Location of fresh-water supplies on Lifuka, Ha'apai Group, Kingdom of Tonga

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Abstract Most of the 3000 inhabitants of Lifuka live in four contiguous villages and have been supplied with water from a well in the middle of the island since 1976. On commencement of operation, the water rapidly became too salty for human consumption. The majority of the island is low-lying and consists of highly porous, uplifted coral limestone. Hydrogeological assessment found the fresh-water lens to be very thin and strongly influenced by tidal mixing, sea level changes and drought. Comparison with the morphology of Bermuda led a search for improved water quality on the western side of the island using geophysical methods and installation of salinity monitoring wells. A younger deposit of shelly, coral sand on the leeward side has a lower permeability, with a thicker fresh-water lens and is under less influence of tidal mixing with salt water.

INTRODUCTION

Lifuka is the largest centre of population in the Ha'apai Group of islands in the Kingdom of Tonga. It lies to the southeast of Fiji and to the south of Western Samoa at 174°21'W 19°49'S. Most of the island's 3000 inhabitants live in four contiguous villages on the western (leeward) side of the island. Water supply to the villages comes from a single well (No. 46, Fig. 1) in the centre of the widest part of the island. The well was constructed in 1976 and shortly after it commenced pumping, the water became too salty for human consumption.

The well water is used mainly for washing, with drinking water coming from rainfall collected in cement tanks and old cisterns.

GEOLOGICAL SETTING

The majority of the island is low-lying and consists of a highly porous, uplifted coral limestone. It occupies a geological block along the Tonga Ridge which is at the tectonic boundary of the Australia-India Plate and the subducting Pacific Plate. Tilting of the block resulted in an uplifting of the eastern coast.

Covering the higher parts of the island is a volcanic ash soil (andesitic tephra), up to three metres thick and probably derived from the chain of volcanic islands to the west, despite the prevailing southeast trade winds. The western coast area has a younger deposit of shelly, coral sand which is weakly consolidated to a maximum thickness of about five metres. The villages are built over the area of coral sand.

The original vegetation has long since disappeared and been replaced with coconut palms, with some mango and breadfruit trees in the garden plantations. The population lives on subsistence farming, fishing and the production of handicrafts.

CLIMATE AND HYDROLOGY

The Ha'apai group of islands has a sub-tropical climate and lies in a relatively dry zone of Tonga, between the region of influence associated with the South Pacific Convergence Zone over northern Tonga, and rainfall associated with the jet stream and other extra-tropical weather features in southern Tonga (Thompson, 1986). Rainfall averages about 1716 mm per year (1947-1990) and there is a marked seasonality; a wet season from November to April and a dry season from May to October (PPK Consultants Pty Ltd, 1991).

The rainfall is variable from year to year ranging from 826 mm (1983) to 2641 mm (1957). Lifuka can expect tropical cyclones almost every year, frequently with a deluge of rain. In contrast, during the "El Niño" phenomenon, severe droughts have affected the island.

The estimated Penman potential evapotranspiration is 1548 mm per year (Thompson, 1986). The estimated recharge on Lifuka based on a water balance

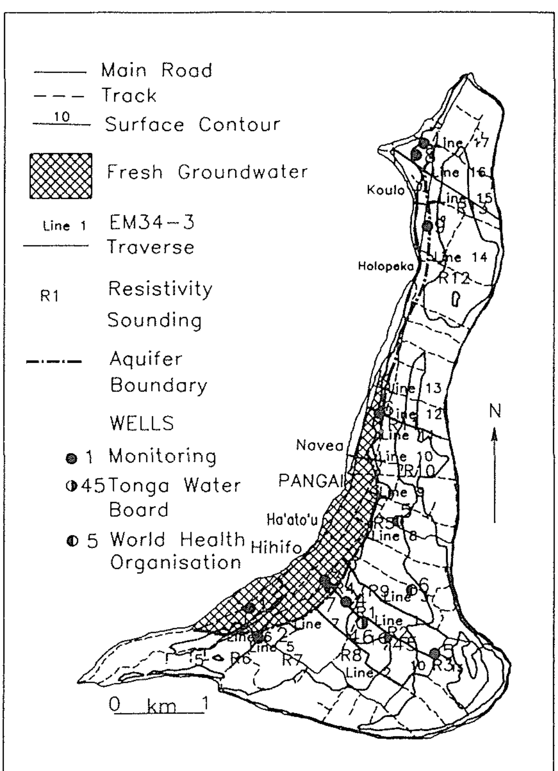

Fig. 1 Hydrogeology of Lifuka.

simulation is 478 mm per year or 28% of the mean annual rainfall (Falkland, 1991). Turnover of water in the aquifer is about three years, using an assumed thickness of fresh water of 5 m.

The high porosity of the soil and the underlying rock preclude the presence of surface water and runoff.

HYDROGEOLOGICAL STUDY

Previous investigation

A study for the World Health Organization (Stoll, 1987), included three test wells drilled to assess the thickness of the fresh-water lens (Nos 5 to 7, Fig 1). Results showed, that over the main part of the island the lens was either only a few metres thick, or entirely absent. Monitoring of water levels in the water supply well showed a tidal response of 0.3 m, however, in a private well in the village close to the sea, the fluctuation was only 20 mm.

At the beginning of the current study the author's attention was brought to the similarities between the islands of Lifuka in Tonga and Bermuda in the Caribbean (Vacher, 1978). In each case, two different geological formations resulted in markedly dissimilar aquifer properties. With sufficient knowledge of the aquifer properties and distribution, wells in both cases could be selectively placed to take advantage of the formation with the lower susceptibility to salt-water intrusion.

Well census

The investigation commenced with a census of all wells on the island resulting in a preliminary plan of the distribution of fresh water around the villages. However, nothing was known of the salinity pattern between the villages and the pumped well which had turned salty, apart from the WHO salinity profile wells.

Geophysical study

Two geophysical methods were employed to study the distribution of the fresh water under the island. These were; electromagnetic traversing and resistivity using vertical electrical soundings.

Electromagnetic traverses were carried out along east-west tracks (Fig. 1) using an EM34-3 instrument with 10 and 20 m coil separations. Readings were taken at 10 and 20 m intervals, respectively. An abrupt change in conductivity readings was apparent on many of the lines, (e.g Fig. 2), where readings changed in one or two stations from less than 20 to about 60 mS m^{-1}. A line connecting the transition points on the map showed the demarcation between the two concealed aquifer types, viz. coral limestone with salty water and weakly lithified sand with fresh water.

Comparison between the geophysical map of aquifers and the soil map of Lifuka (Wilson & Beecroft, 1983) showed a correlation between soil type and aquifers

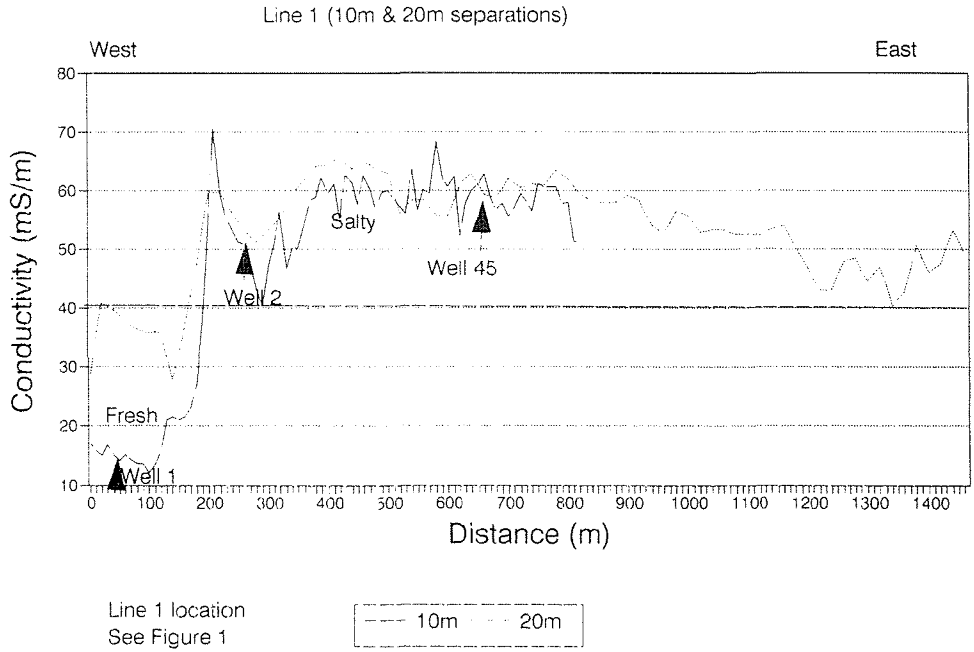

Fig. 2 Lifuka EM34-3 survey.

(Fig. 3). On closer inspection it was found that in some localities north and south of the villages the boundary between aquifers was expressed as a slight ridge 1-2 m high. The small ridge is possibly an eroded palaeo-shoreline of the island which was subsequently partly buried by deposition of sand and volcanic ash.

The electrical resistivity soundings were carried out in the area of the coral limestone only, due to a lack of suitable sites within and close to the villages. Thus, the results showed no development of a fresh-water lens of measurable thickness.

Test drilling

Several monitoring wells (Nos 1 to 9, Fig. 1) were drilled on each side of the line of the aquifer boundary. These were equipped with tubes at different depths with slots over the bottom 0.3 m of each. Monitoring of electrical conductivity of the water in the slotted section of the tubes confirmed the findings of the geophysical methods. To the west of the line, the fresh-water lens was between 0.5 and 6 m thick. To the east of the line, fresh water was absent or only recorded at the water table.

WELL-FIELD DESIGN

A new well-field to extract a sustainable yield of fresh water for the whole population of Lifuka was designed on the results of the study and the estimated annual recharge (1310 kl day^{-1} km^{-2}). The projected water demand is 132 kl per day at start up,

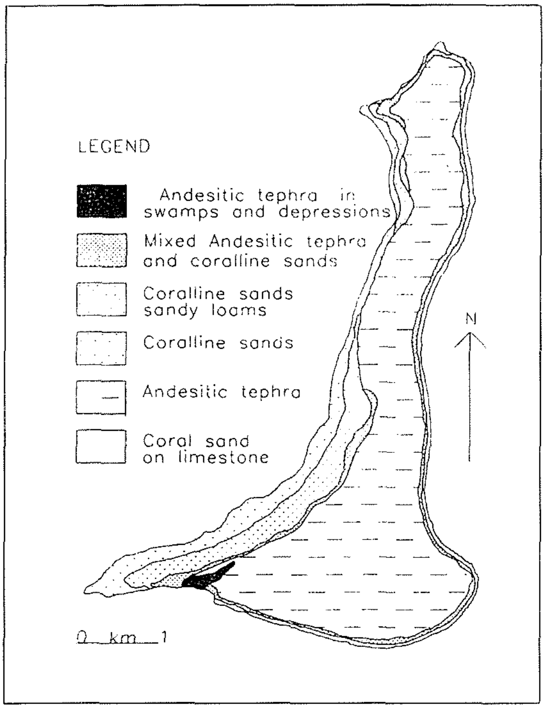

Fig. 3 Soils of Lifuka (after Wilson & Beecroft, 1983).

increasing to 528 kl per day in the year 2011 (PPK Consultants Pty Ltd, 1991). Initially, 12 wells are planned, the final number will depend on a re-assessment of recharge and monitoring of salinity levels.

There was a concern about the location of the wells, as there is contamination of the shallow aquifer beneath the villages. The water table averages only 3-4 m below the houses and most of the toilet facilities are pit latrines. Faecal contamination has been identified by coliform testing, and dumping of refuse has been observed in many of the open private wells.

The new well-field design is a linear arrangement of wells outside the village and parallel to the boundary of the aquifers (Fig. 1). Adequate separation of the wells from the village can be achieved by placing the wells within 100 m of the aquifer boundary. This will reduce the risk of drawing contaminated water from storage below the village.

The existing well was equipped with a pump producing about 3 l s^{-1}. It was observed that at this rate it lowered the water table and allowed salt water to flow upward through the porous limestone in the floor of the well. The initial fresh-water layer in the well was less than 0.5 m thick.

The new well-field design is based on a much lower pumping rate of 0.5 l s^{-1} for each well. Long term pumping rates will be assessed according to the results of an initial salinity monitoring program. The flow rate and salinity are to be tested first on a private well using a solar powered pump.

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