100 ml). Although the spring water was fairly clean, the tap water in the village was found more contaminated. Thus the water becomes contaminated inside the system (tanks and pipes) or contaminated water entered the system during previous rainfall.

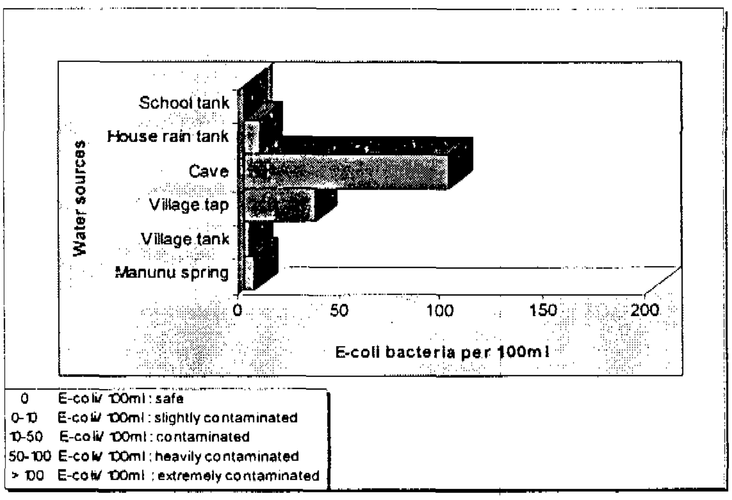

Figure 12: Biological water quality, Natokalau

7.1.4 Chemical water quality

Water samples were taken from Manunu spring, Natokalau cave and the school rainwater tank for the chemical analysis for major ions (Table 6). Each of these sources contained potable water with ion concentrations within the WHO guidelines for safe drinking water. The sample from Natokalau cave showed a slight elevation in chloride and sulfate concentrations, indicating some saltwater contamination.

7.1.5 Operation and maintenance

At the time of the survey (25/7/94) the water reticulation system was open 24 hours per day. Rationing is only practised during droughts.

There is no regular maintenance, but if something breaks down some action will be undertaken eventually, as shown in the following example. Early in 1993 the reticulated water system stopped working. For about a year the village managed with the cave water and hiring trucks for water transport from other villages. Eventually three or four men went up to the spring and cleaned out the accumulated mud and debris. This solved the problem and the village was able to use spring water again.

7.2 Groundwater investigation

The groundwater investigation for this village concentrated on Vakadranu valley located south of the village. A quick reconnaissance was made of the cave system within the limestone terrace behind and to the north of the village.

7.2.1 Site observations

Vakadranu valley Vakadranu valley is located about 1 kilometre to the south of Natokalau and has a catchment area of over 1.3 km^2 (Figure 10). The valley has a large alluvial/coastal plain associated with it. At about 700 metres inland this plain narrows from about 400 metres to around 100 metres wide. Vakadranu Creek contained ponded and sporadically slightly flowing water at least up to 900 metres inland. Electrical conductivities of the water measured at various points along the creek, and the depth of the creek channel, have been noted on Figure 10. Brackish water was found at least 200 metres inland, and a slight amount of saltwater contamination up to 700 metres inland.

Vakauwava cave This cave is located at the base of the limestone terrace behind the village. It contains fresh water (690 µS/cm) and is tidal. This water was reported to have been saline during a PWD survey conducted in 1982.

Intertidal spring On the coast, adjacent to the village, is a spring within the intertidal zone. The electrical conductivity of this water was about 12 000 μS/cm indicating ground water flow. The adjacent seawater was measured at 39 000 μS/cm.

Naivakauru cave A traverse of Naivakauru[1] cave was made from the drainage inlet on the inland side of the limestone terrace to the cave exit at Waidamudamu pond. At the mouth of the cave the stream has cut the channel down to the volcanic bedrock. This channel follows the bedrock at a steep grade to a few metres above sea level, where it begins to flow over travertine deposits. At sea level the main passage passes through several cavernous rooms that have passages leading up. One of the these rooms contained bats, suggesting that there is higher entrance. As the passage approaches the coastal plain it begins to branch. The cave system extended below sea level and most of the traverse through this area had to be swum.

This submerged cave system represents a huge volume of stored water. Even though the water at this particular place under the limestone terraces is brackish (3500 μS/cm), there are other places on the island that have fresh water within the cave systems. The potential exists to upgrade this type of source with underground dams constructed within the coastal plains. However, this suggestion is only academic since this would be a very expensive project and there are many other, more economic, sources of water on the island.

7.2.2 Geophysical observations

The geophysical investigation at Vakadranu consisted of four sets of electrical resistivity and seismic soundings. A summary of the geophysical interpretations is presented in Tables 8 and 9. The general make up of the alluvial/colluvial deposits, beginning from the surface, is as follows: about two metres of superficial deposits, a layer, 30 to 40 Ωm, of water-saturated alluvium (fresh to brackish), a 5- to 12-Ωm layer of clays, and 30-Ωm bedrock. Site NAT1, 200 metres from the coast, is within the coastal-plain deposits as indicated by the high-resistivity superficial layer. Bedrock was recorded at sites NAT3 and NAT4 at 43 and 35 metres below ground level, respectively. The seismic soundings at each site indicated that the top of the water table below ground level was as follows: NAT1, 2 m; NAT2, not apparent; NAT3, 5.2 m; and NAT4, 2.7 m.

7.2.3 Hydrogeology

There are potentially two exploitable aquifers within Vakadranu valley beneath the proposed borehole site. The first is within the alluvial/colluvial deposits which

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[1]where water subsides or disappears

overlie the low-resistivity clay layer. The other is a confined aquifer between this clay layer and the bedrock.

Another potential groundwater site is located on the plateau south of Vakadranu and is described in section 8.2.3.

7.2.4 Groundwater potential and borehole recommendations

The proposed borehole site, as indicated on Figure 10, is located adjacent to Vakadranu Creek, about 700 metres inland from the coast, where the alluvial plain begins to narrow. To exploit the upper aquifer the borehole would have to be drilled to a depth of about 12 metres. To reach the lower aquifer the depth would have to be about 40 metres. The lower aquifer has the potential for a greater amount of water than the upper aquifer. The decision to drill the lower aquifer should wait upon the results of drilling at valley AP2 and at Lomati. The catchment above the proposed borehole site is about 1.1 km^2 in area. This catchment area should provide a sustainable yield of about 0.82 litres per second. If only 30% of the calculated sustainable yield was available from the upper aquifer, this would supply water at a rate of 0.25 litres per second. For a population of 179 people (1986 census) this yield would provide each inhabitant of Natokalau with 119 litres of water per day. There is easy access to this site for a drill rig.

The Vakauwava cave water is fresh and could be easily exploited. This source has two drawbacks which may make it not worth pursuing. These are that the water will have to be treated to ensure that it is safe to drink, and that it runs a moderate to high risk of saltwater contamination if over exploited in the dry season. A more detailed study will be necessary in order to estimate a sustainable yield for this source.

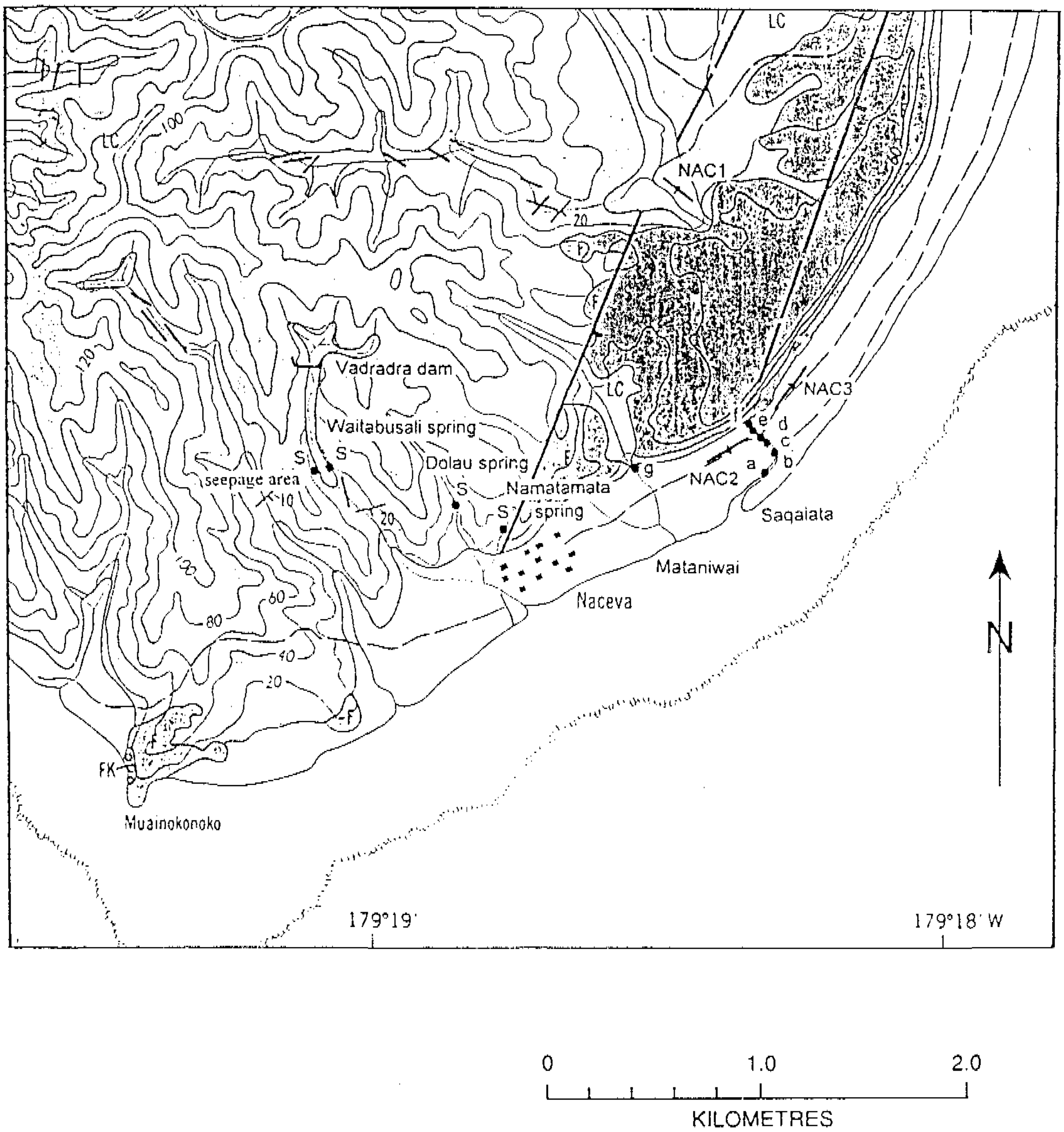
7.3 Conclusions and recommendations

7.3.1 Conclusions

Natokalau's present water supply system meets most of the villager's water needs. To help the village get through droughts, the water storage capabilities in the village can be improved. A borehole can either supplement or replace the current water supply. This borehole can also be used for the Vakadranu Estate and/or be used to supplement the water needs of the neighbouring village Naceva.

7.3.2 Recommendations

1. The existing water supply system needs to be inspected and repaired as necessary.
2. The spring-capture structure needs to be improved in order to protect the spring from surface runoff and other forms of contamination. This protection will provide a safer water source with good water quality.
3. Rainwater harvesting needs to be expanded by adding additional gutters to existing houses, and increasing the total amount of storage within the village. Currently only 13.7% of the available roof area is being used and current rainwater storage capacity is 5 m^3.
4. A borehole site has been located in the Vakadranu valley. This source is expected to have a potential yield of 0.35 l/s (150 l/p/d). Justification for a borehole can include the supplementation of the village's current water source, the revitalisation of the village economy through the estate and supplying of water to Naceva village.



LEGEND

- • S - spring
- dam
- • a - electrical conductivity measurement site
- geophysical sounding site

surface water electrical conductivities
a - 3500 μS/cm
b - 1270 μS/cm
c - 650 μS/cm
d - 521 μS/cm
e - 476 μS/cm
f - 473 μS/cm
g - 420 μS/cm

Figure 13 : Naceva location map, Cicia

8 Naceva

Naceva is the smallest village on Cicia, with 19 households and 122 people as counted during the census in 1986. During this survey (26/7/94), 121 people were counted. The village has no school and the children go to Mabula or Natokalau. It is located on the south of Cicia on a coastal plain with a high limestone cliff behind it. PWD reported that this village had ongoing water supply problems. For locations refer to Figures 13 and 14.

8.1 Present water situation

8.1.1 Water sources

Waitabusali spring Waitabusali[1] spring is located on a hillside in the second valley west of the village. The spring was developed in 1971 to supply the village with tap water. It has a concrete collection box (1.9x2m wide, 1m deep) from which water flows through a screened pipe to the tank. The electrical conductivity was measured as 490 µS/cm. Although the water level drops, the spring is said to never dry up.

Vadradra dam Vadradra dam is located up hill from Waitabusali spring, and water is piped to the same tank. The dam is fed by a spring and by seepage through *dalo* patches upstream (25 m above the dam). Between the *dalo* patch and the dam is a waterfall of several metres over volcanic bedrock. The dam was built in 1986 when Waitabusali spring did not provide a sufficient water supply. The dam is open to contamination by animals and surface runoff. Water is brownish and its electrical conductivity was 558 µS/cm.

Tank The 6500-gallon tank was built around 1986 and is at present not leaking. The tank was almost full on 26/7/94 and water flow into the tank was 0.5 l/s. This can supply 122 people with 350 litres each per day. The floater valve at the inlet closes the inlet when the tank is full.

Dolau spring Dolau spring is located near the village. Water from the spring is collected in an open square concrete box in the creek bed 10 m downstream of the actual spring. Old pipes that used to supply the village are broken and have not been repaired. Dolau spring had very little water (26/7/94) but villagers say they still use it when their tank is empty.

Namatamata spring Namatamata[2] spring is also near the village. It has a large concrete box (2x2x2 m) but the cover is broken. The pipes to the village are broken and some have been removed by the villagers. The spring was dry on 26/7/94.

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[1] sacred or forbidden water

[2] flowing

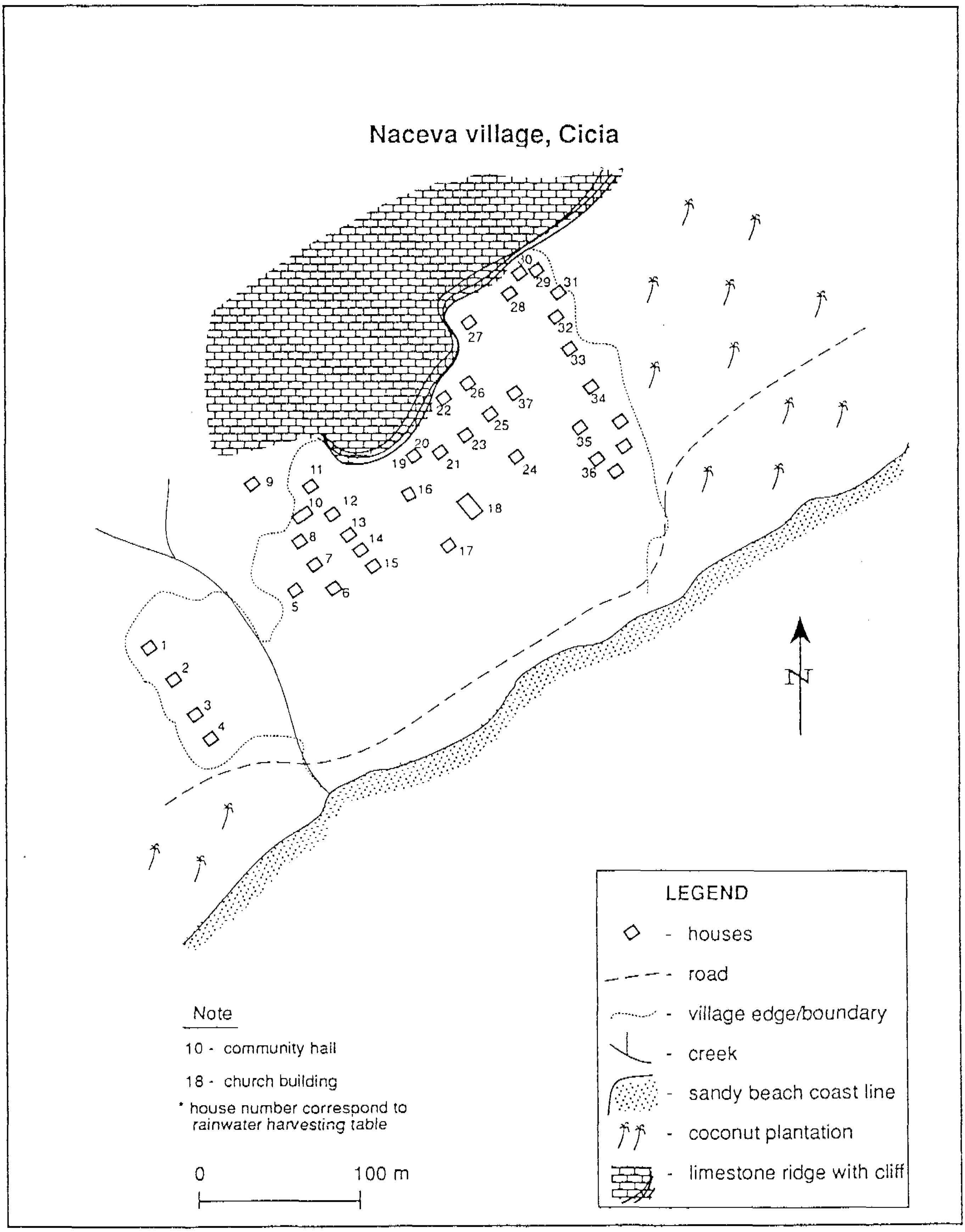

Figure 14: Naceva village map, Cicia

Taps Taps in the village are all communal standpipes except for one house with inside taps, shower and water-flush toilet. Most of the outside standpipes have some kind of construction built around them. For one toilet an old rusty galvanised iron tank was used as protection. Toilets are mainly water-sealed.

Rainwater tanks The only rainwater tank in the village is a square tank (5.5x5.5x2.5 metres) which was built at the old church. Unfortunately the church blew away during a hurricane in 1979. The area where the church was located has been turned into a playground. The villagers have built a new church 23 m away from the tank, without gutters or pipes. Gutter height would be at 3 m, which is above the top of the tank; hence the new church could provide water to the tank if pipes and gutters were fitted.

Only a few houses have gutters, and those are on the landward side of the village. It was said that the water harvested from the seaward side roofs tastes salty. A general problem mentioned was rust affecting gutters, roofs and tanks very quickly.

Rainwater harvesting Currently only 10.9% of the suitable roof area is being used for rainwater harvesting, but without the benefit of rainwater storage tanks (refer to Table 10d).

8.1.2 Water collection and use

On the day of the survey (26/7/94), the tap system was open 24 hours per day. During droughts, rationing is practised by opening the tank valves for an hour in the morning and an hour in the afternoon. The last time the village rationed the water was in December 1993. During that time they also used Dolau spring. From Dolau the people carried water in buckets to the village.

Tap water is used for all purposes. When rainwater is collected it is mainly used for cooking and drinking.

8.1.3 Biological water quality

Vadradra dam and tank water both had a count of 30 E-coli/100 ml, indicating biological contamination. During rains the water gets contaminated from surface flow entering the dam and pipes.

Waitabusali spring water was extremely contaminated at the time of the survey. The source of this contamination needs to be identified and remedial action taken.

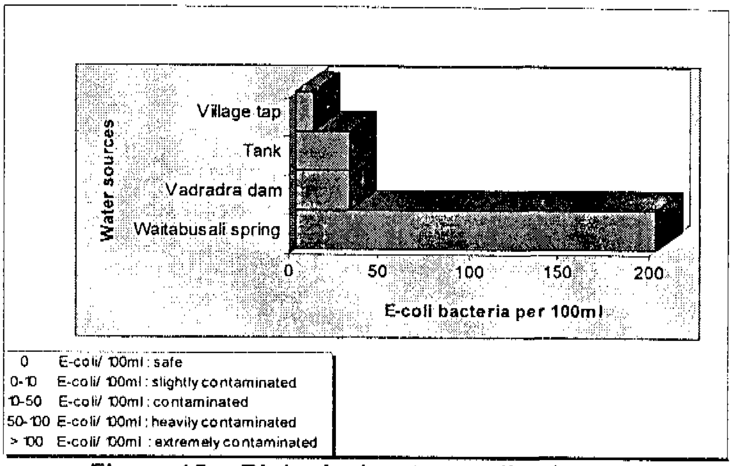

Figure 15: Biological water quality, Naceva

8.1.4 Chemical water quality

Water samples were taken from Vadradra dam, Waitabusali spring and Dolau spring for the chemical analysis for major ions (Table 6). Each of these sources contains water that is potable by chemical considerations, with ion concentrations within the WHO guidelines for safe drinking water.

8.1.5 Operation and maintenance

Water is being rationed when the tank is nearly empty.

8.2 Groundwater investigation

Naceva village does not have the very large catchment areas and alluvial plains that are associated with the other villages on Cicia. Accordingly, the groundwater investigation consisted of reconnaissance geophysical investigations in the colluvial/alluvial deposits inland from the limestone ridge and on the coastal plain, and an inspection of several spring and cave sites.

8.2.1 Site observations

Naceva village is situated on coastal deposits at the base of a limestone wall. This limestone forms a terrace that begins at the village and extends to the north, just inland from the coastal plain. The width of the coastal plain ranges from 180 to 260 metres within the vicinity of th village. Inland from the limestone terrace and to the south of the village is the weathered volcanic terrain that dominates the island's geology.

On the coastal plain north of the village are two streams, Mataniwai and Saqaiata, that flow from caves at the base of the limestone. The catchment areas that feed these streams are identifiable within the weathered volcanics behind the terraces. Butoni Creek, which drains the largest catchment area, disappears under the limestone to emerge from the cave at Saqaiata.

The coastal plain is 4.5 metres above mean sea level at about 100 m inland and 3 metres above mean sea level 200 metres inland at site NAC2. The water level at the mouth Saqaiata cave is at mean sea level. The electrical conductivity of the water at the mouth of Mataniwai was 420 µS/cm and at Saqaiata it was 473 µS/cm. This indicates that the cave water was fresh. The electrical conductivities were also measured along Saqaiata Creek and are recorded in Figure 13. The conductivity of the creek water adjacent to site NAC2 was 521 µS/cm. The Mataniwai Creek bed was dry between the cave exit and the beach.

At the time of the survey there was a minor amount of base flow within Butoni Creek in the valley at site NAC1. Weathered bedrock was noted in the creek bed upstream of site NAC1. Near the limestone terrace the creek begins to cut deeply into the weathered colluvium/alluvium before disappearing into the sinkhole/upper entrance to the Saqaiata cave system. Bedrock was not observed at this point.

There are several entrances to the cave into which Butoni Creek flows, most of which are choked with debris. Debris caught on the face limestone cliff indicates that water backs up to a depth of five to six metres. Access into the cave was obtained through an entrance on the upper left of the cliff face. After the first few metres of a tangle of limestone blocks, a solution channel opened up that was high enough to walk up right. This was followed for about 15 metres and gave no appearance of pinching out at this point.

Several seepage areas were noted in the valley that contains Vadradra dam and Waitabusali spring. The spring capture system used for Waitabusali spring is using only a small portion of the available seepage. The actual seepage area is 20 metres wide, but the existing spring box is only two metres wide.

8.2.2 Geophysical observations

One electrical resistivity and one seismic sounding were conducted within the colluvial/alluvial deposits inland of the limestone terrace. The elevation of the resistivity sounding site was about two metres higher than the creek bed on the side of an alluvial terrace, and the seismic site was about seven metres above the creek bed on the top of the terrace. The elevation of the site is about 30 metres above sea level.

The electrical sounding at site NAC1 produced a five-layer curve indicating that there is about 28 metres of colluvium/alluvium and weathered bedrock. The first 8.5 metres below ground level consists of three layers, with resistivities of 18 Ωm (1.5 m), 5 Ωm (5 m) and 40 Ωm (2 m) respectively. Beneath this is a 20 metre 4-Ωm layer, and then bedrock of 20 Ωm. The seismic sounding indicated 1.1 metres of loose topsoil and 2.6 metres of a more compact soil overlying what may be saturated colluvium/alluvium. Bedrock begins at a depth of about 13 m.

Two sets of soundings were carried out on the coastal plain north of the village, at sites NAC2 and NAC3. Site NAC2 is located about 200 metres from the coast. The electrical sounding indicated one metre of topsoil overlying 3 metres of dry sand. Beneath the dry sand is a 5-Ωm layer that corresponds to saline groundwater. The high contrast in the resistivities between the dry sand layer and the saline layer may have masked the existence of a fresh- or brackish-water lens. Surface-water conductivities along Saqaiata Creek support the possibility of at least a thin freshwater lens. The seismic sounding at this site indicates that the top of the water table is 4.4 metres below the surface. Site NAC3, about 180 m inland, has layering similar to site NAC2 but with a 13-Ωm saturated layer beginning at 3.7 metres below ground level. This higher resistivity indicates that the groundwater under this site may be less saline than that at site NAC2. As in NAC2, any lens development would be masked by the resistivity contrasts.

8.2.3 Hydrogeology

The colluvial/alluvial deposits within the lower Butoni Creek catchment are not extensive in area and are deeply incised (exposing weathered bedrock in places), which make them a poor prospect for a suitable aquifer.

Groundwater from the weathered volcanic terrain could possibly be obtained from the bedrock/weathered-bedrock interface as well as between the individual volcanic flows that make up the bedrock. A suitable area for this possible source, but not investigated with geophysics at this time, is the weathered volcanic plateau located to the north of Butoni valley (indicated on 13). The weathering here is probably very deep since there appears to have been relatively little erosion from this area. Support for the existence of an aquifer in this area is the existence of Manunu spring (see Natokalau, Section 7) to the side of the plateau.

Within the base of the limestone terrace is an aquifer that can be reached from the coastal plain through caves at Mataniwai and Saqaiata. (Access to the water table may be possible from cave entrances and sink holes on the inland side of the terrace.) The water at these two cave exits, at the time of the survey, was fresh (420 μS/cm and 474 μS/cm), indicating a possible water source. It was reported that during heavy rains water jets out of these caves at a high velocity.

8.2.4 Groundwater potential and borehole recommendations

The Waitabusali spring seepage is currently being under-used. The upgrading of this spring would increase dry-season yield, and would improve the water quality. This upgrading would require an infiltration gallery to be placed across the width of the seepage area, constructed to maximise water collection at the time of low water flow. This work can be done without disturbing the existing spring box.

There is a possibility of finding adequate groundwater within the weathered volcanic rock on the volcanic plateau located midway between Natokalau and Naceva (Vakadranu plateau). Support for the existence of an aquifer in this area is the existence of Manunu spring. This investigation should include several EM-profiles to locate the fault that crosses the plateau and the borehole should be sited to intercept this fault near sea level. If an exploratory borehole were to be drilled, it should go to the depth of sea level at about 40 metres and be completed to 6- or 8-inch diameter (borehole depth based on depth to sea level). A borehole at this location is expected to have a maximum sustainable yield of about 0.5 l/s (370 l/p/d). There is easy access to this site for a drill rig. (The authors do not know which village owns the land.)

There appears to be a large amount of fresh water being stored at the base of the limestone terrace. This water could possibly be used by the village, but it would have to be treated in order to ensure that it is safe to drink. Abstraction of this water could be problematic. The outlets at Mataniwai and Saqaiata may not be suitable for pumping due to the very high rate of discharge reported during heavy rains by the villagers. A carefully engineered water-diversion structure may solve this problem. The inlets on the interior side of the limestone terrace may not be suitable for access due to the large amount of debris and flooding involved. It may be possible to find another route to the water table by exploring some of the other caves and sink holes associated with this terrace. This water may also be abstracted from shallow wells placed on the coastal plain at the base of the limestone terrace, if placed near fractures (further investigations would be necessary).

8.3 Conclusions and recommendations

8.3.1 Conclusions

Naceva village has several options for improving their water situation. These include upgrading current spring-capture systems, increasing water storage capabilities and expanding the rainwater harvesting system. The groundwater options for this village are to use the aquifer within the limestone terrace, and to drill a borehole on the plateau north of Butoni near Vakadranu Estate. There are two potential problems with this second option. The first is that the pumping of a borehole on the plateau may effect the yield of Waitabusali spring (the current water source of Natokalau village) and the second is land ownership. The development of the limestone aquifer will need further investigations.

Waitabusali spring can be upgraded to significantly increase its yield and improve water quality. The upgrading could involve the construction of an infiltration gallery across the width of the seepage area. This gallery can be made below the existing spring box so as not to disrupt the existing supply, and still be piped to the nearby main tank. The lower collection elevation should increase the yield during times of low flow. This source has the potential for providing the village with a sufficient water supply.

8.3.2 Recommendations

1. Upgrade Waitabusali spring with an infiltration gallery, and provide necessary protective structures.
2. Once Waitabusali spring has been upgraded, the valve from Vadradra dam should be closed during times of good water flow from existing springs. The dam collects creek bed seepage and surface runoff, both are easily contaminated. Providing effective protective structures seem not practical. This source would be a good candidate for a slow sand filtration set-up for water treatment.
3. Rainwater harvesting systems should be developed. Currently only 10.9% of the available roof area is being used but current rainwater storage capacity is 0 m^3 (no permanent rainwater storage tanks were noted).
4. Increase water storage capabilities of the village.
5. Repair and protect the Dolau and Namatamata spring structures and repair the pipe line to the village.
6. Investigate the two possibilities for groundwater development:
    a. Using the limestone aquifer within the base of the limestone terrace.
    b. Drilling a borehole on the volcanic plateau located adjacent to the Vakadranu Estate. This borehole is expected to have a maximum sustainable yield of 0.5 l/s (370 l/p/d).

9 Mabula

Mabula is the largest village on the island Cicia. It is located on a coastal plain surrounded by hills. It had 46 households with 301 inhabitants during the census in 1986. At the date of the survey (27/7/94) 318 villagers were counted. Mabula has a primary school. PWD reported that this village had a good water supply. For locations refer to Figures 16 and 17.

9.1 Present water situation

9.1.1 Water sources

Eba dam Eba dam is located 2.5 km northeast of the village in Mabula East valley. The dam catches water from a creek. The actual source is in a flat valley with a *dalo* patch approximately 40 m upstream. The dam is open to contamination from human and animal activities and surface run off. Water from the dam is piped directly to the village, bypassing the existing tank. The flow rate into the dam was 0.07 l/s (27/7/94). The electrical conductivity was measured as 443 μS/cm and the pH was 7.

Delainadi dam Delainadi dam is located on a tributary of Eba Creek, about 500 m downstream from Eba dam. Water inside the dam looks brownish. The electrical conductivity was 161 μS/cm. Pipes from this dam are connected to the main pipe from Eba dam. The flow rate from Delainadi dam was not measured.

Tank The village used a tank that was built in 1978; however, due to leaks in the pipes or the tank it has been abandoned, and water is now piped directly to the taps. The women in the village think they do not have enough standpipes.

Qeleqele spring Qeleqele[1] spring is located at the head of Sosolevu[2] Creek, in the valley north of Eba Creek. The spring is protected by a concrete box (1x1x1 metres). The old pipes that used to supply the village are broken and have not been repaired.

Dulo spring Just outside the village on the northeastern side is Dulo spring. This spring was developed in 1957. The spring box is 3x3x1.5 metres and has clear water which looked clean. The electrical conductivity was 864 μS/cm. From the spring box the water is piped to a storage box at a flow rate of 0.01 l/s. Dulo spring supplies water to two taps in the village. The storage box was nearly empty during the survey. The area around the storage box was wet, and the villagers claimed that it was much wetter in the past. This reduction in moisture has been most apparent during the last five years. (The villagers think there is a relation with the pine tree plantation up hill. However, it could also be caused by low rainfall over those last years).

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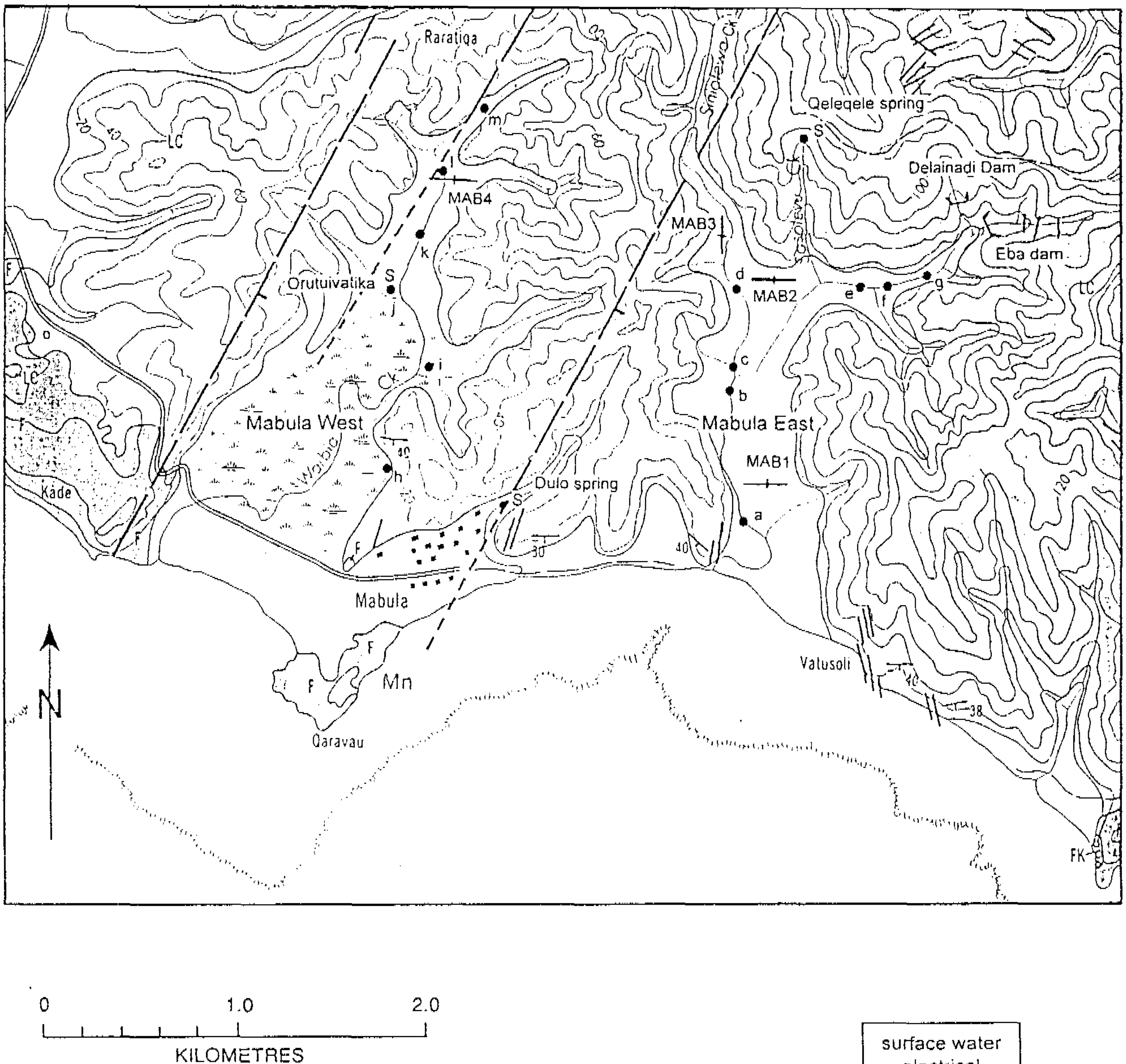
[1]soily or earthy

[2]very muddy



LEGEND

- S - spring
- a - electrical conductivity measurement site
- geophysical sounding site
- B - borehole site

surface water electrical conductivities
a - 2000 μS/cm
b - 1030 μS/cm
c - 510 μS/cm
d - 450 μS/cm
e - 1050 μS/cm
f - 538 μS/cm
g - 375 μS/cm
h - 1200 μS/cm
i - 1489 μS/cm
j - 931 μS/cm
k - 588 μS/cm
l - 750 μS/cm
m - 572 μS/cm

Figure 16 : Mabula location map, Cicia

Near the spring is a bathing pool that was dug out by the villagers. The pool water was green with algae.

Rainwater tanks Mabula has one private galvanised iron tank, several 44-gallon drums, a school tank and a PWD-constructed rainwater catchment tank up the hill behind the school. There are the remains of an old (1944 or older) church tank within the village. The present church has no tank or gutters, although the village still plans to construct those.

The school tank is a circular Humes tank (iron bound concrete slabs) and is connected to two taps (one at the school and one at a nearby house). Between the school buildings is an old square concrete tank which is not used anymore.

The tank on the hill is also a Humes tank with iron bands falling off. Tank, gutters and pipes need repair. Only four of the five houses feed the rainwater tank; two of these have gutters on both sides.

Rainwater harvesting Currently only 16.9% of the suitable roof area is being used for rainwater harvesting. The total rainwater storage capacity is 148 m^3 (32 000 UK gallons) - refer to Table 10c for details.

Sanitation All households have water-sealed toilets. For the school, the village has recently built a new toilet block with flush toilets. To supply those with water the villagers are extending the existing pipe system to the school using 6-cm PVC pipes.

9.1.2 Water collection and use

Tap water is used for all purposes. Where rainwater is available, it is primarily used for drinking and cooking.

The rainwater system serving five houses on the hill was empty on 27/7/94. The last rains had fallen in May and the tanks were empty by June. One full tank is used up in one or two months. When the tank is empty the people carry buckets up hill from the village (a distance of 200 to 400 metres). The water from the rainwater tank is preferred to the village tap water.

The pool near Dulo spring is used for bathing.

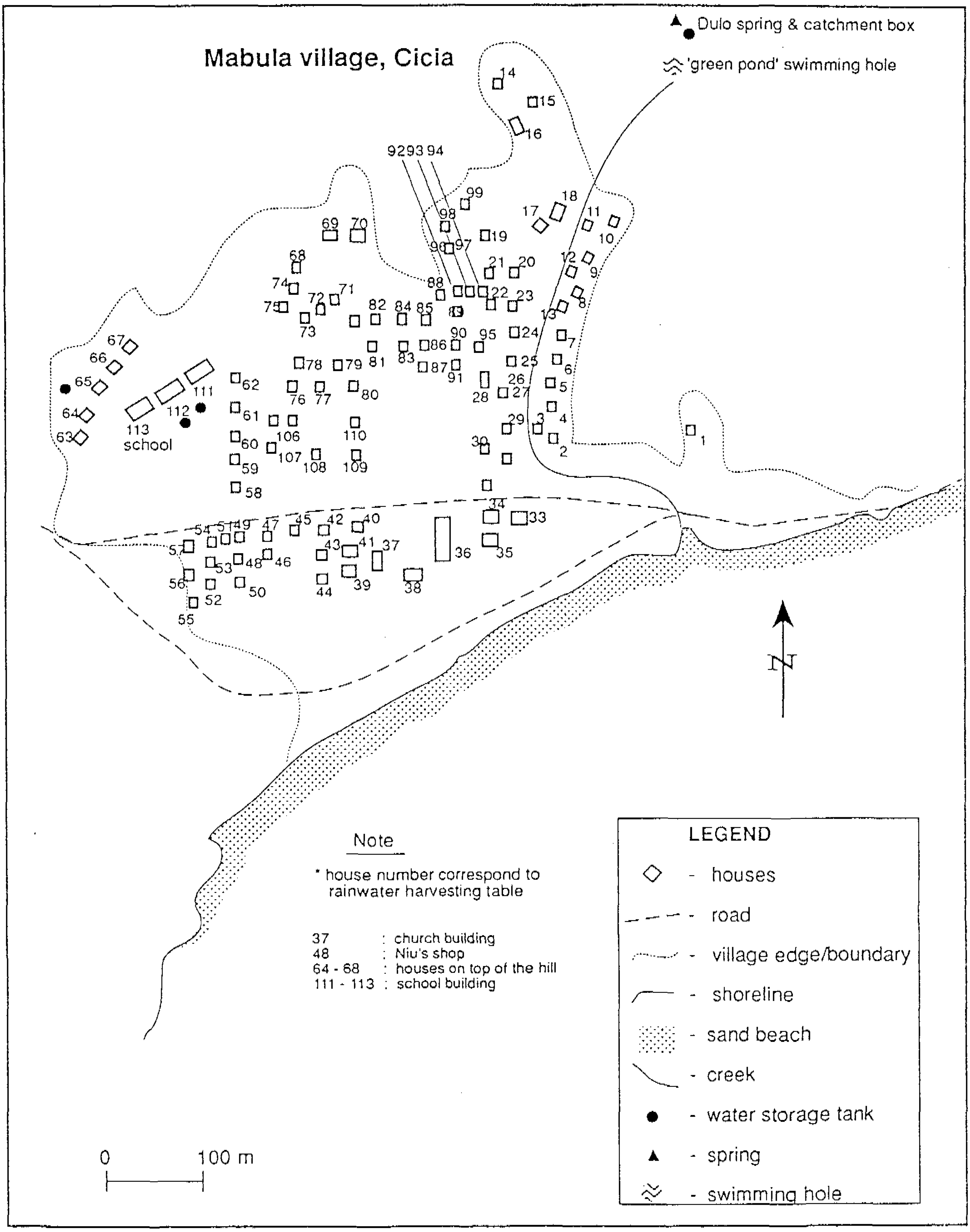


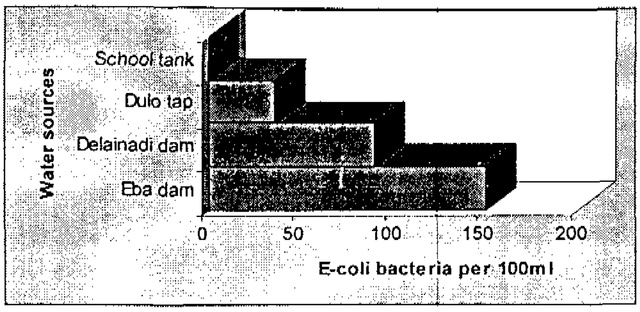
Figure 17: Mabula village map, Cicia

9.1.3 Biological water quality

The rainwater in the school tank was found to be free of E-coli bacteria and therefore safe for human consumption.

Both dams supplying the village taps were found to be grossly contaminated.

The Dulo spring water was also contaminated.



0	E-coli/ 100ml : safe
0-10	E-coli/ 100ml : slightly contaminated
10-50	E-coli/ 100ml : contaminated
50-100	E-coli/ 100ml : heavily contaminated
> 100	E-coli/ 100ml : extremely contaminated

Figure 18: Biological water quality, Mabula

9.1.4 Chemical water quality

Water samples were taken from Eba dam, Delainadi dam, Qeleqele spring, and Dulo spring for the chemical analysis for major ions (Table 6). Each of these sources contains water that is potable (chemical considerations only) with ion concentrations within the WHO guidelines for safe drinking water. The ion concentrations of the samples from Delainadi spring and Qeleqele spring are similar, as expected due to their close proximity. The ion concentrations of the sample from the nearby Eba dam are significantly different, perhaps indicating a change in lithology or degree of alteration of the rocks.

9.1.5 Operation and maintenance

The village owns and maintains the reticulation system. When asked, some women replied that the village has no money and no one to make repairs. However the villagers are building a new extension to the school toilets.

The rainwater system which was built by PWD is village owned. However, one of the women living on the hill did not know whether it was the village or the government that was responsible for maintenance. She opined that the village didn't have the money nor the materials to do anything. The last time PWD had a look at the tank was in January 1994, but she thought nothing had happened afterwards.

9.2 Groundwater investigation

The groundwater investigation for Mabula was carried out in both of the large valleys associated with this village. The large valley to the east of the village is designated as Mabula East and that to the west as Mabula West. Three sites were investigated with geophysics in the Mabula East valley and one site in the Mabula

West valley. The electrical conductivity of the surface water was also measured at various places in both valleys.

9.2.1 Site observations

Mabula East The lower section of this valley's alluvial plain experiences occasional inundation with saltwater for at least 500 m inland, due to its low elevation. Relatively high electrical conductivities were measured for surface waters for about 500 metres inland along the main drainage channel. Along the Eba tributary, up to about 100 metres beyond Sosolevu Creek the conductivities were around 1000 µS/cm, possibly indicating residual saltwater contamination of the soils. The Sinialewa Creek tributary contained fresh water with conductivities around 450 µS/cm. Surface water conductivities indicate the extent of saltwater contamination and are shown in Figure 16.

Mabula West Inland from a coastal plain 250 metres wide is a brackish-water swamp, the island's largest, which extends inland another 850 metres. Just inland from the swamp is a spring/pond similar to the one described for valley AP4. This spring, Orutuivatika, is about 3.5 metres in diameter and at least 3 metres deep (including soft mud). The electrical conductivity of this water was measured at 931 µS/cm.

9.2.2 Geophysical observations

In Mabula East, the electrical resistivity sounding at site MAB1, 300 metres inland from the coast, indicates saltwater below a depth of 3.5 metres. The depth to bedrock at this site was not determined. The electrical resistivity sounding equipment at site MAB2 apparently straddled parts of the valley with different amounts of saltwater contamination. The resulting readings were unstable and produced a non-interpretable resistivity curve. The seismic sounding at site MAB2 indicated that weathered bedrock (2875 m/s) begins at 14 metres below ground level. Neither the seismic sounding at site MAB1 nor the one at MAB2 indicated the top of the water table. Only a seismic sounding was conducted at site MAB3, and it indicates that the top of the water table is at 2.8 metres below the surface and the bedrock is at a depth of 14 metres. The velocities of the material at water table depths were low (462 to 593 m/s), suggesting material with high clay content.

The electrical resistivity sounding at site MAB4 in the valley west of Mabula indicates that there is about 9.7 metres of alluvial/colluvial deposits overlying the bedrock. The seismic sounding at this site indicates that the top of the water table is at 1.6 metres below the surface and the bedrock is at a depth of 14 metres.

9.2.3 Hydrogeology

A considerable area of the alluvial plains in both valleys shows evidence of saltwater contamination. A freshwater aquifer is expected to exist within the weathered bedrock and in the lower alluvial/colluvial deposits located in the back portions of the alluvial plains.

Mabula East There are two main tributaries that feed into the main alluvial plain: Eba Creek and Sinialewa Creek. Both catchments have areas of about 0.825 km^2. The saltwater-contaminated soils (based on surface-water electrical conductivity) of the main part of the alluvial plain extend up to Sosolevu Creek on the Eba tributary. The soils of the Sinialewa part of the alluvial plain appear to be free of this contamination. This difference in soil salinities may indicate that the sediments in the Sinialewa Creek part of the plain are more porous (allowing more flushing) than those in the Eba Creek part. The mouth of the Sinialewa tributary was chosen for a borehole site based on the surface water conductivities and size of the catchment area.

Mabula West The back part of this alluvial plain also has a potential for exploitable groundwater. The catchment above the 'safe' drilling area is about 0.6 km^2 in area. Since the groundwater potential here is not as great as for the Sinialewa borehole site, no site has been selected.

9.2.4 Groundwater potential and borehole recommendations

Mabula borehole site A borehole site was selected within the Mabula East valley at the mouth of the valley containing Sinialewa Creek where it opens onto the main alluvial plain (refer to Figure 16) The catchment above this site is 0.825 km^2 in area. This source is expected to have a maximum sustainable yield of about 0.61 l/s (175 l/p/d). The depth of the borehole should be about 15 metres and the hole should be finished to a 6- or 8-inch diameter. A minor amount of clearing may be necessary for access to this site by a drill rig.

9.3 Conclusions and recommendations

9.3.1 Conclusions

Mabula's reticulated water supply comes from two small dams. The water is piped from the source without the use of storage tanks. The present water supply is sufficient for most of the villager's needs. A small part of the village and the school are built on a hill and are not served by the present system. During this investigation the pipe line was being extended to the school. When the water demand begins to exceed the current supply, one of the first remedial actions should be to build water storage into the reticulation system. Groundwater can be developed within the Mabula East valley if the situation warrants it.

9.3.2 Recommendations

1. Repair and expand the existing rainwater harvesting system for the houses on the hill near the school.
2. Treatment of the reticulated water is recommended.
3. The rainwater harvesting system over the whole village should be expanded for water quality reasons. Currently only 16.9 % of the available roof area is being used and current rainwater storage capacity is 148 m^3.
4. Existing protective structures at Dulo and Qeleqele springs need to be improved (protection from surface water and other forms of contamination) in order to provide a safer water source.
5. When current demand increases, build water storage tanks into the present reticulation system.
6. A borehole site has been chosen in the large Mabula East valley. This source is expected to have a maximum potential yield of 0.61 l/s (175 l/p/d).

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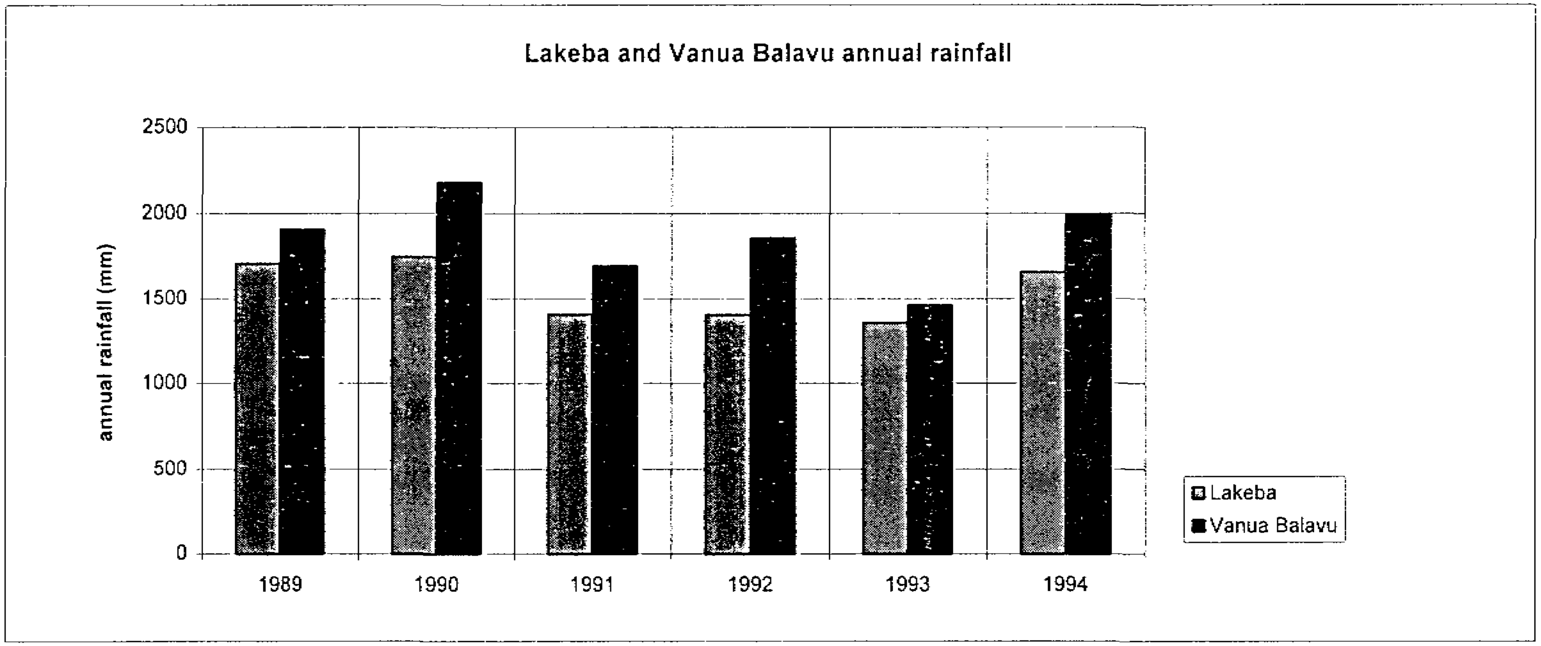
Tables

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	yearly total	
1955	110	311	242	129	315	138	47	331	222	131	447	524	2946	1955
1956	486	381	527	101	88	125	78	152	46	208	287	26	2504	1956
1957	212	329	369	416	223	119	31	129	181	21	207	287	2525	1957
1958	209	68	227	215	206	9	37	88	29	36	233	76	1432	1958
1959	310	116	202	281	220	72	53	59	138	149	51	165	1816	1959
1960	139	224	514	302	69	128	168	38	88	178	218	159	2225	1960
1961	157	350	120	255	108	138	36	75	80	76	235	477	2107	1961
average (1955-61)	*232*	*254*	*314*	*243*	*176*	*104*	*64*	*124*	*112*	*114*	*240*	*245*	*2222*	
1979	266	114	523	101	387	181	42	73	199	60	75	50	2069	1979
1980	148	74	611	315	31	53	55	162	76	375	93	126	2121	1980
1981	238	250	94	177	177	42	34	28	65	70	97	234	1505	1981
1982	306	177	242	135	246	59	33	181	150	211	109	60	1909	1982
1983	286	145	334	40	74	18	30	70	44	85	129	104	1357	1983
1984	232	168	213	346	52	101	29	56	90	17	204	67	1575	1984
1985	135	427	431	94	197	89	67	27	43	81	7	112	1709	1985
1986	120	141	247	458	85	137	49	84	41	143	3	567	2074	1986
1987	16	390	362	73	55	75	30	31	14	7	114	304	1470	1987
1988	206	185	245	220	257	47	60	64	59	113	62	193	1710	1988
average (1979-88)	*195*	*207*	*330*	*196*	*156*	*80*	*43*	*78*	*78*	*116*	*89*	*182*	*1750*	
1989	206	185	245	220	257	47	60	64	59	113	62	193	1711	1989
1990	146	177	196	44	128	230	177	133	118	91	176	136	1752	1990
1991	396	213	204	164	33	49	58	77	69	33	37	76	1409	1991
1992	158	36	206	108	21	51	63	153	62	194	62	293	1407	1992
1993	66	222	371	91	86	44	14	246	33	42	22	121	1358	1993
1994	422	148	211	127	64	124	64	18	74	7	229	173	1661	1994
average (1989-94)	*232*	*164*	*239*	*126*	*98*	*91*	*73*	*115*	*69*	*80*	*98*	*165*	*1550*	
23 year average	*216*	*210*	*301*	*192*	*147*	*90*	*57*	*102*	*86*	*106*	*137*	*197*	*1841*	

Table 1: Lakeba rainfall data



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	yearly total
1989	177	268	188	205	250	209	25	26	103	213	205	44	1912
1990	176	57	230	136	261	283	155	57	98	84	340	305	2183
1991	605	275	180	97	45	39	44	34	89	20	166	104	1698
1992	216	146	208	175	88	50	83	60	97	284	71	382	1861
1993	52	105	247	123	86	37	19	163	398	81	21	134	1465
1994	303	359	499	110	50	139	67	27	82	41	76	245	1998
6 year average	255	202	259	141	130	126	66	61	144	121	147	202	1853

Table 2: Vanua Balavu rainfall data

Potential Evapotranspiration (Thornthwaite)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T =	26.9	27.2	26.95	26.35	25.25	24.65	23.7	23.7	24.1	24.9	25.65	26.35
im =	12.5	12.7	12.5	12.1	11.3	10.9	10.3	10.3	10.6	11.1	11.6	12.1
Nm =	1.10	1.07	1.03	0.98	0.93	0.91	0.92	0.96	1.00	1.05	1.09	1.11
Em =	141.8	147.0	142.6	132.5	115.2	106.5	93.7	93.7	98.9	110.1	121.3	132.5
PE =	155.9	156.8	146.2	129.2	107.5	96.7	85.8	89.7	98.9	115.6	132.4	146.8

Water balance (Penman (1950); Lloyd, et al (1991))

P =	194.9	207.1	330	195.9	156.1	80.1	42.8	77.5	78	116.3	89.4	181.7
WD =	39.0	50.3	183.8	66.7	48.6	-16.6	-43.0	-12.2	-20.9	0.7	-43.0	34.9
CWD =	-61.3	-11.0	0.0	0.0	0.0	-16.6	-59.6	-71.9	-92.9	-92.2	-135.2	-100.3
SMD =	0.0	0.0	0.0	0.0	0.0	-16.6	-51.0	-52.2	-54.3	-53.6	-58.5	-23.7
AE =	155.9	156.8	146.2	129.2	107.5	96.7	77.1	78.7	80.1	115.6	96.4	146.8
AW =	19.3	50.3	183.8	66.7	48.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0

T = mean monthly temperature
im = monthly heat index
Nm = mean monthly daylight factors for the latitude of 18°S
Em = unadjusted evaporation
PE = potential evaporation
P = mean monthly precipitation (mm)
WD = water deficit
CWD = cumulative water deficit
SMD = soil moisture deficit
AE = actual evaporation
AW = available water

Yearly	**(mm)**
mean precipitation :	1750
potential evapotranspiration :	1462
actual evapotranspiration :	1387
available water :	369

Table 3: Water balance calculations for Lakeba

Potential Evapotranspiration (Thornthwaite)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T =	27.6	27.9	27.7	26.7	26.0	25.1	24.4	24.4	24.9	25.8	26.1	27.2
im =	13.0	13.2	13.0	12.3	11.9	11.2	10.8	10.8	11.1	11.7	11.9	12.7
Nm =	1.08	1.06	1.02	0.98	0.94	0.93	0.93	0.97	1.00	1.04	1.08	1.09
Em =	154.5	160.4	156.5	137.7	125.6	111.1	100.7	100.7	108.1	122.3	127.3	146.9
PE =	167.4	169.8	159.1	135.4	118.3	102.8	94.0	97.4	108.1	127.4	136.8	160.4

Water balance (Penman (1950); Lloyd, et al (1991))

P =	144	200	196	190	157	219	52	28	69	172	167	143
WD =	-23.4	30.2	36.9	54.6	38.7	116.2	-42.0	-69.4	-39.1	44.6	30.2	-17.4
CWD =	-116.5	-86.3	-49.4	0.0	0.0	0.0	-42.0	-111.4	-150.5	-105.8	-75.7	-93.1
SMD =	-56.7	-26.5	0.0	0.0	0.0	0.0	-42.1	-56.1	-60.0	-15.4	0.0	-54.3
AE =	146.4	169.8	159.1	135.4	118.3	102.8	94.0	42.0	72.9	127.4	136.8	197.3
AW =	0.0	0.0	10.4	54.6	38.7	116.2	0.0	0.0	0.0	0.0	14.8	0.0

T = mean monthly temperature
im = monthly heat index
Nm = mean monthly daylight factors for the latitude of 18°S
Em = unadjusted evaporation
PE = potential evaporation
P = mean monthly precipitation (mm)
WD = water deficit
CWD = cumulative water deficit
SMD = soil moisture deficit
AE = actual evaporation
AW = available water

Yearly	(mm)
mean precipitation :	1737
potential evapotranspiration :	1577
actual evapotranspiration :	1502
available water :	235

Table 4: Water balance calculations for Vanua Balavu

Date	source of sample	Faecal coliform count			Chem analysis
		Volume (ml)	count	E-coli / 100ml	sample no.
21.7.94 26.7.94	Vede raintank (Tar)	100 100	1 21	1 21	- -
21.7.94	Vede spring (Tar)	50	uncountable		TM 94/01
21.7.94	Tarakua dam (Tar)	50 100	uncountable uncountable		TM 94/03 -
21.7.94	reservoir tank (Tar)	100	uncountable		TM 94/02
21.7.94	P&T tank fiberglass (Tar)	10	1	10	-
21.7.94	hospital tank (Tar)	100	0	0	TM 94/04
26.7.94	tap water (Tar)	10 50	10 11	100 22	- -
22.7.94	Lomati dam	10 50	53 > 200	530 > 400	TM 94/05 -
22.7.94	tap water (Lom)	50	52	104	-
22.7.94	Korokalou spring (Lom)	10 50	40 > 200	400 > 400	TM 94/06 -
25.7.94	Navakauwava cave (Nat)	10 50	31 51	310 102	TM 94/07 -
25.7.94	school tank (Nat)	100	0	0	TM 94/08
25.7.94	Manunu spring (Nat)	10 50	1 0	10 0	TM 94/09 -
25.7.94 26.7.94	2 x 44 gal drums (Nat)	50 100 100	8 8 6	16 8 6	- - -
25.7.94 26.7.94	tap water (Nat)	50 100 50	7 37 3	14 37 6	- - -
25.7.94	storage tank (Nat)	10 50	0 2	0 4	- -
26.7.94	Vadradra dam (Nac)	50	15	30	TM 94/10
26.7.94	Waitabusali spring (Nac)	10 50	107 uncountable	1070	TM 94/11 -
26.7.94	Dolau pond (Nac)	-	-	-	TM 94/12
26.7.94	reservoir tank (Nac)	50	15	30	-
26.7.94	tap water (Nac)	10 50	1 3	10 6	- -
27.7.94	Dulo tap water (Mab)	10 50	7 18	70 36	TM 94/16 -
27.7.94	school tank (Mab)	50 100	0 0	0 0	- -
27.7.94	Eba dam (Mab)	10 50	15 uncountable	150	TM 94/13
27.7.94	Delainadi dam (Mab)	10 50	9 uncountable	90	TM 94/14
27.7.94	Qeleqele spring (Mab)	-	-	-	TM 94/15

Table 5a: Biological water quality test results, Cicia

National Water Quality Laboratory, Kinoya *samples taken 26/7/94*						
Location	Tap PWD Depot	Tarakua tap	Tarakua raintank	Natokalau raintank	Natokalau cave	Natokalau tap
Sample nr	B01/94	B02/94	B03/94	B04/94	B05/94	B06/94
Chlorine mg/l	-	-	-	-	-	-
total coliform/100ml	70	148	10	0	88	165
faecal coliform /100ml	**44**	**50**	**6**	**0**	**53**	**65**

Oxfam DelAgua Biokit *samples taken 26/7/94*						
Location	Tap PWD Depot	Tarakua tap	Tarakua raintank	Natokalau raintank	Natokalau cave	Natokalau tap
date	7/26/94	7/26/94	7/26/94	7/26/94	7/26/94	7/26/94
colony count	(turned yellow, no count)	10/10ml & 11/50ml	21/100ml	6/100ml	-	3/50ml
faecal coliform /100ml		**100 & 22**	**21**	**6**	-	**6**
samples taken at other date						
date			7/21/94	7/25/94	7/25/94	7/25/94
count			1/100ml	8/50ml & 8/100ml	31/10ml & 51/50ml	7/50ml & 35/100ml
faecal coliform /100ml	-	-	**1**	**16 & 8**	**310 & 102**	**14 & 35**

Samples were taken from six water sources.
They were tested with the Oxfam Del Agua Biokit as well as
at the National Water Quality Laboratory (PWD) at Kinoya
This table shows the results

Table 5b: Comparison of biological water quality results; Cicia

Ions Analysed		Tarakua				Lomati		Natokalau			WHO drinking water standard
		Vede spring	reservoir tank	Tarakua dam	hospital tank	Nawalevu dam	Korokalou sprg	Natokalau cave	school tank	Manunu spring	
Collector's number		*TM 94/01*	*TM 94/02*	*TM 94/03*	*TM 94/04*	*TM 94/05*	*TM 94/06*	*TM 94/07*	*TM 94/08*	*TM 94/09*	
Lab sample number		10989	10990	10991	10992	10993	10994	10995	10996	10997	
Cations (mg/l)	calcium (Ca)	9	18	17	7	6	4	27	4	22	-
	magnesium (Mg)	5.6	7.4	7.4	1.6	2.6	1.4	8	0.6	4.2	-
	sodium (Na)	35	27	27	9	24	50	97	7.2	32	200 (2)
	potassium (K)	1.29	0.71	0.78	0.42	0.71	0.65	2.9	0.49	2.11	-
	manganese (Mn)	0.15	0.03	0.14	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.04	0.5 (3)
	iron (Fe)	0.19	0.02	0.03	0.05	0.88	0.12	< 0.02	< 0.02	< 0.02	0.3 (4) /1-3 (2)
Anions (mg/l)	bicarbonate (HC	74	113	115	29	39	105	146	17	110	-
	sulphate (SO4)	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	21	< 0.04	< 0.04	500 (5)
	chloride (Cl)	52	30	30	13	36	34	145	10	40	250 (2)
conductivity (µs)		-	240	242	-	152	-	688/690	81	358	-
TDS (mg/l)	Evap. 180	204	382	210	58	146	240	442	34	218	-
	sum ions	177	196	197.35	60.07	109	195	447	39.29	210	1000 (2)
Total hardness CaCO3		45.52	75	73	24	26	16	100	12.46	72	500 (2)
pH		7.4	6.6	7.5	7.5	7.2	7.3	7.1	7.5	7.1	6.5 - 9.0 (1)
Ionic Balance		3.85%	0.05%	1.36%	2.53%	0.98%	3.23%	4.70%	1.23%	0.71%	-

Ions Analysed		Naceva			Mabula				Valley AP3		WHO drinking water standard
		Vadradra dam	aitabusali spr	Dolau pond	Eba dam	Delainadi dam	Qeleqele sprin	Dulo spring	AP3-1	AP3-2	
Collector's number		*TM 94/10*	*TM 94/11*	*TM 94/12*	*TM 94/13*	*TM 94/14*	*TM 94/15*	*TM 94/16*	*TM 94/17*	*TM 94/18*	
Lab sample number		10998	10999	11000	11001	11002	11003	11004	11005	11006	
Cations (mg/l)	calcium (Ca)	31	5	19	37	8	9	68	80	47	
	magnesium (Mg)	18	2.2	10	18	3.6	3	50	50	20	-
	sodium (Na)	79	105	71	42	29	31	58	98	60	200 (2)
	potassium (K)	0.67	1.12	1.1	1.1	0.68	0.88	1.43	0.8	0.68	-
	manganese (Mn)	0.13	< 0.02	0.03	0.04	0.19	0.02	< 0.02	1.51	0.14	0.5 (3)
	iron (Fe)	0.02	< 0.02	0.07	< 0.02	0.02	< 0.02	< 0.02	1.37	< 0.02	0.3 (4) /1-3 (2)
Anions (mg/l)	bicarbonate (HC	307	241	202	224	85	102	323	561	217	-
	sulphate (SO4)	< 0.04	1.64	4.11	< 0.04	2.46	1.64	< 0.04	7.81	3.29	500 (5)
	chloride (Cl)	54	48	67	36	26	18	115	140	109	250 (2)
conductivity (µs)		558	490	488	443	161	204	-	-	-	-
TDS (mg/l)	Evap. 180	402	380	334	318	192	204	500	1402	385	-
	sum ions	490	404	374	387	155	166	594	940	457	1000 (2)
Total hardness CaCO3		152	22	89	166	35	35	323	406	199	500 (2)
pH		7.8	7.6	7.4	8.3	7.8	7.3	7.5	6.3	7.3	6.5 - 9.0 (1)
Ionic Balance		0.54%	3.02%	3.88%	4.34%	4.71%	3.43%	2.73%	3.07%	0.58%	-

TDS : Total Dissolve Solids

pH : Lab measurement

(1) = optimum range but there is no guideline

(2) = taste susceptibility

(3) = health guideline

(4) = stains laundry

(5) = health recommendation

Table 6: Chemical Analysis of water samples; Cicia

Electrical resistivity interpretations		
site	resistivity (ohm.m)	thickness (m)
TAR1	9	0.5
	35	6
	14	40
	200	
TAR2	12.5	1
	9	3
	6	4
AP2-1	400	0.25
	480	2.5
	60	7
	3	
AP2-2	7	0.9
	400	20
	10 - 40	
AP2-3		
upper layers were un-interpretable		
lower layers in the 5 to 15 ohm.m range		
AP2-4	10	0.4
	6	10
	15	
AP3-1		
un-interpretable results		
AP3-2	8	1
	3.1	3
	20	
AP3-3	12	0.5
	7	5
	25	
LOM1	10	1
	5	1.5
	2	20
	200	
LOM2	4.5	0.9
	1.8	9
	10	
LOM3	33	1.4
	12	35
	30	

Electrical resistivity interpretations		
site	resistivity (ohm.m)	thickness (m)
NAT1	500	0.5
	900	1.7
	40	8
	12	
NAT2	10	1
	5	1.5
	40	8
	6	
NAT3	13	1
	10	0.5
	30	12
	5	30
	30	
NAT4	12	0.5
	8	0.5
	12	8
	5	16
	30	
NAC1	18	1.5
	5	5
	40	2
	4	20
NAC2	110	1
	20	
	1350	3
	5	
NAC3	110	0.7
	1700	3
	13	
MAB1	4	1
	9	2.5
	1.8	
MAB2		
un-interpretable results		
MAB3	6	0.3
	4.2	2
	10	10
	20	

Table 7: Electrical resistivity interpretations; Cicia

Seismic Soundings		
site	velocity (m/s)	thickness (m)
TAR1	406	1.8
	626	14
	1889	
TAR2	68	0.4
	224	2.6
	1869	11
	4364	
AP2-1	287	2
	1260	4
	1783	
AP2-2	397	4.6
	1580	14
	3500	
AP2-3	323	4.6
	1875	15
	3500	
AP2-4	73	0.41
	376	2.26
	1444	6.9
	2169	
AP3		
no seismic soundings performed		
LOM1	150	0.67
	400	2.75
	716	11.47
	1050	
LOM2	55.6	0.35
	379.3	2.7
	621.2	15.7
	2821.4	
LOM3	45.5	0.6
	608.7	11.2
	2821	

Seismic Soundings		
site	velocity (m/s)	thickness (m)
NAT1	333	
	1536	15*
NAT2	133	1.8
	1263	5
	1724	12.5*
	3500**	
NAT3	294	5.2
	2000	12.7
	3500**	
NAT4	43	0.4
	313	2.3
	1818	13.9*
	3500	
NAC1	183.3	1.12
	648.6	2.56
	1180.9	
NAC2	65.2	0.15
	666.7	3.16
	972.2	9.42
	3750	
NAC3	200	0.86
	555.6	3.5
	1886.8	
MAB1	100	1.24
	462	3.94
	1067	
MAB2	87	1
	593	12.9
	2875	
MAB3	80	0.54
	725	2.31
	1643	11.27
	3583	

* minimum thickness, based on assumed bedrock velocity and finnal shot distence

** *assumed bedrock velocity, based on sounding NAT-4*

Table 8: Seismic sounding interpretations; Cicia

SITE: AP3-1	
Depth	*Lithological Description*
0 - 0.7	stiff brown sandy (gritty) clay, brown clay with some sand, gravel and occasional charcoal
0.7	struck water; electric conductivity of water - 1225 µS
0.7 - 0.9	stiff grey brown sandy clay
1.09	electric conductivity of water - 1480 µS
1.1 - 1.5	grey brown sandy clay
1.5	grey brown sandy clay with large weathered rock fragments
1.5 - 2.8	grey brown sandy clay
2.8-4.2	blue grey clay with orange mottling (slightly sandy)
4.2	END

SITE: AP3-3	
Depth (m)	Lithological description
0.0 - 0.1	brown clay top soil
0.1 - 1.0	weathered colluvium of white, orange, red, yellow, green, particles of silts & clays with brown clay matrix
1.0 - 1.7	weathered gravel and rock fragments
1.7 - 1.8	black carbonaceous clay, no sand
1.8	struck water; electric conductivity of water - 650 µS
1.8 - 2.0	black carbonaceous
2.0	END OF HOLE

SITE: AP 3-4	
Depth (m)	Lithological Description
0 - 1.5	brown clay silt
1.5	struck water; electric conductivity of water - 738 µS
1.5 - 2.0	brown clay silt
2.0	END OF HOLE

Figure 9: Auger-hole profiles, Valley AP3, Cicia

population:	133		
total roof area:	4995 m ²	100	%
roof area with gutters and tank:	1427 m ²	28.6	%
roof area with gutters only:	629 m ²	12.6	%
tank volume:	17750 UKgallo	80.7	m ³
storage capacity per person:	607 litres		

This table presents the details of the buildings in Tarakua village. Only buildings with galvanised iron roofs are considered for roof catchment systems presented in total roof area. The details provided are roof dimensions, length of gutters, volume of tanks, and population. The buildings are categorised as "buildings without gutters", "buildings with gutters but without permanent storage" and "buildings with gutters and storage tanks". The survey was coducted on 21/7/94.

Buildings with gutters and storage tanks

No.	occu	type	use	length	width	area	gutters(m)	tank (UK gallon)	
1	10	G	H	7.5	5.5	41.3	7.5	850	
3	5	G	H	11.0	5.4	59.4	16.5	1400	2 tanks
4	-	G	PO	8.3	6.5	54.0	16.6	1400	2 tanks
5	1	G	PO	8.5	8.5	72.3	17.0	1300	2 tanks
6	-	G	H	7.0	5.0	35.0	14.0	700	half roof collects
7	2	G	H	7.0	5.0	35.0	7.0	700	
12	5	G	H	10.4	6.7	69.7	10.4	800	
15	3	G	H	11.0	11.5	126.5	-	1500	no gutters
22	-	G	C	24.5	11.8	289.1	12.3	8000	not used
48	-	G	H	5.4	5.9	31.9	10.8	1500	
"		"	"	10.0	7.2	72.0	10.0		
59	3	G	H	11.3	7.8	88.1	22.6	1300	
62	4	G	HS	14.5	7.0	101.5	29.0	1500	2 tanks
63	1	G	HS	13.0	7.0	91.0	26.0	2000	2 tanks
64	-	G	HS	19.0	6.5	123.5	38.0	1150	2 tanks
		G	"	4.0	3.3	13.2		350	
76	3	G	H	14.5	8.5	123.3	9.0	1300	
total	37			187		1427	247	17750	

Buildings with gutters but no storage tanks

No.	occu	type	use	length	width	area	gutters(m)	
9	8	G	H	9.7	8.3	80.5	9.7	
18	7	G	H	14.5	8.5	123.3	14.5	
23	5	G	H	10.0	5.0	50.0	1.5	
54	-	G	S	30.0	12.5	375.0	30.0	+broken tank
65	4	G	H	7.5	9.0		5	
total	24			72		629	61	

Buildings without gutters and storage tanks

No.	occu	type	use	length	width	area
2	2	G	H	5.9	5.5	32.5
8	-	G	K	5.8	4.6	26.7
10	2	G	H	7.5	5.5	41.3
11	-	G	K	4.9	4.3	21.1
13	-	G	K	6.5	5.0	32.5
14	1	G	H	6.9	7.1	49.0
16	-	G	H	11.0	7.5	82.5
17	-	G	O	7.8	5.5	42.9
19	-	G	H	7.5	5.5	41.3
20	-	G	K	6.0	4.0	24.0
21	-	G	O	8.0	7.0	56.0
24	-	G	H	7.5	5.5	41.3
25	-	G	H	7.5	5.5	41.3
26	3	G	H	7.5	5.5	41.3
27	-	G	H	8.0	7.0	56.0
28	5	G	H	10.2	7.5	76.5
29	-	G	K	8.0	7.5	60.0
30	6	G	K	7.0	5.0	35.0
31	-	G	H	9.5	6.5	61.8
32	-	G	H	7.5	5.5	41.3
33	3	G	H	6.5	6.5	42.3
34	-	G	H	7.5	5.5	41.3
35	-	G	O	5.3	5.0	26.5
36	7	G	H	9.5	8.8	83.6
37	-	G	O	5.0	5.5	27.5
38	-	G	H	12.3	12.5	153.8
39	-	G	H	9.5	5.0	47.5
40	-	G	H	8.0	8.8	70.4
total	29			214		1397

Buildings without gutters and storage tanks

No.	occu	type	use	length	width	area
41	-	G	K	9.0	8.0	72.0
42	6	G	H	8.0	5.0	40.0
43	-	G	K	5.5	4.0	22.0
44	3	G	H	7.5	5.5	41.3
45	-	G	K	5.5	4.0	22.0
46	3	G	H	8.0	6.0	48.0
47	-	G	K	7.7	5.7	43.9
49	6	G	H	7.5	5.5	41.3
50	-	G	H	10.1	6.2	62.6
51	1	G	H	7.5	5.5	41.3
52	-	G	S	7.0	5.0	35.0
53	-	G	S	10.0	6.2	62.0
55	3	G	S	8.0	5.7	45.6
56	-	G	S	8.0	6.0	48.0
57	-	G	S	8.0	5.7	45.6
58	-	G	S	8.0	5.7	45.6
60	-	G	H	8.0	5.5	44.0
61	-	G	K	9.5	5.0	47.5
66	1	G	H	7.0	7.0	49.0
67	6	G	H	11.0	9.5	104.5
68	-	G	H	8.0	7.0	56.0
69	-	G	H	14.0	9.0	126.0
70	4	G	H	16.0	9.5	152.0
71	-	G	H	7.0	7.0	49.0
72	-	G	H	7.5	5.5	41.3
73	-	G	H	7.5	7.5	56.3
74	-	G	H	8.0	9.0	72.0
75	10	G	H	5.0	6.0	30.0
total	43			91		1543.6

No. : building number (see Fig 3a)
occu : number of occupants
type : Galvanised iron roof
Thatched roof
use : House Post Office
Kitchen HoSpital
School Other
Church
area : flat roof area (length x width)

Table 10a: Rainwater harvesting; Tarakua, Cicia

population:	283			
total roof area:	5478	2	100	%
roof area with gutters and tank:	577	2	10.5	%
roof area with gutters only:	441	2	8.0	%
tank volume:	1450	UKgallon	6.6	m 3
storage capacity per person:	23	litres		

This table presents the details of the buildings in Lomati village. Only buildings with galvanised iron roofs are considered for roof catchment systems presented in total roof area. The details provided are roof dimensions, length of gutters, volume of tanks, and population. The buildings are categorised as "buildings without gutters", "buildings with gutters but without permanent storage" and "buildings with gutters and storage tanks". The survey was coducted on 22/7/94.

Buildings with gutters and storage tanks

No.	occu	type	use	length	width	area	gutters(m)	tank (UK gallon)	
76	-	G	C	-	-	235.0	32.0	-	not used
91	3	G	H	15.5	19.2	297.6	14.9	900	
93	3	G	H	8.0	5.5	44.0	4.0	550	
total	6			24		577	51	1450	

Buildings with gutters but no storage tanks

No.	occu	type	use	length	width	area	gutters(m)
1	3	G	H	10.0	6.6	66.0	1.8
2	-	G	K	4.3	3.0	12.9	1.2
16	-	G	K	6.8	4.9	33.3	2.0
17	-	G	O	4.0	2.5	10.0	1.0
28	-	G	K	5.0	4.2	21.0	2.0
35	-	G	K	6.2	3.4	21.1	12.4
37	-	G	K	5.0	4.0	20.0	1.0
42	-	G	K	5.0	3.5	17.5	5.0
48	-	G	O	6.7	6.7	44.9	3.0
54	4	G	H	8.0	8.0	64.0	6.0
77	2	G	H	5.0	6.0	30.0	5.0
78	1	G	H	5.3	8.7	46.1	5.3
81	-	G	K	6.0	4.8	28.8	1.0
95	-	G	H	5.0	5.0	25.0	5.8
total	10			82		441	53

No. : building number (see Fig 3b)
occu : number of occupants
type : Galvanised iron roof
Thatched roof
use : House Post Office
Kitchen Health Station
School Other
Church
area : flat roof area (length x width)

Buildings without gutters and storage tanks

No.	occu	type	use	length	width	area
3	5	G	H&K	12.0	5.5	66.0
4	8	G	H&K	11.8	10.0	118.0
5	3	G	H	8.0	5.5	44.0
6	-	G	K	3.5	2.0	7.0
7	5	G	H	8.0	5.5	44.0
8	3	G	H	5.7	5.0	28.5
9	-	G	K	5.7	4.7	26.8
10	4	G	H	9.5	6.0	57.0
11	-	G	K	4.7	4.5	21.2
12	1	G	H	7.5	5.0	37.5
13	5	G	H	8.0	5.5	44.0
14	-	G	O	8.0	5.5	44.0
15	7	G	H	8.0	9.0	72.0
18	-	G	H	4.7	3.5	16.5
19	4	G	H	4.5	4.5	20.3
20	-	G	K	3.0	2.5	7.5
21	5	G	H	8.0	5.5	44.0
22	2	G	H	8.0	5.5	44.0
23	6	G	H	8.0	8.0	64.0
24	4	G	H	8.0	8.0	64.0
25	3	G	H	8.0	8.0	64.0
26	6	G	H	10.0	6.5	65.0
27	4	G	H	10.0	6.5	65.0
29	2	G	H	8.0	5.5	44.0
30	-	G	K	4.5	4.0	18.0
31	2	G	H	8.0	5.5	44.0
32	5	G	H	8.0	5.5	44.0
33	-	G	K	4.5	3.7	16.7
34	5	G	H	4.0	5.2	20.8
36	5	G	H	8.0	5.5	44.0
38	3	G	H	8.0	5.5	44.0
39	-	G	H	7.5	4.9	36.8
40	-	G	H	10.0	6.5	65.0
41	1	G	H	10.0	8.5	85.0
43	4	G	H	8.0	8.0	64.0
44	-	G	H	8.0	5.5	44.0
45	-	G	H	8.0	8.0	64.0
46	5	G	H	8.0	5.5	44.0
47	5	G	H	5.2	5.5	28.6
49	6	G	H	8.0	6.0	48.0
50	2	G	H	8.0	8.0	64.0
51	4	G	H	8.0	8.0	64.0
52	-	G	K	6.0	4.0	24.0
53	5	G	H	8.0	5.5	44.0
55	-	G	K	6.5	4.8	31.2
56	4	G	H	10.0	6.5	65.0
57	5	G	H	8.0	6.2	49.6
total	138			353		2161

Buildings without gutters and storage tanks

No.	occu	type	use	length	width	area
58	5	G	H	5.6	5.5	30.8
59	-	G	K	4.0	4.0	16.0
60	3	G	H	9.5	9.0	85.5
61	4	G	H	10.0	6.0	60.0
62	-	G	K	7.0	6.0	42.0
63	4	G	H	8.0	5.5	44.0
64	7	G	H	10.0	6.5	65.0
65	8	G	H	5.5	4.6	25.3
66	-	G	O	13.0	10.0	130.0
67	-	G	O	5.8	5.8	33.6
68	7	G	H	10.0	10.0	100.0
69	-	G	K	6.0	5.0	30.0
70	3	G	H	8.0	5.5	44.0
71	3	G	H	8.0	5.5	44.0
72	5	G	H	8.0	5.5	44.0
73	8	G	H	8.0	5.5	44.0
74	1	G	H	4.3	4.8	20.6
75	6	G	H	4.2	4.1	17.2
79	-	G	K	5.0	3.4	17.0
80	8	G	H	7.6	5.2	39.5
82	-	G	H	7.6	5.2	39.5
83	-	G	K	6.0	4.8	28.8
84	4	G	H	7.6	5.2	39.5
85	-	G	K	6.0	4.8	28.8
86	-	G	S	11.0	6.3	69.3
87	-	G	S	9.7	9.0	87.3
88	-	G	S	22.0	10.0	220.0
89	-	G	S	9.7	9.0	87.3
90	-	G	H	8.0	5.5	44.0
92	2	G	H	8.0	8.0	64.0
94	3	G	H	8.0	8.0	64.0
96	1	G	H	8.0	5.5	44.0
97	3	G	H	4.0	6.0	24.0
98	5	G	H	4.0	6.0	24.0
99	6	G	H	6.0	6.0	36.0
100	1	G	H	5.0	4.0	20.0
101	1	G	H	8.0	5.5	44.0
102	4	G	H	10.0	6.5	65.0
103	4	G	H	9.8	5.2	51.0
104	3	G	H	10.0	6.5	65.0
105	5	G	H	10.0	6.5	65.0
106	6	G	H	6.0	6.0	36.0
107	5	G	H	8.0	5.5	44.0
108	4	G	H	8.0	5.5	44.0
109	-	G	H	6.0	5.5	33.0
total	129			354		2300

Table 10b: Rainwater harvesting; Lomati, Cicia

population:	148		
total roof area:	1760 m^2	100	%
roof area with gutters and tank:	241 m^2	13.7	%
roof area with gutters only:	95 m^2	5.4	%
tank volume:	1100 UKgallon	5	m^3
storage capacity per person:	34 litres		

This table presents the details of the buildings in Natokalau village. Only buildings with galvanised iron roofs are considered for roof catchment systems presented in total roof area. The details provided are roof dimensions, length of gutters, volume of tanks, and population. The buildings are categorised as "buildings without gutters", "buildings with gutters but without permanent storage" and "buildings with gutters and storage tanks". The survey was coducted on 25/7/94.

Buildings with gutters and storage tanks

No.	occu	type	use	length	width	area	gutters(m)	tank (UK gallon)	
10	-	G	H	8.0	8.0	64.0	5.0	100	2drums
50	-	G	S	19.9	8.9	177.1	9.8	1000	fiberglass
total	0			28		241	15	1100	

Buildings with gutters but no storage tanks

No.	occu	type	use	length	width	area	gutters(m)
6	-	G	H	8.0	5.8	46.4	1.0
31	5	G	H	6.6	7.3	48.2	4.9
total	5			15		95	6

No. : building number (see Fig 3c)
occu : number of occupants
type : Galvanised iron roof
Thatched roof
use : House Post Office
Kitchen Health Station
School Other
Church
area : flat roof area (length x width)

Buildings without gutters and storage tanks

No.	occu	type	use	length	width	area
1	1	G	H	8.0	6.0	48.0
2	6	G	H	5.5	7.2	39.6
3	4	G	H	8.0	6.0	48.0
4	3	G	H	8.0	6.0	48.0
5	4	G	H	5.5	7.0	38.5
7	-	G	K	4.5	7.5	33.8
8	5	G	H	8.0	8.5	68.0
9	13	G	H	5.5	6.1	33.6
11	6	G	H	8.0	5.0	40.0
12	-	G	K	4.7	4.2	19.7
13	1	G	H	4.7	5.5	25.9
14	-	G	H	8.0	8.5	68.0
15	7	G	H	8.0	5.5	44.0
16	5	G	H	8.0	5.5	44.0
17	4	G	H	6.7	7.0	46.9
18	-	G	H	6.0	6.0	36.0
19	-	G	H	8.0	6.0	48.0
20	-	G	H	8.0	6.7	53.6
21	5	G	H	8.0	5.5	44.0
22	7	G	H	8.0	6.0	48.0
23	4	G	H	5.1	6.3	32.1
24	-	G	H	8.0	5.5	44.0
25	5	G	H	8.0	5.5	44.0
26	3	G	H	11.2	10.5	118
27	3	G	H	9.9	11.6	115
total	86			181		1228

Buildings without gutters and storage tanks

No.	occu	type	use	length	width	area
28	3	G	H	8.0	6.3	50.4
29	-	G	O	5.8	8.4	48.7
30	-	G	K	4.9	6.2	30.4
32	4	G	H	8.0	6.0	48.0
33	4	G	H	8.0	5.5	44.0
34	2	G	H	8.0	6.0	48.0
35	5	G	H	8.0	6.0	48.0
36	4	G	H	8.0	5.5	44.0
37	-	G	H	8.0	5.5	44.0
38	-	G	H	7.5	7.9	59.3
39	6	G	H	8.0	5.5	44.0
40	5	G	H	8.0	6.0	48.0
41	2	G	H	8.0	5.5	44.0
42	5	G	H	8.0	6.0	48.0
43	3	G	H	8.0	6.0	48.0
44	4	G	H	8.0	5.5	44.0
45	-	G	C	15.8	11.4	180.1
46	4	G	H	4.1	5.5	22.6
47	-	G	H	8.3	7.7	63.9
48	3	G	H	4.0	5.4	21.6
49	-	G	S	11.5	6.4	73.6
51	-	G	S	7.4	5.3	39.2
52	-	G	H	7.6	5.5	41.8
53	3	G	H	7.6	5.5	41.8
54	-	G	H	7.6	5.5	41.8
total	57			196		196

Table10c: Rainwater harvesting; Natokalau, Cicia

population:	121		
total roof area:	1950 m^2	100	%
roof area with gutters and tank:	0 m^2	0	%
roof area with gutters only:	213 m^2	10.9	%
tank volume:	0 UKgallon	0	m^3
storage capacity per person:	0 litres		

This table presents the details of the buildings in Naceva village. Only buildings with galvanised iron roofs are considered for roof catchment systems presented in total roof area. The details provided are roof dimensions, length of gutters, volume of tanks, and population. The buildings are categorised as "buildings without gutters", "buildings with gutters but without permanent storage" and "buildings with storage tanks but no gutters". The survey was coducted on 26/7/94.

Buildings with storage tanks but no gutters

No.	occu	type	use	length	width	area	gutters(m)	tank (UK gallon)	
18	-	G	C	22.5	12.5	281.3	-	16500	empty
total	0			23		281	0	0	

Buildings with gutters but no storage tanks

No.	occu	type	use	length	width	area	gutters(m)
13	1	G	H	8.0	5.5	44.0	3.5
22	9	G	H	4.8	7.8	37.4	4.0
27	3	G	H	8.0	5.5	44.0	8.0
33	6	G	H	8.0	5.5	44.0	3.0
34	3	G	H	8.0	5.5	44.0	3.0
total	22			37		213	22

Buildings without gutters and storage tanks

No.	occu	type	use	length	width	area
1	-	G	-	8.3	5.8	48.1
2	8	G	H	8.0	5.5	44.0
3	4	G	H	8.0	5.5	44.0
4	-	G	O	4.8	5.6	26.9
5	3	G	H	8.0	5.5	44.0
6	7	G	H	8.0	5.5	44.0
7	6	G	H	8.0	8.7	69.6
8	6	G	H	8.0	5.5	44.0
9	-	G	H	8.0	5.5	44.0
10	-	G	H	13.5	7.0	94.5
11	-	G	K	7.5	4.5	33.8
12	3	G	H	8.0	5.5	44.0
14	4	G	H	8.0	5.5	44.0
15	3	G	H	8.0	5.5	44.0
16	4	G	H	14.6	12.2	178.12
17	3	G	H	8.0	5.5	44.0
19	7	G	H	6.9	3.8	26.2
20	-	G	K	3.1	3.0	9.3
21	5	G	H	8.0	5.5	44.0
23	9	G	H	8.0	5.5	44.0
24	1	G	H	8.0	5.5	44.0
25	6	G	H	8.0	5.5	44.0
26	-	G	H	8.0	5.5	44.0
28	-	G	H	8.0	5.5	44.0
29	2	G	H	8.0	5.5	44.0
30	6	G	H	5.0	5.5	27.5
31	-	G	K	5.3	4.3	22.8
32	-	G	H	8.0	5.5	44.0
35	-	G	H	9.1	5.5	50.1
36	6	G	H	6.5	5.0	32.5
37	6	G	H	8.0	5.5	44.0
total	99			139		1455

No. : building number (see Fig 3d)
occu : number of occupants
type : Galvanised iron roof
Thatched roof
use : House, Post Office, Kitchen, Health Station, School, Other, Church
area : flat roof area (length x width)

Table 10d: Rainwater harvesting; Naceva, Cicia

population:	318			
total roof area:	6730	m^2	100	%
roof area with gutters and tank:	1134	m^2	16.9	%
roof area with gutters only:	762	m^2	11.3	%
tank volume:	32620	UKgallon	148	m^3
storage capacity per person:	466	litres		

This table presents the details of the buildings in Mabula village. Only buildings with galvanised iron roofs are considered for roof catchment systems presented in total roof area. The details provided are roof dimensions, length of gutters, volume of tanks, and population. The buildings are categorised as "buildings without gutters", "buildings with gutters but without permanent storage" and "buildings with gutters and storage tanks". The survey was coducted on 27/7/94.

Buildings with gutters and storage tanks

No.	occu	type	use	length	width	area	gutters(m)	tank (UK gallon)	
58	5	G	H	8.2	5.8	47.6	8.2	400	
64	2	G	H	8.2	5.8	47.6	8.2	12000	leaking
65	-	G	H	8.0	11.8	94.4	16.0		same tank as 64
66	5	G	H	8.2	5.8	47.6	9.2		same tank as 64
67	4	G	H	8.2	5.8	47.6	16.4		same tank as 64
68	3	G	H	13.5	8.4	113.4	9.0	44	
69	5	G	H	8.2	5.8	47.6	2.5	44	
99	4	G	H	7.6	9.6	73.0	15.9	132	
114	-	G	S	18.0	9.3	167.4	30.0	3000	not used
115	-	G	S	27.7	10.2	282.5	48.5	20000	
116	-	G	S	18.0	9.2	165.6	18.4		same tank as 115
total	28			134		1134	182	32620	

Buildings with gutters but no storage tanks

No.	occu	type	use	length	width	area	gutters(m)
5	-	G	K	5.0	4.6	23.0	3.0
6	5	G	H	8.2	5.8	47.6	8.2
8	2	G	H	8.2	5.8	47.6	4.1
24	6	G	H	19.4	12.5	242.5	10.0
38	6	G	H	8.2	11.2	91.8	1.0
54	5	G	H	8.2	5.8	47.6	1.0
76	5	G	H	8.2	5.8	47.6	4.1
81	3	G	H	6.3	5.9	37.2	2.0
85	4	G	H	8.2	5.8	47.6	10.3
93	4	G	H	5.0	7.0	35.0	3.3
95	6	G	H	8.2	5.8	47.6	8.2
103	5	G	H	8.2	5.8	47.6	8.2
total	51			101		762	63

No. : building number (see Fig 3e)
occu : number of occupants
type : Galvanised iron roof
Thatched roof
use : House Post Office
Kitchen Health Station
School Other
Church
area : flat roof area (length x width)

Buildings without gutters and storage tanks

No.	occu	type	use	length	width	area
1	-	G	H	8.0	5.5	44.0
2	3	G	H	10.4	6.5	67.6
3	3	G	H	8.2	5.8	47.6
4	3	G	H	8.2	5.8	47.6
7	-	G	H	8.2	5.8	47.6
9	5	G	H	8.2	5.8	47.6
10	3	G	H	8.2	5.8	47.6
11	-	G	K	8.3	3.7	30.7
12	4	T	H	6.0	6.0	36.0
13	3	G	H	4.8	5.0	24.0
14	5	G	H	8.2	5.8	47.6
15	1	G	H	8.2	5.8	47.6
16	5	T	H	6.0	6.0	36.0
17	-	G	O	7.0	5.0	35.0
18	-	G	K	7.2	4.2	30.2
19	3	G	H	5.7	5.8	33.1
20	-	G	K	10.9	5.5	60.0
21	4	G	H	8.2	5.8	47.6
22	3	G	H	8.2	5.8	47.6
23	2	G	H	8.2	5.8	47.6
25	3	G	H	5.6	6.5	36.4
26	4	G	H	8.2	5.8	47.6
27	2	G	H	8.2	5.8	47.6
28	-	G	O	5.5	4.5	24.8
29	3	G	H	5.9	6.2	36.6
30	3	G	H	8.2	5.8	47.6
31	3	G	H	8.2	5.8	47.6
32	4	T	H	5.3	5.2	27.6
33	-	G	K	5.9	4.2	24.8
34	5	G	H	5.3	5.2	27.6
35	-	G	K	4.6	4.9	22.5
36	4	G	H	5.6	6.0	33.6
37	-	G	C	28.6	23.0	657.8
39	-	T	H	6.1	6.0	36.6
40	6	G	H	11.6	5.7	66.1
41	-	G	H	6.3	5.7	35.9
42	3	G	H	8.2	5.8	47.6
43	3	G	H	9.4	5.5	51.7
44	3	G	H	8.2	5.8	47.6
45	-	G	H	8.2	5.8	47.6
46	5	G	H	8.2	5.8	47.6
47	6	G	H	8.2	5.8	47.6
48	-	G	O	8.3	5.3	44.0
49	2	G	H	8.2	5.8	47.6
50	-	G	K	4.7	4.2	19.7
51	-	G	H	10.0	10.5	105.0
52	-	G	O	8.2	5.8	47.6
total	106			375		2509.8

Buildings without gutters and storage tanks

No.	occu	type	use	length	width	area
53	5	G	H	8.2	5.8	47.6
55	4	G	H	8.0	5.8	46.4
56	5	G	H	8.2	5.8	47.6
57	4	G	H	4.5	4.5	20.3
59	1	G	H	7.6	5.8	44.1
60	5	G	H	7.6	5.8	44.1
61	5	G	H	7.6	5.8	44.1
62	-	G	H	7.6	5.8	44.1
63	5	G	H	7.6	5.8	44.1
70	-	G	H	8.2	5.8	47.6
71	-	G	H	8.2	5.8	47.6
72	3	G	H	8.2	5.8	47.6
73	5	G	H	8.2	7.8	64.0
74	-	G	H	5.9	4.9	28.9
75	-	G	H	8.2	5.8	47.6
77	7	G	H	8.2	5.8	47.6
78	5	G	H	8.2	5.8	47.6
79	7	G	H	8.2	5.8	47.6
80	4	G	H	8.2	5.8	47.6
82	6	G	H	8.2	9.0	73.8
83	4	G	H	8.2	5.8	47.6
84	1	G	H	8.2	5.8	47.6
86	5	G	H	8.2	5.8	47.6
87	5	G	H	8.2	5.8	47.6
88	2	G	H	8.2	5.8	47.6
89	1	G	H	13.1	7.8	102.18
90	1	G	H	8.2	5.8	47.6
91	-	G	H	8.2	5.8	47.6
92	-	G	H	8.2	5.8	47.6
94	2	G	H	8.2	5.8	47.6
96	5	G	H	8.2	5.8	47.6
98	2	G	H	9.8	6.4	62.7
97	2	G	H	8.2	5.8	47.6
100	4	G	H	8.2	5.8	47.6
101	6	G	H	8.2	5.8	47.6
102	-	G	K	6.0	5.1	30.6
104	4	G	H	8.2	5.8	47.6
105	2	G	H	6.4	6.0	38.4
106	1	G	H	15.9	10.4	165.4
107	2	G	H	6.4	10.6	67.8
108	4	G	H	8.2	5.8	47.6
109	1	G	H	5.9	5.7	33.6
110	3	G	H	8.2	5.8	47.6
111	5	G	H	8.5	5.1	43.4
112	-	G	S	9.5	5.3	50.4
113	-	G	S	9.0	4.3	38.7
total	133			133		2323.4

Table 10e: Rainwater harvesting; Mabula, Cicia

site	population 1986 census	type of source	catchment area sq km	est. sustainable yield available water = 235 (mm) cu m/d	l/s	l/p/d	well characteristics depth (m)	lithology
valley AP1	-	infiltr. gallery	0.65	41.9	0.48	-	-	coastal
valley AP2	204	borehole	0.85	54.7	0.63	268	15	allu./coll.
valley AP3 *	-	borehole	0.53	34.1	0.39	-	-	allu./coll.
valley AP4	-	infiltr. gallery	0.225	14.5	0.17	-	-	coastal
Lomati (LOM1)	252	borehole	5.8	373	4.32	1480	30	allu./coll.
Lomati (LOM2)	252	borehole	5.8	373	4.32	1480	25	allu./coll.
Vakadranu (shallow) **	179	borehole	1.1	21.24	0.25	119	12	allu./coll.
Vakadranu (deep)	179	borehole	1.1	70.8	0.82	396	40	allu./coll.
Plateaux	122	borehole	0.7	45.1	0.52	370	40	volcanic
Mabula East	301	borehole	0.8	51.5	0.6	171	15	allu./coll.
Tarakua dam ***	204	stream/spring	0.35	22.5	0.26	110	-	volcanic

* sustainable yield calculation for valley AP3, not a borehole recommendation.
** sustainable yield estimated at 30 % of the valley's potential
*** Existing water source of Tarakua village, most of this water is lost due to leakage.
(estimated sustainable yield for groundwater flow from above dam site.)

cu m/d: volume of water in cubic metres per day
l/s: maximum pump rate (continuous) in litres per second
l/p/d: litres per person per day based on 1986 census populations

lithology:
coastal - carbonate sands and gravels
allu./coll. - alluvium and colluvium of clay, sand and gravel. (May involve drilling into weathered bedrock.)
volcanic - weathered and unweathered volcanic rock

Table 11: Borehole summary, Cicia

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