WATER RESOURCES ASSESSMENT

BANABA (Ocean Island)

REPUBLIC OF KIRIBATI
Smoothed edges
of dugged-in caves
implying layer after layer
of unseen colours
old geology
in the dark
no light
to comfort
the eye of a naked ape
grasping for knowledge
performing sacred rites
anything to withstand
the sense binding fears
of death and after death
true essences of a human life

From the little poem "Harakiri"
in "Old life, death wishes"
by Birdman Frank Holweg
Nou-nou Editions
Arnhem NL 2000

"All we need is water, stability of water.
You can see what was done here in eighty
years of colonial rule - the technology
here was the finest in the world. Let's bring
that technology back and show the world
what can be done to rehabilitate a place."

Stacey King – Banaba Homecoming Trip Organiser

(Banaba is just six square kilometers in area. It has no
natural water supply on its surface: collected rainwater is
the only readily available source of freshwater, and there
may be no rain for years on end.)
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EXECUTIVE SUMMARY

Banaba is a raised coral atoll in the western-most territory of the Republic of Kiribati in the Central Pacific close to the Equator (0° 52’S, 169° 32’E). The interior of the island has been mined for its phosphate deposits from 1900 until 1979 mainly by the British Phosphate Commission (BPC). The island, formerly known as Ocean Island, measures only 6 km² and is fairly isolated with the nearest islands being Kuria (400 km to the ENE which is an atoll south of Tarawa, and Nauru, a raised coral atoll (258 km to the west).

A detailed assessment of Banaba’s groundwater has been called for following recent droughts, and in response to possible rehabilitation of, and resettlement on the island. Freshwater resources are limited and pose a constraint to any form of development. In addition, the Kiribati’s Ministry of Natural Resources, Works and Energy is considering the possibility of re-opening phosphate mining on the island.

A mission was undertaken to Banaba from 5 to 18 August 2000 to make an assessment of the water resources on Banaba, and also to determine the grade and quality of the remaining phosphate deposits on the island.

Water has always been a major constraint in the development of Banaba. There are no rivers or other surface water on Banaba, and rainwater rapidly drains through the fissured limestone.

The current population of around 400 Banabans is now relying on rainwater, which is collected by roof catchments of individual houses, the hospital, the church and various other buildings. In addition, three desalination units were shipped in from Tarawa to deliver water during the El-Niño-related drought in 1997/1998. Water stored in three BPC reservoirs since 1979 was delivered to individual houses during this emergency situation.

For many years the possibility of exploiting the groundwater lens on Banaba has been suggested in order to overcome long periods of drought. However, it has never been thoroughly investigated, and this mission is a first step towards understanding the hydrogeology of Banaba.

To address the freshwater problem on Banaba, three sources were investigated during our mission: a groundwater survey including geophysical detection methods; a roof catchment survey assessing potential and existing catchments; and storage facilities and the use of desalination units.

Water existing in caves might be useful as drinking water in emergency situations if the system which was in use during WWII can be replaced. The total volume of the three pools investigated amounts to around 300 m³, which could serve a population of 400 people for a period of around 25 days. A realistic assessment of the groundwater reserves on Banaba can only be achieved if test drilling is undertaken. Springs should be located more precisely and carefully mapped, and where possible sampled, in order to obtain real information on the occurrence of groundwater and seepage and its quality at the discharge point.

The water-supply system on Banaba can still be upgraded and it is recommended that the asbestos roofs of the hospital are replaced by aluminum, and that the water tanks are reinforced. Since the residential flats are almost uninhabitable, it is recommended to relocate the remaining residents, demolish the flats, and use the aluminum roofs and gutters for upgrading the roof catchments in Ooma or elsewhere. A team of a water engineer, a welder, a plumber, a mason and a health inspector should spend a minimum of two weeks to repair and upgrade the system.

Two of the desalination units were repaired by staff of the Ministry of Natural Resources, Works and Energy during this visit after having been unused for a long time. It is recommended that an assessment of suitable emergency desalination systems is carried out and that timely maintenance of the systems is secured.
1 INTRODUCTION

Banaba is a raised coral atoll in the westernmost territory of the Republic of Kiribati in the Central Pacific close to the Equator (0°52'S, 169°32'E). The interior of the island has been mined for its phosphate deposits from 1900 until 1979 mainly by the British Phosphate Commission. The island, formerly known as Ocean Island and Panopa, measures only 6 km² in area, and is fairly isolated with the nearest islands being Kuria (400 km to the ENE which is an atoll south of Tarawa), and Nauru, a raised coral atoll (258 km to the west); see Figure 1.1.

Figure 1.1 Location of Western Kiribati and Banaba in the Pacific (from: Burgess, 1987)

A detailed assessment of Banaba’s groundwater has been called for following recent droughts, and in response to possible rehabilitation of, and resettlement on the island. Freshwater resources are limited and pose a constraint to any form of development. In addition Kiribati’s Ministry of Natural Resources, Works and Energy is considering the possibility of re-opening phosphate mining on the island (Kamaie, B., 1997).

A mission was undertaken to Banaba from 5 to 18 August to make an assessment of the water resources on Banaba, and also to determine the grade and quality of any remaining phosphate deposits on the island (see SOPAC Task Profile in Appendix 1 and Contact persons in Appendix 2).

1.1 Climate

Similar to the other islands of Western Kiribati, Banaba is hot and humid throughout the year. The earliest climatological observations in Western Kiribati began in 1903 on Banaba and continued until the 1980s. The weather is governed chiefly by the seasonal movements of the Inter Tropical Convergence Zone (ITCZ) and the Equatorial Doldrum Belt (EDB). Temperatures are constantly high with little variation. The mean daily temperature is around 29°C and the average relative humidity is 82%.

Winds between north-east and south-east bring rainfall with large annual and seasonal variability. The period of lowest mean monthly rainfall starts in May and lasts until November. From December until April the monthly rainfall is on average higher than 120 mm. Table 1.1 and Figure 1.2 show the mean monthly rainfall and evaporation derived from data in the period 1951-1980 (Burgess, 1987).

<table>
<thead>
<tr>
<th></th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
<th>TOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>271</td>
<td>226</td>
<td>172</td>
<td>144</td>
<td>114</td>
<td>103</td>
<td>118</td>
<td>101</td>
<td>89</td>
<td>110</td>
<td>108</td>
<td>215</td>
<td>1771</td>
</tr>
<tr>
<td>E$_{\text{pan}}$</td>
<td>205</td>
<td>201</td>
<td>218</td>
<td>191</td>
<td>183</td>
<td>167</td>
<td>174</td>
<td>204</td>
<td>208</td>
<td>212</td>
<td>193</td>
<td>188</td>
<td>2344</td>
</tr>
</tbody>
</table>

The rainfall intensities tend to be high and rainfall is usually localised. From rainfall data recorded from 1905 to 1984 the highest annual rainfall on Banaba appears to have been
4448 mm in 1919. Since accurate rainfall recordings are missing for the period after 1984 we will assume that the lowest annual rainfall occurred in 1917 with an amount of 362 mm.

Figure 1.2 Mean monthly rainfall Banaba (mm)

Figure 1.3 shows how the mean annual rainfall is distributed over the region. It can be noted that Tarawa receives a similar amount of rainfall whereas Nauru is considerably wetter.

Figure 1.3 Mean annual rainfall over Western Kiribati (from: Burgess, 1987)

In the period after 1984, a long period of drought has been reported by Banabans which lasted for almost seven years, from 1993 until early 2000 according to local sources. During these years, which included the El-Niño years of 1997/1998, almost no rainwater could be harvested and there was therefore hardly any recharge to the aquifer.

1.2 Geology

The geology of Banaba has been described by Hutchinson (1950). Similar to Nauru, Banaba is a raised coral atoll, with a maximum elevation of 86 m above mean sea level. The island is elliptical in shape and measures 2800 meters by 2200 meters.

The central area consists of an inland plateau of dolomitic limestone with a phosphate capping that is now largely mined out, exposing a karrenfeld, a landscape of karst pinnacles (see photo 11, Appendix 7b). Karstic subsidence features occur such as dolines, but unlike on Nauru, there are no large depressions reaching the water table.
Reef developed during or following emergence phase
Reef facies produced during stable or submergence phases
Basaltic core that was initially a volcanic island

Figure 1.4 On the left, Banaba with indication of the extent of workings, and on the right, a cross section of a raised coral atoll.

There is a fringing reef flat of marine denudation about 100 meters wide around the island, the modern shore has been cut back into the island. Along the northwest shore there is a raised beach up to 9 meters high. On the southern shore a shallow bay has been cut out adjacent to vertical cliffs 4 to 9 meters high, consisting of fragmentary coral lying on consolidated coral rock. The original phosphate capping may have been as thick as 24 meters though usually not over 15 meters thick. A cross-section of a raised coral atoll is provided in Figure 1.4 as well as a map of Banaba with an indication of the extent of phosphate workings up to 1986. On the Aerial Photograph in Appendix 3, the landscape resulting from the mining operation can be clearly identified.

The dolomitised coral, when stripped of phosphate, is seen to be cut by at least three raised shorelines. The central part of the island is relatively flat and is considered to represent the site of a lagoon. The whole of the dolomite surface, wherever exposed, is dissected into pinnacles forming a karrenfeld, possibly due to the radial and concentric cracking of the uplifted island (Hutchinson, 1950).

The phosphate usually occurs as crumbly surface or subsurface deposits. These deposits occur as nests (small isolated masses of phosphate) or fill pits from a few metres to a few dozen metres in depth, separated by walls and pinnacles of very hard dolomitic limestone.

Phosphate deposits should not be confused with guano, which is a build-up of bird droppings that can be directly applied as fertilizer. Guanos can form calcium phosphates by the combination of their phosphoric elements with limestone under the effect of rain (Dupon, 1989). The phosphate deposits found on Banaba were reportedly rich in phosphate. Shipments of phosphate leaving Banaba between 1921 and 1934 contained an average $P_2O_5$ content of 40 %. Unlike guano, tricalcium phosphate (forming the deposits on Banaba), needs processing to make it soluble enough to be directly available to plants. It is converted into superphosphate by adding sulphuric acid. The British Phosphate Commission (BPC) extracted 21 million tonnes of phosphate ore during mining operations between 1900 and 1979.

1.3 Vegetation

The mining operation involved removal of the original vegetation (see Figure 1.5) and topsoil, causing a situation whereby certain species have disappeared after severe droughts. Nevertheless, the vegetation has shown a remarkable regeneration after being destroyed. The regrowth of natural vegetation in combination with the steep limestone pinnacles makes large parts of the island almost inaccessible. Certain species of fruit-bearing trees have been introduced during the mining operation. Banana trees have disappeared during the last drought period but limited numbers of coconut palms and pandanus trees can still be found.
1.4 Population and economy

After WWII ended, widespread destruction of houses and infrastructure on Banaba made it impossible for the hundreds of deported Banabans to return so they agreed to resettle for two years on Rabi, off the coast of Vanua Levu in Fiji. Rabi had been bought in 1942 by the British Phosphate Commission (BPC) with Banaban phosphate trust money. The first Banabans arrived in 1945 and within two years voted to remain on Rabi. Now citizens of Fiji, the Banabans have become a separate community and are represented by the Banaba Island Council in Suva.

After Kiribati became an independent nation in 1979 the island was abandoned by BPC and the original number of around 8000 inhabitants, consisting of BPC employees and local Banabans, decreased drastically to around 2000. Only a small number of Banabans remained on the island.

Data from the 10-year National Water Master Plan (Ministry of Works and Energy, 1994) show how the population has fluctuated over the last twenty years on Banaba.

Table 1.2 Population Census

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Banaba</td>
<td>2201</td>
<td>46</td>
<td>284</td>
<td>500*</td>
<td>400~500**</td>
</tr>
</tbody>
</table>

* according to David Christopher, Rabi M.P. in the Kiribati House of Assembly, 23rd October 1996
** estimate SOPAC household survey, August 2000

The population as of August 2000 is estimated to be about 400 to 500, of which 70 % are living in residential houses in Ooma village. The remaining 30 % are living in prefab flats or small houses in Anteren, Teonaoraki and Tabwewa villages (see Appendix 4, Map 1).

Economic activities on the island are restricted to cultivation of some secondary crops like cassava, cucumber and carrots, catching fish and trading imported canned food. A government ship visits the island on an irregular basis once or twice every three months, bringing medical supplies and goods. Medical facilities on the island are very limited since the hospital facilities have almost been totally destroyed. A nurse from Tarawa used to visit Banaba and in case of emergencies medical assistance is sought via a radio transmitter.
Only four vehicles are operational on the island, comprising two old tractors, one old truck with trailer and one 4-WD jeep. The state of the vehicles is poor and they need almost continuous maintenance and repair. Diesel and Super is supplied by government ship and stored in barrels near the harbour in Ooma.

The old machinery used by the British Phosphate Commission is in a state of decay and it appears very unlikely that any of the phosphate machinery can be made operational again. Almost all the existing houses of former BPC employees are in a dilapidated state. No maintenance has occurred in the past twenty years and most houses suffered from destruction after Kiribati becoming independent in 1979.

1.5 Water-demand survey

The projected drinking-water demand on Banaba was obtained from the draft 10-year National Water Master Plan. With an estimated population of 500, daily personal consumption is projected at 27.5 L which equals ca. 110 L/household.\(^1\)

<table>
<thead>
<tr>
<th>YEAR 2000</th>
<th>YEAR 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 1.3 Projected drinking-water demand (m\(^3\)/day)


A small social survey carried out among several households on Banaba indicated that each household required approximately 160 L/week for washing; 80 L/day for bathing; 20 L/day for drinking and cooking and 20 L/day for washing dishes, resulting in a total demand of (±) 143 L per household. Thus, total consumption for a population of 500 will amount to 18 m\(^3\)/day equal to 36 L/p/day.

2 WATER RESOURCES ASSESSMENT

2.1 General

Water has always been a major constraint in the development of Banaba. There are no rivers or surface-water areas on Banaba, and rainwater rapidly drains through the fissured limestone.

During the mining period, a comprehensive water-supply system was serving a total population of around 8000 people consisting of mining labourers and administrative personnel as well as local Banabans.

Rainwater was collected by an extensive system of roof catchments which were connected by galvanised pipes to storage tanks. In addition, ballast water shipped in empty ore ships was pumped into large reservoirs of the British Phosphate Commission (BPC) and was distributed to individual houses by tank trucks and to the industrial area by pipes. Since the mining has ceased the ships are not able to deliver water as the moorings have been removed and large ships not able to cross the reef to the harbour in Ooma.

The current population of around 500 Banabans is now relying on rainwater which is collected by roof catchments of individual houses, the hospital, the church and various other buildings. In addition, three desalination units were shipped in from Tarawa to deliver water during the extensive drought in 1997/1998. None of the three units was working at the time of our mission.

\(^1\) The assumption was made that each household consists, on average, of four persons.
Water stored in the BPC reservoirs since 1979 was delivered to individual houses during drought periods in the last twenty years. A mission in 1989 reported that three of the tanks were full or nearly full (ODA, 1980) while in 1996 an estimated total amount of about 6000 m$^3$ was still left (Win, 1996). During the last few years, water from the tanks has been distributed to certain households by truck, and the tanks are expected to be half full totalling an amount of 4000 m$^3$. The water probably originated from an Australian port city and appears to still be of acceptable quality with an EC reading of 522 µS and no coliform bacteria (during tests in 1989).

Within the coral limestone there is a series of caves, locally known as Bangabanga, at different levels, some which are known to contain water. Drought periods during the Second World War led the Japanese military to pump water from pools in the caves. There is little information available on the extent of other caves, their location and the amount of water stored within them.

Exploitation of the groundwater lens on the island has been suggested for many years, but has never been thoroughly investigated. An investigation of groundwater abstraction was made in neighbouring Nauru, where phosphate mining is still continuing and water supply has been totally dependent on desalination technology in recent years. A study on the hydrogeology of Nauru was carried out by Jacobsen and Hill (1988), the fieldwork being carried out in 1987. The hydrogeological situation in Nauru bears much resemblance to that in Banaba and the results of the geophysical survey and drilling programme carried out in Nauru were very useful in this study (Jacobsen & Hill, 1988). Findings on future groundwater abstraction on Nauru might prove important for similar developments in Banaba.

To address the current freshwater problem on Banaba, three sources were investigated during our mission: a groundwater survey using geophysical detection methods; a rainwater survey, assessing potential and existing roof catchments and storage facilities; and the use of desalinated water.

### 2.2 Groundwater

#### 2.2.1 Geo-electrical soundings

Fresh groundwater underneath small islands normally takes the form of a lens, floating upon saline water with an interface in between. The transition zone between fresh and brackish groundwater is usually relatively thin if undisturbed and can be detected using geo-electrical soundings.

A resistivity measurement is carried out using four electrodes on line (Figure 2.1). A known current is injected using two current electrodes (A and B) and the resulting voltage difference between two measuring electrodes (M and N) is measured. The quotient of current and voltage differences multiplied by a geometrical factor for the electrode separations gives the “apparent resistivity” (van Putten, 1989).
A number of measurements are made with increasing electrode spacing, resulting in measurements of resistivities of ever-deeper layers. The apparent resistivity calculated from the soundings is plotted versus the current-electrode spacing, resulting in a “sounding curve”. The curve is interpreted by curve matching with standard curves and leads to definition of a number of distinctive earth layers of various thicknesses with various resistivities.

The electrical resistivity is a function of the composition of the deposits, the degree of water saturation and the salinity of the water. Typical resistivity values for rock/water mixtures are provided in Table 2.1.

**Table 2.1 Typical resistivity values**

<table>
<thead>
<tr>
<th>Description</th>
<th>Resistivity Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coral sand saturated with sea water</td>
<td>2-10 Ohm m</td>
</tr>
<tr>
<td>Hard coral saturated with sea water</td>
<td>5-15 Ohm m</td>
</tr>
<tr>
<td>Sand or rock saturated with freshwater</td>
<td>50-300 Ohm m</td>
</tr>
<tr>
<td>Dry sand or rock with very little water</td>
<td>500-3000 Ohm m</td>
</tr>
</tbody>
</table>

(From: Dale, D., 1986)

Altogether geo-electrical soundings were executed at different elevations to determine the depth and thickness of a possible freshwater lens which is expected at or around mean sea level. The method used was the Offset Wenner configuration with the ABEM Terrameter SAS 300B instrument. A manual for the geophysical method can be found in Appendix 5.

Map 1 shows the locations of the soundings. The bearings of the soundings were chosen, as far as possible, parallel to the coastline and along the contour lines, where a uniform lithology and geology can be expected. Routine interpretation of the resistivity curves is only possible with a horizontal and uniform stratification.

Attempts were made to extend the multi-core Wenner cables as far as possible up to a maximum spacing of 128 m. In some cases the inaccessible pinnacle-karst landscape made reliable data collection difficult. The lack of sufficient soil development and the hardness of the limestone bedrock made penetration of the pins to the required depth impossible in the interior of the island. Moreover, any linear section can only be found along the former mine access roads where distortion of the field curves can occur, due to channeling of electrical current through the low-resistivity soil and phosphate forming the road foundation.

In general, the Offset Wenner curves (numbered Ban 001 to Ban 014) show an increasing resistivity associated with the limestone above the water table. At the depth where the
groundwater level can be expected (i.e. just above mean sea level) the resistivity should drop to lower values.

Drilling on Nauru indicated that the water table invariably lies just above mean sea-level (Jacobsen & Hill, 1988). Therefore we applied their assumption that the resistivity models are constrained to comply with this observation, meaning that the depth of resistivity reduction associated with the top of the aquifer has been set close to mean sea level.

In Appendix 6 the Offset Wenner readings are provided. The soundings taken in the interior on the highest point on the island (Ban 004, 005 and 007) show ever-increasing resistivities, indicating that the resistance of the limestone bedrock is too high to apply this method in the centre of the island. Apparently the penetration of the electrical current is insufficient to reach the water table, possibly because of the occurrence of cavities and honeycombs. Similarly, the soundings in the interior of Nauru neither could be interpreted accurately. The soundings at lower elevations show better results.

Interpretation of the soundings was done by iterative modeling with the software package RINVERT for Windows version 2.0. As far as possible a four-layer model was applied with the following characteristics.

<table>
<thead>
<tr>
<th>Table 2.2 Four-layer model for Banaba soundings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness range (m)</td>
</tr>
<tr>
<td>1 Topsoil</td>
</tr>
<tr>
<td>2 Dry limestone/phosphate</td>
</tr>
<tr>
<td>3 Freshwater</td>
</tr>
<tr>
<td>4 Saline water</td>
</tr>
</tbody>
</table>

* Sometimes exceeding 50,000 ohm*m

Hydrogeological interpretations of the resistivity models Ban001 to Ban014 are shown in Table 2.3. Note that where an extra layer needed to be inserted the four colours shown above do not match. The altitude provided is only indicative and the error margin of the fit is provided between brackets.

<table>
<thead>
<tr>
<th>Table 2.3 Geophysical models Banaba</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Sounding</td>
</tr>
<tr>
<td>(altitude = 7 m AMSL)</td>
</tr>
<tr>
<td>thickness</td>
</tr>
<tr>
<td>(m)</td>
</tr>
<tr>
<td>Layer 1</td>
</tr>
<tr>
<td>Layer 2</td>
</tr>
<tr>
<td>Layer 3</td>
</tr>
<tr>
<td>Layer 4</td>
</tr>
<tr>
<td>Layer 5</td>
</tr>
</tbody>
</table>

* No appropriate model found

<table>
<thead>
<tr>
<th>No. of Sounding</th>
<th>4 (9.4 % rms)*</th>
<th>5 (10.3 % rms)*</th>
<th>6 (24.1 % rms)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>(altitude = 60 m AMSL)</td>
<td>(altitude = 63 m AMSL)</td>
<td>(altitude = 17 m AMSL)</td>
<td></td>
</tr>
<tr>
<td>thickness</td>
<td>resistivity</td>
<td>thickness</td>
<td>resistivity</td>
</tr>
<tr>
<td>(m)</td>
<td>(ohm m)</td>
<td>(m)</td>
<td>(ohm m)</td>
</tr>
<tr>
<td>Layer 1</td>
<td>1.6</td>
<td>2000</td>
<td>0.8</td>
</tr>
<tr>
<td>Layer 2</td>
<td>61</td>
<td>80 000</td>
<td>60</td>
</tr>
<tr>
<td>Layer 3</td>
<td>20</td>
<td>300</td>
<td>20</td>
</tr>
<tr>
<td>Layer 4</td>
<td>∞</td>
<td>10</td>
<td>∞</td>
</tr>
</tbody>
</table>
### Modeling Summary

**Ban001  Bukinterike North Road (7 m AMSL)**

The sounding provided no clear indication of the freshwater layer, which is expected to be very limited (thinner than 2 m) so close to the coastline. It is known that an airport strip is to be constructed in the near future at this hardly accessible site.

**Ban002  Sportsfield (65 m AMSL)**

**Ban003  Stockpile (62 m AMSL)**

**Ban004  Road from Stockpile to Sportsfield (60 m +MSL)**

**Ban005  Road from Sportsfield to Hospital (63 m +MSL)**

The soundings at Ban002, Ban003, Ban004 and Ban005 all show very high resistivities. The resistance of the limestone bedrock is so high that the relatively thin freshwater layer could not be clearly detected. Furthermore, the occurrence of cavities and honeycombs makes the analysis extremely difficult. From the interpretation of the soundings, Ban004 proves the most reliable, with the freshwater lens starting 62.5 m below the surface with a thickness of around 30 m.

**Ban006  Sydney Point (17 m +MSL)**

At Sydney point on the southeastern tip of the island the pinnacle-karst limestone borders a sandy beach. Freshwater is expected at 10 m below ground level, but interpretation for thickness was inconclusive.
Ban007  East Road north (52 m +MSL)
Ban008  East Road center (54 m +MSL)

In the interior on the east side of the island the soundings Ban007 and Ban008 show similar penetration problems similar to those experienced at the stockpile and sportsground. Expected freshwater lens at 51 m below surface but no indication of its thickness.

Ban009  Lilian point high (24 m +MSL)
Ban010  Lilian point low (18 m +MSL)

Near Lilian point, in between smaller pinnacles near the coast, the soundings prove more reliable, with freshwater lens expected at 23 m on the high side with 20-m thickness, and closer to the coastline at 12 m below ground level where the thickness diminishes to 12 m.

Ban011  Police Station high (25 m +MSL)
Ban012  Police Station low (8 m +MSL)

On the road near the police station on the western side of the island, two soundings were carried out with similar results. At 22 m below ground level on the high site a thickness of 24 m of freshwater is interpreted, and at the lower site at a depth of 14 m below ground level is a freshwater layer with interpreted thickness unreliable.

Ban013  Factories (22 +MSL)

The resistivity curve is largely distorted by the occurrence of metal pipes and electricity wires near the main phosphate factories, and no reliable thickness can be extracted.

Ban014  East Road south (52 +MSL)

The last sounding shows at 50 m below ground level a freshwater lens with a thickness of 30 m.

From these interpretations we can conclude that the resistivity curves have all to be treated with great caution, and that the best fits only provide a slight indication of the occurrence of freshwater lenses. Interpretation of geo-electrical soundings should always be calibrated with borehole logs. Since no boreholes were ever drilled to the water table on Banaba, a drilling programme will be a prerequisite for any further study. See chapter 3 for further recommendations.

Figure 2.2 shows a schematic cross-section through the island, indicating the extent of the freshwater lens, the mixing zone and the saltwater as interpreted from the soundings. See also Map 1. The heights indicated might differ from the cross-section because of projections. The top of the freshwater lens would be expected to be just above mean sea level (MSL).
Any future drilling should preferably occur somewhere at an accessible site located far enough from the coastline so that the freshwater lens is of sufficient thickness.

### 2.2.2 Speleology

With no surface water on the island, caves played an important role in the survival of the Banabans. Because the caves or bangabangas were considered sacred, only females were permitted to enter them. Many of these caves were destroyed by phosphate mining in later years.

A cave system was visited; it consists of three pools with freshwater. The existence of caves containing freshwater has been known by Banabans for years. The caves are locally known as Bangabanga. During World War II Japanese soldiers exploited this water resource to survive the drought by installing extraction pipes deep in the caves.

The cave that was visited is situated ca. 250 m northeast of the stockpile as is shown in Map 1. The water resource at this location consists of three perched water bodies at a depth of circa 12 m below the surface and 50 m above the true groundwater level. Rainwater enters through fissures in the limestone and forms a cascade and interconnected pools. Samples were taken for further analysis on water quality and possible contamination by mining activities. Electrical conductivity readings of 200 µS/cm and a pH of around 8 indicate that the water might be potable. Stalactites and stalagmites are abundant in the caves and the weathering residue terra rossa (i.e. red earth) can be found just above the water level.

Table 2.4 shows the conductivity of samples P1, P2 and P3 taken on 14 August 2000.

<table>
<thead>
<tr>
<th>Pool</th>
<th>area (m²)</th>
<th>average water depth (m)</th>
<th>total volume (m³)</th>
<th>EC (µS/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>50</td>
<td>0.20</td>
<td>10</td>
<td>169</td>
</tr>
<tr>
<td>P2</td>
<td>80</td>
<td>0.40</td>
<td>32</td>
<td>213</td>
</tr>
<tr>
<td>P3</td>
<td>200</td>
<td>1.30</td>
<td>260</td>
<td>220</td>
</tr>
</tbody>
</table>

The sample from the second pool was analysed in the laboratory of the Institute of Applied Sciences at the USP in Suva, Fiji. The results are shown below.
The source might provide useful drinking water in emergency situations if the extraction system can be replaced. Water levels in the pools were measured and compared with the levels taken during a visit in 1996. The total volume of the three pools will amount to around 300 m$^3$, which could serve a population of 400 people for a period of around 25 days.

### 2.2.3 Springs

An attempt was made to locate and sample several springs situated at or near the coastline. The locations of two former springs are indicated on Map 1. Unfortunately these appeared to be dry at the time of the fieldwork or had disappeared altogether in recent years. In wetter periods these and other springs should be located more precisely and carefully mapped, and where possible sampled, in order to obtain information on the occurrence of groundwater and seepage at the discharge point and water quality.

### 2.2.4 Groundwater recharge

Each groundwater reservoir has a certain recharge and, on average, an equal discharge. Recharge and discharge are flows of groundwater and can be expressed in volume per time per specific area (mm/year). Banaba island receives recharge from rainfall percolating through the limestone fissures down to the groundwater lens. Almost the whole island can be considered as recharge area because no permanent surface water exists, and direct runoff to the sea is almost negligible. The recharge is assumed to be uniform throughout the island with the exception of the low-lying area nearest to the ocean.

![Water Balance](image)

**Figure 2.3 Freshwater-saltwater relationship under oceanic island (from: Falkland, 1992)**

A Water Balance can be used to estimate the groundwater recharge using the following formula:

\[
R = P - R_o - \text{ET}_{\text{act}} + \delta S
\]

where
- $R$ = recharge (mm/day)
- $P$ = precipitation (mm/day)
- $R_o$ = runoff (mm/day)
- $\text{ET}_{\text{act}}$ = actual evapotranspiration (mm/day)
- $\delta S$ = storage change (mm/day)

**Precipitation**

The average annual rainfall derived from 1951-1980 data is 1771 mm.
Runoff

As mentioned before, surface runoff on Banaba is limited and only an arbitrary figure can be provided. The area contributing to runoff is estimated as that percentage of the catchment with elevations below 5 m AMSL. This area constitutes around 6.5 % of the total area of Banaba and, with an annual rainfall of 1771 mm, this results in a runoff value of 115 mm.

Evapotranspiration

Actual evapotranspiration (ET\textsubscript{act}) is a function of the potential evapotranspiration (ET\textsubscript{pot}) and depends on the soil moisture and vegetation. Since no data are available on the soil moisture conditions, and since hardly any vegetation exists on Banaba, it will be difficult to provide a good estimation for ET\textsubscript{act}. Two methods were applied in this study:

Method 1

Actual evapotranspiration equals potential evapotranspiration when soil water available to the crop is adequate. This situation will most likely not apply for most of the time in Banaba which has only sparse vegetation and very localised rainfall with high intensities. To arrive at a reasonably reliable figure, we assume the actual evapotranspiration to be equal to 75 % of the potential evapotranspiration.

Potential evapotranspiration can be calculated via:

\[ ET_{pot} = ET_o \times k_c \]

where \( ET_o \) = reference evapotranspiration for grass
\( k_c \) = crop coefficient

A fixed crop coefficient of 0.8 (RH (Relative Humidity) > 70 %) is applied for the total growing period (Doorenbos & Kasam, 1986).

The reference evapotranspiration, in turn, can be derived from:

\[ ET_o = E_{pan} \times k_{pan} \]

where \( E_{pan} \) = pan evaporation
\( k_{pan} \) = pan coefficient

The pan coefficient (\( k_{pan} \)) is estimated at 0.85 under conditions of high humidity (i.e. RH\textsubscript{mean} > 70 %) and light winds (< 175 km/day) (from Doorenbos & Kasam, 1986). Pan evaporation data are available for Tarawa (1981-1986) which has a climate similar to that of Banaba (Burgess, 1987).

The table below shows the results of the calculations and provides monthly values for \( E_{pan} \), \( ET_o \), \( ET_{pot} \) and \( ET_{act} \).

\begin{table}[h]
\centering
\begin{tabular}{lcccccccccccc}
\hline
\textbf{Month} & JAN & FEB & MAR & APR & MAY & JUN & JUL & AUG & SEP & OCT & NOV & DEC & TOT \\
\hline
\textbf{\( E_{pan} \)} & 205 & 201 & 218 & 191 & 183 & 167 & 174 & 204 & 208 & 212 & 193 & 188 & 2344 \\
\textbf{\( ET_{pot} \)} & 139 & 137 & 148 & 130 & 124 & 114 & 118 & 139 & 141 & 144 & 131 & 128 & 1594 \\
\textbf{\( ET_{act} \)} & 105 & 103 & 111 & 97 & 93 & 85 & 89 & 104 & 106 & 108 & 98 & 96 & 1195 \\
\hline
\end{tabular}
\caption{Mean monthly evaporation and evapotranspiration (mm)}
\end{table}
Method 2

Potential Evapotranspiration can also be calculated on the basis of Fleming’s (1987) formula derived for Tarawa. The empirical relationship takes the form:

$$ET_{pot} = 115 + \frac{(300 – P)^2}{1286}$$

where

- $ET_{pot}$ = potential evapotranspiration (mm/month)
- $P$ = precipitation (mm/month)

Using the rainfall data from Banaba (Table 1.1), the following estimates can be provided for the potential evapotranspiration, assuming that the actual evapotranspiration is equal to 75% of $ET_{pot}$.

| Table 2.7 Estimated monthly potential evapotranspiration (mm) |
|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOT |
| P | 271 | 226 | 172 | 144 | 114 | 103 | 118 | 101 | 89 | 110 | 108 | 215 | 1771 |
| $ET_{pot}$ | 116 | 119 | 127 | 133 | 142 | 145 | 141 | 146 | 150 | 143 | 144 | 121 | 1627 |
| $ET_{act}$ | 87 | 89 | 95 | 100 | 107 | 109 | 106 | 110 | 113 | 107 | 108 | 91 | 1220 |

The two methods give comparable results, values for $ET_{act}$ being 1195 and 1220 mm.

Storage change

If the water balance is made for an average one-year period, the storage change can be assumed to be zero.

Water Balance

To arrive at a conservative number for the recharge, a value of 1220 mm/year was used for the actual evapotranspiration.

$$R = P – R_0 – ET_{act} + δS$$

$$R = 1771 - 115 - 1220 = 436 \text{ mm}$$

Thus the recharge on Banaba can be estimated for the 1951-1980 period at 436 mm per year, equal to 24.6% of the average precipitation. In the hydrogeological study on Nauru (Jacobsen & Hill, 1988) a fixed percentage of the rainfall (40%) was adopted for the recharge ratio which resulted in a value of 796 mm. If for Banaba, with a similar extensive bare karrenfeld surface, a ratio of 40% is applied, the recharge amounts to 708 mm.

Burgess (1987) gives the results of a water-balance study for Banaba using a soil moisture balance representative for coral soils (available soil moisture = 140 mm). Since the soils on Banaba are not well developed the results should be treated with caution.

Table 2.8 Water balance Banaba 1971-1985 (mm)

| Table 2.8 Water balance Banaba 1971-1985 (mm) |
|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | TOT |
| $ET_{pot}$ | 160 | 153 | 172 | 150 | 149 | 141 | 143 | 156 | 184 | 178 | 180 | 161 | 1927 |
| P | 272 | 219 | 213 | 161 | 122 | 129 | 151 | 130 | 89 | 125 | 113 | 253 | 1977 |
| WP | 33 | 38 | 55 | 56 | 49 | 33 | 33 | 53 | 92 | 87 | 83 | 51 | 663 |
| ND | 7 | 7 | 11 | 13 | 12 | 8 | 8 | 11 | 16 | 16 | 15 | 11 | 135 |
| $R + R_0$ | 141 | 116 | 110 | 76 | 24 | 7 | 32 | 44 | 21 | 13 | 25 | 86 | 695 |
| NR | 5 | 4 | 4 | 3 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 3 | 29 |

where

- $ET_{pot}$ = potential evapotranspiration (mm/month)
- $P$ = precipitation (mm/month)
In this water balance the runoff can be considered as recharge plus actual runoff since almost all surface storm flow will drain eventually via fissures in the limestone to the groundwater body. When \( R + R_o = 695 \text{ mm} \) and actual runoff is 6.5 % of the rainfall, a recharge rate can be obtained of: 695 \( - 0.065 \times 1977 = 566 \text{ mm} \) equal to 28.6 % of the rainfall in the period 1971-1985.

Other methods to estimate recharge include chloride mass-balance method. Because of the conservative nature of the chloride ion (\( \text{Cl}^- \)) it is not absorbed by sediment particles, does not participate in chemical reactions and moves through the unsaturated zone at the same velocity as water particles. Evapotranspiration is the only process that concentrates the Cl\(^-\) ion in groundwater. Although no chloride analysis was carried out, the electrical conductivity (EC) measured in the samples of the cave water, representing groundwater (\( \text{EC}_{gw} \)), as well as samples from the water-supply system, representing rainfall (\( \text{EC}_{rf} \)), may provide an indication of the recharge. Hence, when EC values are taken from the deepest cave P3 (Table 2.4), and rainfall from the Fatima church RC 1 (Table 2.12), the following calculation can be made for the recharge:

\[
R (\%) = \frac{\text{EC}_{rf}}{\text{EC}_{gw}}
\]

\[
R = \frac{54}{220} = 24.5 \%
\]

This result compares very well with the other estimates made above, with the water balances 24.6 % and 28.6 %.

### 2.2.5 Safe yield

The optimum withdrawal of groundwater resources can only be a part of the recharge. It is advisable to restrict the withdrawal to a certain percentage of the recharge. If a value for the safe yield is taken of 30 %, as is commonly applied (Meinardi, 1991), with a conservative recharge value of 436 mm/year the maximum withdrawal amounts to: 436 mm \( \times 0.30 = 130.8 \text{ mm/year} \). Considering the total surface area of Banaba (6 km\(^2\)), this amount will equal 784 800 m\(^3\)/year or 2150 m\(^3\)/day.

However, considering the fracturing of the limestone, and the extensive cave systems at or around mean sea level where the freshwater lens is expected, a value of 10 % for the maximum withdrawal might be more appropriate, resulting in an amount of 261 000 m\(^3\)/year (equal to 716 m\(^3\)/day or 8 L/s). This amount is still more than 50 times the projected drinking-water demand in 2004 (see Table 1.3).

The safe yield is defined as the amount of water that can be withdrawn from a groundwater basin without producing an undesired result such as saltwater intrusion or inducing transport of contaminated water.

A critical aspect of preventing groundwater pollution is the identification of the recharge area of the aquifer. The test drilling sites should be located such that pollution from former mining equipment or work sites is minimised (i.e. away from the stockpile and industrial area).
2.3 Rainwater

2.3.1 Roof Catchment Survey

A survey was carried out in which all houses and facilities on Banaba were visited and mapped using the Global Positioning System (GPS), to assess the current state of the water-supply system, to map the existing roof catchments and to assess the potential for future improvement and development. Additionally, a small social survey was carried out in several households to obtain information on the current water demand, existing water practices and water availability.

The water-supply scheme that exists in Ooma consisted of a large catchment area formed by the hospital buildings located 60 m AMSL. Water was collected from the hospital roofs and stored in three reservoirs. It was further distributed by gravity to tanks and reservoirs serving the residential area at lower elevations. This source was supplemented by roof catchments and storage tanks at almost every individual house.

The residents of Tabiang and Tabwewa were totally reliant on their own roof catchments and storage tanks. The water supply to the industrial area near the harbour was mostly dependent on shipped water stored in the large BPC reservoirs.

In order to facilitate the survey, a distinction was made for different types of houses, buildings or constructions. Five types of property could be classified as can be seen in Table 2.9 and photographs 36-40 as can be found in Appendix 7e.

<table>
<thead>
<tr>
<th>No</th>
<th>Type</th>
<th>Surface area (m²)*</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td>Industrial building</td>
<td>1000</td>
<td>Shed or barn, tiled or galvanised iron roof</td>
</tr>
<tr>
<td>2)</td>
<td>Flat</td>
<td>400</td>
<td>Two storeys, 40 apartments, flat galvanised-iron roof</td>
</tr>
<tr>
<td>3)</td>
<td>Large house</td>
<td>180</td>
<td>Tiled roof</td>
</tr>
<tr>
<td>4)</td>
<td>Small house</td>
<td>60</td>
<td>Flat roof</td>
</tr>
<tr>
<td>5)</td>
<td>Tank</td>
<td>–</td>
<td>Reservoir or storage facility</td>
</tr>
</tbody>
</table>

*approximate area only

At each site, the type of building was determined as well as the presence of a roof, gutters, tanks (including the material and capacity) and tank cover. A database has been attached to a Geographical Information System (GIS/Mapinfo) containing information on the current state of the roof catchments. The data can be found in Appendix 4 with the areas and storage capacity at each site. Map 2 shows the houses and buildings on Banaba with the types indicated in different colours and the numbers of the buildings indicated in red.

Type 1
The industrial buildings (photo 36) have no potential catchment area considering their state of decay and the fact that pressure pumps are needed to lift the water to the higher residential areas. Only the roofs of buildings nos 47 and 48 could potentially be used to collect water, but installation of tanks and gutters at these sites is needed. It is recommended to remove all the galvanised iron and PVC gutters which are in a reasonable condition and use them for rainwater harvesting at large houses in Ooma.

Type 2
The pre-fabricated flats (photo 37) are all of the same shape and size (10 m x 40 m) and consist of two-storey, reinforced-concrete apartment blocks (nos 68–104 and 115–136). Adjacent to each flat, eight water tanks with a capacity of 5 m³ are connected by gutters to the aluminum roof. The majority of the apartments are unoccupied while a few serve as residence for only one or two families including livestock (pigs). The majority of the tanks are
in a state of collapse, and the concrete covers are mostly dilapidated, resulting in water being infested with algae and providing a breeding ground for mosquitoes.

**Type 3**
The larger houses (e.g. photo 38) typically have A-shaped roofs with gutters connected to one or two large ferro-cement reservoirs (ca. 20 m³). Additionally, a 1-m³ steel tank is commonly placed on top of a steel construction, to supply the water under pressure via PVC pipes to the house. More recently, 5-m³ PVC tanks have been imported to replace ferro-cement tanks that have collapsed altogether.

**Type 4**
The smaller houses (e.g. photo 39) are only partly used as catchment area. The houses located between the hospital and the industrial area (nos 7 and 15-20) receive water mostly via the reticulated system originating from the hospital tanks (no. 6). The smaller houses in the outskirts use small PVC tanks or steel drums to collect water from the metal roofs.

**Type 5**
The reservoirs and tanks on the island are classified as type 5 and are mainly made of ferro-cement or Steel (e.g. photo 40). Capacities range from 20 m³ (small tanks, photos 28, 41) to 4380-m³ large steel reservoirs which were used to store ballast water from BPC ships (photo 17).

Although the hospital buildings (no. 5) have lost their purpose for medical activities, they still serve as a large rainwater catchment. The premises is inhabited by four families only, and consists of 16 buildings with asbestos roofs. The effect of asbestos on the quality of the water and possible contamination is not known yet, and this should be carefully monitored. The four tanks with a total capacity of 1488 m³ (no.6) connected to the hospital roofs are leaking, and the pipes of the reticulated system need maintenance (photos 32, 33, 34).

The survey showed that the roofs of all the buildings on Banaba have a potential catchment area of 36 000 m², of which 22 000 m² is actually collecting water by gutters. If the surface area of the flats is subtracted this results in 7000 m². This total surface can capture 700 m³ in a month with 100 mm rainfall.

The majority of the tanks in the industrial area are considered useless. The potential remaining storage capacity is 17 000 m³ including the three large reservoirs (no. 114). If these reservoirs and some smaller ones are excluded, a total storage capacity of 3900 m³ exists, inclusive of 1488 m³ for the four tanks at the hospital (no. 5).

A database has been created with an indication of the storage capacity, and actual roof catchment area with gutters, for every building. The Database is linked to a GIS for Banaba so that properties where improvements are needed can be visualised. Appendix 4 contains the data for the more than 150 buildings and houses on Banaba.

### 2.3.2 Required roof catchment area and storage capacity

The following computations were made to calculate the required roof catchment and storage to meet estimated water demand.

Population (August 2000): 500  
Water demand: \( Q = 36 \text{ liters/day/person} \) (see paragraph 1.5)  
Annual rainfall: 1771 mm  
Evaporation and leakage: 20%  

Projected daily consumption: \( Q = 36 \times 500 \times 1.20 = 21600 \text{ L} = 21.6 \text{ m}^3 \)
**Required roof catchment area:**

Precipitation = 1771 mm  
Annual consumption: 365 x 21.6 = 7884 m$^3$  
Required roof catchment area: 7884/1771 = 4452 m$^2$  
Dry period is 4 months (125 days)  
Required storage capacity: 125 x 21.6 = 2700 m$^3$

Dry period is 12 months (365 days)  
Required storage capacity: 365 x 21.6 = 7884 m$^3$

**Table 2.10 Actual and potential roof catchment area and storage capacity**

<table>
<thead>
<tr>
<th>CA (m$^2$)</th>
<th>PCA (m$^2$)</th>
<th>ACA (m$^2$)</th>
<th>PSC (m$^3$)</th>
<th>ACA-2 (m$^2$)</th>
<th>ASC-2 (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>43 300</td>
<td>36 050</td>
<td>22 310</td>
<td>3900</td>
<td>7110</td>
</tr>
</tbody>
</table>

**LEGEND**

CA = Catchment Area (including all houses)  
PCA = Potential Catchment Area (including all houses with roofs)  
ACA = Actual Catchment Area (including all houses with roofs and gutters)  
PSC = Potential Storage Capacity (including all tanks connected to houses with roofs and gutters)  
ACA-2 = Actual Catchment Area (without type 2 houses)  
ASC-2 = Actual Storage Capacity (without type 2 houses)

From these figures it can be concluded that the potential and actual roof catchment area exceeds the required surface of 4452 m$^2$.

The potentially available storage, 3900 m$^3$, is sufficient to overcome a 6-month drought provided that the current system is maintained and repaired for large leakages. If the large BPC reservoirs (no. 114) can be upgraded and used for future storage, there will be sufficient system storage to overcome droughts of 12 months assuming the tanks to be full at the start of a drought (17 000 m$^3$).

A method exists to determine the optimum ratio between storage capacity and roof catchment area. Rainwater-harvesting systems are often designed using some statistical indicator of the rainfall for a given place. When the rainfall is meager and shows large fluctuations, then a design based on any single statistical indicator can be misleading. The programme SimTanka, developed for rainwater-harvesting programmes in India, was used. It takes into account the fluctuations in the rainfall, giving each fluctuation its right importance for determining the size of the rainwater-harvesting system (Vyas, 1996). Since no monthly data were directly available for Banaba, monthly rainfall figures from Nauru were used as input for the SimTanka simulation. Neighbouring Nauru is characterised by similarly fluctuating monthly rainfall although it receives a higher annual precipitation (1994 mm versus 1771 mm for Banaba). Roof-catchment sizes and storage capacities were optimised with different reliability ratios. For the computations the assumptions were made that a population of 500 persons consume 36 L/day per person, that no water is used for agricultural purposes and leakages are to be ignored.

**Table 2.11 SimTanka Simulation for Banaba with Nauru rainfall data (1972-1986)**

<table>
<thead>
<tr>
<th>Reliability*</th>
<th>75 %</th>
<th>85 %</th>
<th>95 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof catchment size (m$^2$)</td>
<td>4410</td>
<td>4410</td>
<td>4410</td>
</tr>
<tr>
<td>Storage capacity (m$^3$)</td>
<td>4129</td>
<td>8035</td>
<td>11383</td>
</tr>
</tbody>
</table>

*Percentage of the time that monthly demand can be met

The simulation shows that a roof catchment size of 4410 m$^2$ would be sufficient, but that the storage capacity has to increase to 4129 m$^3$ to arrive at a 75 % reliability. When data from 1946 until 1986 are used the storage capacity should be 4800 m$^2$ with 4700 m$^3$ storage for a 75 % reliability. A 95 % reliability can even be achieved if BPC tanks are upgraded to their
full potential. In times of drought a desalination unit should be on standby and operational, and a water-conservation scheme should be designed to build-up adequate storage.

Currently the Banaba Administration provides A$12 000 a month to support technicians to work on water management on the island including a carpenter and a driver. In addition, an island community worker assists in the delivery of water by tanker.

2.4 Desalinated water

There were three Reverse-Osmosis Desalination Units on Banaba at the time of the mission. The units were delivered after droughts hit Banaba in 1997/1998. Because of the malfunctioning of the units, the supply of desalinated water had stopped soon after installation, which is proven by the meters that read 72 and 128 working hours only. Engineers from the Ministry of Natural Resources, Works and Energy brought filters and spare parts to repair the units which resulted in two being operational again by the end of the fieldwork. The water from the desalination units is stored in three 5-m³ PVC tanks near the boat harbour (photo 43) and subsequently delivered to individual houses by tanker truck at a cost of A$15 per trip of 2000 litres (photo 42).

2.5 Water-Quality Considerations

Water samples were taken from the existing water-supply system which extracts water from the hospital roof catchment. Samples were also take from the BPC reservoirs and from the desalination units. The results of the analyses can be found in Table 2.12.

<table>
<thead>
<tr>
<th></th>
<th>RC 1 Fatima church (no. 53)</th>
<th>RC 2 Reservoir (no. 33)</th>
<th>RC3 Hospital tank (no. 6)</th>
<th>Banaba House BPC tank (no. 114)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.8</td>
<td>7.5</td>
<td>7.3</td>
<td>7.5</td>
</tr>
<tr>
<td>EC (µS/cm)</td>
<td>54</td>
<td>80</td>
<td>85</td>
<td>264</td>
</tr>
</tbody>
</table>

Since the hospital roof consists mainly of asbestos, the water from this catchment might very well be contaminated and carcinogenic. If the roof catchment system is to be upgraded the roofs should be removed and replaced by galvanised iron.

Concerns were expressed on leaching of heavy metals, such as cadmium, which naturally occur in phosphate deposits. The water samples from the cave underneath the mining area (Table 2.5) proved to be free from cadmium and lead, but additional monitoring should be performed on the occurrence of heavy metals in the groundwater once exploitation takes place. The terra rossa found in the caves indicates that high concentrations on iron (Fe) and other metals can be expected.
3 RECOMMENDATIONS

3.1 Roof catchment

Since the flats are almost uninhabitable, it is recommended to relocate the remaining residents, demolish the flats, and use the aluminum roofs and gutters for upgrading the roof catchments in Ooma or elsewhere. From the total of 59 flats 47 still have a roof and gutters. This amounts to 18 800 m$^2$ of aluminum plate and approximately 1880 m of gutter, which will be more than sufficient to upgrade the roof catchments of residential houses.

The existing water-supply scheme can be upgraded by making use of the galvanised iron roofs and gutters of the 59 prefab flats that should be demolished.

The water-supply system at the hospital can still be upgraded, and it is recommended that the asbestos roofs are replaced by aluminum and that the water tanks are reinforced. A team consisting of a water engineer, a welder, a plumber, a mason and a health inspector should spend a minimum of two weeks to repair and upgrade the system, as has previously been suggested by a mission undertaken by the UN (Win, 1996). Further suggestions to install sand filters and fit all the tanks with handpumps should still be considered, as well as the installation of a zonal system to isolate water that should be used only in times of drought. An estimation was provided for the total cost for gutters and associated fittings at A$53 200 but this has to be recalculated.

If a decision has been made to construct an airstrip on Banaba the planners should consider using the tarmac as a rainwater-catchment area and adjust the design of the airstrip accordingly.

The school in Tabiang needs urgent assistance in upgrading their water supply. The gutters of the school building are missing or broken, and the two water tanks providing water for the children are half broken and their contents polluted. Although a survey of the school by the Public Works Department was done in 1997 recommending improvement of the situation, nothing has been achieved since then.

3.2 Drilling programme

A realistic assessment of the groundwater reserves on Banaba can only be achieved if test drilling is undertaken. The complication of drilling through cavities has been reported in Jacobsen & Hill (1988) for Nauru.

In order to avoid saltwater intrusion that affects the freshwater lens, it is suggested to locate test drillings in the centre of the island. Although the drilling will be considerably difficult, the location of water reservoirs at high altitude makes a reticulated system using gravity possible, with obvious advantages for further distribution.

The proposed drilling programme should consist of one production borehole and two observation boreholes. The latter holes will consist of multi-level piezometers to enable monitoring of vertical salinity profiles.

In a similar situation on Nauru it is suggested by the driller to use piezometers consisting of four PVC tubes, each with a diameter of 32 mm. If possible it is recommended that the shallowest tube be a 50-mm PVC tube in order to accommodate a suitable water-level and salinity sensor (Falkland, 2000). It is likely that the drilling will take approximately two weeks to complete, excluding establishment and mobilisation time.

The following recommended workplan was derived from the draft proposal that Ecowise Environmental produced for the drilling programme on Nauru. It is advised that any drilling on
Banaba would occur after the exercise in Nauru so that difficulties can be overcome and experiences carried over.

A water-balance model using daily rainfall and estimates of evapotranspiration should be used to generate a sequence of estimated monthly recharge values. This model should be based on one which has been used in numerous water-balance studies of small islands and should use all available daily rainfall data from 1901 to 1980 and recent data from the 90’s. If evaporation or climatic data are available, they should also be used to estimate potential evapotranspiration for use in the model.

To assist with the recharge study, it is further recommended that two automatic (tipping-bucket) raingauges and two water-level/salinity sensors be installed in the middle of the island. All would be equipped with data loggers and would be set to record data at resolutions of a few minutes.

The analysis of rainfall and water-level/salinity data will enable the recharge to groundwater to be more accurately assessed. In particular, the response time between rainfall and groundwater-level increases (and salinity decreases) can be determined. This will help in calibrating the water-balance model to estimate the monthly series of recharge values.

The sequence of work would typically be:

- estimate monthly recharge using a recharge model that has been used for a number of small-island studies, but using actual and estimated data;
- develop and calibrate the groundwater model SUTRA against actual data; and
- model the effect of various pumping rates on the freshwater lens.

3.3 Groundwater monitoring program

A groundwater monitoring program should be developed including:

- Salinity monitoring of groundwater in the observation and production boreholes. The salinity of the water from the production well should be measured initially each week, and later this could possibly be reduced to every two weeks or month, depending on results obtained and the dynamic response and time lag of the aquifer to recharge events. The observation boreholes should be monitored every month initially, but based on experience elsewhere, this can probably be reduced to once every three months after a few months of monitoring.
- Bacteriological monitoring. There are no facilities on the island to conduct standard tests (total coliforms and faecal coliforms) and portable laboratory equipment will need to be purchased.

Based on current knowledge of the island and monitoring programs that have been established on other Pacific Islands, preliminary equipment requirements for ongoing monitoring are recommended as follows:

- A portable salinity (electrical-conductivity) meter should be purchased for field use. A suitable instrument which has been widely tested in other island environments would cost approximately A$800 (TPS WP84).
- A water-level measuring device (‘dipper’) for measuring water level in the observation well tubes. This should be capable of measuring to 70-m and hence a 100-m instrument will be required. It should be equipped with light and buzzer to indicate water level once the tape has reached the required level. The approximate cost of a suitable, robust dipper is approximately A$800 (Geotest 100-m dipper).
- A flow meter should be installed on the outlet pipeline from the proposed production pump. The approximate cost of a 50-mm Kent meter with facility for data logging is A$600.
• Tipping-bucket raingauge with in-built data logger, to be sited in the centre of the island so as to accurately measure rainfall input at a time resolution of minutes. The approximate cost per unit is A$800.
• Water-level and salinity sensors/data logger with associated communications cable to be used for detailed study of the effect of pumping on the underlying freshwater zone. Approximate cost per unit is A$5000 (Greenspan Pty Ltd).
• A portable computer will be required to download the loggers. Downloading, editing and checking of data from the water-level and salinity recorders and tipping-bucket raingauge should occur every month. A$1500 (Psion Workabout).

Input by a water-resources consultant will be required for procurement, installation and training in the use of the equipment.

The tops of production and observation borehole casings will need to be accurately surveyed to obtain levels (to within +/- 20 mm) above mean sea level (MSL). This will allow measurements of groundwater water levels (relative to tops of borehole casings) to be measured relative to MSL. These data will provide additional useful information about the nature of the freshwater lens.

A number of inputs would be required from the Government of Kiribati to enable the investigations to be conducted and to install any water-supply scheme. A preliminary list of requirements is given below:
• All available meteorological data.
• Survey data including benchmarks and reduced levels (relative to MSL).
• Former water and sanitation reports.
• Establishing regulatory framework including water-related administration, legislation and pricing aspects.
• Assistance with conduct of community consultation meetings.
• Funding infrastructure repairs.

Further information may be required during the course of the investigations.
4 CONCLUSIONS

4.1 Roof catchments

The water-supply system on Banaba can still be upgraded, and it is recommended that the asbestos roofs of the hospital are replaced by aluminum and that the water tanks are reinforced.

Since the flats are almost uninhabitable it can be recommended to relocate the remaining residents, demolish the flats, and use the aluminum roofs and gutters for upgrading the roof catchments in Ooma or elsewhere.

A team consisting of a water engineer, a welder, a plumber, a mason and a health inspector should spend a minimum of two weeks to repair and upgrade the system. Those repairs should provide sufficient catchment area and storage for a 75 % reliability of monthly water supply. Incorporating the BPC tanks into the system (which requires repairs and installation of pumps) would increase the reliability to even as much as 95 %.

4.2 Groundwater

Water existing in caves might be useful as drinking water in emergency situations if the extraction system can be replaced. The total volume of the three investigated pools will amount to around 300 m$^3$, which could serve a population of 400 people for a period of around 25 days.

A realistic assessment of the groundwater reserves on Banaba can only be achieved if a test drilling is undertaken. A workplan to execute the test is provided in 3.2 and 3.3. However, a preliminary estimate of the safe yield indicates that 10 % of recharge [where recharge = 24 % of precipitation] would provide 50 times the estimated water demand (716 m$^3$/day compared to 21 m$^3$/day), i.e. more than an order of magnitude greater. At least initially, the option to assess groundwater seems reasonable. Its exploitation may however require careful consideration, with low pumping rates used to minimise saline up-coning.

Springs should be located more precisely and carefully mapped and where possible sampled, in order to obtain real information on the occurrence of groundwater and seepage at the discharge point and its quality.

4.3 Desalination

Two of the desalination units were repaired by staff of the Ministry of Natural Resources, Works and Energy during this visit after having been idle for a long time. It is recommended that an assessment of suitable emergency desalination systems be carried out and that timely maintenance of the systems be secured. The units should be connected to the reticulated system to allow use of the storage available.
5 REFERENCES


Dale, D., 1986, Coral Island Hydrology, DSIR, Commonwealth Science Council


APPENDICES

Appendix 1: SOPAC Task Profile

Appendix 2: Contacts

Appendix 3: Aerial Photograph

Appendix 4: Roof catchment survey

Appendix 5: Geophysical Methodology (David Scott SOPAC Miscellaneous report 354)

Appendix 6: Geophysical Modelling Data

Appendix 7: Photos

Appendix 8: CD ROM of Digital Images
Appendix 1

SOPAC Task Profile
Banaba Feasibility Study on Groundwater Resources

KIRIBATI

Task: KI 1999.022  SOPAC Unit: Water Resources Unit

Task: KI 1999.022  SOPAC Unit: Water Resources Unit

Completed

Proposed: 27-May-99  Started: 01-Aug-00  Cancelled:
Approved: 31-Oct-99  Deferred: 01-Mar-01

Objectives:

Assessment of the water resources of Banaba Island.

Proposed - A geological map, sections and accompanying reports.
Output - Co-ordination of data relating to water supply and civil engineering.
- Recommendations for next phase of the study - whether further detailed study is needed or not.

Background:

Detailed assessment of Banaba's groundwater resources have been called for following recent droughts and in response to the growing interest in the possibility of rehabilitation and resettlement of the island. Fresh water resources are limited and pose a constraint to any form of development.

A field mission has been completed in Banaba in August 2000 to map surface geological units and undertake an electrical resistivity survey of selected sites to identify possible fresh water lenses. A mission technical report of findings is currently being written up.

Equipment Needs

To be advised.

Work Plan:

- Literature research and rainfall data collection plus other water-related data.
- Site survey
  - Map surface geological units and describe the different designated units and correlate with the aerial photograph
  - Undertake an electrical resistivity survey of Banaba selected sites
  - Conduct a social survey - interview people in water consumption issues plus other social water-related issues
- Office work
  - Analyse the ER results and determine the best estimate for the volume of the existing groundwater resources
  - Evaluate the social water-related issues
  - Identify alternative potable water sources if not enough groundwater resources found on Banaba for instance construction of water tank, desalination consideration.
  - Make recommendations on further work if needed with details
- Report writing

Information:

Clients: Kiribati Government

SOPAC Personnel:
Harald Scholzel, Economist Civil Engineer
Marc Overmars

Other Personnel:
PWD Assistant Water Engineer
PWD Hydrogeologist

Outcomes


Publications:

Articles:

Presentations:

Other:

Review Evaluation:

Funding Sources:
Kiribati Government
SOPAC
Appendix 2

Contacts
The following people were consulted or were assisting during the visit to Banaba:

Kaburaro Ruaia, Permanent Secretary
Naomi Atauea, Moiua Aroito, Moluongo, Tabuaki, Teitia, Peter Iabeta
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Baranika Etuati
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Aren Baoa
Video Producer/Trainer
The Secretariat of the Pacific Community
Regional Media Centre
Private Mail Bag
Suva, Fiji Islands
Tel: (679) 370 733
Fax: (679) 370 021
Appendix 3

Aerial Photograph
Appendix 4

Roof Catchment Survey Data
## APPENDIX 4  Roof Catchment Survey

* The numbers of the properties are indicated on Map 2

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Total Units: 43300 m², 36050 m², 22310 m², 3900 m³, 7110 m², 2137 m³

**LEGEND**

T = Type (1,2,3,4 or 5)
R = Roof existing (Y/N)
G = Gutter (Y/N)
WT = Water Tank (number)
WTT = Water Tank Type (FC=Ferro Cement; S=Steel; P=PVC; N=none)
C = Cover (Y/N)
Cap = Capacity (in m3)
CA = Catchment Area (in m2)
PCA = Potential Catchment Area (in m2)
ACA = Actual Catchment Area (in m2)
PSC = Potential Storage Capacity (in m3)
ACA-2 = Actual Catchment Area without type 2 houses (in m2)
ASC-2 = Actual Storage Capacity without type 2 houses (in m3)
Appendix 5

Geophysical Methodology

(SOPAC Miscellaneous report 354 by Scott, D., 1999)
Appendix 6

Geophysical Modelling Data
## Geophysical Modelling Data

### Offset Wenner Readings Banaba (ohm*m)

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### Offset Wenner Soundings

![Offset Wenner Soundings](image)

### Elevation Offset Wenner Soundings

![Elevation Offset Wenner Soundings](image)

- Ban001 Bukinterike North Road
- Ban002 Sportsfield
- Ban003 Stockpile
- Ban004 Road from Stockpile to Sportsfield
- Ban005 Road from Sportsfield to Hospital
- Ban006 Sydney Point
- Ban007 East Road north
- Ban008 East Road center
- Ban009 Airstrip high
- Ban010 Airstrip low
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