NIUE COASTAL WATER QUALITY AND GROUNDWATER RESOURCES ASSESSMENT

Prepared by

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SUMMARY

The aims of the study were:

1. to conduct a coastal water quality survey, concentrating on the Alofi area where problems with fish poisoning (*Ciguatera*) have been experienced; and
2. to undertake a survey of the freshwater resources on the island, and also to assess whether groundwater was also contaminated with land-based pollution, and acting as the pathway for transmitting this to the coastal waters.

Both these studies were of limited extent but attempted to provide the country of Niue with some initial baseline information and interpretation on their coastal water quality and freshwater resources. It is hoped that the current study will help enable Niue to obtain funding and support to undertake more detailed surveys in these areas.

The coastal water quality survey indicated that land-based activities (e.g. septic tank and stormwater discharges), are impacting upon the coastal water quality. Significant increases in the nutrients, nitrate and phosphate were observed in the vicinity of the main town of Alofi, in comparison to levels at background sites. The link between this land-based pollution and the fish toxicity has not been proved or disproved, but coastal water contamination contributes to the stressing and deterioration of the coastal fishery environment. The toxic dinoflagellate responsible for *Ciguatera* poisoning benefits from degraded reef conditons. Several recommendations for reducing pollutant discharges to the coastal environment and reducing the risk of *Ciguatera* poisoning are made in this report.

Hydrochemical assessment of the karstic limestone aquifer confirms a freshwater lens to exist across the entire island, but its thickness requires further investigation. The aquifer is dominated by karstic flow and nitrate concentrations around Alofi confirm it is highly vulnerable to surficial land use activities, including storm wave over-topping. Conventional sustainable yield assessments suggest annual groundwater abstraction is less than 1% of annual recharge, and therefore the aquifer remains sustainable. Nearly all groundwater is discharged to coastal and possibly submarine springs. However, a more detailed yield assessment suggests the aquifer can only store 3 months of recharge, and given the perceived rapidity of its response to recharge events and subsequent immediate spring discharge, the freshwater lens is likely to reduce considerably during the annual 'dry' period of 3 or more months. Groundwater storage should be adequate to provide at least a minimum of five months water supply through these dry months and therefore in an average year the island should have adequate water resources. In drought years, 8-9 months of no recharge have been estimated, and the lens would be expected to shrink in size accordingly. Individual abstraction wells may become saline during these periods. Historical data indicates individual borehole yields of 0.75 l/s should prevent saline up-coning, but boreholes with larger

yields might create saline up-coning if drawdowns exceed 0.5 m. Finally the lack of data on freshwater lens geometry and responses to recharge events means the lens is not adequately understood. In depth groundwater monitoring should commence as a priority.

BACKGROUND

In recent years, the incidences of fish poisoning (Ciguatera) have been increasing in Niue, particularly around the main settlement and port area of Alofi (Yeeting 2003). A number of people who have eaten fish have become seriously ill. Ciguatera poisoning usually begins developing within 12-24 hours of eating contaminated fish with the victims initially experiencing the gastrointestinal symptoms of numbness and tingling of hands and feet, dizziness, altered hot/cold perception, muscle aches, and low heart rates and blood pressure. In extreme cases, death occurs through respiratory failure. The outbreak was cause for grave concern to the people and Government of Niue and for exploring the reasons for this outbreak. Niue's surrounding coral reefs and ocean are a very important resource for the country, providing food for the local population and economic benefits from fishing and tourism.

The reasons for the recent increases in the incidences of Ciguatera poisoning in Niue are unknown. The dinoflagellate, *Gambierdiscus toxicus* has been identified as the organism causing the poisoning (Yeeting 2003). This organism is found in tropical and sub-tropical regions worldwide and is known to have preference for attaching itself to algae. In Niue the main fish species implicated in the poisonings are grazers (e.g. parrotfish), which strengthens this assumption. Under normal natural situations, algae are present on coral reefs only in limited amounts. However, increased nutrient levels can help lead to algae becoming dominant over corals. Disturbances such as cyclones and coral bleaching events, and freshwater inputs, may also kill corals, which opens up substrate for algal colonization. Overfishing of algal-grazing fishes and invertebrates also helps the establishment of algae on coral reefs (McCook, 1999; Szmant, 2002).

Anecdotal evidence suggests that some of the reefs are degraded (dead and bleached corals, increased algal growth) near the port of Alofi (Yeeting 2002) and a macro-algal (seaweed) bloom occurred around 2-3 years ago (Fisheries Dept., pers. comm.). This may be due to decreased water quality in the Alofi area due to land-based sources of pollution. Basic household sanitation systems are present on Niue (septic tanks, pit latrines), which provide minimal treatment of effluent. The coral rock of Niue is very porous (Terry and Nunn 2003) so this effluent (containing nutrients to 'fertilise' algae) will readily reach the coastal fringes in groundwater flows. Therefore Niue's fringing reefs are likely to be particularly susceptible to land-based pollution. Unfortunately no baseline surveys of Niue's coastal water quality exist.

The main aim of the current study was to conduct a coastal water quality survey, concentrating on the Alofi area where most of the problems have been observed. Additionally, and with the presence of SOPAC hydrogeologists on the island during the SOPAC 2003 Annual Session, a limited survey of the freshwater resources on the island was also undertaken, to assess whether groundwater was also contaminated with land-based pollution, and acting as the pathway for transmitting this to the coastal waters.

During the groundwater assessment it became apparent that both groundwater abstraction and effluent disposal to the groundwater were anticipated to increase, and as such the vulnerability of the aquifer and a reassessment of its sustainable yield were also identified as priority actions. It should be noted that fieldwork was carried out during September 2003 and predated the events of Cyclone Heta in December 2003.

LITERATURE REVIEW OF NIUE HYDROGEOLOGY (1957-1985)

Niue geology and hydrogeology has been investigated periodically since 1957. Schofield (1959) carried out magnetic surveys identifying correctly that Niue is an uplifted high carbonate island with a land area of approximately 259 km^2 lying at 19°S, 169°W in the central Southwest Pacific (Figure 1). It has a maximum thickness of limestone of 68 m above sea level with a series of wave-cut terraces and platforms associated with periods of uplift. The island consists of more than 500 m limestone below sea level (Terry and Nunn 2003) underlain by a caldera-shaped volcanic structure (Schofield, 1959).

Niue topography shows the highest ground to be around the edge of the island with a lower plateau in the centre. This has been widely interpreted as an upthrust atoll reef and a former atoll lagoon centre (Schofield et al).

Chasms exist around the coast, most notably at Vailoa, Matapa, Togo, Vaikona, with smaller structures and 'pools' at Limu and elsewhere. Most of these appear to be sub-parallel to the general coastline and are presumably associated with faulting (Schofield, 1959) which has subsequently undergone extensive dissolution. Most contain freshwater springs and issues.

Soils on the island are poorly developed, and rainfall is expected to infiltrate rapidly through the extensive secondary porosity (dissolution features) within the limestone rock. There are no surface water features on the island at all. There are however a number of caves, both perched and below/at sea level containing freshwater around Niue.

In 1957, apart from a 60-m deep hand-dug well in Fonuakula (depth to 1 m below sea level, with 14 mg/l Cl), the islanders relied entirely upon cave water. Infiltrating water perched in caves at Ulupaka, Vaipuna, Vaipula, Kapihi, Tupoua, and Tukuofe, with elevations of between 36 and 45 m above sea level, and containing 12-16 mg/l Chloride, *i.e.* almost identical to rainwater (Schofield, 1959). Groundwater levels in the well at Fonukula of 2-3 m above sea level, indicated the potential for an extensive groundwater lens beneath the island, which was supported by resistivity surveys, with freshwater thicknesses of typically 15 m and beyond 30 m being interpreted.

The extensive expanse and thickness of the limestone (compared to most atoll islands) provides a large aquifer volume, despite its limited storage capacity being restricted to that of the dissolution features. Jacobson and Hill (1980a, 1980b) Jacobson (1984, 1985) conducted extensive resistivity measurements on the island and concluded that the lens was thinner in the middle (40-80m) than the outer edges of the island (50-170 m). Their own groundwater level measurements however contradict this geophysical interpretation, with groundwater level contours having a maximum near the middle of the island at 1.8 m reducing towards the coastline [the Ghyben-Hertzberg relationship stating that depth of freshwater lens below sea level is proportional to the groundwater head above sea level in a ratio of 1:40 – note this is more typically observed at 1:20, but the relationship remains true].

Jacobson (1984) estimated groundwater porosity at 25% from resistivity and laboratory measurement. The effective porosity is however considered by these authors to be a small fraction of this, with the majority of groundwater flow restricted to the karst fissure network. Pumping tests provided specific capacity data as an approximation to rock permeability. Estimates of transmissivity varied from 130-1100 m^2/d, with individual yields of up to 3.5-4.0 l/s. The relevance of these values to the aquifer permeability as a whole is debatable given the obvious dominance of karstic conduit flow, as witnessed by coastal springs and cave development.

A later assessment (Williams, 1985) using data from 25 borehole sites, focused on groundwater level and downhole conductivity profiling. This again indicated elevated ridges of the groundwater table near the former fringing reef, with lower water levels in the centre of the island. Well transmissivities were estimated between 16-10,000 m^2/d (equating to permeabilities of 0.5 to 300 m/d). Measured groundwater lens thicknesses using downhole electrical conductivity probes showed the complexity of the karstic groundwater system, with boreholes up to 3.5 km inland showing brackish groundwater, whilst others only 10 m away recording fresh groundwater. This was interpreted latterly as relating to the depth of the borehole into and beneath the freshwater lens, hence providing pathways for saline up-coning. Elsewhere, the profiles showed 30-40 m thickness of the freshwater lense towards the middle of the island at Hago (DH8), Fatamanu (DH7) and Atiu (DH5).

SURVEY METHODS

Study area description location

Niue has a relatively small fringing reef system (area of 620 ha, Dalzell et al. 1993) located very close to the main shoreline. The inter-tidal area is small, or non-existent in some areas, and most of the reef area is subtidal. The limited reef area provides for about half of Niue's fisheries production (9.3 tonnes/m^2 reef/year, Dalzell et al. 1993) and hence is a very important resource. Fishing activities include gathering shellfish, trolling and bait-fishing, spearfishing and flyfishing.

The population of Niue is approximately 1600 (density of 6 people/km^2). The bulk of the population is located near the main commercial center of Alofi and in twelve small villages around the island. A number of hotels and smaller guesthouses are present in the Alofi area. Each village has a limited but effective untreated reticulated water supply system consisting of an abstraction borehole, a water storage tank and a distribution system. There are however no reticulated sewage systems on Niue, with most households having individual septic tanks. The main port area is situated at Alofi also but no enclosed harbour is present, so visiting ships and yachts must anchor offshore.

Sampling sites

A map of Niue Island and the locations of the groundwater abstraction boreholes is shown in Figure.1

Freshwater samples were collected wherever possible from sampling taps installed on the rising main at each borehole location. Occasionally water samples had to be obtained directly from the water storage tank, where a sampling tap was not available. The borehole was allowed to discharge until the conductivity/temperature/pH probes recorded stable groundwater parameters. Depth-to-the-water-table readings were carried out using a dip-meter with a 100 m cable. Dip-readings are reported to the top of the PVC dip-casing. Conductivity and pH measurements were performed immediately at each site using calibrated meters.

It was intended that groundwater samples would be analysed at USP Fiji for a major ions suite. This however did not occur, and other than in-field hydrochemical parameters only nitrate and faecal bacteria were analysed for, in keeping with the focus on coastal water pollution.

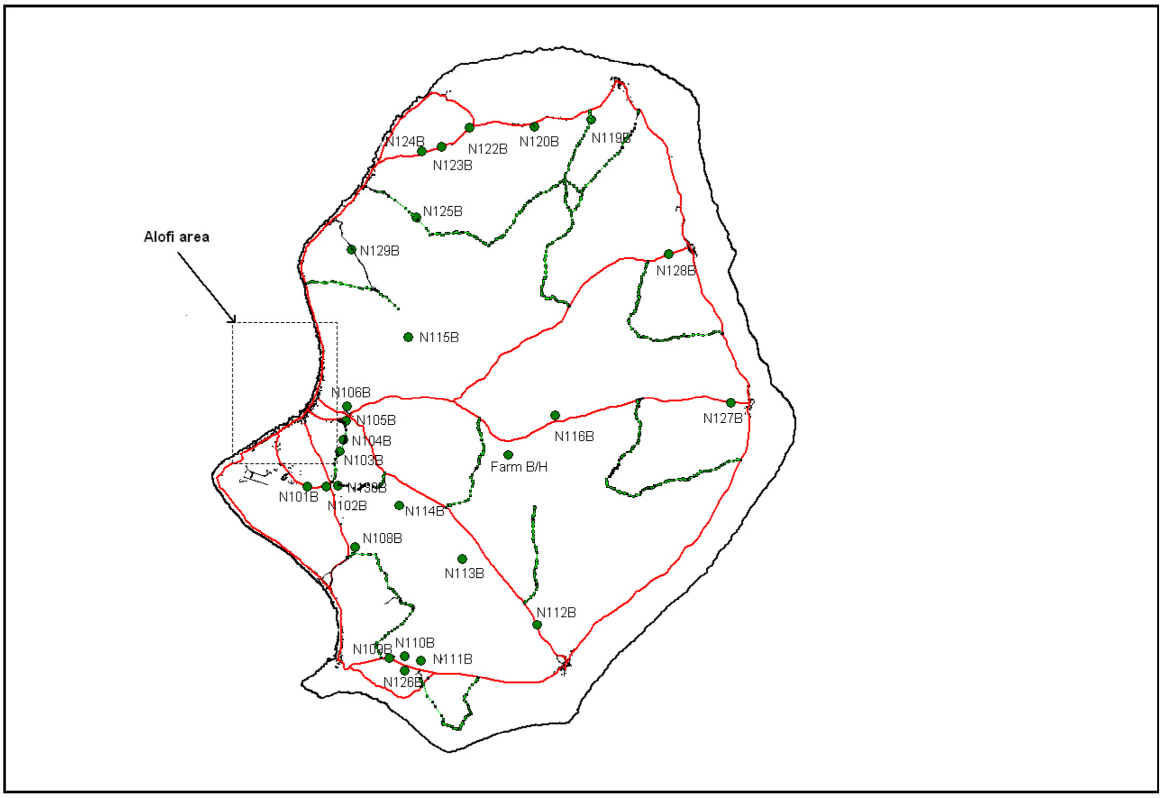

Figure 1. Map of Niue showing borehole locations. The area of the main town Alofi where the majority of the coastal water sampling was undertaken is also shown.

Table 1: Groundwater Sampling Locations.

Borehole	Location	Southing	Westing
N119B	Mutalau b/h		
	Hikutavake		
	Vaipapahi farm		
	Tuapa		
N129B	Makefu	19 00 36.4	169 54 29.2
Spring	Limu Chasm		
N120B	Toi	18 58 30.7	169 51 11.5
N119B	Mutalau		
N128B	Lakepa	19 00 41.1	169 48 46.4
	Vailoa (cave)		
	Makato Vailoa (chasm)	19 02 15.2	169 55 01.6
Farm	Tumau	19 04 08.1	169 51 50.7
N127B	Liku	19 03 13.6	169 47 39.4
N112B	Hakupu	19 07 01.0	169 51 08.8
N126B	Vaiea/Talamaitoga	19 07 49.3	169 53 31.4
N109B	Avatele	19 07 36.3	169 53.41

N108B	Tamakautoga	19 05 42.2	169 54 26.2
N101B	SP1	19 04 40.2	169 55 17.7
N103B	SP2	19 04 39.6	169 54 56.8
N104B	SP3	19 04 04.7	169 54 42.0
N105B	SP4	19 03 53.8	169 54 36.6

Coastal water sampling sites are listed below in Table 2. Coastal water sampling was concentrated around the Alofi area where the Ciguatera problems were most evident. Some other sites were chosen to represent 'background levels' as there did not appear to be any pollution sources nearby. The sites were sampled during a range of tidal states but were attempted to be collected close to low tide.

Table 2: Coastal Water Sampling Locations.

Sample#	Location	Southing	Westing
1	South of Aliuto Point	19 04 34.0	169 57 05.0
2	Off rubbish dump	19 04 16.8	169 56 54.6
3	Off Claytons Bar	19 04 04.04	169 56 37.5
4	Off Public Works D	19 03 56.02	169 56 24.0
5	Off Niue Hotel	19 03 52.03	169 56 16.1
6	Off Niue Hospital	19 03 42.8	169 55 58.9
7	Huanaki Point	19 03 37.1	169 55 51.7
8	Opaahi Point	19 03 32.8	169 55 38.7
9	Off Capes food bar	19 03 27.4	169 55 35.7
10	Anatoga Landing	19 03 24.0	169 55 25.1
11	Utuko	19 03 19.0	169 55 23.2
12	Off Alofi Church	19 03 15.5	169 55 20.2
13	Niue Wharf	19 03 11.0	169 55 14.8
14	Off fuel tanks	19 03 07.1	169 55 15.9
15	North of fuel tanks	19 02 57.8	169 55 11.2
16	Makato	19 02 54.8	169 55 08.5
17	Makato sea track	19 02 42.8	169 55 06.5
18	Off catholic mission	19 02 23.8	169 55 07.1
19	In marine protected area	19 01 19.1	169 55 23.6
20	Wharf transect 2	19 03 09.0	169 55 16.7
21	Wharf transect 3	19 03 07.0	169 55 19.8
22	Wharf transect 4	19 03 03.5	169 55 24.9
23	Off Falefono 1	19 03 07.3	169 55 32
24	Off Falefono in middle of yachts	19 03 12.7	169 55 25.4
25	Off Falefono inshore sample	19 03 14.6	169 55 22.7
27	Beach near fuel tanks	19 03 09.2	169 55 12.8
28	Beach south of Alofi Wharf	19 03 13.2	169 55 13.9
29	Behind Alofi Church	19 03 16.2	169 55 16.4
30	Cove south of Alofi	19 03 21.8	164 55 22.1
31	Beach south of falefono	19 03 20.5	169 55 18.4
32	Beach on wharf side of Falefono	19 03 16.0	169 55 16.4
33	Limu swimming hole (northern side)	18 58 30.9	169 53 46.5

Sampling and analysis

Coastal water samples were collected from near the shoreline at the various sites from a depth of about 10 cm below the water surface. Each sample was collected in an acid-cleaned polypropylene bottle, which was rinsed three times with the sample solution prior to collection. Filtering (Whatman GF/C, 1.2 μm pore size filters) of the samples was immediately carried out to remove any large particles, plankton and bacteria. For samples destined for nitrate and phosphate analysis poisoning with mercuric chloride (1 drop saturated solution per 100 mL of sample) was also used to further aid in the preservation of the samples. For analysis of ammonia, sub-samples were preserved with a phenol solution (Strickland and Parsons 1972). During transport back to the laboratory the samples were kept in an ice cooler and upon arrival they were refrigerated at 4°C until analysis. Analysis of nutrients in the samples was performed on an autoanalyser (Skalar San Plus) using the low nutrient level methods supplied by the manufacturer. A reference material (MOOS1) obtained from the National Research Council of Canada was diluted by a factor of 10 and analysed. Acceptable results for nitrate and phosphate were obtained, indicating that the analyses were performed accurately.

For the seawater samples, all nutrient standards were made in low-nutrient seawater (LNSW) and this water was also used as the rinse liquid in the autoanalyser. This LNSW was prepared by collecting open ocean seawater (far away from any pollution sources) in a polyethylene bottle, leaving in the sunlight for at least 2 weeks, and siphoning off the upper portion for use. It is considered necessary to use this LNSW for low-level nutrient analysis in seawater, as contamination is likely at these levels if artificial seawater is prepared instead (Kirkwood, 1994). Salinity of the samples was measured using a calibrated conductivity meter.

Freshwater samples were collected mainly from specific sampling taps installed at each borehole location. Height of the water table readings were carried out using a dip-meter with a 100 m cable. Dip-readings are reported to the top of the PVC dip-casing. Conductivity and pH measurements were performed immediately at each site using calibrated meters.

COASTAL WATERS SURVEY RESULTS AND DISCUSSION

Coastal Water Survey Results

Figure 2 shows the results of the coastal water quality sampling transect conducted in September 2003 (raw data can be found in the Appendix to this report). The coastal water in the Alofi area had nutrient levels (in particular phosphate) that were elevated over background levels (i.e. sites 1 and 2). The sites immediately north of Alofi appeared to show elevated levels compared to the sites to the south. This is likely due to the (prevailing) southeasterly current and wind direction carrying effluent northwards.

Figure 3 shows the results of the coastal water quality monitoring conducted in the Alofi area in more detail with additional sites on the shoreline (sites 27-32) and two transects outwards perpendicular from the shoreline (Transect 1 sites 13, 20-22; transect 2 sites 12, 23-25) shown. Nutrient levels in the shoreline samples are generally elevated compared to the coastal water, which indicates land-based sources of pollution. The site 22 sample appears to be an anomaly to this general trend. The nitrogen to phosphorus (N:P) ratio found in the samples (see Appendix) was generally low compared to that normally found in open ocean seawater (N:P ca. 14). This suggested that the coastal waters of Niue are nitrate limited but as the sampling in the current study was conducted on only one occasion further sampling is required to confirm these results.

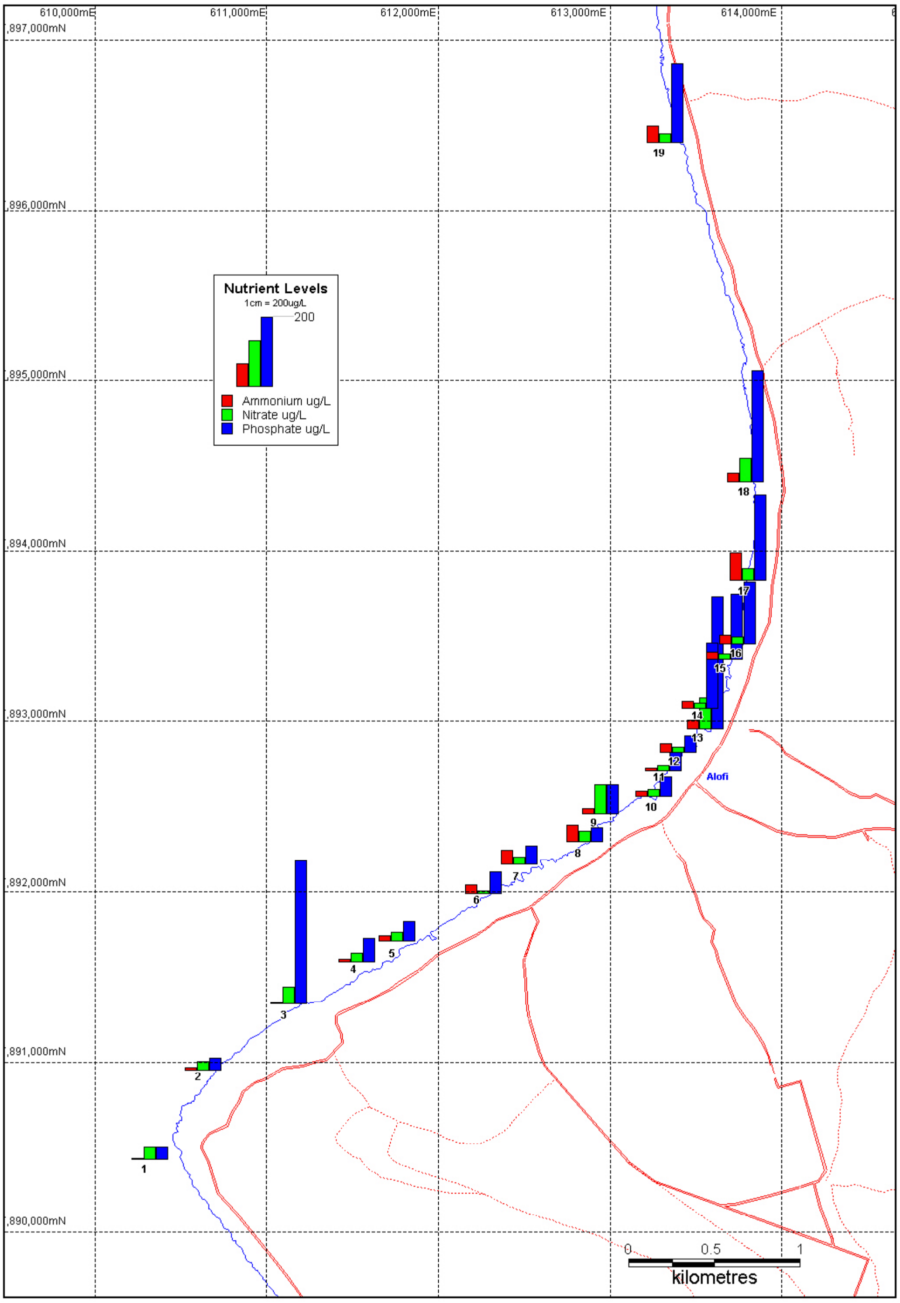

Figure 2: Coastal Water Quality Results for western Niue.

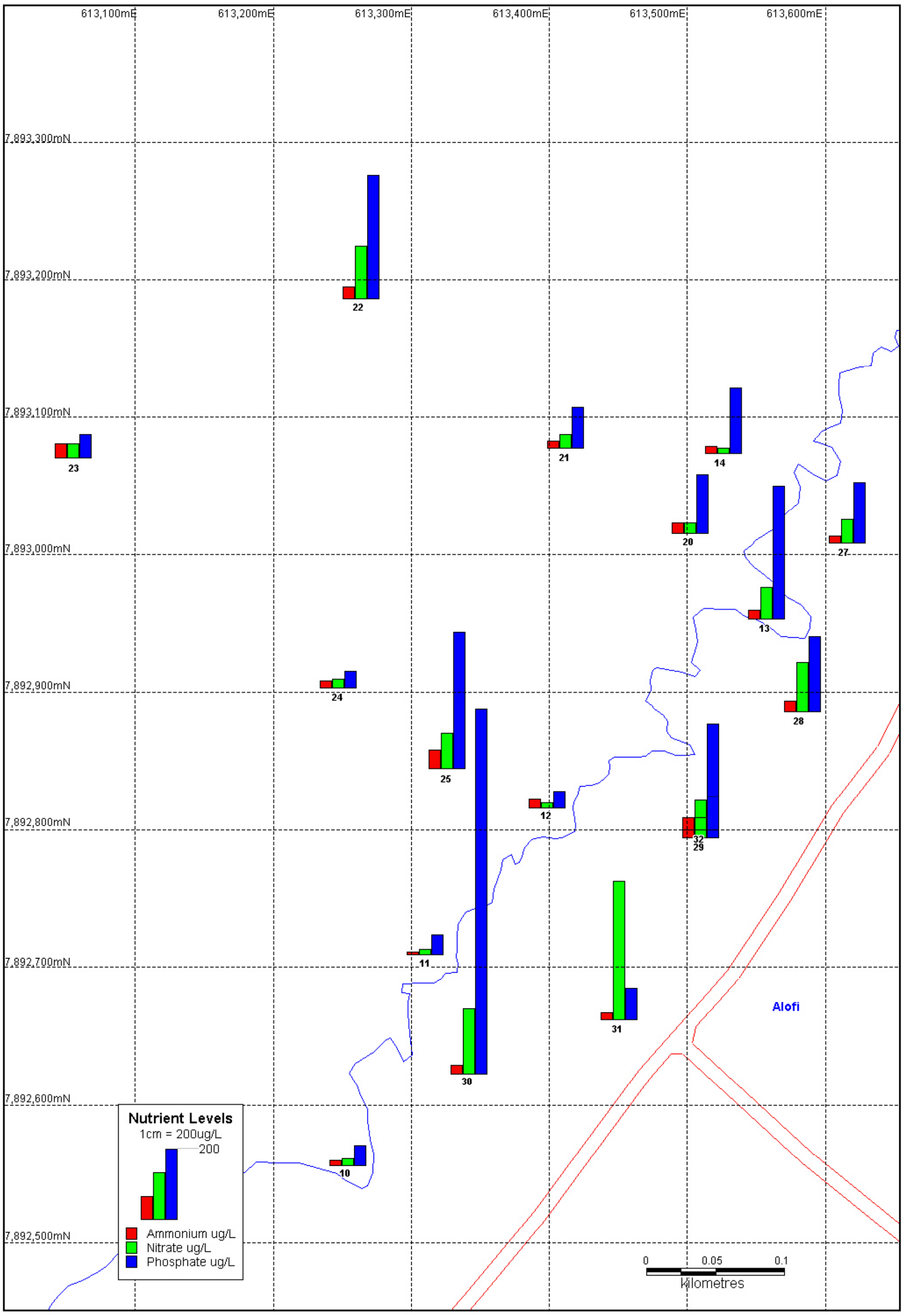

Figure 3: Coastal water quality results around Alofi.

Coastal Waters Discussion and Analysis

It is difficult to determine from the current results whether the elevated nutrient levels have contributed to algal growth and indirectly to the *Ciguatera* outbreak. However, it is a possibility as if excess nutrients are present, and coral reefs are degraded by coral bleaching events and other physical disturbances (e.g. freshwater inputs, siltation), algae may become more dominant. The recent *Ciguatera* outbreak was observed from late 2001 although several other outbreaks have been reported over the past 20 years (Yeeting 2003). There was a Pacific-wide coral bleaching event in 1999, which may have allowed algae to become more dominant, which would provide an increased amount of suitable habitat for the dinoflagellate that carries the *Ciguatera* toxin.

The major sources of the elevated nutrients in Niue's nearshore coastal waters are likely to be from human waste discharges from septic tanks and other household or agricultural chemicals (e.g., detergents, fertilisers). In the predominantly coral and limestone rock that is found on Niue, preferential effluent flow paths would occur and effluent may be able to travel long distances (e.g. from center of island to coast). The development of an advanced (tertiary) sewage treatment system may help the problem but this option is likely to be prohibitively expensive. Therefore the focus of the relevant authorities should be to reduce the input of nutrients to the coastal water. Several low-cost options to consider are:

1. To regularly inspect and maintain existing sanitation systems. Contamination of groundwater occurs when septic tanks fail because of poor maintenance (Dillion 1997). When septic tanks become full of sludge, the treatment time in the tank is reduced, the sewage can backflow if the perforated pipe becomes clogged, and continuous (rather than intermittent) seepage of effluent occurs. Septic tanks and pit latrines need to have sludge removed at intervals of between 2-10 years (depending on amount of usage). The sludge must also be disposed of properly and this should not be done in proximity to any water supply well. Sludge can be dried and incorporated with compost and spread (in thin amounts) over garden soils or under forests. Continuing communication to the local communities of the need for proper siting, construction and maintenance of septic tanks is required. An additional inexpensive alternative may be to use planted vegetated zones at the septic tanks outlets. Plants that are able to grow in this wet environment (e.g. taro) may uptake significant amounts of nutrients.
2. Composting toilets should be trialed on the island and resorts should also trial 'ecologically friendly' toilet systems and install treatment facilities if possible.
3. Another practical option to consider may be a switch to the use of non phosphate-containing detergents on Niue. The possible influence of the application of nitrogen and phosphate-containing agricultural fertilizers needs also to be considered.

4. On a government level, water quality standards could be developed into legislation and effluent discharges made to conform to them.

5. It is important that the coral reef areas around Alofi are protected and maintained in good condition. Establishing more marine protected areas would help protect herbivores which graze the algae upon which the dinoflagellate that harbours *Ciguatera* establishes. This would result in less suitable habitat.

6. Ship ballast or bilge water should also not be discharged in this area. Bilge water may contain oil, which could harm the coral while ballast water may contain foreign organisms, and this could have been the entry method for the latest outbreak of Ciguatera. Yachts should continue to be instructed not to discharge their toilet waste while moored near Alofi.

7. Runoff of freshwater and silt (and other materials) from the wharf area is believed to be large at the moment as the concrete driveway and wharf area slopes directly down to the sea with no water diversion on the upper portions. This should be more closely examined and if possible silt should be trapped and freshwater diverted or diffused before reaching the sea.

GROUNDWATER SURVEY RESULTS AND HYDROGEOLOGICAL ANALYSIS

Groundwater Survey Results

The hydrochemical data collected from the survey sampling is tabulated below. Clearly the well depth, as well as casing, screen and pump depths will influence the depth at which water is abstracted and thus its salinity, and thus available construction details of the abstraction boreholes is also provided (see Table 4).

Table 3: Hydrochemical Survey Results.

Borehole ID	Location	Depth (mbref pt)	EC (uS/cm)	pH	Nitrate (mg/L)	Faecal Bacteria risk	Discharge Rate (l/s)	Comments
N119B	Mutalau b/h	52.3	531	8.4	0.6	high		
	Hikutavake		550	8.3	0.4	high		
	Vaipapahi farm		503	8.5	0.4	high		
	Tuapa	56.02	557	8.2	0.4	none		
N129B	Makefu	58.2	n/a			n/a	n/a	1
Spring	Limu Chasm	n/a	28,700			n/a	100-200	2
N120B	Toi	n/a	611	8.4	0.5	none	n/a	3
N119B	Mutalau	52.4	541			n/a	0.67	4
N128B	Lakepa	40.05	580	7.5	0.5	low	1.72	5
	Vailoa (cave)		240	8.2	0.3	high		6
	Makato Vailoa (chasm)		230	8	0.2	high		7
Farm	Tumau		306	8.2	<0.1	none		8
N127B	Liku	39.82	579	7.7	0.1	none		
N112B	Hakupu	38.15	370	7.9	0.1	none		9
N126B	Vaiea/Talamaitoga		342	8.1	0.4	high		10
N109B	Avatele		344	8.2	0.4	none		11
N108B	Tamakautoga		387	8.3	0.1	low		
N101B	SP1		340	8.3	0.7	high		
N103B	SP2	54.76	368	8.1	0.7	none		
N104B	SP3	50.28	439	7.9	0.2	high		
N105B	SP4	49.72	461	7.9	0.1	high		

1 Bore not operational. Borehole appears to be dry from dip reading (?)
2 Wave entered fissure just before measuring. Red algae on rocks identifies freshwater spring.
3 Borehole closed, sample taken from tank. 90-m^3 tank empties over 3-4 days, supplying 6 households totalling 20 people (0.35 l/s for 24 hour pumping), with a water demand of approx 1 m^3/capita/day.
4 Meter reading 72 292.5 m^3, installed in 1997. (0.3 l/s for 24 hour pumping)
5 Meter reading 43 985.97 m^3, installed approx 2 years, supplying 100 people (0.7 l/s for 24 hour pumping) (demand 600 lpd)
6 Freshwater cave near Alofi
7 Freshwater pool at bottom of a chasm near Alofi
8 Farm/household supply in the centre of the island
9 Pump operating at time of dip
10 no dip hole
11 no dip hole

With the exception of the Limu Chasm (which was sampled immediately after a wave entered the 'pools'), all samples record freshwater. The distribution of this freshwater is shown on Figure 4. It is worth noting that the first 9 samples (down to Lakepa) located in the northern half of the island, were measured on 25 September 2003, whilst the remaining 12 in the southern half of the island were sampled on the following day. In the intervening night, there was heavy rainfall on the island. It is not clear to what extent the reduction in average conductivities on the second day is a geographical distribution or represents the response to rainfall recharge.

Hydrogeological Analysis and Interpretation

Sampling and analysis results show that the freshest groundwater is found in the centre of the island and also in a coastal chasm spring. Slightly higher salinities are located towards the coast and near the more heavily abstracted aquifer areas around Alofi.

The interpretation of hydrochemical data is subject to equivalence, that is to say, a number of different explanations can explain the distribution observed. Lower conductivities usually reflect proximity to recharge sources *i.e.* rainfall, whilst higher conductivities caused by more saline groundwaters, can indicate saline intrusion, down-gradient groundwater flow, over-abstraction, saline up-coning and/or surficial contamination. It is difficult to isolate these causes without further hydrochemical analysis.

However what can be identified is that recharge waters rapidly reach the coast and are discharged at coastal springs, whilst more conductive groundwater can be identified further inland. This indicates the limestone has several types of flow system which includes both a rapid karst conduit system, presumably connected in part to the caves and chasms, and a more diffuse dissolution system, across the island as a whole which receives rapid recharge but cannot transmit it to the coast as rapidly as the conduit system.

None of the boreholes (and therefore the aquifer as a whole) show evidence of over-abstraction, with conductivities all fresh and some close to rainwater concentrations.

However what the rapid recharge and discharge of the aquifer system (as inferred by the low conductivities) does suggest is that the aquifer is not only highly vulnerable to surficial land-use activities, but that it also has limited storage, with much of the monthly recharge lost immediately to the sea, and thus conventional approaches of assessing annual recharge and thus sustainable and drought yield if applied to this aquifer, as they have been in the past, might be erroneous and over estimate available groundwater resources.

Figure 4. Location of groundwater sample sites.

Table 4: Water supply borehole construction details.

Location	Casing diam	Types of Materials	Depth Water Bore	W.L. (m)	Max Head (m)	Depth Pump inlet set at(m)	Available Drawdown (m)	Date pump installed	Galvanise Column diameter (mm)	Flow Rate	Pump type	Power supply
Alofi SP1	100	Casing-Class 9Pvc, Screen Stainless Steel	Unknown	54.84				1997	50	80lpm	SP8A 15	5kw 3 ph
Alofi SP2	125	Casing-Class 9Pvc, Screen Stainless Steel	Unknown	55.92		53.42	**-2.50**	26/12/92	65	120lpm	SP8A18	3.7kw3 ph
Alofi SP3	125	Casing-Class 9Pvc, Screen Stainless Steel	Unknown	50.05		51.81	**1.76**	04/02/1995	65	110lpm	SP8A18	3.7kw3 ph
Alofi SP4	125	Casing-Class 9Pvc, Screen Stainless Steel	Unknown	50.31		52.15	**1.84**	10/01/1998	65	80lpm	SP8A15	2.2kw3 ph
Tamakautoga	125	Casing-Class 12Pvc, Screen Stainless Steel	52.50	43.35	**9.15**	46.85	**3.50**	13/8/2001	65		SP 8a 15	2.2kw 1ph
Avatele	125	Casing-Class 12Pvc, Screen Stainless Steel	57.50	54.86	**2.64**	56.36	**1.50**	1991	65		SP 8a 15	2.2kw 1ph
Vaiea	125		**61.00**	**47.00**	**14.00**	50.55	**3.55**	1/3/97	50		SP 8a 15	2.2kw 1ph
Hakupu	125	Casing-Class 9Pvc, Screen Stainless Steel	Unknown	39.82		41.31	**1.49**	21/5/95	80		SP 8a 15	2.2kw 1ph
Liku	125	Casing-Class 9Pvc, Screen Stainless Steel	70.00	41.71	**28.29**	43.21	**1.50**	20/11/95	65		SP 8a 15	2.2kw 1ph
Lakepa	125	Casing-Class 9Pvc, Screen Stainless Steel	Unknown	41.82		42.41	**0.59**	1991	50		SP 8a 15	2.2kw 1ph
Mutalau	125	Casing-Class 9Pvc, Screen Stainless Steel	61.50	54.73	**6.77**	53.58	**-1.15**	25/7/02	50		SP 8a 15	2.2kw 1ph
Toi	100		Unknown	54.10		55.60	**1.50**	12/04/2000	50 & 65		SP 8a 15	1.5kw 1ph
Hikutavake	125	Casing-Class 9Pvc, Screen Stainless Steel	75.00	58.26	**16.74**	60.30	**2.04**	03/01/2002	50		SP 8a 15	2.2kw 1ph
Namukulu	125	Casing-Class 9Pvc, Screen Stainless Steel	Unknown	58.30		61.25	**2.95**	09/05/2002	50		SP 8a 15	2.2kw 1ph
Tuapa	125	Casing-Class 9Pvc, Screen Stainless Steel	60.00	57.58	**2.42**	59.08	**1.50**	06/02/1998	50		SP 8a 15	2.2kw 1ph
Makefu	125		**72.70**	**61.33**	**11.37**			30/5/96	40		Mono 24v	solar

a) Aquifer Vulnerability

The vulnerability of the aquifer to surficial activities is confirmed by the higher nitrate levels in boreholes near Alofi. Whilst these levels are low by global standards, given the low population density and limited agricultural and commercial activity to date, they do however give a clear indication that improper disposal of commercial effluents, leachates and sludges into the ground will rapidly pollute the freshwater lens.

It is understood a new fish cannery is expected to open within the next year, and that this facility intends to dispose of its saline and biologically-enriched effluent into the limestone bedrock. This could be potentially devastating to the aquifer in the immediate locality. It is highly recommended that a full EIA is carried out at the cost of the proposed developer to investigate the potential impact of this activity on the groundwater lens.

Future proposed activities which warrant further consideration, from an aquifer vulnerability perspective, include expansion of hotels and the treatment and disposal of sewage effluent, and the increase in commercial agriculture especially vanilla, and the extensive use of pesticides, insecticides and fertilizers.

It is recommended that land-use zoning be introduced as part of the planning process, which considers the likelihood of a proposed activity affecting the aquifer. Protection zones around the public water supply abstractions could then be introduced and enforced. Such protection zones could be used to assist in the location (or relocation after Cyclone Heta) of petrol stations, chemical stores, dumps and so on. Whilst unsightly on the coastal cliff edge, the location of the island landfill, is probably in its optimum location, down gradient and distant from the public water supplies.

In the aftermath of Cyclone Heta, the destruction of property and natural vegetation presents a high risk and a vulnerable time for the aquifer as a whole. Furthermore it is likely that the aquifer has become salinized to some extent with waves reported as over-topping the island on the western side of the island. Heavy rainfall will help to 'flush out' the saline water, but the vulnerability of the aquifer to these events, particularly on the western side from which the main cyclone tract approaches, should be considered during water resources planning. It might for example be prudent to have stand-by emergency abstraction wells located in the middle of the island, that could be activated by PWD should the wells on the western coast become temporarily salinized after tropical storm and cyclonic events. These wells could supply a water tanker, which would distribute to the storage tanks in the villages.

b) Aquifer Sustainable Yield

The second issue which the hydrochemical sampling has highlighted is the rapid movement and discharge of very fresh and therefore very recently-recharged groundwaters. This has implications for the ability of the limestone aquifer to actually store the infiltrating rainwater.

The conventional approach to assessing sustainable yield is to consider annual recharge. This approach was used by Jacobson (1984). Jacobson estimated an annual rainfall of 2000 mm, evaporation of 1415 mm/year, and a recharge of 625 mm/yr (using monthly estimates), of which 85% recharges in the period December to April.

Revisiting the rainfall and evaporation data (see Tables 5-7 below), SOPAC calculates the average annual rainfall to be 1940 mm/yr, evaporation 1611 mm/yr and annual recharge to be 616 mm/yr (using monthly estimates), which is 32% of average annual rainfall.

Table 5: Monthly Rainfall Data (1990-2002).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Av
January	126	242	61	187	490	85	486	142.1	59.1	335.5	389.2	250.9	391.6	250
February	353	511	106	217	53	239	76	195.1	405.5	538.2	281	273.1	148.5	261
March	157	315	174	191	113	227	326	200.7	85.6	128.2	291.2	299.3	314.3	217
April	313	38	156	462	103	140	138	276	52.4	270.5	281.6	346.4	146.1	209
May	183	132	343	67	83	164	379	42.4	10.7	45.5	128.9	126.2	145.3	142
June	107	58	28	34	78	95	121	85	36	69.3	37.7	203.2	19.4	75
July	216	62	177	68	131	47	23	89.6	45.2	35.5	160.1	172	191.7	109
August	6	42	194	210	62	235	23	88.9	39	88.4	179.3	47.4	98.7	101
September	127	77	102	204	104	63	18	93.4	35.2	172.2	89.9	53.3	50.7	92
October	87	7	322	104	607	96	170	11.3	152.9	340.4	311.5	42.6	79.5	179
November	70	134	57	8	148	227	114	69.6	62.2	352.1	158.2	105.4	130.5	126
December	137	53	306	178	316	50	221	66.3	237.5	274.1	157.1	179.5	140.8	178
Total	**1882**	**1671**	**2026**	**1930**	**2288**	**1668**	**2095**	**1360.4**	**1221.3**	**2649.9**	**2465.7**	**2099.3**	**1857.1**	**1940**

Table 6: Monthly Pan Evaporation Data (1989 – 1999).

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	*Av*
January	132.0	174.3	140.4	174.0	157.8	177.9	130.2	407.3	154.0	153.2	204.9	182.4
February	152.0	156.0	137.3	149.4	197.9	131.3	59.1	111.6	122.3	169.6	225.9	146.6
March	183.0	144.0	177.7	130.1	127.9	170.1	85.4	163.0	135.3	126.2	148.7	144.7
April	127.0	134.0	117.1	142.0	-	121.1	44.4	192.4	195.4	127.1	123.8	132.4
May	109.0	91.8	117.5	112.1	117.3	103.1	88.4	198.8	99.5	125.8	128.4	117.4
June	118.0	114.0	-	102.5	95.1	123.2	60.5	137.2	85.9	119.8	85.4	104.2
July	111.0	105.0	-	86.9	107.2	-	31.6	118.4	122.9	88.9	128.1	100.0
August	142.0	144.0	-	102.1	88.9	-	43.0	135.3	106.7	110.1	125.8	110.9
September	156.0	145.5	-	125.2	121.1	122.0	25.5	143.2	102.9	141.6	130.8	121.4
October	134.8	150.1	-	121.8	157.6	144.0	28.2	169.5	154.2	184.8	-	138.3
November	167.3	189.6	153.9	162.3	188.4	161.8	50.8	157.1	164.2	242.7	-	163.8
December	170.0	169.9	175.3	163.4	148.5	122.9	102.3	169.6	144.5	144.6	126.2	148.8
Annual	**1702.1**	**1718.2**	**1019.2**	**1571.8**	**1507.7**	**1377.4**	**749.4**	**2103.4**	**1587.8**	**1734.4**	**1428.0**	**1610.9**

Table 7: Effective Rainfall (Direct Recharge): Rainfall – Evaporation.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Av
January	0	101.6	0	29.2	312.1	0	78.7	0	0	130.6	65
February	197	373.7	0	19.1	0	179.9	0	72.8	235.9	312.3	139
March	13	137.3	43.9	63.1	0	141.6	163	65.4	0	0	63
April	179	0	14	n/a	0	95.6	0	80.6	0	146.7	57
May	91.2	14.5	230.9	0	0	75.6	180.2	0	0	0	59
June	0	n/a	0	0	0	34.5	0	0	0	0	4
July	111	n/a	90.1	0	n/a	15.4	0	0	0	0	27
August	0	n/a	91.9	121.1	n/a	192	0	0	0	0	51
September	0	n/a	0	82.9	0	37.5	0	0	0	41.4	20
October	0	n/a	200.2	0	463	67.8	0.5	0	0	n/a	91
November	0	0	0	0	0	176.2	0	0	0	n/a	20
December	0	0	142.6	29.5	193.1	0	51.4	0	92.9	147.9	66
Annual Total (5-6)	163.8	651.8	454.2	422.3	910.6	918.6	-8.4	-227.4	-513.1	1221.9	662
Total (this table)	591.2	627.1	813.6	344.9	968.2	1016.1	473.8	218.8	328.8	778.9	616

The use of annual average recharge figures, calculated on a monthly or even weekly basis is common practice for groundwater resources assessments. Typically then a percentage of the annual average recharge is used as the sustainable yield, say 30%. Such an approach assumes however that the aquifer has storage far in excess of a single year of recharge, perhaps decades or even centuries of storage for large aquifers, and that as long as average recharge is not exceeded over many consecutive years, then the aquifer will continue to be sustainable.

Taking this approach for the moment, we can refer to Table 7 and see that for 3 years (1996-1998) effective rainfall was 77, 35, and 53% of average recharge respectively, an extended period of drought in the Pacific. If the aquifer had considerable years of storage then given the plentiful years of recharge in 1994, 1995 and 1999 this might not be overly a concern. Furthermore, when we look at individual months, we see that even in these drought years, at least two months are calculated to have had good recharge.

However, where this approach falls down for small islands, and especially karstic limestone small islands, is that the total storage within the aquifer may not be several years of recharge, and indeed much of the recharge, as witnessed at coastal springs around the island, may not remain in the aquifer for more than a few days or even hours.

If we assume the effective porosity of the karstic limestone to be 1% (a usual assumption for such karstic limestones), an average freshwater lens of 15 m (*i.e.* half that observed by Williams at the centre of the island) and an area of 200 km^2, the total water stored in the island is calculated at approximately 30 Mm^3. Assuming a recharge rate of 616 mm/yr (giving 123 Mm^3/yr for 200 km^2), this 30 Mm^3 equates to only 3 months of average recharge storage, *i.e.* 25% of a year. It is therefore easy to foresee, that the freshwater lens will reduce dramatically in size after only one ‘dry’ season. The freshwater lens, despite its considerable size (in Pacific terms), is therefore highly vulnerable to drought.

To highlight this point further, Table 7 shows that 8 out of 10 years have months when recharge is calculated at being zero for three consecutive months or more. Recharge is often limited to specific ‘wet’ months, and predominantly occurs between December and April. This suggests that the freshwater lens is in a constant state of dynamic flux, and will reduce in size rapidly between May and November each year. The need to introduce a freshwater lens monitoring network to the island is a major priority, given the likelihood of such large sub-annual variations in the lens size and therefore yield.

Ironically this rapid groundwater throughflow and replacement or ‘flushing’ of the aquifer storage, will actually help Niue’s groundwater to recover after salinization by the storm surges of Cyclone

Heta. In an average year, the groundwater freshwater lens should be able to recover largely within three to six months.

Again the problem we have to consider is how much of the calculated recharge even stays within the island for three months. An annual recharge of 123 Mm^3/yr equates to 335,000 m^3/d or 4000 l/s. If the recharge rate and size of the freshwater lens are correct, then theoretically, apart from groundwater abstraction, 4000 l/s (which is a massive amount of water) should discharge from the limestone continuously. Most of this is likely to discharge at the coast as the 8 discrete springs (Williams, 1985) in the chasms and caves. Limu Pool was observed to be discharging at approximately 100 l/s, and such chasms as Matapa are expected to discharge at much greater rates than this, given the size of the chasm and its apparent relative freshness. It is quite possible to believe at least 2000 l/s could be discharged from these 8 springs alone.

There will also be more diffuse seepages along the coast and possibly large submarine seepages undetectable without coastal conductivity surveys. With a coastline of approximately 40 km length, diffuse seepage of 4000 l/s, would equate to 0.1 litre per second (6 litres per minute) per meter length of coastline. This would be effectively unnoticeable entering the coastal waters. It is understood however a large submarine spring has recently been detected during environmental surveys (pers. comm. Andre Siohane).

Flow meters on some of the abstraction boreholes suggest that demand is between 500-1000 litres per person per day. This is high and might be in part due to leakage losses in the rural systems (SOPAC found cement encrustation in toilet cisterns was wasting 60% of water during demand management surveys in 2000), water wastage, use for livestock and market cropping, and of course inaccurate flow meters.

However, for the purposes of water resources planning, if we assume a maximum population of 2000 (including visitors) with a per daily personal consumption of 1000 litres, total public water supply abstraction would be 2000 m^3/d or 23 l/s. This appears to correlate well with the 16 No public water supply wells abstracting at between 80-120 l/min (totalling 26 l/s).

Clearly this abstraction rate as a fraction of the annual recharge rate (or hypothesized coastal discharge rate which is the same thing in the absence of any other surficial discharges) is minimal at approximately < 1%. Nevertheless, the rapidity by which the freshwater lens recharges and discharges, means the storage at any one time is estimated to be only three months of recharge (30 Mm^3/yr). In dry periods, groundwater discharge from the springs will reduce, but the amount the aquifer needs to discharge to prevent saline intrusion is unknown.

Theoretically spring discharges will reduce during dry periods as the groundwater level reduces, but as the period of the drought extends towards and beyond three months, the lens will reduce in size as the spring discharges lag behind the recharge events. Therefore despite the 30 Mm^3 anticipated to be held in aquifer storage, not all of this will be available to supply the 2000 m^3/d required by the populace, due to continued spring flow and the lack of borehole coverage on the island. It may be as little as 10% or even 1% is actually available. 1% however would still provide five months water supply, which except during drought years would be sufficient before the wet months return. In reality however, as the lens shrinks saline up-coning will affect wells individually long before the overall aquifer yield fails. The next section of the report considers this issue in more detail.

c) Abstraction Borehole Sustainable Yields

Issues relating to the limits of abstraction are really more to do with individual borehole yield, and the likelihood of inducing saline up-coning, as identified near DH4 and DH6 (Williams, 1985), both of which are >3 km inland. This only goes to confirm the vulnerability of abstracting groundwater from a freshwater lens perhaps only 10-15 m thick, using vertical boreholes.

Specific capacity pumping tests (Jacobson and Hill, 1980a) provide an indication of what sustainable yields of individual boreholes might be achievable. A test in the south of the island yielding 3.82 l/s for 2.10 m drawdown (1.82 l/s/m) suggests a yield of 80-120 l/min might result in 2.4-3.6 metres of drawdown. According to conventional Ghybern-Hertzberg hypothesis, saline up-coning occurs in accordance with the 1:40 ratio of groundwater head above the mean water table. Jacobson and Hill reported groundwater levels of up to 1.8 m above sea level, and Williams up to 3 m but more typically <2.0 m. Where the drawdown in the pumping well reduces the groundwater level, saline up-coning will occur. When that up-coning reaches the borehole, saline groundwater will be pumped.

It is important therefore to not only minimize drawdown *i.e.* it is better to pump at a low rate for longer periods than higher rate for shorter periods, but also pumping water levels should be measured regularly and must not be allowed to go below mean sea level. For the borehole test pumped above, clearly a rate of <80 l/min is required to ensure drawdown does not reduce the groundwater level to below mean sea level. 45 l/min (0.75 l/s or) would give 1.36 metres drawdown, which should give a pumping water level of >0.3 m if the bore was located anywhere on the island and prevent saline up-coning.

A second test by Jacobson in the north of the island gave 3.52 l/s for 0.28 m drawdown (12.64 l/s/m), which would suggest yields of this amount were sustainable for this borehole. This demonstrates the heterogeneity of the limestone and the need to carry out specific yield tests on all boreholes as a matter of operational design and planning. Yields of individual boreholes can be set accordingly. Furthermore, conductivity monitoring of each abstraction should be carried out routinely (monthly) to provide advanced warning of increasingly saline wells. Where this happens abstraction rates can be reduced to try to prevent the well being salinized altogether.

CONCLUSIONS

The following conclusions can be drawn from this study:

1. The coastal survey, whilst of limited, extent shows that land-based activities are impacting the coastal water quality.

2. The link between this land-based pollution and the fish toxicity has not been proved or disproved, but the coastal water contamination will contribute to the stressing and deterioration of the coastal fishery environment per se.

3. Hydrochemical assessment of the karstic limestone aquifer confirms a freshwater lens exists across the entire island, but its thickness requires further investigation.

4. The aquifer is dominated by karstic flow and nitrate concentrations around Alofi confirm it is highly vulnerable to surficial land-use activities, including storm-wave over-topping.

5. Conventional sustainable yield assessments suggest annual groundwater abstraction is less than 1% of annual recharge, and therefore the aquifer remains sustainable. Nearly all groundwater is discharged to coastal and possibly submarine springs.

6. However, a more detailed yield assessment suggests the aquifer can only store 3 months of recharge, and given the perceived rapidity of its response to recharge events and subsequent immediate spring discharge, the freshwater lens is likely to reduce considerably during the annual ‘dry’ period of 3 or more months.

7. Groundwater storage should be adequate to provide at least a minimum of five months water supply through these dry months and therefore in an average year the island should have adequate water resources.

8. In drought years, 8-9 months of no recharge have been estimated, and the lens would be expected to shrink in size accordingly. Individual abstraction wells may become saline during these periods.

9. Historical data indicates individual borehole yields of 0.75 l/s should prevent saline up-coning, but boreholes with larger yields might create saline up-coning if drawdowns exceed 0.5 m.

10. Finally the lack of data on freshwater lens geometry and responses to recharge events means the lens is not adequately understood. Groundwater monitoring must commence as a priority.

RECOMMENDATIONS

The study has the following recommendations:

1. Further work is required to examine sources of contamination around the Port area of Alofi and to confirm results of the initial coastal water survey.

2. Local personnel should be trained to conduct on-going water quality monitoring.

3. A land and coastal management plan should be developed for the Alofi port area.

4. A full water resource investigation needs to be carried out. A submission for funding for this has already gone through the Niue National Council and is now being assessed by UNESCO.

5. It is highly recommended that a full EIA is carried out at the cost of the proposed developer to investigate the potential impact of the proposed fish cannery effluent disposal on the groundwater lens.

6. It is recommended that land-use zoning be introduced as part of the planning process, which considers the likelihood of a proposed activity affecting the aquifer. Protection zones around the public water supply abstractions could then be introduced and enforced.

7. It would be prudent to have ‘stand-by’ emergency abstraction wells located in the middle of the island, that could be activated by PWD should the wells on the western coast become temporarily salinized after tropical storm and cyclonic events.

8. There is an immediate need to introduce a freshwater lens monitoring network to the island as a major priority, given the study suggests large sub-annual variations in the lens size, and therefore yield, occur.

9. Specific capacity yield tests should be carried out on all boreholes as a matter of operational design and planning, to determine drawdown and therefore the potential for saline up-coning.

10. Conductivity monitoring of each abstraction site should be carried out routinely (at least monthly) to provide advanced warning of increasingly saline wells, and enable abstraction rate reduction.

11. More detailed investigation of the freshwater lens is required and should include topographic leveling of all boreholes, caves and springs to a common datum; monthly dipping, flow and EC measurements of each well, spring and cave; specific observation wells instrumented with pressure and conductivity transducers, a data-logged rain gauge installed; and, if adequate financing can be secured, the drilling of purpose-designed monitoring wells, geophysically downhole logged and fitted with multi-level samplers/probes.

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APPENDIX: WATER QUALITY DATA FROM COASTAL WATER

Sample#	Salinity	Temp (°C)	NH4 (μg/L)	NO3-N (μg/L)	PO4-P μg/L)	N (μM)	P (μM)	N:P ratio
1	32.8	25.7	5.2	35.2	37.3	2.5	1.2	2.1
2	32.8	25.8	13.1	25	38.2	1.8	1.2	1.4
3	32.7	25.8	6.8	47.2	398.1	3.4	12.8	0.3
4	32.7	25.8	9.6	24.9	69.8	1.8	2.3	0.8
5	32.4	25.7	14.0	26.1	57.7	1.9	1.9	1.0
6	32.7	25.8	24.9	12.8	61.7	0.9	2.0	0.5
7	32.5	25.8	43.9	21.8	51.9	1.6	1.7	0.9
8	32.3	25.7	49.0	30.8	41	2.2	1.3	1.7
9	32.2	25.7	16.2	82.2	82.4	5.9	2.7	2.2
10	32.7	25.8	18.2	21.3	58.2	1.5	1.9	0.8
11	32.8	25.7	11.6	16.1	59.5	1.2	1.9	0.6
12	32.8	25.8	24.6	14.5	46.7	1.0	1.5	0.7
13	32.6	25.8	26.4	87.5	367.7	6.3	11.9	0.5
14	32.8	25.8	23.2	16.9	182.6	1.2	5.9	0.2
15	32.9	25.7	21.5	13.3	183.2	1.0	5.9	0.2
16	32.8	25.8	26.7	21.3	175.2	1.5	5.7	0.3
17	32.8	25.8	77.2	34.4	240.4	2.5	7.8	0.3
18	32.8	25.8	28.2	67.3	309.1	4.8	10.0	0.5
19	32.8	25.7	47.3	27.6	223.1	2.0	7.2	0.3
20	32.8	25.8	32.7	31.7	161.8	2.3	5.2	0.4
21	32.9	25.8	23.2	41.4	117	3.0	3.8	0.8
22	32.7	25.8	35.4	145.4	339.9	10.4	11.0	0.9
23	32.8	25.8	41.0	40.7	68.2	2.9	2.2	1.3
24	32.8	25.8	18.5	27.4	46	2.0	1.5	1.3
25	32.8	25.8	54.8	101.8	378.3	7.3	12.2	0.6
27	31.5	26.5	22.5	68.8	167.2	4.9	5.4	0.9
28	33.5	26.5	30.4	134.3	209	9.6	6.7	1.4
29	35.2	27.2	40.2	104.7	314.4	7.5	10.1	0.7
30	30.1	25.3	26.7	186.6	1008.8	13.3	32.5	0.4
31	18	24.8	21.8	385.5	90	27.5	2.9	9.5
32	32.4	27.4	34.6	36.7	92.6	2.6	3.0	0.9
33	14.7		52.1	133.3	258.6	9.5	8.3	1.1