# ASSESSMENT OF WATER RESOURCES MANONO ISLAND, SAMOA

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# SUMMARY

The work described in this report is the outcome of a request from the Samoa Water Authority (letter dated 24 of July 1997) to SOPAC to carry out an assessment of the water resources on Manono Island, Samoa (Appendix 1).

Manono Island supports approximately 1130 people in six major settlements - Faleu, Lepuia'i, Apai, Satilagi, Salua, Satoi - all located near the coast. Presently, the islanders water consumption relies on rainwater stored in household and a few community tanks. At Salua, Faleu, Lepuai'i and Apai the water supply is backed-up by non-potable water from shallow wells. A reticulation system installed in 1975 and fed by an undersea pipeline from Upolu is entirely out of operation although several attempts have been made to rehabilitate it. The present study recommends that the water supply of Manono Island should rely on rainwater catchments and storage tanks. Groundwater may be used as a backup system, however further investigations are required.

Rainfall on Manono Island is about 2500 mm a year. A roof catchment inventory shows that Manono Island has not yet fully developed its rainwater resource. Simply extending contributing roof size areas can make major improvements to the water situation at low costs. In the long term, both storage capacity and contributing roof sizes should be increased to reach a storage capacity of $3 m^3$/capita and a matching roof area of $3\ m^2/m^3$ storage. This would provide a safe water supply of ~30 l/c/d (less than 1% shortfall) under the presumptions expressed in the report that a ratio of $6\ m^2/m^3$ would provide 50 l/c/d (less than 1% shortfall).

The groundwater assessment based on resistivity tests suggests the existence of a freshwater lens close to mean sea level. However, the interpretation of the resistivity tests is not straightforward and allows a 3-layer or 4-layer model for the underground structure. If an exploitable groundwater body is confirmed by drilling, the groundwater resource could be used as a supplement to the roof catchment water supply. Existing contaminated wells could then be closed.

# ACKNOWLEDGEMENTS

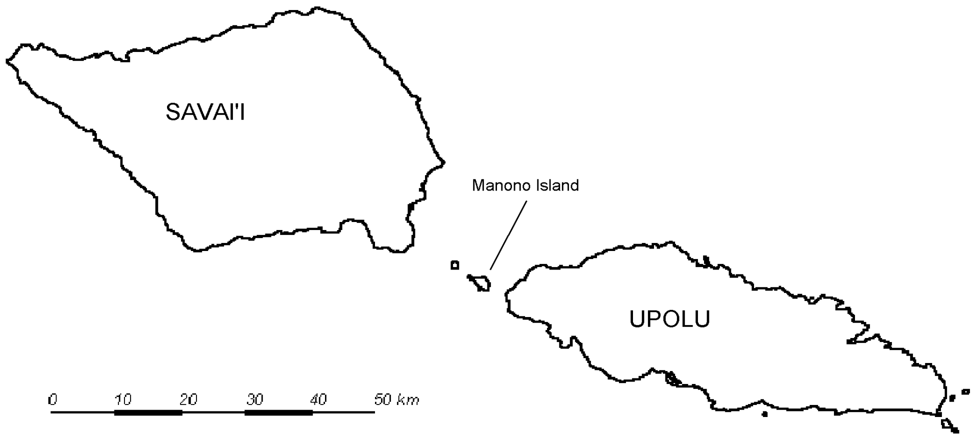
Major funding contributors to this study were the United Nations Development Programme (UNDP) and the Government of Samoa through the Samoa Water Authority (SWA).

Special acknowledgement has to be made to Samuel Samuel from the SWA and Faaftia Brown from the Apia Observatory for their dedicated contribution to this study during the fieldwork.

# INTRODUCTION AND OBJECTIVE

This study was undertaken in Samoa on behalf of the Director, Samoa Water Authority over the period 19 August to 27 August 1997. It included briefings, discussions, meetings carried out in Apia and field investigations on Manono Island.

The objective of this study was the assessment of water resources for further development of the water supply system on Manono Island (see Figure 21). The terms of reference (TOR)
for this study have been included as Appendix 1. All work was carried out as part of the regular work program of the SOPAC Water Resource Unit.




Manono Island

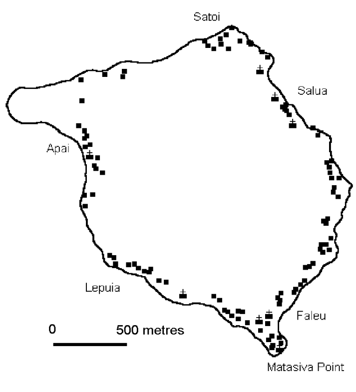



Figure 1: General location of Manono Island, Samoa

# BACKGROUND

## General

Samoa (former Western Samoa) is located between 13-15 °S and 168-173° W. Samoa consists of two large islands, Upolu and Savai'i, and several small islands. Total land area is about 2934 sq km. The capital, Apia, is on the island of Upolu as are the centre of commerce, trade and industry, the main seaport and the main airport.

The south and southeast windward coasts receive from 5000 mm to 7000 mm of rain annually. The leeward sides receive from 2000 mm to 3000 mm and the long-term average annual rainfall for Apia is 3072 mm (Pacific Islands Yearbook, 1994). Evapotranspiration at the coast is estimated by Kear & Wood (1959) to be 1600 mm. The dry season is considered to be from May to September, when relatively little rain falls.

Samoa is almost wholly composed of basic volcanic rocks (olivine basalt, picrite basalt, olivine dolerite of the alkali basalt suite) Some offshore islands are composed of marine volcanic tuff. The volcanic origins of Samoa have resulted in a terrain with abundant streams and waterfalls. However, the western part of Upolu and large parts of northeast Savai'i lack any surface water due to the highly permeable Mulifanua Volcanic rocks of the more recent eruptions. Hence, sub-surface and groundwater are the most common source of water supply in these areas.

Manono Island is situated between the two main islands west of Upolu and southeast of Savai'i at about 13º 50' S and 172º 07' W. It is located inside the reef at a distance 3.8 km from Upolu (Appendix 2). The total land area is approximately 2.94 sq. km and the total population of Manono Island is approximately 1130 (1986 last available census). Manono has a central volcanic peak rising, approximately 100 metres above sea level. The northern part of the island is relatively steep compared with the southern part (Figure 2).

Figure 2: View of Manono Island looking west from Upolu

The existing water supply relies entirely on rainwater. During dry periods, mainly from June to December the islanders face severe water problems if there are extended periods without any rain (longest recorded period without rain was 38 days, Rofe et al. 1996). In the last 20 years several attempts have been made to provide a safe water supply for Manono Island through a submarine pipeline from Upolu. The maintenance and operation of this scheme has proven very difficult with the result that the SWA decided to have the water resources on Manono Island investigated before making any decision for further development.

## Previous work on the Geology and Hydrogeology in Samoa

The New Zealand Geological Survey completed the first investigation on the geology and hydrogeology of Samoa (Kear and Wood, 1959). The report includes two geological maps and two hydrogeological maps of the country. Black and white copies of the geological maps are attached to this report as Appendix 2.

According to Kear and Wood (1959), the Samoa Islands are composed almost wholly of basic volcanic rocks, which are divided into six formations on the basis of weathering and erosion criteria. The oldest formation (Fagaloa Volcanic Rocks) erupted in the Pliocene, while the last eruptions of Aopo Volcanic Rocks took place in 1911. The geological map done by Kear and Wood (1959) is still the only document available on the geology of Samoa. The geological maps are reported in Appendix 2. Manono Island is formed entirely by Mulifanua Volcanic Rocks. This young volcanic formation (dated Last Glaciation) consists of more or less vesicular basalt interbedded with aa flows. The surface topography is often controlled by uneroded flows. Basalt boulders are common at the surface, but normally the weathering process has developed a thin layer of soil and weathered rock.

Subsequently, a review of the hydrogeology and water supply of Samoa was carried out (Kear, Kammer and Brands, 1979). However, no additional regional geological surveys have been undertaken. The results of these later hydrogeological investigations, which included results from drilling and a review of available methods to investigate groundwater occurrence, gave a good source of background information.

In 1979, some geophysical investigations to integrate and to correlate available data obtained from the drilling project were carried out (Risk, 1979). Resistivity and magnetic measurements as well as magnetic measurements were made on different volcanic units and provide useful suggestions for further geophysical investigations were provided.

## General features of the Manono Island supply area

Generally, it can be stated that Manono Island has a subsistence economy with a little trade of traditional goods such as mats, handicrafts and fish for cash income generation. A significant number of Manono people work on the main islands and provide island families with cash. In regards to the water demand this suggests relatively high fluctuations in the demand between working days and weekends.

In recent years Manono was provided with a diesel generator, run by the Samoa Power Authority, and a grid serves the whole island. The generator delivers electricity 6 hours a day from 18.00 – 24.00 and the electricity is metered for all households. Since electrification, the need for cash became more pressing due to electric bills and the purchase of electric devices such as television, stereos etc. Nevertheless, it can be assumed that the islanders could contribute to the rehabilitation of Manono’s water supply system. This could be either by being charged for consumption in case of a reticulation system, or by contributing to the improvement of the roof catchments.

The 1986 census recorded that 1130 persons inhabit the island. There is neither significant livestock on the island nor commercial consumers, to increase the freshwater demand.

Nearly all lower lying parts of the island are densely planted and extensively used for subsistence such crops as coconut trees, different types of bananas, kasava etc. The more steeper central and northern parts are covered with bush. It is assumed that a shifting cultivation practice is used, which could be a significant factor if land was required for a groundwater supply system.

The villages of Manono Island - Faleu, Lepuai'i, Apai, Satilagi, Salua, Satoi - are located close to the shoreline. Nearly all houses are located within 100 m of the shoreline and do not generally extend to levels more than 10 m above sea level. Only near Satoi some houses are up to 20 m above sea level, while a school near Matasiva Point is situated at about 25 m above mean sea level. This means that the supply area could be relatively easily supplied by a reticulation system and would consist of only one pressure zone.

## History of the Manono Island water supply system and previous work

Since around 1975 Manono Island had been served by a 50 mm ring main around the island, which was supplied from a service reservoir of 125 $m^3$ capacity near Satoi, at the eastern part of the island (Cameron, 1987). The reservoir is made of local rocks embedded in concrete and has a floor level at 30 m above sea level. An 80 mm diameter undersea pipeline fed the reservoir from Upolu which integrated the Manono system into the West Coast Coastal Supply System of the SWA. This coastal supply system receives water from boreholes at Faleolo, Upolu, in the north, and from boreholes inland of Samatau in the south. A check-valve on Manono was designed to prevent water from leaking back to the main island system.

From the very beginning the system never performed according to expectations. Insufficient water reached the island because of supply and pressure limitations. The inability to fill the storage tank led to frustrated villagers destroying the 50 mm diameter ring-pipeline.

Understandably, due to the poor performance several attempts were made to improve the supply system. The first step was made in 1985 with the design of a booster-pump system on Manono. This system was designed to boost incoming water from the undersea pipeline from its location close to the Manono Hospital clockwise through the new 100 mm diameter PVC ring-pipeline on the island and fill the 125 $m^3$ storage tank.

When New Zealand aid funds became available the proposed booster-pump system was revised and, instead, a new pump on the main land was installed due to the following reservations about the booster-pump scheme.

- It was expected that the maintenance of a pump on Manono would cause major problems.
- In the event of a submarine pipeline failure the supply would be contaminated with saltwater.
- By delivering the water to the reservoir on Manono for distribution the cost of the reticulation on the island could be reduced compared to the booster-pump system.

However, a new 100 mm diameter PVC ring-pipeline was laid on Manono and a pump was installed on Upolu in 1985. The system failed due to leaks in the submarine pipeline caused by the high hydraulic head (46 m) and only part of the planned 5 l/s flow rate found its way to the island storage tank. Efforts to detect the leaks were fruitless and a second pump on Manono was built to deliver water to the storage tank. A satisfactory solution to the low flow rate was never found and the performance of the system was very poor and costly. In the meantime the water supply of Manono relied entirely on rainfall stored in household reservoirs and a few brackish water wells near the coast.

In 1990 a feasibility study (Works Consultancy Service, 1990) was carried out to consider the rehabilitation of the water supply system. The study concluded that the most economic solution was as follows.

- Construction of a new service reservoir supplied by the existing Samatau pump on Upolu.
- Construction of a new 100 mm diameter pipe from the reservoir to the coast near Manonouta (at the southwest of Upolu).
- Construction of a new 150 mm diameter Polyethylene undersea pipeline to Manono Island.
- Rehabilitation of the existing water mains on Manono Island and on mainland Upolu.
- Installation of full domestic water metering in all villages from Faleolo to Samatau and on Manono Island. A water tariff of 25 sene[1] (US$ 0.11) per cubic metre was recommended.

[1] This corresponds to the price of one Electricity Unit 1 kW

The capital cost of the proposal was estimated to be WST 1.13 Million or US$ 500,000 at 1990 prices, with an annual operating cost of WST 122,000 (US$ 54,000). If no metering was to be introduced a 150 mm pipeline should replace the 100 mm pipeline to the reservoir at an estimated WST 1.35 Million (US$ 600,000) capital cost and WST 16,200 (US$ 7,200) operating cost per year.

No funding source has yet been found to implement this proposed water supply scheme.

## Present status of the Manono Island water supply system

The present demand of drinking water is almost totally covered by rainwater stored in household tanks. People supplement their water demand by taking water from shallow wells where available. This water is not potable. The status of the roof catchments and storage tanks as well as the shallow wells are described below.

The 100 mm diameter PVC ring-pipeline, which was installed in 1985, is definitely out of operation. It is partially dismantled by the islanders and used for other purposes (gutters, discharge pipes etc). The northern part of the island is entirely stripped of the pipeline. In many other parts of the island the exposed pipes are broken or weakened by exposure to sunlight. It is assumed that the pipeline can’t be rehabilitated. The status of the 80 mm diameter undersea pipeline is unknown. But deducing from previous studies (Work Consultancy Service, 1990 and Niyazaki et al, 1986) and considering that no maintenance has been undertaken it is considered a fair assumption that it also needs to be replaced. The 125 $m^3$ storage tank is stripped of its fittings. The cover has been removed and the tank is partially overgrown. Nevertheless, it is believed that the reservoir could be brought back in operation if necessary.

Under normal conditions stored rainwater meets the demand for potable water. However, during the dry season people frequently run out of rainwater and are forced to use shallow well water for drinking purposes. Apart from the health risks of using contaminated water people are compelled to walk great distances with heavy bucket loads (La Roche, 1991).

# FIELD METHODS AND DATA ACQUISITION

## General

The process to assess the water resources for the further development of the water supply on Manono included an initial desk study, followed by fieldwork during the period 19 - 27 August 1997, and finally the analysis of the data collected and compilation of this report.

During the desk study available documents (see references), topographical and geological maps and aerial photographs were examined and led to different options for the future water supply. (It should be noted that the Works Consultancy Service had already carried out a comprehensive feasibility study for a new reticulation system as a possible option in 1990.) Taking into consideration economic factors the desk study suggested three options for the further development of the water supply on Manono:

- Development through increased use groundwater.
- Further development of roof rainwater catchments.
- A combination of these options.

The subsequent field trip provided the opportunity to gather background information or data (e.g. rainfall registers) from different organisations involved in water supply systems such as the SWA, the Apia Observatory (Meteorological Service and Hydrologic Service) and the Land and Environment Department.

During the field trip the groundwater resource on Manono was investigated through geophysical methods (resistivity tests) and is described below.

Roof rainwater catchments are well known in Manono and suggestions have been already made for their further development (La Roche, 1991). However, a comprehensive analysis of the roof catchments had not been undertaken. Therefore the work program for the field trip included an inventory of the status of the roof catchments on Manono as well as the analysis of available rainfall data to assess the resource.

Water quality tests in near shore shallow wells were undertaken, both to analyse the water quality with regard to its use as drinking water and water conductivity to determine influence of the nearby salt interface. All tests were carried out with a DELAGUA standard field testing kit. Bacteriological quality testing is referred to a 100 ml sample.

## Aerial Photographs

A series of aerial photographs taken in 1970 were found at the Department of Land and Survey. Unfortunately the quality did not allow an accurate 3D analysis with the stereoscope. A regional structure oriented about E-W can be observed, which is similar to orientations observed in basalt rock outcrops on Manono Island. There is not enough data to advance the hypothesis that water circulation is mainly driven by fractures.

In front of Apai beach, the aerial photos provide evidence of the presence of beachrock which forms at the coincidence of fresh water/salt water mixing, where Eh/pH equilibrium changes allows the precipitation of calcium carbonate.

## Rainfall

Rainfall data is not recorded on Manono Island. Daily rainfall data was retrieved as hard copy for relatively close hydrologic stations at Salelologa on Savai'i from 22 March 1996 to 16 June 1997, for Samatau on Upolu from 1 January 1996 to 30 June 1997 and for Faleolo Airport as monthly rainfall data from January 1982 until July 1995. Hourly rainfall data for Faleolo was made available for 1985 and 1986. No additional data could be found.

It was expected that this rainfall data could be correlated since all three stations are located on the dry side of Samoa and within a distance within of 20 km. However, the correlation analysis between Salelologa and Samatau, taking into account about 300 records, shows that the correlation coefficient is less than $r_c = 0.2$ and therefore not correlated. In this context it must be mentioned that, at least in parts, the data retrieved from the Apia Observatory is questionable, i.e. when it comes to records for the 30$^{th}$ and 31$^{st}$ of February in 1997 for the stations in Samatau and Salelologa. The double check for Faleolo Airport between the monthly data and the hourly data showed inconsistencies for the monthly averages. A possible explanation might be that Faleolo has two stations and hence two record-sheets although differences up to 80 % between two stations at the same location are hard to explain.

However, Rofe et al (1996) suggest that Manono receives an annual average rainfall between 2500 mm and 3000 mm and total evapotranspiration can amount to 1600 mm (according to information from the New Zealand Meteorological Service). These values match the rainfall data obtained for Faleolo Airport where geographical patterns are similar. For this report it is therefore assumed that the Faleolo station represents the average rainfall on Manono.

## Groundwater Assessment

A first phase of data collection was undertaken before carrying out the field survey on Manono. All regional information available was collected to allow correlation between fieldwork carried out on the main island and the geological and morphological features of Manono. A copy of the field report made by Apia Observatory on drilling and water pumping in four boreholes (Samatau 1, Samatau 2, Faleolo Terminal and Tausagi) was used to acquire more information about groundwater occurrence in Mulifanua volcanic rocks (Apia Observatory 1977a, 1977b, 1982a and 1982b).

In the field, water table measurements of water temperature and conductivity in coastal springs together with resistivity soundings were carried out in order to assess groundwater resources.

### Geophysics survey

Seven electrical resistivity soundings were carried out on Manono Island with the aim to test the presence of a freshwater aquifer and to determine its thickness and the depth of the saltwater interface.

The location of these seven soundings is shown in Figure 3.

Electrical resistivity soundings are based on the concept that an induced electrical current circulating in the ground can be measured at the outlet and referred to the resistivity of the rocks encountered.

Since the presence of water (salted or fresh) causes a variation in the resistivity of a rock, these methods are well suited to detect the presence of a saturated zone. Saltwater and freshwater also have different values of resistivity, but, because of some limitations in resistivity methodology itself and the mixing caused by tidal oscillation, the interface between freshwater and saltwater is not easily detectable.

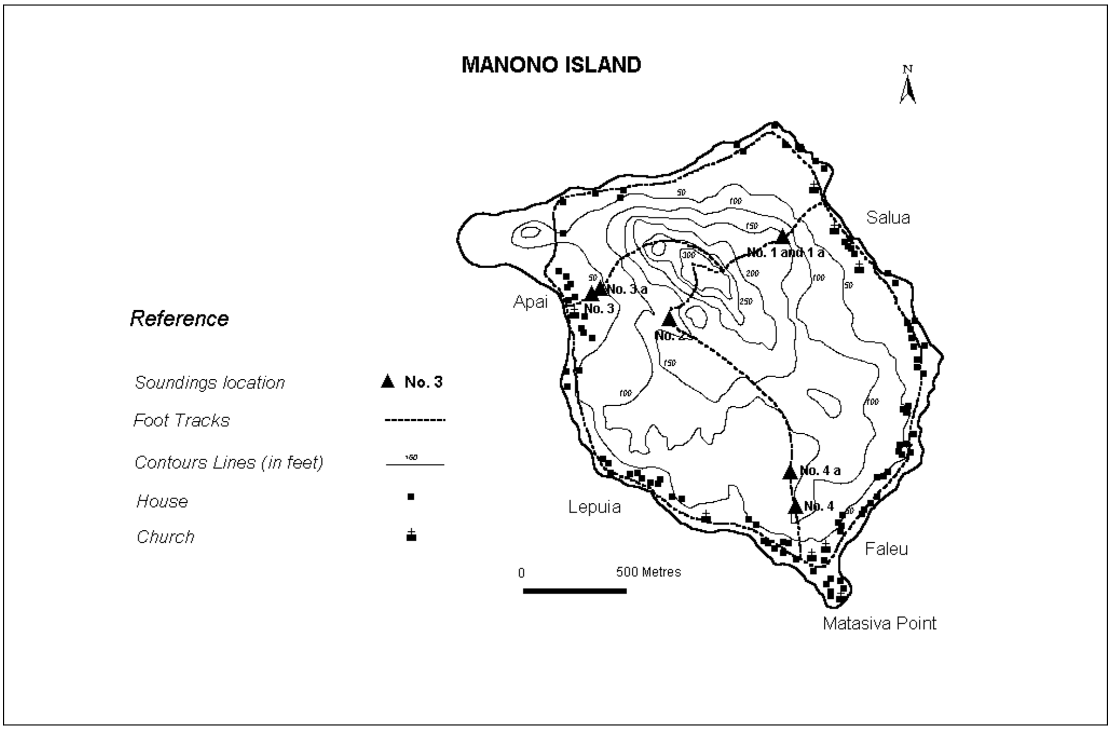



Figure 3: Location of electrical soundings

An ABEM Terrameter SAS 300 was used which consists of a basic unit, which can be supplemented as desired with the SAS 2000 Booster. Rechargeable Ni-Cd batteries gave the power supply. Steel spikes were used both as current electrodes A-B and potential electrodes M-N. Cables connect each electrode to the main unit. During the field survey, ground resistivity measurement were made using the Schlumberger array. It consists of four co-linear symmetrically arranged electrodes A-M-N-B placed as shown in the next figure.

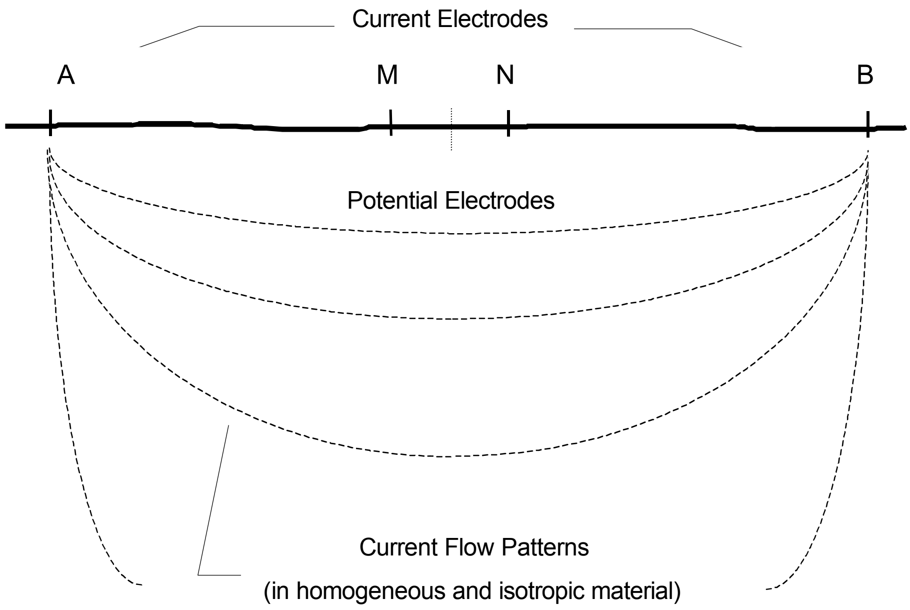



Figure 4: Schlumberger electrode array. AB distance ≥ 5MN distance

A current I is passed into the ground through electrodes A and B causing a potential ΔV between electrodes M and N. Knowing the potential ΔV, the current I and K (a geometric factors depending by electrode arrangement) resistivity ρ can be calculated as:

$$\rho = K \frac{\Delta V}{I}$$

If the measurement of ρ is made over a semi-infinite space of homogeneous and isotropic material, then the value of ρ computed from the equation above will be the true resistivity of that material. However, if the medium is not homogeneous and (or) anisotropic (as common under field conditions) then the resistivity computed is called an apparent resistivity $\rho_a$.

The apparent resistivity $\rho_a$ is a function of several variables: the electrode spacing, the electrode array and the true resistivities and other characteristics of the subsurface materials, such as layer thickness, angle of dip and anisotropic properties.

A sounding at a particular site consist of about 23 measurements made with different AB/2 values. AB/2 is the distance from A (or B) to the centre of the array. During the Manono survey AB/2 ranged from 1 m to 170 m. As AB/2 is increased, the current penetrates deeper into the ground and the apparent resistivities progressively reflect the influences of deeper layers.

Resistivity has an enormous range which far exceed any other physical property; e.g. $10^{-6}$ ohm*m (graphite) to $10^{12}$ ohm*m (marble). Typical field measurements of resistivity have the following orders of magnitude in ohm*m:

| | |
|---|---|
| 10,000 | dry sands or sandstone |
| 1000 - 2500 | fresh igneous and metamorphic rocks |
| 300 - 600 | dune sand aquifers |
| 80 - 300 | alluvial sand/gravel aquifers |
| > 100 | saturated sandstone |
| 50 - 100 | freshwater lenses |
| 1 - 30 | saline aquifers |

Resistivity sounding methods perform at their best in a horizontal layered situation. For this reason all the soundings were oriented, as much as possible, parallel to the coastline.

Some problems were encountered during the choice of the sounding sites, because of the dense forest vegetation covering the inland of the island. These problems also sometimes affected the straightness of the array, which could have affected some of the results.

### Roof catchment inventory

To assess the present use of the rainwater resource a comprehensive inventory of rainwater storage tanks and the associated roof catchment areas was undertaken. Data collected through direct inspection included:

- Effective storage capacity,
- Roof type,
- Gutter length,
- Location of system,
- Ownership of System,

Ownership of the system was determined to deduce the accessibility[2] to the water for different users. All data was recorded in hard copy by house to house visit and later entered into a spreadsheet (Appendix 3).

## Analysing design parameters

In order to provide information on design parameters for the design options considered in this study the actual and future demand for potable and non-potable water have been estimated. Contrary to the previous studies the present work presumes much lower demands. The presumptions justifying this are described below.

### Estimating the demand for potable water

The 1986 census in Table 1 shows a population of 1130 inhabiting Manono Island, and a slight decrease compared with 1971.

| **Census** | **1971** | **1976** | **1981** | **1986** |
|---|---|---|---|---|
| Faleu | 430 | 462 | 213 | 353 |
| Lepuai'I | 227 | 210 | 443 | 310 |
| Apai | 127 | 89 | 99 | 112 |
| Satuilagi | 95 | 137 | 142 | 128 |
| Salua | 196 | 147 | 175 | 155 |
| Satoi | 84 | 122 | 80 | 72 |
| **Total** | **1159** | **1167** | **1152** | **1130** |

Table 1: Census results on Manono Island

The number of livestock or other consumers (e.g. hotels and industry) is negligible. It seems therefore conservative to assume that the supply area contains about 1200 consumers.

During the week only part of the population lives on the island and does not consume water. This is irrelevant for the design of a reticulation system fed from the main island where the flow rate is the main design factor and the maximum number of possible consumers (= max. demand) determines all relevant design parameters. However, it becomes extremely

[2] It is understood that the Samoan social system makes privately owned water storage accessible to different users.

important when the demand is to be satisfied by stored rainwater because of the restriction that only stored rainwater can be consumed.

Estimating the water supply requirements

Estimating the water supply requirements is not easy as the actual consumption has never been metered.

Based on the interviews of islanders and on short duration measurements carried out during the fieldwork it is very likely that the daily consumption per capita (l/c/d) is significantly less than 40 l/c/d. However, the supply restricts the consumption since people can’t consume as much water as they would like. It was further observed that the demand for drinking water does not exceed 25 l/c/d, which would leave less than 15 l/c/d, as demand for non-drinking water (actually provided by the shallow wells). Using these numbers any new water supply scheme should be designed to safely provide at least 50 l/c/d.

In general water supply schemes are designed to meet the demand for at least 20 years. On Manono further socio-economic development, in particular the introduction of flush-toilets and a more westernised life style, is likely to contribute to an increase in water demand per capita while census data suggest that a population increase is unlikely. Therefore a water supply scheme on Manono Island should be capable of meeting a demand of 80 l/c/d. This demand is fairly low in the context of Pacific Island Countries where daily capita design demands exceed 300 - 400 l/c/d. However, these numbers do not represent real demand but include water losses due to leaks and wastage of water. The chosen demand rate (80 l/c/d) represents a realistic approach for this study by reflecting the present infrastructure (e.g. no flush toilets, no household taps etc) and grade of social organisation on Manono.

# RESULTS

## Water quality of existing wells

Out of 23 shallow wells located in Salua (3 wells), Faleu (6 wells) Lepuai'i (8 wells) and Apai (6 wells) 9 wells were tested for conductivity, temperature, pH-value, turbidity and faecal coliform bacteria (per 100 ml). Table 2 and 3 show where and how many wells have been tested and the results (values, which exceed WHO Guideline standards are highlighted).

| Location | | | Laufalo Point 3 wells | | | Apai 6 wells | |
|---|---|---|---|---|---|---|---|
| Well | | | S1 | S2 | S3 | A1 | A2 |
| Observations | Unit | WHO Guideline | | | | | |
| Date of Test | [-] | | | | 20/08/97 | | |
| Time | [-] | | 12.00 | 12.20 | 12.45 | 15.50 | 16.15 |
| Diameter | [m] | | 1.00 | 1.00 | 1.00 | 0.70 | 0.50 |
| Depth | [m] | | 1.50 | 2.00 | 1.70 | 1.10 | 1.20 |
| Estimated Yield | [l/min] | | 30* | 30* | 30* | 30* | 30* |
| Conductivity (25º C) | [ms] | - | 470.0 | 620.0 | 780.0 | 3400.0 | 2389.0 |
| Temperature | [C] | - | 25.2 | 26.3 | 25.7 | 25.6 | 25.4 |
| TDS*,3 | | 1000 | 307 | 405 | 510 | 2354 | 1654 |
| PH-value | [-] | < 8 | 7.5 | 7.5 | 7.5 | 7.5 | 7.9 |
| Turbidity | [NTU] | < 5 | 130.0 | < 5 | < 5 | < 5 | < 5 |
| Coliform Bacteria | [Col./ 100ml] | 0 | 2.0 | 2.0 | 3.0 | 50.0 | 60.0 |

*Total Dissolved Solids: Conductivity (25º C)/ 1,0955 *f with f = 0,7159 if Cond. less than 833 and f = 0,7585 if Cond greater than 833.

3 Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potasium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water. TDS in drinking water originate from natural sources, sewage, urban run-off, and industrial wastewater.

Table 2: Results of Water Quality Tests at Laufalo Point and Apai

| Location | | | Matasiva Point<br>6 wells at this point | | | Lepuai'i<br>8 wells at this point | |
|---|---|---|---|---|---|---|---|
| Well | | | M1 | M2 | M3 | L1 | L2 |
| Observations | Unit | WHO Guideline | | | | | |
| Date of Test | [-] | | 20/08/97 | | | 20/08/97 | |
| Time | [-] | | 13.50 | 14.15 | 14.30 | 15.05 | 15.20 |
| Diameter | [m] | | 1.00 | 0.80 | 0.70 | 0.80 | 0.90 |
| Depth | [m] | | 0.90 | 0.95 | 1.10 | 1.30 | 1.45 |
| Estimated Yield | [l/min] | | 30* | 30* | 30* | 30* | 30* |
| Conductivity (25º C) | [ms] | - | 1565.0 | 1234.0 | 1010.0 | 1018.0 | 780.0 |
| Temperature | [C] | - | 25.8 | 26.1 | 28.8 | 25.7 | 25.8 |
| TDS* | | 1000 | 1084 | 854 | 699 | 705 | 510 |
| PH-value | [-] | < 8 | 7.5 | 7.3 | 7.3 | 7.5 | 7.4 |
| Turbidity | [NTU] | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 |
| Coliform Bacteria | [Col./ 100ml] | 0 | 5.0 | 12.0 | 15.0 | 16.0 | 100.0 |

*Total Dissolved Solids: Conductivity (25º C)/ 1,0955 *f with f = 0,7159 if Cond. less than 833 and f = 0,7585 if Cond greater than 833.

Table 3: Results of Water Quality Tests at Matasiva Point and Lepuai'i

No well meets the WHO guideline standard for faecal coliform bacteria, which requires no detectable bacteriological colony (E. Coli) in a 100 ml sample. The results show that the WHO guideline value for total dissolved solids (less than 1000 mg/l) is exceeded by the wells in Apai and one well (M1) at Matasiva Point, however, it should be noted that no health risk is related to the guideline value for TDS.

## Assessment of Groundwater Resource

### Resistivity Tests

For each location a resistivity sounding was carried out. All the field data collected during the survey are presented in a chart and plotted on log-log paper (apparent resistivity Vs electrode spacing AB/2) in Appendix 5.

As can be noticed, of the total of 7 soundings only three soundings present results that can be well interpreted (No. 1a No. 3, and No. 4a), while one (No. 4) can only confirm the results obtained from No. 4a, placed nearby.

This was probably due to the fact that the Mulifanua Volcanic Rocks show a range of different geological properties. The lithology is composed of grey or black basalt more or less vesicular sometimes interbedded with layers of aa flows. Since the young age (Last Glaciation, about 120,000 years ago) of these rocks has not allowed an intensive and homogeneous weathering process, their porosity varies from place to place. As mentioned above, resistivity method better performs in a horizontal layering with homogeneous properties.

Interpretation of the Results

Major limitations of the electrical resistivity method are resolution, suppression and equivalence. They are all associated with the concept of relative thickness (RT), which is defined as the ratio of the thickness of a layer to the depth to the top of the layer.

As a general rule, the resistivity method cannot resolve thin layers (RT<0.1). It follows that the method can resolve considerable detail near the surface, but can see only bulk zones at depth.

Even a reasonable thick layer (0.1<RT<1) may not be detected if resistivity contrast is inadequate. This is likely to happen with a layer of intermediate resistivity, which is sandwiched between one layer that is more conductive and another layer which is more resistive. Such a layer is said to be suppressed.

It is possible for several alternative earth models to give essentially the same field response. Such models are equivalent because the resistivity method cannot distinguish between them. Equivalence occurs in layers that have a relative thickness, which is small, yet is large enough to be resolved. If the conductive layer is conductive (relative to the layer underneath), all models have the same thickness/resistivity ratio (known as longitudinal conductance). If the equivalent layer is resistive, all models have the same thickness×resistivity product (known as transverse resistance).

Modelling the Results

The final results of the geo-electrical soundings modelling have been included to Appendix 5. They show basically the presence of three layers.

The first layer represents the topsoil. The different values of resistivity and thickness show that the weathering processes that lead to the topsoil formation varies from place to place because of the young age of the Mulifanua Rocks, they are not yet widely developed.

The second layer is quite similar for all the three soundings interpreted.
It represent a layer of dry volcanic rock with a resistivity ranging near 2000 ohm*m. This value is typical for dry Mulifanua Volcanic Rocks, as reported by Risk (1979) on Upolu.

The third layer has a very low resistivity, ranging from 20 to 3.1 ohm*m. This resistivity value suggest the presence of a saltwater saturated layer.

Since the depth of the upper limit of the third layer is located substantially above estimated mean sea level, the only reasonable explanation is that the resistivity method can not resolve this third layer correctly. Basically in this setting, it is not possible to have a saltwater saturated layer above sea level.

It is possible to split the lower layer in two (or more) layers. Assuming a four-layer model, the resistivity value for the (new) third layer that fits the field results is about 50 ohm*m.

The ambiguities concerning the resolution of the saturated zone have already been mentioned by Risk in his report (1979). Basically the boundary between the dry and the wet zone can be easily detected, but different interpretations can be made to solve for the saturated zone. This is mainly due for of two reasons: the difference of resistivity value between dry rocks and brackish/saltwater that generates a steep curve that often hides inflections, and the tide pulse that alters water layering.

The results of the four-layer configuration are not unique and definitive. Even splitting the lower layer in two, there could be other equivalent results for the third layer. As can be noticed, the four-layer model lowers the saltwater interface more or less to mean sea level but there is still a problem to clearly define the layering of the water (both fresh and salt) saturated layer.

The only clear result seems to be the lower boundary of the "dry zone" (dry volcanic rock layer), where the abrupt fall of resistivity doesn't allow inserting any layer with a resistivity value indicating further "dry layers".

The equivalence ambiguity could also be applied to layer 2. The results of different solutions, in this case, shows that the range of resistivity values that fit the curve goes from 2000 ohm*m to 1400 ohm*m. This in any case shows undoubtedly the presence of a dry rock layer. For the second layer resistivity (1400 ohm*m), the thickness difference is two metre.

As mentioned before, the value of 2000 ohm*m has been chosen as the most appropriate, because of similarity with the geophysical investigation carried out in 1979 on the same volcanic rocks (Risk 1979).

The results are summarised in Table 4 and Table 5.

| No. of Sounding | 1 a (altitude ≈ 45 m above msl) | | 3 (altitude ≈ 15 m above msl) | | 4 a (altitude ≈ 25 m above msl) | |
|---|---|---|---|---|---|---|
| | thickness (m) | Resistivity (ohm*m) | thickness (m) | resistivity (ohm*m) | thickness (m) | resistivity (ohm*m) |
| Layer 1 | 3 | 393 | 0.6 | 55 | 0.4 | 50 |
| Layer 2 | 7.7 | 2000 | 6.5 | 2000 | 7 | 2000 |
| Layer 3 | ¥ | 23 | ¥ | 3.1 | ¥ | 6.3 |

Table 4: 3-layer model

| No. of Sounding | 1 a (altitude ≈ 45 m above msl) | | 3 (altitude ≈ 15 m above msl) | | 4 a (altitude ≈ 25 m above msl) | |
|---|---|---|---|---|---|---|
| | thickness (m) | Resistivity (ohm*m) | thickness (m) | resistivity (ohm*m) | thickness (m) | resistivity (ohm*m) |
| Layer 1 | 2.8 | 393 | 0.6 | 54 | 0.4 | 50 |
| Layer 2 | 7.5 | 2000 | 6.4 | 2000 | 6.2 | 2000 |
| Layer 3 | 35 | 50 | 8 | 50 | 18 | 50 |
| Layer 4 | ¥ | 17.5 | ¥ | 3.1 | ¥ | 4.9 |

Table 5: 4-layer model

All the modelling results of the field data are reported at the end of this report in Appendix 6. They were made with a software package named RINVERT that allows both forward modelling and inverse modelling of the field data. An equivalence analysis is carried out on the inverse modelling results.

All the results are shown with a statistical parameter (RMS, Root-Mean-Square) indicating the goodness of fit between field data and model data computed at the same positions.

### Hydrogeological Interpretation

From the three geophysical soundings interpreted, there is a saturated layer located under the soil surface. The 3-layer models show the upper limit of a saline aquifer at a depth above mean sea level. As noted before, the presence of such a saltwater aquifer is unlikely at that elevation.

The four-layer model is an attempt to solve the lower water saturated layer and, as a result, the presence of a freshwater aquifer appears. It is not possible to solve clearly this low resistivity layer. It seems that the freshwater/saltwater interface is located at least at mean sea level or even a little lower.

Previous studies and observations (Kear and Wood, 1959; Risk, 1979; Kear, Kammer and Brands 1979) on Mulifanua Rocks describe this geological unit as quite permeable and, because of this, having a low hydraulic gradient. Water table is usually less than one metre above sea level. Saline interface is located several metres below sea level, according to freshwater/saltwater equilibrium.

From the interpretation of Manono Island results it appears that the water table is located a few meters under the soil, well above mean sea level with a saline interface close to sea level.

These results suggest that the rocks forming Manono Island have a lower hydraulic conductivity, compared to the same volcanic rocks observed on Upolu. A low permeability could explain the high water table, but not the presence of the saltwater interface at mean sea level. A very conductive rock layer located more or less at sea level could cause this raising of the mixing zone.

Figure 5 illustrate the result for the 3-layer and the 4-layer model. Previous work does not confirm all these different features and only further investigation could help to better understand and interpret actual knowledge on groundwater circulation on Manono Island.

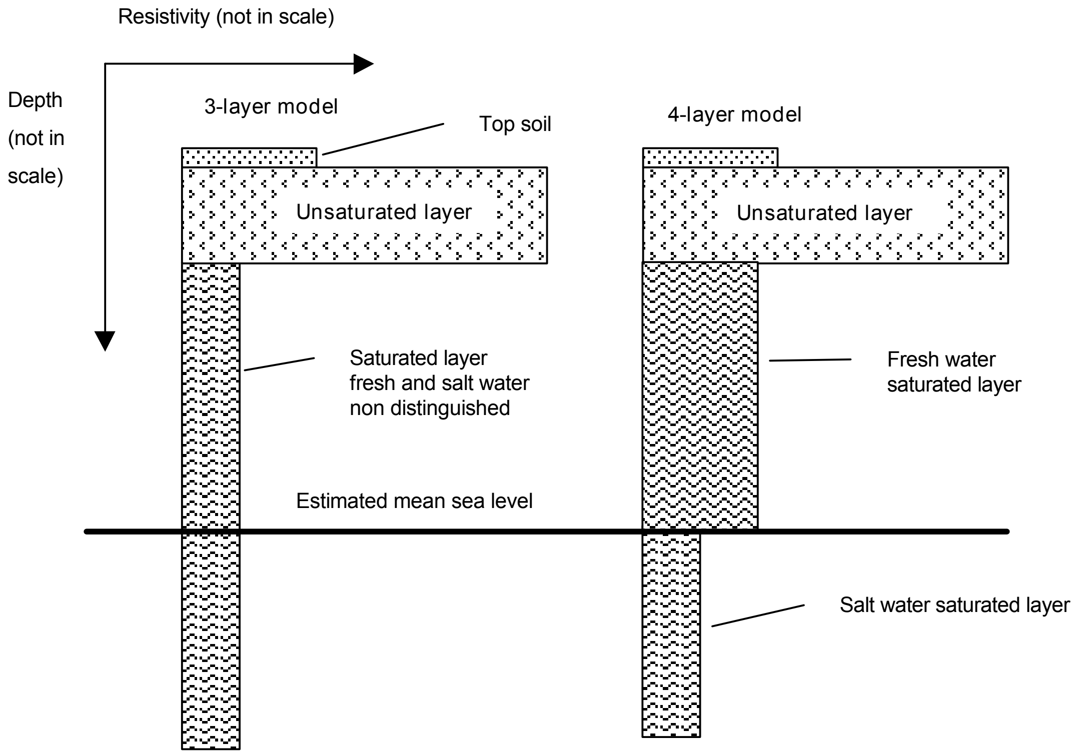



Figure 5: Interpretation of resistivity soundings as a 3-layer model and 4-layer model

## Rainwater Catchment

A total of 123 rainwater catchment systems were inspected. Most tanks are 1.70 m x 1.70 m rectangular ferro-cement tanks with an storage capacity of about 4.3 $m^3$ or circular ferro-cement tanks with a diameter of 3.5 m and effective height of 2 m which provides about 19 $m^3$ storage capacity.

The overall storage capacity is about 1611 $m^3$ and the effective installed roof area is 4442 $m^2$. Note that these numbers do not serve for storage simulation processes but to deduce some key numbers for rainwater catchments.

Without considering any system losses the total installed storage capacity $S_{ic}$ amounts to 1.3 $m^3$ per capita ($S_{ic}$ = 1611/1200) and is far away from the recommended ratio $S_{ic}$.=3:1

(UNDP 1992). The ratio between effective area and effective storage capacity on Manono is about 2.8:1 which comes just close to the recommended ratio of 3: 1 (UNDP 1992). The installed effective roof catchment area allows the collection of a maximum of 11105 $m^3$ per year with a rainfall of 2500 mm. This gives a maximum consumption of 25.4 l/c/d taking into account a population of 1,200. The same analysis broken down to the village is presented in Table 6.

| | Number of Systems | Installed Storage | Eff. Roof Area | Population 1986 | Roof/Tank Ratio | Tank/Popu Ratio |
|---|---|---|---|---|---|---|
| | [-] | [$m^3$] | [$m^2$] | [-] | [m] | [$m^3$/cap] |
| Faleu | 46 | 454.7 | 1184. | 353 | 2.6 | 1.3 |
| Lepuai'i | 17 | 290.2 | 889.0 | 310 | 3.1 | 0.9 |
| Apai | 17 | 269.2 | 972.9 | 112 | 3.6 | 2.4 |
| Salua | 23 | 309.9 | 798.1 | 283 | 2.6 | 1.1 |
| Satoi | 20 | 333.5 | 596.7 | 72 | 1.8 | 4.6 |
| Total | 123 | 1657.5 | 4440.7 | 1130 | - | - |

Table 6: Roof catchment systems installed by villages

The ratio between tank capacity and population varies from 0.9 in Lepuai'i up to 4.6 in Satoi while the roof/tank ratio ranges from 1.8 $m^3$/capita in Satoi up to 3.6 $m^3$/capita in Apai.

However, the actual performance of the system depends on the yearly precipitation, evapotranspiration, the run-off coefficient, and most important the distribution of the precipitation and is therefore less than the theoretical value. To evaluate the performance of the roof catchment systems on Manono simulations were undertaken for both standard tanks found on the Island taking into consideration the different design parameters and different assumptions listed in Table 7. The aim of the simulation was to model which roof size should be related to the two standard tanks (highlighted columns in Table 7) and if the roof size is less than the optimal size, to show what shortfall can be expected. Here shortfall is understood as a period when no water for consumption is available from the tank.

The basic data for the simulation was daily rainfall from Faleolo Airport. The first step of the simulation was to convert the daily amount of rain to a flow rate (litres/day) from which the consumption (here 210 litres/day; a 7 person household using 30 l/d/c) was deducted and the difference added to the actual storage. A day where the inflow (= rain) is less than the outflow (=consumption) and the difference can not balanced by the storage (= tank is empty or close to) is a shortfall day. Table 7 shows how these shortfall days can accumulate to shortfall periods. And more generally speaking the table shows for different roof catchment systems how many shortfall periods are to be expected and how long they last.

| General Design Parameters:<br>7 Person per Household, Daily Water Consumption: 30 l/c/d<br>Losses due to improper connections, evapotranspiration etc: 30 % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| System | Standard Tank<br>Circular, Ferro-Cement<br>Diameter = 3.50 m<br>Height = 2.0 m<br>Tank Storage Capacity: 19.26 $m^3$ | | | | Standard Tank<br>Rectangular, Ferro-Cement<br>Length = 1.70 m x 1.70 m<br>Height = 2.0 m<br>Tank Storage Capacity: 5.79 $m^3$ | | | |
| Roof Size [$m^2$] | 20 | 40 | 60 | 61.7 | 20 | 40 | 60 | 118.6 |
| Initial [1.] Storage Volume [$m^3$] | 1692 | 7854 | 18641 | 18641 | 1692 | 4744 | 4751 | 4771 |
| Number of Days without any Water left in Tank (Shortfall) during Simulation | 516 | 204 | 5 | 0 | 516 | 263 | 132 | 0 |
| Shortfall as Percentage of Simulation period (2 years = 730 days) | 71% | 28% | 1% | 0% | 71% | 36% | 18% | 0% |
| Number of Periods without any Water left in Tank (Shortfall) | 44 | 29 | 2 | 0 | 44 | 36 | 24 | 0 |
| Number of Shortfall Periods: | | | | | | | | |
| Up to 1 Day[2] | 10 | 14 | 2 | 0 | 10 | 16 | 14 | 0 |
| Up to 5 Days | 7 | 5 | 0 | 0 | 7 | 7 | 6 | 0 |
| Up to 10 Days | 13 | 6 | 0 | 0 | 13 | 8 | 1 | 0 |
| Up to 20 Days | 6 | 1 | 0 | 0 | 6 | 1 | 1 | 0 |
| Up to 30 Days | 3 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| Longer than 30 Days | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Longest Period without rain in Days | 42 | 24 | 3 | 0 | 42 | 24 | 22 | 0 |

1. The initial storage volume was calculated so that the end volume after the two-year simulation matches the initial storage volume.
2. It may confuse that in this row the number of shortfall periods rises with an increased roof size but the results are correct. The increased roof size reduces the length as well as the number of shortfall periods i.e. a up to thirty days shortfall period can be reduced to 3 (or more) shorter periods

Table 7: Roof Catchment Simulation for Manono Island

Figure 6 to Figure 9 illustrate the information given in Table 7 for the 19.26 $m^3$ tank and a 40 $m^2$ roof for 1985 and 1986. All other variables are the same as listed in Table 7. The figures show that the tank never fills totally and the system as a whole produces a total shortfall period of 28 % of the simulation period of 730 days, which equals 204 days. To overcome this intolerable situation either daily consumption has to be reduced or, preferably, the roof catchment area has to be extended. As Table 7 shows a mere 20 $m^2$ increase in roof size reduces shortfall from 20 % to 1 %.

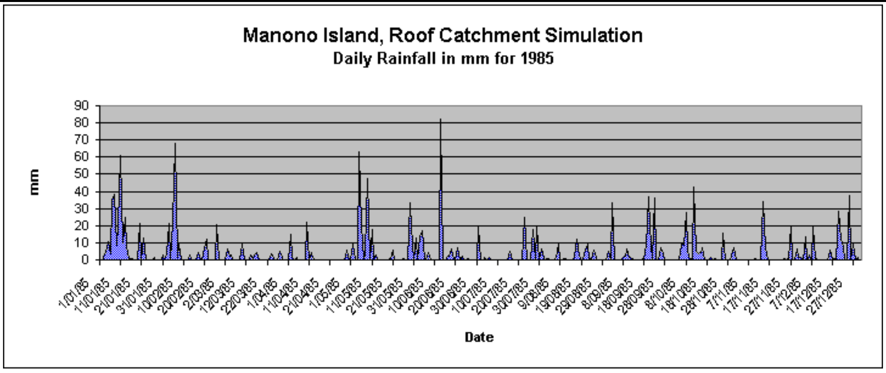



Figure 6: Daily rainfall in millimeters for Faleolo Airport in 1985

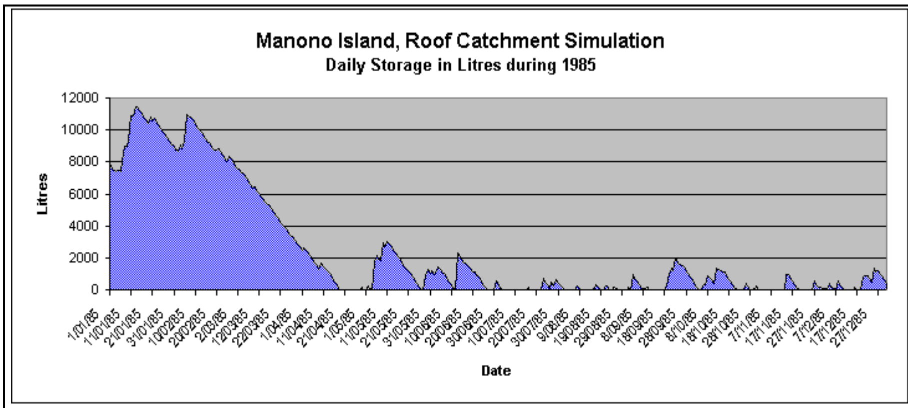



Figure 7: Daily Storage in litres for 1985 in a 19260 litres tank

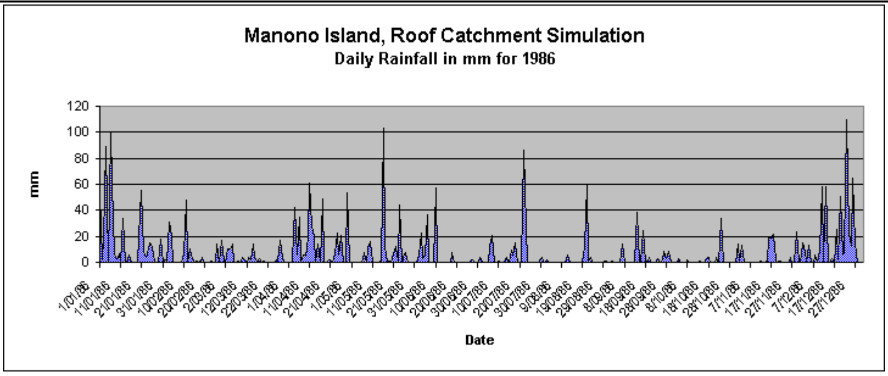



Figure 8: Daily rainfall in millimeters for Faleolo Airport in 1986

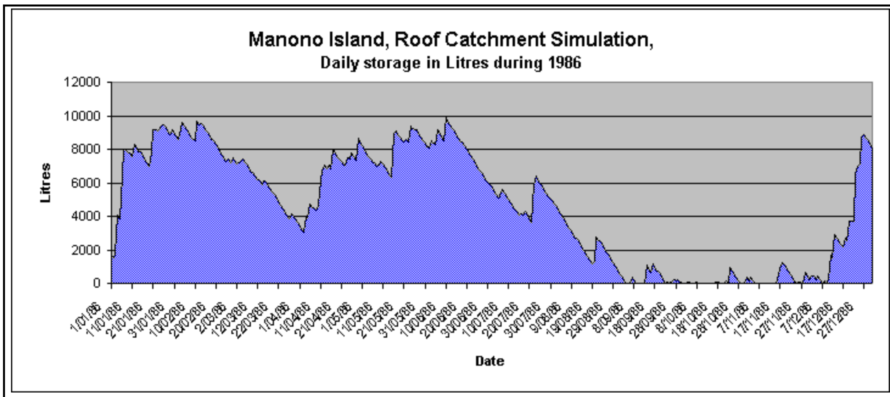



Figure 9: Daily Storage in litres for 1986 in a 19260 litres tank

Figure 10 shows the results of the same simulations in more general manner. Each of the diagrams was made for a given shortfall percentage (1%, 5%and 10%) taken in consideration the rainfall data of Faleolo Airport for 1985 and 1986.

Further each diagram contains six curves for different tank sizes (500 l, 1000 l, 5000 l, 10000 l, 20000 l and 50000 l). Choosing a desired consumption rate and a tank size leads to the required roof size. For example: Wanting less than 1 % shortfall and a daily consumption of 200 litres/day per system leads to about 110 $m^2$ roof size with a 5000 litres tank while a 10000 litres tank requires just 70 $m^2$ of roof size.

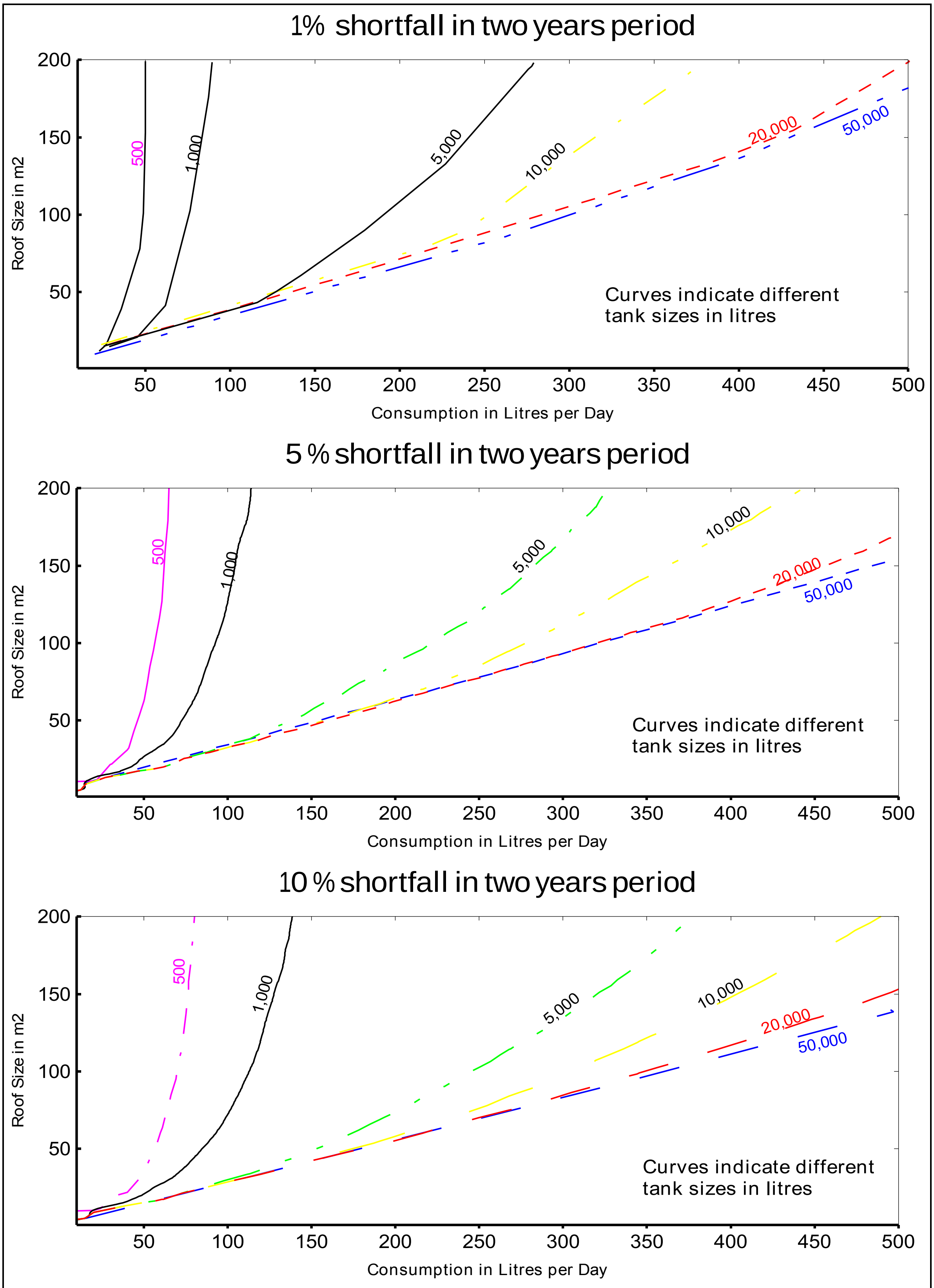



Figure 10: Roof size over consumption for various tank sizes and given shortfall in the two-year period 1985-1986

Other information such as determining the possible consumption for a given tank size and chosen shortfall can be retrieved by interpolation between the “tank-curves” in Figure 10.

## Manono Island Water Supply System

Table 8 summarises the design parameters for options considered viable for a sustainable Manono Island water supply system.

| | | Actual Demand | | Future Demand | |
|---|---|---|---|---|---|
| | | Option 1 | Option 2 | Option 1 | Option 2 |
| Parameter | Unit | Value | Value | Value | Value |
| Total Demand | [l/c/d] | 50 | 50 | 80 | 80 |
| Demand covered by rainwater* | [l/c/d] | 30 | 0 | 30 | 0 |
| Demand to be covered by groundwater | [l/c/d] | 20 | 50 | 50 | 80 |
| Population | [c] | 1200 | 1200 | 1200 | 1200 |
| Total demand | [m3/d] | 24 | 60 | 60 | 96 |
| Average Flow Rate | [l/s] | 0.28 | 0.7 | 0.7 | 1.1 |
| Design Flow for Bores (6 hours pumping)** | [l/s] | 1.1 | 2.8 | 2.8 | 4.4 |
| Design Flow for Main Pipe (6 hours pumping) | [l/s] | 1.1 | 2.8 | 2.8 | 4.4 |
| Distribution Pipes from Storage (Peak Flow Factor 2.0) | [l/s] | 0.56 | 1.4 | 1.4 | 2.24 |

* It is assumed that not more than 50 l/c/d can be safely provided through rainwater.

** Present electricity supply is 6 hours daily

Table 8: Design parameters for Manono Island water supply system

In regards to the investigation and further development of the groundwater resource drilling should be commenced as soon as practicable with the aim to collect as much data as possible from the drilling activity by ensuring the following:

- Drilling sites to be located very close to previous geophysical soundings sites, not only in order to calibrate the geophysical survey, but also because these sites are sufficiently inland to avoid immediate saltwater contamination;
- During the drilling there must be a constant monitoring of water quality (water conductivity and temperature);
- Drillings must be stopped as soon as water conductivity reaches a value of 1,000 μS/cm (at 25 °C) that indicates the proximity to the saltwater interface;
- After the drilling some simple slug tests (Lefranc Constant Head Test and Variable Head Test) could be carried out to test, in a preliminary way, the aquifer properties;

The results from the drilling will give a clear idea of the groundwater potential of Manono Island.

In case the drilling results indicate a certain groundwater potential further pumping tests must be carried out. These further tests will have to assess the sustainable yield for the pumps taking into consideration possible risk of saltwater intrusion. The definitive system of exploitation (vertical borehole or horizontal gallery) can be decided after the results of the drilling phase. Water table depth will be a key factor in the choice of which extraction system has to be used.

Once the presence of an exploitable groundwater resource is confirmed SWA should establish the best way to incorporate this additional resource with the roof catchment system.

# CONCLUSIONS

## Water in shallow wells

The water quality of tested shallow wells does not meet guideline values set by the WHO. The untreated water from those wells should not be used as drinking water.

## Groundwater Assessment

Resistivity methods have indicated the possibility that a freshwater saturated layer exists under the surface on Manono Island.

Difficulties in interpretation and ambiguities related to the methodology itself leave a considerable amount of uncertainty about the depth and extent of any freshwater.
The only clear way to resolve that uncertainty would be to drill a borehole nearby one or more of the resistivity soundings. This would also allow a better calibration of the sounding results and provide a better understanding of the freshwater/saltwater relationship under the saturated zone.

## Roof Catchments

From the roof catchment inventory and the simulations it can be deduced that the rainwater resource is under-used on Manono Island. Although no direct rainfall data were available for the island the simulation gives valuable indications for the improvement of the roof catchments:

- Considering that many households already have a rainwater tank the improvements can be obtained by enhancing the performance of the catchment area rather than by building new tank capacity.
- Some villages on the island lack sufficient tank capacity. (Faleu, Lepuai'i, and Salua).
- The simulation shows that the standard tank of 19.26 $m^3$ requires a contributing roof size off about 60 $m^2$ for a shortfall period of no greater than 1 % while the other standard form of rainwater tank, the 5.79 $m^3$ required more than 100 $m^2$ respectively.

This would provide a safe rainwater supply of 30 l/c/d per system (210 l/c/d per 7 people household).

- A safe supply of 50 l/c/d per system (350 l/c/d per 7 people household) would require 125 $m^2$ of roof size for the 19.26 $m^3$ storage tank. Smaller storage tanks are not recommendable. At the same time the supply of 50 l/c/d is seen as the upper limit for a safe water supply (less than 1% shortfall) through rainwater on Manono.
- Too many public buildings do not have any rainwater catchment system installed or the resource potential is insufficiently exploited.

Final conclusion

Both the groundwater and rainwater/roof catchment assessments suggest that it is possible to provide enough drinking water for the islanders on Manono. From the experience to date with the undersea pipeline the upgrading of that system appears not feasible.

# RECOMMENDATIONS

1. The Manono water supply should rely on roof catchment systems supplemented by groundwater, the latter to be investigated and developed, to substitute for the use of contaminated shallow well water. The near future target for the water supply should be to provide safe 50 l/c/d (less than 1% shortfall) and in the long term 80 l/c/d.

2. An inexpensive ad-hoc means to overcome hardships in the water supply roof catchment efficiency is to provide wider and better guttering and by fitting community buildings and churches with efficient roof catchment systems. The SWA should provide the islanders with technical assistance to ensure the efficiency of the systems. Figure 10 and Table 7 should be used as reference.

3. In the long term the deployment of more tanks with matching roof sizes should be encouraged and support, (both financial and technical assistance) should be granted as available. As the long-term goal a relation both of tank capacity to population and roof size to tank capacity of 3:1 should be targeted.

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