UNESCO

INTERNATIONAL HYDROLOGICAL PROGRAMME

Integration of social and technical science in groundwater monitoring and management

Groundwater pollution study on Lifuka, Ha'apai, Tonga
Recharge study on Bonriki, South Tarawa, Kiribati

by

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Contents

Abbreviations

ACTEW	(Australian Capital Territory) Electricity and Water (Australia)
ADB	Asian Development Bank
CIE	Consultation, Information and Education
CSC	Commonwealth Science Council
FSM	Federated States of Micronesia
IHP	International Hydrological Programme (of UNESCO)
MESD	Ministry of Environment and Social Development (Kiribati)
MHARD	Ministry of Home Affairs and Rural Development (Kiribati)
MLSNR	Ministry of Land Survey and Natural Resources (Tonga)
MNR	Ministry of Natural Resources (Kiribati)
MoH	Ministry of Health (Tonga)
MWE	Ministry of Works and Energy (Kiribati)
PUB	Public Utilities Board (Kiribati)
PWD	Public Works Division (Kiribati)
SOPAC	South Pacific Applied Geoscience Council
TWB	Tonga Water Board
UNCDF	United Nations Central Development Fund
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WHO	World Health Organization

Figures

1. Introduction

1.1 Context

On low lying coral islands, potable water is commonly sourced from shallow, fresh groundwater lenses. Although rainwater is also collected in tanks in the wet periods, dependence on the lense for all water needs becomes critical in dry periods. Protecting the groundwater from pollution is a major concern. In the management of reticulated supplies private land is sometimes converted to a public reserve to restrict access and use in an attempt to ensure that groundwater is protected from surface contaminants. Usually this is achieved by a lease agreement between landholders and the government utility and this arrangement can be politically, socially and economically contentious. However in the village context where private wells are still used by landholders, control of pollution sources is more practically complex, while still raising many sociocultural considerations.

This paper describes a groundwater pollution study on the island of Lifuka in the Kingdom of Tonga, in a village where private wells are an important source of water, in addition to dependence on household rainwater tanks and a public reticulated system. Comparison is also made with the findings of a groundwater recharge project, which was undertaken on the island of Tarawa in the Republic of Kiribati, Central Pacific, where a reticulated groundwater system, sourced from a government controlled water reserve, was the primary focus of the study.

Both projects aimed to increase the understanding and effective management of groundwater resources and both projects encountered the often conflicting priorities of environmental conservation and human need. However, from the investigations, it may eventually be perceived that changes in behaviour which protect the natural resource will also sustain human welfare.

The groundwater pollution study in Tonga and the groundwater recharge study in Kiribati were conducted within the framework of the UNESCO International Hydrogeological Programme (IHP) Humid Tropics Programme, and were two of the three field projects recommended at the workshop on Pacific Water Sector Planning, Research and Training in Honiara, Solomon Islands in June 1994. The projects were reviewed and updated at the UNESCO/SOPAC Water Resources Workshop at USP, Suva, Fiji in July 1997.

1.2 Approach

The groundwater pollution study in Tonga was undertaken in two phases between 1996 and 1998 and the experience gained in each phase contributed to the ultimate development of the design and goals of the project. It became apparent in Phase One that it was important to fully integrate the technical and sociocultural aspects of the project, both in the manner in which the study was conducted and in the analysis of the outcomes.

This requirement for a concurrent inter-disciplinary approach also became apparent in the groundwater recharge study on Tarawa in the Republic of Kiribati, which was conducted between 1996 and 1999.

1.3 Summary of contents

The second section of this report will describe the monitoring and experiments undertaken in the groundwater pollution study in Tonga and indicate how the technical and social science components were integrated during the process, and in analysis of the outcomes. The description of the study provides a potential model for groundwater pollution studies in other contexts, both in terms of the techniques that were used for monitoring and collection of relevant data, and in the participation of counterparts, trainees, government personnel and the local community. A summary is provided of the results of the study, which could be used by municipal planners and relevant personnel as a basis for understanding and predicting the impact of sanitation facilities on water quality and community health.

In section three, the groundwater recharge study on Tarawa is briefly outlined with particular focus on the social science investigations. Although this project had a sophisticated technical component, the sociocultural context of the water reserve, in which the project was conducted, was inclined to dominate the study process and some of the outcomes of the research. Lessons learnt from the social science investigations and the experience of conducting the study are summarised, and some suggestions are made which could improve government and community relations in the creation and maintenance of water reserves. The full details of the groundwater recharge study are provided in other reports and technical documents (White et al.1999).

In the fourth section of the document some comparison is made between the groundwater pollution study in Tonga and the recharge study in Kiribati, Both Tonga and Kiribati are Pacific Island cultures, and although the former is Micronesian and the latter is Polynesian, and the status of private land tenure differs in the two countries, there are cultural similarities which were observed in the dynamics of these resource monitoring studies. Common goals and challenges in the two projects are identified, and suggestions are made to improve communication, exchange of information and the potential for building on local custom rather than transposing exotic solutions and strategies.

2. Groundwater Pollution Study in Tonga

2.1 Purpose and goals of the groundwater pollution study

Study Three of the IHP Humid Tropics field projects was concerned with groundwater pollution particularly of a faecal nature, which can occur as a result of inappropriate sanitation facilities and practice. Clean water is essential for human health and groundwater is easily polluted if sanitation systems are constructed too close to water supply sources such wells. The guidelines being used to space latrines and wells were based on research conducted more than 30 years ago in areas such as Europe where the geology is quite different from the Pacific islands. It was intended that the project provide information that would review the current promotion of guidelines that may be contributing to groundwater pollution especially on small islands. The beneficiaries of the project would be the community on the island of Lifuka in Tonga and other communities in the Pacific region with similar geology and water and sanitation concerns. The information from the project could be useful for health regulators, hygiene educators and institutions responsible for setting internationally applied sanitation facility guidelines.

In general, the project could contribute to the sustainable use of groundwater and reduction of waterborne disease by increasing public awareness and responsibility for management of groundwater supplies. In addition the methodology could indicate how a study of this nature could be conducted.

Specifically, there was a need to provide guidelines for siting of water supply sources in relation to sanitation facilities and the siting of sanitation facilities in relation to water supply sources, in order to reduce the potential for pollution of groundwater in Pacific and small island countries.

The village of Pangai-Hihifo on Lifuka island in the Ha'apai Group, in the Kingdom of Tonga was chosen for the study because of population pressures on land, which contained a shallow groundwater aquifer. The groundwater was used for potable supplies and other personal needs, and was vulnerable to pollution. The population of the village was approximately 3500 people.

2.2 Project activities and development

The technical component of the project was designed to measure travel times and decay rates of faecal indicators between potential sources of pollution, such as sanitation facilities and water supply sources such as wells (Furness 1996). This would provide more comprehensive evidence of rate and direction of flow of groundwater, degree of pollution, where pollution is coming from and indicate whether or not there is a safe distance in a village context for the siting of wells and sanitation facilities in relation to each other.

Technical activities undertaken to collect relevant data included:

- surveying of wells and monitoring of water levels and tidal phases-,
- measuring faecal indicator concentration in private wells;
- preparing plans for the layout of wells and toilet facilities;
- testing for nitrates in well samples; and
- dye tracer monitoring which would chart the potential movement of indicators through the soil profile and groundwater.

The immediate aim of the social science component was to determine practices and expectations in relation to water usage and sanitation, and to establish the determinants of distribution and usage of sanitary facilities (including greywater disposal) and wells. The broader goal was to ensure comprehension of, and agreement with, the goals and priorities of the project among the people who site and use sanitation and groundwater supply facilities.

The manner in which the social science component was conducted evolved throughout the project and became increasingly integrated with the technical activities.

Establishing guidelines for protection of groundwater supply requires the cooperation, support and input of the communities concerned to ensure that the guidelines are culturally, geographically and ecologically appropriate, and therefore likely to be applied.

The initial project activities sought a number of outcomes:
collection of data which could be analysed; counterpart participation in, and feedback to, the project process; provision of training to the team members in the conduct of such a study; involvement of the wider community with a view to changing perceptions in relation to water and sanitation management.

2.2.1 Lessons learnt from Phase One

In late April 1996, the study team visited the island of Lifuka for a week to conduct the study. The team consisted of an engineer team leader and a social scientist from Australia, counterparts from Tonga, Western Samoa, and Tuvalu, and a Danish representative from SOPAC. The Science Adviser from UNESCO-Apia and the Manager of the Tonga Water Board also visited the site during the study week.

The technical activities were all undertaken by the project leader and team members, and the social scientist conducted a survey of households in the village of Pangai-Hihifo with the assistance of a translator. The survey consisted of informal discussions with householders and house-site inspections, which included the location and condition of toilets, and water collection and disposal facilities. Details of the technical and social science activities will be further discussed in Section 2.3 of this document.

Certain difficulties arose in the study week, which provided a number of lessons in the planning and management of a cross-cultural, multi-disciplinary project of this nature. In addition, reluctant and polite feedback from team members, after the fieldwork was completed, revealed frustrations that needed to be addressed.

- Timing of the study: - the week chosen for the study coincided with the final preparations for the annual conference of the Wesleyan church, the largest congregation in Tonga, which was being held in Pangai-Hihifo that year. This resulted in late arrivals of some team members due to inability to secure seats on the flights to Lifuka. In addition community members and government personnel were preoccupied with conference preparations and were, therefore, not as receptive to the study as they may have been. Although it is often difficult to avoid or predict local events and preoccupations, major annual gatherings of this nature can be noted and circumvented with a little prior investigation, especially when the fieldwork is of such a short duration.

- Location: the dye tracing experiments were conducted in a public oval and the unprotected site was partially vandalised which affected the results of the study.
- Training and communication: each of the tasks was performed, usually alone, by a team member already skilled in that particular field. As there was insufficient liaison between the team members as a group, there was little understanding of the roles of the other team members, and minimal comprehension of the process and benefits of a multi-disciplinary study. These limitations were somewhat exacerbated by late arrivals and early departures of team members, participants accommodated in different locations and the short duration of the fieldwork. Some of the individual tasks were quite time consuming which reduced opportunity for group interaction.
- Inaccessible monitoring techniques: the dye tracing experiment using Rhodamine-WT required collection of samples by local counterparts, but testing of most of the samples was conducted in Australia by the project leader. Consequently team members did not learn the skills related to the methodology, or directly experience the logic and outcome of the experiments, which is particularly important in an oral society. Reports detailing experimental results are not necessarily thoroughly read or believed. Visual demonstration of cause and effect is essential if perceptions are to change.

2.2.2 Phase Two

As a result of the feedback from the fieldtrip in 1996, and as some of the data collected was incomplete or erroneous, it was decided to extend the groundwater pollution study. Funding was sought to redesign and continue the project.

In 1997, Phase Two of the study was commenced for the International Hydrogeological Program (IHP) of UNESCO and the Commonwealth Science Council (CSC) on 'Groundwater pollution on low lying islands' with administrative and technical support from SOPAC.

UNESCO requested that the following activities were undertaken to complete Phase Two:

- apply Bromide tracer and collect samples;
- test Bromide tracer samples;
- monitor Rhodamine dye tracer in wells adjacent to injection points;
- test for nitrates in well samples (already collected)-,
- re-survey wells and correct error;
- include rainfall data in analysis;
- involve community in monitoring process; and
- prepare information for publication for a number of audiences.

The re-design of the study assumed and facilitated ongoing input and cooperation from personnel from Ministry of Health, Tonga Water Board, Ministry of Land Survey and Natural Resources, and the use of Tonga Water Board data (meteorological and groundwater study). It was also intended that the Tongan personnel would collectively plan and manage the study and that the expatriate input would only be of a supervisory nature.

The second significant change to the design of the project was the location of the dye-tracing experiments. The site should provide protection of the experiments from vandalism and the opportunity for increased involvement in the project by the community. The use of the grounds of a secondary school in Pangai-Hihifo was negotiated with the headmistress and teaching staff.

Thirdly, the materials and equipment used in the dye tracing experiments were chosen to ensure that the process was more accessible to local counterparts and community, while still being capable of producing the necessary data.

In 1997, Phase Two field work was conducted by Mr. Tevita Fatai, Assistant Hydrogeologist, of the Ministry of Lands, Survey and Natural Resources (NMSNR), Tonga, and supervised by Dr Leonie Crennan, Water and Sanitation Strategist, with assistance in data collection from Ministry of Health (MoH) Inspector at Ha'apai, Mr Mosese Fifita, and staff and students of St Joseph's Community School (Fatai 1997).

The completion of Phase Two in 1998 was conducted by Dr Leonie Crennan, Team Leader, Mr. Tevita Fatai from the Ministry of Lands, Survey and Natural Resources, and Mr Timote Fakatava, Head Chemist from the Tonga Water Board, with assistance in data collection from the staff and students of St Joseph's Community School.

2.3 Methodology and Discussion

The methodology adopted in this study was intended to be transferable to other islands with similar conditions and problems. Phase Two of the project was conducted to improve the methodology of the experiments conducted in Phase One, and to achieve more local counterpart and community participation in the process. The key study activities and outcomes of Phase Two are discussed in this section.

2.3.1 Testing for faecal indicators in wells

During 1996 -1997 monitoring of samples from 45 wells within the study area had established that groundwater was polluted. Belatrix Tapealava, Laboratory Assistant from the Tonga Water Board, collected and tested samples from the 45 wells on three occasions over a twelve month period for E-coli, Faecal Coliform and Total Coliform, in both the First and Second Phases of the project (Crennan 1996) (Furness 1996). The presence of faecal indicators was at an unacceptable level of concentration (E.coli >2000/100ml) for human and environmental health. Samples taken from wells outside the village area had a much lower indicator count (E.coli<200/1 00ml).

Over the period of testing the pollution levels appeared to be gradually increasing. It was assumed that the high concentration of pit latrines and septic tanks in the village area may be contributing to this pollution.

Examination of private wells during the house site inspections indicated that the condition of well casing at 20% of the inspected sites could allow ingress of surface pollutants to the groundwater. This would suggest that the faecal contamination could also be from warm blooded domestic animals such as pigs and dogs, and it is difficult to prove otherwise unless the groundwater samples are tested for pathogens or organisms specific to the human gut. However as the use of faecal indicators is a universal method of monitoring water quality, the results from the tests of the private wells were enough to raise alarm and necessitate the collection of collaborative data.

2.3.2 Application and collection of Bromide tracer.

The Bromide tracer experiment which originally involved a 'Small' and 'Large' Scale application was established to examine the rate and direction of groundwater flow over a short period of time, and also over an extended period using Potassium Bromide as a tracer. The application was conducted in June 1997. In August 1998 the Large Scale Bromide tracing application was repeated. The tracer experiments aimed to establish whether contaminants were likely to move from point sources of pollution to water supply sources, and whether pathogens would survive that rate of movement.

a) Method for Small Scale tracing

Potassium Bromide replaced Rhodamine-WT as the main tracer in Phase Two of the study as is discussed in section 2.3.4.

The Small Scale Bromide tracing experiment was initially established in June 1997 to test the rate and direction of groundwater flow over a short period of time using Bromide between monitoring piezometers. A large hole of about six meters square was dug approximately two meters depth to the groundwater table. The walls of the pit were observed to have variable layers of weakly cemented, fine to coarse sand consisting of coral and shell fragments.

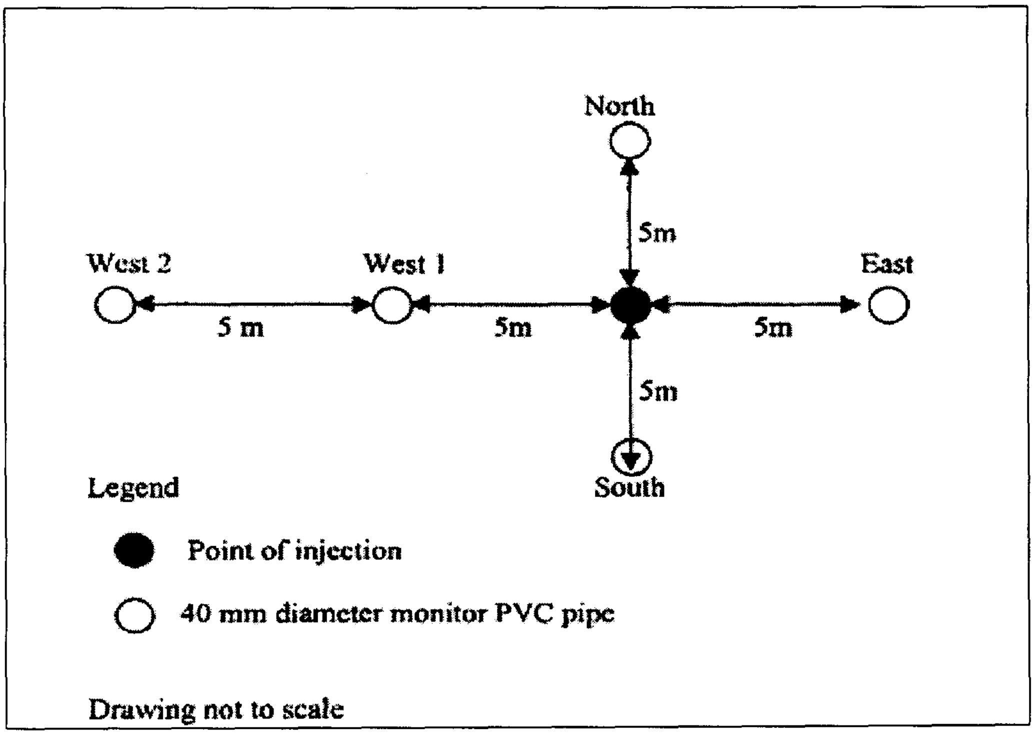

Figure 2.1: Plan view of Small Scale tracing experiment

A total of six piezometers were installed in the base of the hole by inserting 40mm diameter slotted PVC pipes into the ground to about 0.5 – 0.8m depth. The layout of the piezometers was in the shape of a cross (See Figure 2. 1). A central piezometer was used to introduce Bromide concentration to the groundwater table. Surrounding the central piezometer were four monitoring piezometer at equal distances of 0.5 meters in the North, South, East and West directions. One additional monitoring piezometer was located a further 0.5m to the West, which was the closest direction to the sea and assumed to be the most likely direction of groundwater flow on that side of the island.

The Small Scale tracing experiment was commenced on Monday 16 June 1997 at 2.50pm by injection of 800ml of Bromide solution (100gms of Potassium Bromide in 800ml of rainwater) into the central piezometer using a pipette. Groundwater samples were collected every day until June 25 when the study team left Lifuka, and then weekly by the Health Inspector and/or school staff until the end of July 1997.

b) Method for Large Scale tracing

Five boreholes of about 100mm diameter were dug approximately two meters to the water table and into the water table by about 0.8 - 1.0m. Slotted PVC pipes (80mm diameter) were inserted. The layout of the piezometers was in a shape of a cross. (See Figure 2.2). A central piezometer was used to introduce Bromide tracer into the water table. Surrounding the central piezometer were four monitoring piezometers at equal distances of 5 meters in the North, South, East and West directions. PVC caps were used to close each piezometer to prevent the equipment from being vandalised.

At 4pm on Monday 16 June, 1997 1000ml of Bromide solution (100gms of Potassium Bromide in 1 litre of rainwater) was injected into the central piezometer using a pipette. Groundwater samples of the monitoring piezometers were taken weekly until December 1997.

c) *Repeat of large Scale tracing*

In 1997 there was insufficient funding to test the samples collected from the Large or Small Bromide tracing experiment. In 1998 further funding was provided to buy necessary equipment to test the samples.

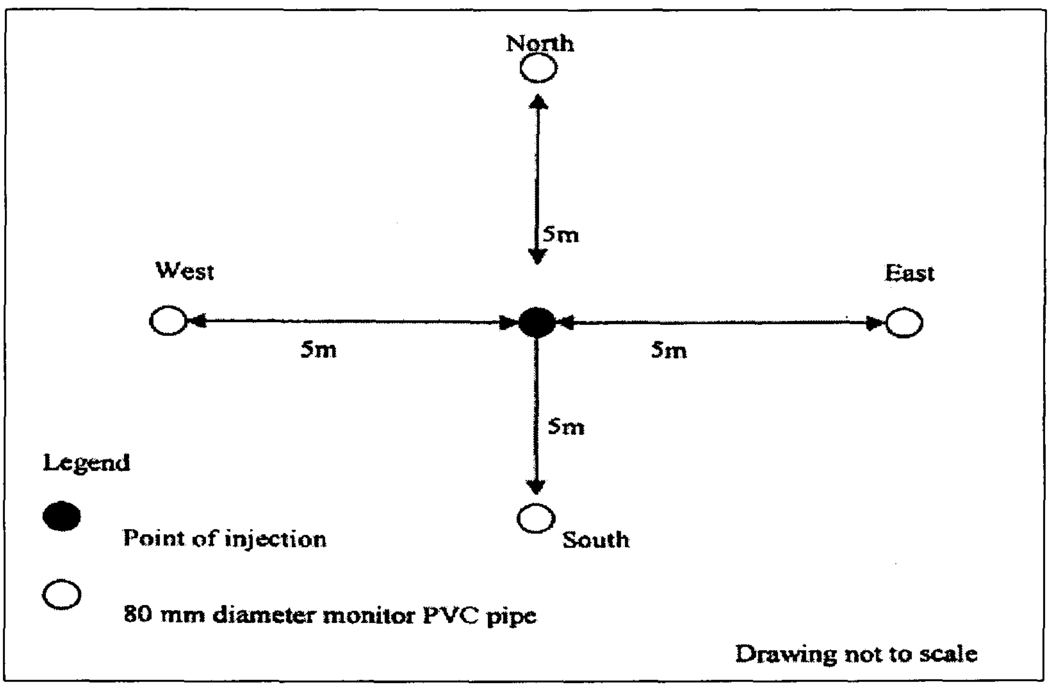

Figure 2.2: Plan view of Large Scale Bromide tracing experiment

From August 24-26 the tracing site at St Joseph's School was re-excavated and the 80mm pipes were re-inserted to groundwater level to allow injection of tracer and collection of samples. Although the pipes were still in place from the 1997 application, the caps had been removed and the pipes had been filled with dirt and stones and therefore could not be re-used. As the piezometers had not been for 12 months, this was to be expected in a school playground. The site was re-excavated, and pipes re-installed by eight senior students from the school with supervision by Hydrogeologist, Tevita Fatai. At 3pm on Wednesday, August 26, 400gms of Potassium Bromide was mixed with one litre of rainwater and poured into the central piezometer, Three litres of rainwater were then poured into the central piezometer to simulate the flush of a septic toilet.

Arrangements were made with the Deputy Principal of the school, Mr Lomano Hausia, for the collection of samples once a week on Wednesdays from the four piezometers, 5 meters North, South, East and West of the central piezometer. The senior students received instruction and were involved in the collection of samples. The necessary equipment including dated sample jars were provided to the school for collection, A base sample was collected from the piezometers prior to application of the tracer. Samples available for testing commence one week after injection of the tracer. The final sample was collected on November 25 and all the samples were then air-freighted to Nuku'alofa for testing at the Tonga Water Board laboratory in December.

2.3.3 Testing of Bromide tracer samples

Samples from the 1997 and 1998 collection were tested for bromide concentrations using a TPS WP-90 Ion/pH/mV Meter with an Ionode Bromide Electrode Br-SIO2, an Intermediate Junction Reference Electrode (4mm plug), and a Temperature/ACT Probe.

a) Calibration of the meter

The meter was calibrated using Custom Ion 1000ppm Bromide, distilled water, and Potassium Nitrate Ionic Strength Adjustment Buffer (ISAB) to stabilise the readings. The required solutions were prepared through a process of dilution:

- 500ml distilled water +50ml of 1000ppm Custom Ion Standard Bromide =100mg/L *Bromide S*
- 10ml of 100mg/L *Bromide S* + 100ml distilled water = 10mg/L *Bromide S*
- 10ml of 10mg/L *Bromide S* + I 00ml distilled water = lmg/L *Bromide S*
- lml of 10mg/L *Bromide S* + 100ml distilled water = .lmg/L *Bromide S*

The average volume of sample available from the 1998 Large Scale Bromide tracing collection was 60ml, so this amount was selected as a Standard volume for calibration. To make up the Primary Standard for calibration, 60ml of lmg/L *Bromide S* was mixed with 2ml of ISAB, and for the Secondary Standard 75 ml of . I mg/L *Bromide S* was mixed with . 75 of ISAB. The Ion Selective, Reference and Temperature sensors were all calibrated together in the Primary and Secondary Standards. Between the Primary and Secondary calibrations, and after testing each sample, the sensors were rinsed in distilled water and blotted dry.

It took several days to calibrate the meter because of technical problems, and it was necessary to contact the manufacturers in Australia to correct some difficulties with the equipment, Fran Gilroy, Senior Chemist from Hobart City Council, and Tony Falkland, Hydrogeologist from ACTEW, Canberra also provided advice. This delay reduced available sampling time.

b) Testing of 1997 Bromide tracer samples

Between August 27 and September 1 1998, attempts were made to test samples collected from June 1997 - December 1997 after the first insertion of bromide in the Small and Large Scale experiments. The testing was conducted at the Tonga Water Board Laboratory by the Head Chemist, Timote Fakatava, with assistance from Tevita Fatai from MLSNR. The bromide meter detected very low and consistent traces of Bromide. A sample of tap water from the Nuku'alofa Tonga Water Board was compared for salinity and Bromide concentration and it registered half the concentration detected in the Ha'apai sample. It is possible that the bromide was actually Chloride, the presence of which would interfere with the testing. The samples were also 12 months old and there is some difference of opinion as to the viability of Bromide tracer samples over that period. As the volume of sample collected in each case was only 10ml, the process of dilution and testing was time consuming, and the dilution could have been creating further distortions. For these reasons it was decided that continuation of the testing of the samples that were collected in 1997 was not useful, and efforts should only be concentrated on testing of the 1998 Bromide tracer samples.

c) Testing of 1998 Bromide Tracer Samples

As previously mentioned, the application of Bromide tracer for the Large Scale experiment was repeated in August 1998 and samples collected for 3 months from the date of insertion, These samples were tested from November 30 to December 7 at the Tonga Water Board laboratory. Two readings were taken from each sample, and the results indicated the potential rate for dispersion of pathogens through the aquifer. The results demonstrate that the Bromide tracer traveled 5m in two weeks in all directions with a slightly faster flow in the direction of the West coast of the island.

Within 2 weeks of insertion of the Bromide tracer, peak concentrations of bromide were detected in at all four piezometers. The presence of Bromide was detected at the same time, North, South, East and West of the central insertion piezometer. See Annex A. 1, which indicates the level of concentrations and low spread from the average concentration at each point on the axis. The concentrations gradually reduced over the following months. The highest concentration occurred in the inland or East piezometer indicating that the flow was slowest in that direction, See Annex A.2 for graph showing rate and direction of dispersion of bromide tracer. The lowest concentrations were detected on the West coast side, and to the South. The South piezometer was 2.5m from the outflow from a large septic tank which may have caused a saturation of the area and therefore a slightly lower concentration to the South, than to the West.

In terms of rate of flow in a particular direction these results concur with the results obtained in the Small Scale Rhodamine dye tracing experiment, which is described in section 2.3.4.

2.3.4 Rhodamine-WT dye tracing

In 1997, the use of a red dye as a visual tracer was undertaken at the suggestion of the local counterparts with the intention that "the public can visually see the results with their own eyes and really believe the outcome of the experiment rather than knowing it from reports and verbal discussion" (Fatai 1997). Rhodamine-WT dye had been used as tracer in 1996 in Phase One of the study, but the samples which were collected by the local Health Inspector were taken to Australia by the project leader for testing with a flurometer. The Tongan team members felt that this was not a useful or demonstrative strategy for education and information in regard to water pollution, either for themselves or the wider community.

a) Small Scale dye tracing using Rhodamine

This experiment was carried out in June 1997 within the same setting and using the same method as the Bromide Small Scale tracing experiment (Refer Figure 2. 1). The difference was that the surrounding piezometers were 0.3m apart and Rhodamine-WT dye was used as a tracer to be monitored with the naked eye. After excavation and installation of the piezometers at St Joseph's school, the monitoring was commenced on Monday 16 June 1997, when 5ml of Rhodamine-WT dye was injected into the central piezometers to the groundwater table. Groundwater samples were taken from the monitoring piezometers regularly by the study team and inspected for traces of the Rhodamine dye.

Four litres of water were injected into the middle piezometers twice a day for the first week to simulate the head of a flush toilet. Samples were taken each day at 9pm and 3pm.

On the morning of Tuesday 24 June 1997, traces of Rhodamine-WT dye were observed with the naked eye in the sample collected from West monitoring piezometer i.e. in the direction of the coast. The pink colour increased in this peizometer over the next few days to a bright red and then decreased over 3 days. The pink colouring was observed in the sample collected on July 11 from the South piezometer and from the East piezometer on June 17 when the last sample was collected from this experiment.

b) Comparison of the Rhodamine-WT and Bromide tracers

The dye appeared to move much slower than the Bromide tracer. The dye traveled 300mm in one direction in 8 days, and the Bromide tracer traveled 5000mm in all directions in 14 days. However it is likely that the Rhodamine-WT reached the West piezometer, and probably the other piezometers, much earlier than it could be detected by the naked eye, as the Rhodamine-WT is usually monitored using a flurometer which detects presence that would otherwise be invisible.

A comparative study of the two tracers in the same application could be useful. In terms of direction of groundwater movement, the results from the two tracers concur. In terms of rate of movement or dispersion the results do not conflict, nor are they conclusive. Monitoring, over the same distance for the same period of time in the same soil conditions, taking into account the different qualities of the two tracers would be required to obtain conclusive results. In a saturated column study, Rhodamine-WT dye displayed a retardation factor of 5 compared with simultaneous movement of E.coli. (Dillon 1996). Inorganic tracers such as Bromide appear to more closely simulate the behaviour of pathogenic organisms, so assuming that the Rhodamine-WT travels 5 times slower than the Bromide, the rate of movement indicated by the Small Scale dye tracing results would be 1.5m in eight days, or 3m in two weeks. If allowance is made, for earlier detection of presence of the dye using a flurometer, then this result is not inconsistent with the rate of 5m in two weeks evidenced by the Large Scale Bromide tracing.

c) *Large Scale dye tracing using Rhodamine-WT*

Two sites were selected for these experiments, both in the village, one close to the sea and the other further inland. These experiments were carried out again with the intention to allow the public to observe the results. 70ml of Rhodamine-WT dye was injected indirectly into the aquifer at the selected sites on Saturday 21 June 1997.

At Site 1, the Rhodamine-WT was injected into an open pit toilet at a distance of 9.85m uphill from a hand dug well. Two other open pit toilets were at a distances of 17.4m and 27m from the well (see Figure 2 3).

At Site 2 the Rhodamine-WT was injected into an open pit toilet at a distance of 8.7m from a hand dug well on the seaside and 19.5m to another hand dug well inland. Rhodamine-WT was also injected to a septic tank of a flush toilet at a distance of 13m from the well. The well was at a distance of 29.4m to the high water mark on the coast (see Figure 2.4).

d) Collection of samples from wells adjacent to insertion points

The householders who owned the wells were asked to contact the Health Inspector, Mosese Fifita, if they observed any pink colour in the well water. Mr Fifita also agreed to visit the householders once a month to check the well water himself. The Health Inspector went on leave without notice shortly after the trial began and did not return until early 1998. During that period the householders at Site 1 stopped using their well because they had become concerned at the proximity of the two pit toilets as a result of the attention created by this project. So they did not have an opportunity to observe any changes in the water colour. The householders at Site 2 did not report any changes in colour but said family members occupying the house had changed since insertion of the dye and perhaps the pink colour was not noticed. They also reported using the well less since the activities of the project. It was advised by team members that changes in colour of the well water also may not be reported due to the embarrassment of the householder that her/his water source was so directly connected to a toilet.

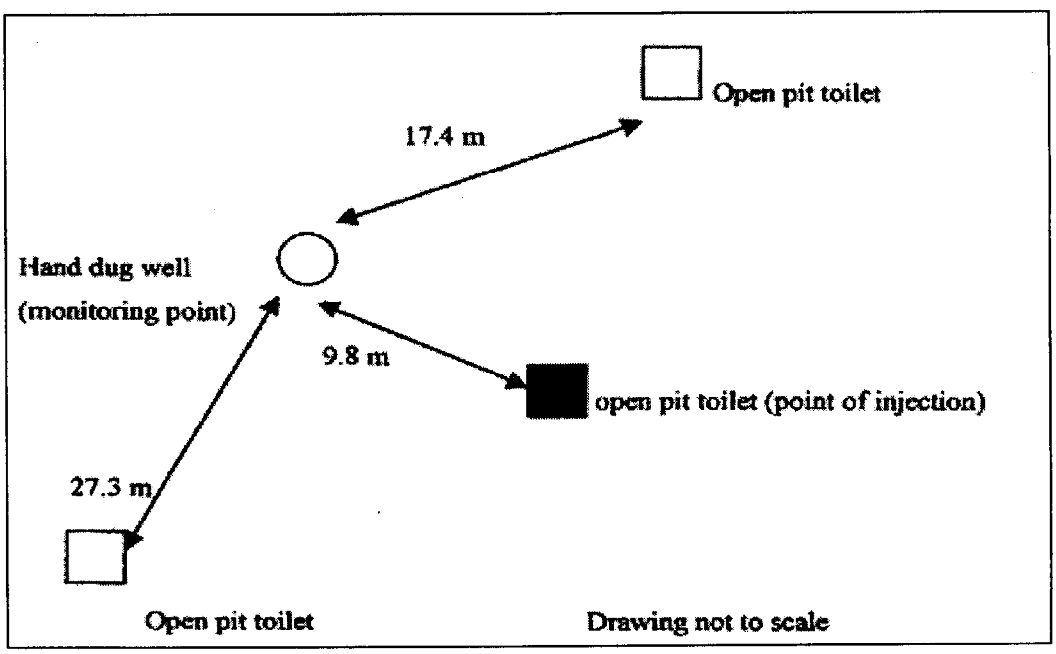

Figure 2.3 Plan View of Large Scale dye tracing SITE 1

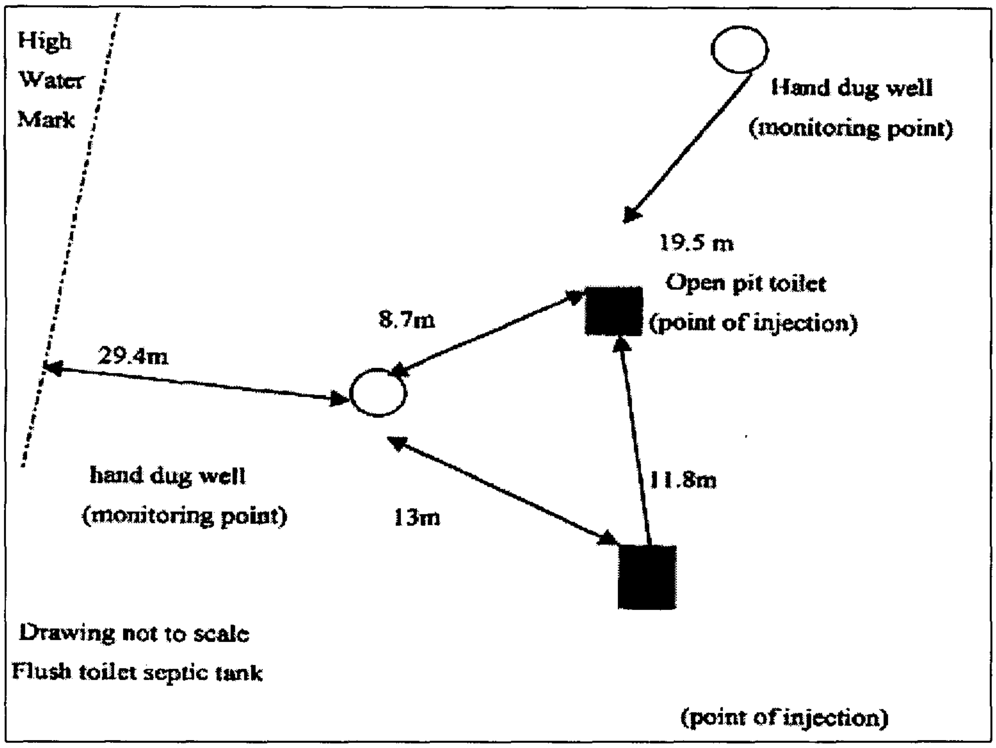

Figure 2.4 Plan View of Large Scale dye tracing SITE 2

If this experiment was to be repeated it would need to be conducted in a more controlled environment, eg. at a school where a number of people are responsible for monitoring, and where the implications would be less personal if the dye tracer, which had been inserted into a toilet, appeared in a well.

2.3. 5 Survey of groundwater levels

In June 1997, private residential and Tonga Water Board wells located within the study area were surveyed and the groundwater levels were measured to obtain the groundwater elevation. A total of 50 wells were surveyed, using a surveyor's level for the vertical elevation of the reference point of groundwater measurements and a GPS for the horizontal coordinate,

The survey team consisted of Hydrogeologist, Tevita Fatai and two paid labourers. Several errors were found on the initial survey in 1997. It was found to be caused by an instrumental error and the miscloses on the leveling. In 1998, the instrument was readjusted at base before leaving for the study area and the survey was conducted more carefully and in a more precise way.

On the 20th and 21st of August 1998, a total of 42 private and 8 Tonga Water Board wells within the study area were surveyed and the groundwater levels were measured to obtain the groundwater elevation and hence deduce groundwater flow direction at the time of monitoring. A surveyor level was used to survey the vertical elevation of the reference point of groundwater measurements and a GPS for the horizontal coordinate.

The survey was carried out using an existing Benchmark established on the island in 1991 with a height of 7.44 meters above mean sea level. It was conducted using the standard practice method of working from the Benchmark and completing a loop back to the Benchmark. The data collected was used to draw a contour map of the relative level of water to mean sea level (RLWL) in order to deduce the groundwater flow direction at the time of monitoring (see Annex B. I and B.2)

The relative level of water level (RLWL) was found to be around 0.2 to 0.3 meters above mean sea level (August 1998 mean sea level) in most parts of the village area, and approximately 0.4 meters at the south eastern area. From analysing the RLWL contour map, it is clearly seen that the underground water is slightly flowing to the West direction (to the coast side of the village study area). However, there was a slight reversal in water level at Tonga Water Board wells W17 and W19, which was believed to be the influence of drawdown caused by the pump operating during the time of the survey. The reversal in well numbers 26 and 25 could be due to tidal influence and/or the geology of the area.

a) Geology of Lifuka

The island of Lifuka is situated at 19°48'S and 174°21'W with an area of 11.5 square kilometres. It is low lying and elongated in a north-south direction and reaches a maximum elevation of 15 meters near the cliff-lined east coast. The eastern and central areas of the island of Lifuka are composed of coral and algal limestone, overlaid by up to three meters of volcanic ash. On the western side and mainly under the villages, younger sandy soil and soft sand rock has built up from accretion on the lee side of the island. Within the soft rock is a discontinuous layer of volcanic ash, close to the present day mean sea level (Furness 1996).

2.3.6 Inclusion of rainfall data in analysis

From August to mid November 1998, during the period of collection of samples from the Large Scale Bromide tracing experiment, a sustained drought had affected the island of Lifuka. This meant that the aquifer was not recharged and demand would have increased to replace rainwater, and supplement the increasingly saline and low-pressure reticulated Tonga Water Board supply. This may have allowed the tracer to move more slowly at higher concentrations. At the time of the field studies in 1997, very low rainfall was also recorded.

The monthly rainfall record during the time of the study is tabulated below as supplied by the Meteorology Unit, Nuku'alofa.

Year	Jan	**Feb**	Mar	Apr	**May**	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1997	213	**315**	133	287	**98**	13	108	94	93	73	70	89	1586
1998	42	68	124	66	**28**	108	75	**21**	**2**	11	179		

The Tonga Water Board had installed a rain gauge on Lifuka, and daily rainfall data for 1998 was recorded but not during the study periods in the second half of 1997 and 1998. It was reported that the drought broke in Ha'apai "in the middle of the month" which may have accounted for the drop in Bromide concentrations that occurred between the November 18 and November 25 collection of samples (See Annex 1).

It could be useful to repeat the experiment in a wet season. It is assumed that the tracers may be dispersed more quickly through the water table in a wet season. However increased extraction from the groundwater during a dry season may partly balance this trend.

2.3.7 Testing for Nitrates in well samples

As previously mentioned samples were taken from private wells on three occasions during Phase One and Two of the study and tested at the Tonga Water Board laboratory for faecal indicators. These tests revealed that in most cases E-coli counts were in excess of 2000 per 100ml. This would make the water unfit for drinking, washing of food, bathing and most household use where consumption or exposure to open cuts was possible, especially for children. It was intended in June 1997 that Nitrate levels would also be assessed at the Tonga Water Board laboratory, to further indicate the nature, concentration and potential health risks of contaminants in the samples. However the necessary reagents had not arrived at the time of the June field study, nor were they obtained in the ensuing months. By the time of the August 1998 completion period of the project, the samples had been thrown out by laboratory staff.

2.3.8 Involvement of Community in Monitoring Process

From the outset in 1997, Phase Two of the study was designed to increase counterpart and community involvement in the monitoring process as a strategy of Consultation, Information and Education (CIE). The CIE process was facilitated through choice of location, equipment, personnel and involvement with associated activities, which supported the study. This was in addition to a Phase One community survey summarised in section 2.3.9 of this document. The rationale and outcome of the changes in strategy are described below.

(a) Location of test sites

The Principal of Joseph's School was approached to allow the main study to he conducted within the school grounds for several reasons.

1. To avoid the experiment from being vandalised, (which occurred in Phase One when the study equipment, located in a public playing field, was destroyed by youths)

2. The school students and staff maintained a clean surface environment in their grounds, which would reduce the possibility of contamination of the study site.

3. The students and staff would have "ownership" of the project increasing general community awareness of the goals of the study.

4. The students and staff would be actively involved in the installation and maintenance of the study site in the following manner.

- A group of eight senior student boys excavated the site and assisted with installation of the piezometers. Their term school fees were paid in return for their labour, thus ensuring that their parents were aware of the project.
- Students assisted the science teacher, My Lomano Hausia, with collection of samples.
- Students and staff observed the appearance of Rhodamine dye in the Small Scale experiment.
- Students and staff participated in a workshop given by the Hydrogeologist on the goals and outcome of the study
- Students and staff participated in the production of a video that described the study, and linked it to a related project on ecological sanitation

(b) *Materials and equipment*

As previously mentioned Rhodamine-WT dye was used as a visual demonstration of movement of groundwater. The use of a flurometer to detect the concentration of Rhodamine-WT was abandoned after Phase One because it involved the transport of the samples out of Tonga to Australia, or the transport of sensitive and cumbersome equipment to Tonga. It was also possible for the samples to deteriorate if exposed to light, which made collection conditions demanding for local personnel.

The appearance of the pink dye in the samples taken from the monitoring piezometers proved to be a very effective demonstration of the movement of groundwater. The school and staff assembled on site for a workshop on the procedure and implications of the study in the Tongan language presented by team member, Hydrogeologist, Tevita Fatai from MLSNR. It appeared that some local people were not aware of the extent and nature of the aquifer, and particularly that it can transport microscopic material from one point to another. As many locals were dubious about the germ theory, the visible demonstration of groundwater movement using the dye advanced the notion that pollution from sanitation facilities could be impacting upon their water sources. It also demonstrated that any substance that may enter the groundwater through wells or other excavations such as rubbish pits could remain there and travel from one area to another, potentially becoming a health hazard.

The use of the Bromide tracer to give more detailed and long term information also allowed increased community and counterpart participation. The senior students and staff were responsible for collection of samples after the study team had left Lifuka. The Bromide meter was easily transportable and could be used in the laboratory at the Tonga Water Board. The Bromide meter was designed and manufactured in Australia immediately before the 1998 field studies commenced. It was apparently a significant improvement on previous models. However, some teething problems were experienced in its use, but these were eventually sorted out with assistance from the manufacturers and others (refer section 2.3.3 of this document).

(c) *Personnel involved in the study*

In the planning for the Phase Two experiments, it was suggested that an expatriate technical expert should lead the study. While this may have resulted in more sophisticated research, it would not have allowed for the same degree of initiative and active participation by the local counterparts. It has been observed that where a specialist expert is involved, other team members will allow the expert to solve technical problems that may arise, especially in cross-cultural situations. This obstacle can be overcome if the expert has the necessary time, patience, and culturally appropriate communication skills to transfer multidisciplinary information, and delegate responsibility to the counterparts. Unfortunately, this is sometimes not the case, particularly in low budget, short-input research projects of this nature.

In this study, all team members including the team leader, experienced a steep learning curve, and the process allowed a genuine team effort with a trans-disciplinary approach. Each team member became involved in activities and analysis outside their field and contributed to creative problem solving and to community awareness, within the resources available for the study. Although there may have been some technical errors or delays in the process, the team members became aware of those limitations and would be able improve on methodology in future studies. The Tongan team members are now capable of adapting the methodology to alternative sites in Tonga, and assist other researchers in the Region to conduct similar studies using tracers in groundwater for a variety of purposes.

(d) Associated activities

During the two-year period of the LTNESCO study, a related project was being conducted by the Tonga Water Board, which aimed at reducing contamination caused by sanitation facilities. This involved the trial of 15 (13 in private residences, 2 in institutions) composting toilets in the Pangai-Hihifo villages on Lifuka. The composting toilet, which was trialed, was an aboveground installation, which composts human excreta in alternating chambers. Any moisture not evaporated in the process drains to a sealed evapo-transpiration trench. Hence there is no discharge to the environment. After the required period of retention to ensure elimination of any harmful organisms, the compost can be used as a fertiliser (Crennan 1996-1999, AusAID)

The community in the study area of the UNESCO project was exposed to, and participated in complimentary CIE strategies, which demonstrated the potential for groundwater pollution from current sanitation technology, and also introduced a new toilet technology that did not pollute the environment. The composting toilet does not use water so precious water resources are also not wasted in flushing toilets, St Josephs school had one composting toilet as part of the trial, and their water bill was reduced by 2/3 due to the closure of 4 flush toilets, and use of the dry system, and staff reported that the composting toilet was easier and cheaper to maintain. The other trial participants also experienced similar benefits, and as result of the successes of the trial, the composting toilet will be extended to other parts of Tonga if ongoing institutional support is provided.

Note: The composting toilet should be specifically designed to suit the climate and geography of the region and the maintenance capabilities of the users. Introduction of sanitation technology should be undertaken by skilled CIE personnel. Related health and hygiene issues, such as hand washing and food preparation and storage should also be addressed in any sanitation promotion strategy.

2.3.9 Household survey

During Phase One of the study, investigations were carried out by informal discussion with members of the community in their own homes, and through house site inspections of toilets and water collection and disposal facilities. It was intended that the householders include those who have wells to be monitored as part of the IHP project, others who are using water from wells, those who have closed their wells and the wider community. Thirty-five households were randomly selected throughout the village, i.e. approximately 10% of the population of Pangai-Hihifo (Crennan 1996).

These household discussions were undertaken in two stages by the social scientist with the assistance of a local translator. The first stage, which included 28 households in Pangai-Hihifo was conducted over two weeks in February 1996 as part a Tonga Water Board customer survey.

The investigations included the particular concerns of the UNESCO pollution study as well as issues related to demand management of the water supply. The second stage, which covered the five households selected for monitoring in the IHP project, was conducted over four days during the team study week in April 1996.

To understand water and sanitation practice in any society it is necessary to look at many inter-related factors that affect the populations' living conditions. This includes family structure and social status, economics, and the types of water sources and sanitation technology that are accessible in that context. In Pangai-Hihifo, the survey sample was representative of the socioeconomic strata of the population. In the houses visited the water sources relied upon were private wells, rain tanks, and reticulated groundwater supplied by the Tonga Water Board. Use of the water supplied by the Tonga Water Board was metered and attracted a minimal 'line charge'. Some more affluent households had access to all three sources, some were dependent on only one water source.

The toilets used were pit latrines, which were moved around the house site approximately every 6 months, pour flush latrines, and cistern flush toilets attached to a septic tank. At least half the households visited had two toilet types, a pit toilet and either a pour flush or a septic.

The 1996 household survey contributed to understanding potential groundwater pollution by providing information on a number of common practices experiences, and priorities related to water use and sanitation. The relevant findings are summarised below.

***Query**: Reason for choice of sanitary facilities e.g. pit latrines pour flush latrines, cistern flush septics, the new VIPs?*
If people could afford to build a cistern flush toilet and pay for the water it used, they preferred it for convenience and cleanliness. Some people liked the pit latrine because they could dispose of any type of toilet paper or cleansing material in it. Pit toilets were often kept for male relatives even if the household acquired a flush toilet, so that gender segregation could be maintained.

***Query:** Reason for choice of water supply facility ?*
The water from the Tonga Water Board was preferred for convenience as it was reticulated. Rainwater was preferred for quality (purity and taste) and because it was free once a tank had been installed (usually by aid donors). Well water was preferred because it was affordable, reliable, good quality (no chlorine, not so hard, inconsistent or salty as the Tonga Water Board supply), and had an established history of usage. Some wells had been in use for more than a hundred years and had family and community significance. The well water was used by the householders interviewed and their relatives and friends especially in periods of drought. For these reasons, the pollution of the well was of minor consequence and all householders reported they do not use well water for drinking unless it is boiled.

***Query:** The current rationale and practice among the local community for siting of toilets and wells?*

Many of households that were visited had a cistern flush toilet, which was installed in or near the rear of the house for easy access especially at night, and for the sick or elderly. Pit toilets and pour flush latrines were usually installed at the back fence of the yard "on the side where the wind blows away from the house" and away from the road to avoid the smell and being seen entering the toilet. Distance from wells was not mentioned as a determinant for siting of toilets except in one case where the householder was told by the Health Inspector to move his pit latrine away from the well. Wells were sited as close to the living area as practical. In some cases the well was sited first and the house built near the well.

Query: *Disposal of toilet refuse?*
Most householders found toilet paper expensive or difficult to obtain at times, and used newspaper or other material, which they collected beside the flush toilet after use, and later burned. If they had a pit toilet the refuse was disposed in the toilet.

Query: *Disposal of solid waste?*
Solid waste was often disposed in open pits dug approximately a meter into the ground. The pits were sited away from the living area and may or may not be near wells. The proximity to wells did not appear to be a factor in the decision where to site rubbish pits.

Query. *The means of drawing water from wells?*
Usually by rope with an old tin or bucket. Some households had hand pumps. Hand pump wells were considered the most convenient.

Query: *Which water from what source is used for what household need?*
Tonga Water Board water was primarily used for flushing toilets, cleaning the house, sometimes bathing. Well water was used for everything except drinking. Rainwater was primarily used for drinking, bathing, and washing clothes.

Query: *Method of greywater disposal?*
Greywater was discharged to vertical soaks, included with blackwater to septic tank attached to horizontal and vertical trenches, poured on gardens, discharge into a wallow outside kitchen for pigs to frequent.

Query: *The incidence of enteric and waterborne disease in the family, understanding of source of infection, and method of treatment?*
This was difficult to ascertain from the household discussions, as people did not think enteric disease was a problem, or from the hospitals and clinics as there were no records, However the staff at the Hihifo hospital reported that most children under five had diarrhoea. There seemed to be little conviction that current sanitation technology was polluting the groundwater or that polluted groundwater was causing illness currently experienced by the population.
Tourists to Lifuka often reported gastric problems if water from any source was consumed without boiling, or from eating uncooked food.

2.4 Change in Community Perceptions

During the project the activities undertaken by the study team resulted in some immediate changes in perception. This was evidenced by reports of more careful use of well water and voluntary closure of recently constructed wells in close proximity to toilets, or relocation of pit toilets which were in close proximity to wells. Widespread interest in the composting toilets and reduced use of flush toilets also indicated that some people were making the necessary links between water resources and sanitation facilities. Students, teachers and community members, who participated in the study, more fully understood the nature and movement of the freshwater lens.

2.4.1 Government response

Personnel from the Tonga Water Board, the Ministry of Health and the Ministry of Land Survey and Natural Resources who worked on the project, had certainly become more aware of the threats to water resources from current siting and use of toilet facilities. They had also experienced the value of working co-operatively in dealing with these issues. An inter-department approach to common problems was not the usual strategy in Tonga, (or in many other countries).

Other government personnel concerned with public health, environment and education were interviewed in relation to their concerns and community response to the project. AR personnel supported the study and agreed that it was timely that more appropriate and comprehensive guidelines were established for application in Pacific Island conditions. However, what form these guidelines should take, and who should prepare them was less clear.

After the 1996 household survey and the testing of wells for faecal indicators, the results of the study were discussed with the local Health Inspector Mr Fifita. He expressed much concern that so many unregulated private wells were in use. These had been located by the Tonga Water Board customer survey and the UNESCO study team. He wanted to instruct all the households to backfill their wells immediately. It was explained that the use of the wells had to be seen in the overall context of the available water sources, traditional preferences and beliefs, and household needs. Policing the situation would not create a lasting solution to the problems involved. Mr Fifita was asked not to act at that stage, but to wait until a more comprehensive strategy could be developed using, in part, the information gathered from all aspects of the groundwater study. He reluctantly agreed to this request which was an important response in terms of community relations and the long term potential of achieving an educated change in behaviour. It is quite probable his order would have been ignored but it would have created antagonism where co-operation and open dialogue was needed.

In 1998-2000, the Tonga Water Board supply was upgraded and the reticulated water was reported to be much less saline and more reliable. However it is unlikely that most people in Pangai-Hihifo will ever relinquish the self sufficiency that having a private well offers them. And why should they? It would be much more desirable to ensure that it is a sustainable complimentary resource.

Dissemination of the results of this study in written oral, and video form is likely to further change community and government perceptions and increase public awareness and responsibility for sustainable management of groundwater.

However a major shift in perception and behaviour that would contribute to sustainable use of groundwater and reduction of water-borne disease could only be achieved by a comprehensive long term CIE program, and extensive demonstration of strategies that provide practical solutions such as pollution source control.

2.4.2 Preparation of information for publication

A joint report was prepared by the research team during December, 1998 to provide a description of the process and technical and social science outcomes of the study in secular language, which can be understood and used by personnel involved in water and sanitation management (Crennan, Fatai and Fakatava 1998). The preparation of the report was in itself a learning curve for all the team members, particularly regarding the cross cultural exchange of ideas and values. Most of the information in this document comes from that report and earlier project reports. Communities in the Pacific region with similar geological conditions and water and sanitation concerns, health regulators, health and hygiene educators, and institutions concerned with setting internationally applied sanitation facility guidelines can refer to this results of this study to promote strategies that better protect public and environmental health.

The suggestion to use Bromide as a tracer in Phase Two came from a number of sources (Dillon 1996), but a literature search did not reveal much practical information on monitoring relevant to the Pacific island context (Robertson et al, 1989). The methodology, using Bromide and the recent model Bromide meter, integrated with other investigative techniques such as water level survey and faecal indicator testing, evolved in response to social and physical developments as the study progressed. The description of this process will be a useful foundation or reference for others wishing to adapt or refine the application for other environments.

The conclusions and recommendations which follow provide a synopsis of the results of the study that can be extracted and used by community planners as a basis for understanding the potential impact of current sanitation facilities on groundwater quality.

An educational video was made in 1997-1999, which describes the process and findings of the UNESCO project and its links with the Tonga Water Board Composting Toilet Trial mentioned in section 2.3.8 of this document. The staff and students of St Joseph's School, other community members and the IHP team personnel also participated in the scripting and shooting of the Tonga Water Board video in Tongan language. The video has been distributed throughout Tonga to secondary schools and government departments, and a subtitled version could be made available for wider distribution in the Pacific region.

2.5 Conclusions and recommendations from the groundwater pollution study

The study asked the question **'is there a safe distance for siting of sanitation facilities** in **relation to water supply sources"** and the results of the investigations contribute to guidelines on this complex issue
The findings of the study are summarised below:

1. The water in the wells of the villages of Pangai-Hihifo had been tested and in most cases the presence of faecal indicators was at an unacceptable level of concentration (E.coli >2000/100ml) for human and environmental health.
2. Samples taken from wells outside the village area had a much lower indicator count (E.coli<200/100ml) The groundwater in the village area was therefore assumed to be polluted from human and animal activity.
3. Groundwater samples taken from 4 points in proximity to a large septic tank system showed increasingly higher concentrations of E.coli at the points closest to the septic tank The sample from the closet point (2.5m) to the septic tank overflow, had a distinct sewage odour. It therefore can be assumed that at least some of the pollution of the village groundwater was coming from the flush and pit toilets.
4. The questions then remained, 'how fast does the pollution move from the sanitation facility through the water table, and is there a safe distance between pollution source and water supply source that will allow disease causing organisms (pathogens) to be rendered harmless by retention and dilution.
5. The Bromide tracing experiment conducted in this study indicated that, in the soil conditions and geology of the study area, diffusion through the water table of disease causing micro-organisms could occur at a minimum rate of 5 meters a fortnight in all directions.
6. Some micro-organisms responsible for waterborne disease, such as viruses, can live for indefinite periods in cool wet conditions and other pathogens could survive the time taken from diffusion from a toilet to a well within 100 meters in any direction.
7. The Rhodamine-WT dye tracing experiment demonstrated a slightly faster rate of flow from the study area toward the coastal or West side of the island.
8. Survey of 50 wells in the village indicated that the groundwater levels were slightly lower on the West or coastal side of the village, offering an explanation why movement of tracers was slightly faster in that direction.

9. The survey of water levels also indicated that the direction of flow was not always consistent and, at other points in the village it could be moving inland. Therefore, it cannot always be assumed that any protection will be provided by installing a pit or flush toilet on the coast side of a well.
10. It is accepted that effluent from septic tanks and seepage from pit toilets can cause pollution of shallow aquifers. In 1977 the Environment Protection Agency in the USA designated areas with a septic tank density greater than 15 septic tanks per square kilometer as having potential contamination problems (Dillon 1996).
11. In the context of study site in the contiguous village of Pangai-Hihifo on Lifuka, there were approximately 3500 people living in an area of approximately one square kilometer. Most of the 300 house-sites in Pangai-Hihifo had one pit latrine, which was moved every 6-12 months around the house-site, and at least 50% also had a septic tank flush toilet within the house-site, This density of at least 300 toilets per square kilometer indicates widespread contamination of the aquifer.
12. Strategies to protect public and environmental health must address local beliefs and priorities to enable change in perceptions and behaviour
13. From the social component of the study, it was established that private wells are an important and practical supply source for the people of Lifuka, and efforts should be made to protect the viability of the wells, even if an improved reticulated supply is provided. Enforced closures of the private wells is not a constructive solution.
14. As the study indicates that there is no safe distance for siting of wells in relation to current toilet facilities in a village setting of the density of Pangai-Hihifo, strategies such as source control and water treatment are required to reduce the negative impacts of pollution
15. Source control strategies being trialed in the village area included the use of composting toilets which do not discharge waste into the groundwater. The Health Inspector was also promoting the repair, covering and reinforcing of well structure to prevent ingress of pollutants through the wells.
16. A CIE program should be developed using visual and aural aids, which demonstrate the nature and movement of the aquifer and its susceptibility to pollution, and explores appropriate and practical strategies that can protect this essential resource. The program could include the development of a model that used analytical equations describing commonly occurring hydrological conditions incorporated in a graphic display to illustrate the movement of nutrients and pathogens in groundwater. The video version would be adaptable to local languages and site conditions to provide an educational aid and management guide for minimum separation of waste sources from water supply wells.

3.0 Groundwater recharge on coral islands

3.1 Purpose and goals of the recharge study

The social data that serves as the basis for this section arose out of a Groundwater Recharge Study carried out on Bonriki Island Tarawa, in the Republic of Kiribati during 1996-1997. The study was funded as part of the UNESCO International Hydrological Programme, Humid Tropics Programme, and the UNESCO Coastal Regions and Small Islands project,

There were specific technical and social science components in the original design of the study. The author was engaged to undertake social science investigations in co-operation with a local counterpart social worker into the socio-cultural implications of the recharge study and to provide training or demonstration to counterparts/trainees in the process and significance of such investigations,

The technical objectives of the project were to provide techniques for the more accurate estimation of recharge to groundwater systems (freshwater lenses) on coral islands through the physical measurement of factors influencing recharge. The techniques include quantification of rainfall, interception and evapo-transpiration losses under various vegetation regimes, and measurement of soil water, water table and freshwater lense dynamics. The applicability of empirical, analytical and numerical techniques to quantify groundwater recharge was examined.

This project was not designed to provide water managers with all the necessary techniques to estimate sustainable yields from freshwater lenses, but rather to focus on the recharge component. In combination with other essential information on the groundwater system, accurate estimates of recharge can provide water managers with the necessary means to establish estimates of sustainable yields and hence safe extraction rates (White 1995).

3.2 Project activities and development

The intent of the social science investigations was to involve the people of Bonriki village in the project from the outset to completion, in order to obtain their co-operation in the project and identify any concerns or objections to the establishment of equipment and conducting studies in the Bonriki area. The investigation also sought to identify reasons for past vandalism of water supply infrastructure including interference with pump stations and salinity monitoring boreholes. It was intended that the project provide education about the water cycle and catchment management, and in particular the relevance of evapo-transpiration.

The process of involving the Bonriki people included explanation of the objectives and details of the project using appropriate visual aids, and seeking permission to proceed with the study. This was followed by discussion of issues of land ownership and use, water resources and water supply, effects of trees on water and water on trees, and possible climate change, and by seeking the local perceptions of current conditions including the effects of pumping.

It was hoped to gain an oral history of water related problems such as the impact of drought. Some residents were invited to assist with the monitoring process in co-operation with Kiribati government counterparts (eg. checking of equipment, reading rain gauges, feeding ongoing community response back to the project). The invitation was accepted by one resident but not taken up because he relocated to another island during the period of the study. The issue of past vandalism of monitoring equipment was not referred to directly, out of politeness, but a request was made that the if people saw the equipment in the reserve could they please take care of it.

The social science investigations were conducted during two field trips, two weeks in August 1996 and one week in February 1997. Technical investigations were concurrent and extended to 1998 with monitoring being maintained by local staff between visits by technical specialists. The ongoing technical fieldtrips aimed to continue observations in the wet season, but the socio-cultural implications of the study impacted on the technical component long after the social science component was deemed to be complete.

Communication was undertaken with the people of Bonriki in a number of contexts, which included the following:

- formal discussion between the village residents and the Urban Council and the project team in the *maneaba* (traditional meeting house) at the outset of the Study, and six months into the study-,
- informal meetings with village elders and leaders in their homes with the assistance of the social science counterpart as translator;
- one to one discussions with other residents when the opportunity arose;
- the participation of a village representative in the study workshop at the Public Works Department; and
- extensive discussions on land and water management issues with staff of the Division of Agriculture which is situated in the vicinity of the water reserve at Tanaea.

Consultation was also undertaken with personnel from the Ministry of Environment and Social Development, the Ministry of Home Affairs and Rural Development, and the Ministry of Works and Energy. Informal discussions were held with members of the wider community including women's groups.

In the initial two week field trip, team members included the Australian technical and social science consultants, trainees from the Federated States of Micronesia (FSM), Tuvalu, the Cook Islands, and the Kiribati Public Works Department (PWD), and the social science trainee from the Ministry of Environment and Social Development (MESD)

3.3 Social science revelations

The Recharge Study could have been perceived primarily as a technical project, And in the planning stages when a social component was incorporated some scepticism was expressed: "what could be the social implications of evapo-transpiration?".

However it became increasingly apparent that the Recharge Study was being conducted in an ambience of considerable political and social sensitivity and complexity. These factors impacted directly on the progress of the study to some extent, and certainly have long-term implications for management of water resources on Tarawa in the future. Given the longstanding and entrenched nature of the conflicts that emerged, three weeks field work only allowed an overview of the situation, and much of the information gathered relies on hearsay and personal opinions. Review of existing written documents on water and land management in this and similar areas in Tarawa provided extra detail and background but it could take years of research to uncover the depth and breadth of the socioeconomic, political and environmental issues involved. However, one thing was clear: there was serious conflict between the community of Bonriki and the Government of Kiribati regarding the use of fresh groundwater resources.

Sections of Bonriki had been reserved for public purposes to provide a public water supply and an airport for Tarawa, with obvious implications for the local residents, the government and the wider community. The process of community involvement in the Recharge Study, and relevant information and points of interest from the investigations and communications are summarised below as they unfolded.

3.3.1 Formal and informal group discussion

From the formal meetings in the *Maneaba,* and informal group discussions with Bonriki residents and elders in their homes, it became apparent that some residents felt that they had not received sufficient compensation for the use of their land as a water reserve. They complained that they had not been made sufficiently aware of the impact that the reserve and the airport would have on their lives. Apart from the loss of the area for housing and gardens, their coconut trees and *babai* pits (taro) had become virtually non-productive due, they assumed, to excessive water extraction, and they had lost their livelihood and independence. It was reported that the village was previously self sufficient with food and sold copra but since land had been lost to the reserve and the airport, they had to buy coconuts and depend on money from the government and other sources to live. They also complained that the water in their wells had become saline from over pumping.

After the second *maneaba* presentation by the project team which explained the goals and findings of the Recharge Study, one of the residents commented that none of the villagers had believed any of the data offered and regarded the presentation to be a government ploy to avoid further compensation. This was, of course, his opinion. When it was pointed out that the height or salinity of lens has not changed since the introduction of the water reserve, the villagers were sceptical and responded that food trees on the periphery of the reserve were "looking bad" due to the reduction in size of the lense.

The subject of evapo-transpiration and its implications for water management did not appear to interest the residents in the *maneaba* presentation or household discussions. It seemed that were only really concerned about the larger issues of the reserve and the airport and their impact on village life. For example, the elders wished to know if the study would generate local employment, or lead to a greater quantity of water being extracted from the reserve than was currently occurring.

However, the residents' response was not entirely negative. It was indicated that the village residents appreciated being consulted, and that consultation had not been conducted to this extent previously, despite projects of a much greater impact being undertaken in the Bonriki area. Some elders would have preferred more notice prior to the commencement of the study.

3.3.2 One to one discussions

From the one-to-one discussions with a couple of residents who did not seem to be involved in the push for compensation, further information emerged. They suggested that perhaps the fronds of the coconut tress had yellowed and the nuts had become small and scarce because the trees were old and untended, no new trees were being planted, and the nuts and fronds were regularly scavenged by trespassers from the rest of South Tarawa.

It was advised that the *babai* had deteriorated throughout Tarawa from attacks by the babai beetle during the last ten years, and wells may have been saline from recent flooding from the lagoon. The vegetation on the reserve may have suffered from fires lit by teenagers. It seemed that some of the discontent had arisen because the village had become seriously overcrowded by influx of relatives from the outer islands (a pressure being experienced by all of South Tarawa) and the majority of these people were unemployed. Consequently space/land was in very high demand and the available cash from the compensation or lease payments was not sufficient for, or available to, the expanded population. It was suggested that this discontent had been exploited to some extent during the recent elections and senior politicians were covertly encouraging resentment against the current government in regard to the Bonriki reserve.

Since the new government had been elected the landowners had been paid $200 an acre per year (government representatives advised that the payment is $300 an acre per year). The residents of Bonriki also received free supply of water. They reported that they used to have a tap to every house but these are not maintained so now there are three tap stands for whole village. They also use house wells consistently because the reticulated supply is intermittent. When the reticulated water is available they allow the taps to run continuously. The residents did not consider it an advantage to not pay for reticulated water as "the water belongs to Bonriki anyway" and they knew of many people in other parts of South Tarawa who have not received water bills for over a year.

The government was obliged to compensate for losses associated with the use of the land but not for anything below ground level, including the water. Hence the focus by landowners on the affect of extraction on vegetation and consequent loss of livelihood or subsistence (Shalev 1994). It was very doubtful that an increase in rent for use of the land could be negotiated, but if other loss could be proven, then reparation would be arguable. In addition to the agitation for redress, the villagers were taking practical steps to alleviate their difficulties. Against the conditions of agreement for lease of the reserve land, Bonriki residents were moving onto the reserve, building houses and growing vegetables, It was implied that in some cases plots had been sold or rented to them by the landowners. In other cases, the landowners could not refuse their relatives due to the custom of *bubiti* even though they have been compensated by the government for non-use of their land. There were also the children of the landowners who had recently married and needed their own home and gardens. In addition, space was required to bury their dead.

When told to move off the reserve by government personnel, some of the squatters threatened to burn down the pump housing. It seemed that some young male members of the community were adopting increasingly hostile tactics, including vandalism. Monitoring bores that had been providing consistent invaluable information for more than twenty years had been destroyed even within the period of the Recharge Study. It was reported that there had been deliberate pollution of the groundwater on the reserve. Airport infrastructure had also suffered vandalism in recent years. The situation had been exacerbated lately by an ADB report (Kali 1997) which had attributed the deterioration of the coconut trees to over pumping despite being advised by local agronomists that the indicators used were inappropriate and inconclusive.

In addition to dealing with the demands for compensation and the impact of vandalism, senior Ministry personnel were also concerned that the negative attitudes to the reserve among the Bonriki residents would hamper negotiations for further reserves with other communities on Tarawa (Kingston Morrison 1996). This concern was justified as already residents of target villages were reluctant to negotiate, or were demanding excessively high compensation for any proposed water reserve leases. The project team was asked if they could provide proof that water extraction was not causing deterioration of the coconut trees. The Groundwater Recharge study had inadvertently become embroiled in a major political struggle.

3.3.3 Discussions with the wider community

From discussions with the wider community of South Tarawa it emerged that the people of Bonriki were resented because they were perceived as receiving unwarranted special treatment for loss of their land. Many landowners in South Tarawa were suffering the stress of overcrowding, dislocation and increasing demand to accommodate and support relatives from the outer islands (Tebano 1996). It was observed that the Bonriki people still had plenty of breadfruit trees and could easily fish in the lagoon and collect food off the reef as their shoreline was less polluted and degraded than the more populated areas of South Tarawa. There was also some anxiety that the discontented Bonriki residents were 'poisoning' the reticulated water and blackmailing the government to obtain more compensation. From these members of the wider community there was pressure on the government not to listen to the Bonriki residents, and to force the squatters off the reserve.

3.3.4 Training

An integral objective of the study was to provide training and experience, in the social and technical aspects of undertaking this kind of research. Training of local counterparts and the visitors from the other island countries was participatory and reinforced by regular informal discussions and review of the project's progress and a number of structured workshops. The I-Kiribati technical trainees maintained the groundwater monitoring systems between visits from the Australian consultants, despite limited transport and other bureaucratic obstacles, and assisted with analysis of data.

Working with the social science counterpart was only possible on three occasions due to her other commitments as Women's Development Officer. There was some conflict of purpose between the social science training goal and the facilitation of community involvement, as it was usually more effective to work alone in terms of gaining a more candid response from interested parties. Discussing delicate issues with a local person translating can be politically awkward. Skills in accurate translation are hard to achieve without considerable training and experience, which the social science counterpart did not have. In the informal discussions, it was obvious that, at times, she was encouraging interviewees to give the answer she thought the social science consultant wanted to hear.

In the first *maneaba* meeting, the presentation of the objectives of the study by the social science counterpart was significant in itself, as it is not traditional practice for young women to speak in the *maneaba* and she was quite challenged by this experience. In recent times women speaking as government representatives have been increasingly accepted to address the *maneaba*. However, it is likely that the *unimane* (senior men) and the Urban Council would have taken the presentation less seriously because it was delivered by a young, inexperienced woman.

The visiting trainees from other island countries acknowledged that it was very useful to experience a social science component in a technical research project. They referred to situations in their own countries where social and political issues were a major component in water and land management.

Technical training on the February 1997 field trip would have been much more comprehensive than during the August 1996 workshop, as the equipment was well established by this second visit, and many of the earlier difficulties had been ironed out. However it was not possible to fund the return of visiting participants from the other Pacific Island countries. This is one of the challenges associated with short international field trips. It is really only the participants from the host country who have the ongoing time and opportunity to team from the research process. For the visiting participants the most that can be offered in the brief time frame is some demonstration of the techniques involved and an overview of what is required to conduct a project of this nature.

3.4 Lessons learnt from social science investigations

The summary of the social science aspects of the Groundwater Recharge Study suggests that thorough consultation and ratified agreement between government and landowners prior to acquisition of land could prevent development of many of the problems referred to in this study. However this apparently desirable procedure may be complicated by a number of interrelated factors which should be anticipated in the planning of any such consultation. The personnel selected to conduct the negotiations on behalf of government, and in the manner in which the process is conducted, are also vital issues that will determine the efficacy of government/community relations in regard to water resource security.

The situation on South Tarawa is to some extent specific to the culture and history of Kiribati, and to the socio-economic conditions prevailing on that island, but in other respects certain principles may be applied further afield where government bodies are negotiating with communities on water resource use.

In Kiribati, the notion of private land boundaries being determined by a public institution is a colonial imposition that is still not entirely accepted by local residents. In pre-colonial times neighbours were very clear about the dimensions of their plot, the boundaries being determined by such markers as the location of a particular breadfruit tree, or 'sweet' groundwater well. The demarcation and significance of these naturally occurring borders was passed down orally from generation to generation. When the British Land Commissioners and Surveyors delineated and registered land allocations during the mid twentieth century, the technique of drawing straight lines across the width of the atoll left many people feeling they had lost essential parts of their land. So there is an historic distrust of outsiders or government bodies 'carving up' the land for what ever purpose, private or public. This distrust has been exacerbated in some cases by incomplete or erroneous details being recorded by the Land Court, and in the Lands and Survey Division register.

A further overriding condition that will affect community consultation, in Kiribati, where government is acquiring land for water resource use (or for any other public benefit for that matter), is the fact that the notion of public responsibility is a non traditional value. What people do with their land and their resources is their business. The historic personal relationship to the land and the pressures of extended family obligation are far more compelling than the expectation of co-operation or sacrifice for the common public good.

Centralised control of land for public purposes is a superimposed notion inherited from a period of foreign rule. Also, during the colonial and postcolonial process of acquisition, thorough consultation with the private sector was not the custom. The more recent promotion of community consultation prior to, or during acquisition, or if certain activities are planned on the land is, yet again, an introduced notion, and to some extent, is not that attractive to the government personnel who are being advised by expatriate consultants, to undertake it. This may be because local government personnel are aware of the long standing complexities of the situation which they feel are better avoided. And they may even have direct or indirect personal involvement in the issues due to the small closely-knit community.

If there is no personal investment in the situation there is also the customary inclination not to get involved in what is perceived as other péople's business. A common response from government personnel to the proposal for community consultation is that they do not wish to give the locals the opportunity to complain. However, the foreign donors fund most research projects so the community consultation goes ahead often within a very tight schedule, and sometimes without sufficient preparatory background. If government personnel are not entirely convinced of the wisdom of the proposed consultative process it may be sabotaged in a variety of subtle ways. For example, the choice of an inexperienced young person who had no interest in the goals of the project, as social science counterpart, could be interpreted as an indication that the local bureaucracy did not consider the consultation process as a high priority. The choice of counterparts for social science work is **in** itself a political issue.

There is a traditional process of consensus within a the village structure in the maneaba context but this was based on allegiance to, and respect for the senior citizens particularly the old men of the village, the *unimane*. Staff from any government Organisation are often perceived by the wider community as an assembly of individuals whose primary motivation is the promotion and support of their family's interests. That self-interest may be seen as being furthered under the guise of the activities of the Ministry concerned.

Therefore it could be useful to have personnel conducting consultation and negotiation on behalf of government who are respected in their own right, for example, an *unimane* from another village or an esteemed and experienced community worker, or someone unrelated to the local family networks ie an expatriate. If this facilitator's role is to be undertaken by an expatriate then attention has to be paid to prevailing mores of communication.

3.5 Comments and suggestions arising out of recharge study

From the experience of the study, certain activities can be suggested to facilitate government/community relations. These activities may seem onerous and time consuming but it is predicted that the effort will be well spent. They may avoid complications in the future that can be far more onerous and time consuming in the long term for all concerned.

Prior to acquisition of private land for public purposes it is advisable to undertake thorough consultation with landowners and affected community. Firstly the government body should clarify what they wish to achieve from the consultations, and what is negotiable. The person or persons conducting the consultations on behalf of government should be respected individuals in the community, or respected visitors, with effective listening skills. They should, as much as possible, have no personal interest in the outcome of the discussions. Informal private discussions should be conducted in addition to formal group presentations. Adequate time should be allowed for both parties to cover all relevant issues and to consult with other stakeholders, and then provide feedback. This may take many months, and the process should be consistent and methodical.

The aim of these interactions is to ascertain the nature of the landowners' relationship to the land (and water resource) from a legal and traditional values point of view, to address that relationship when calculating compensation, and to incorporate whatever is agreed upon into an accessible legal document that is signed by all interested parties. In the case of leases, it may also be useful to negotiate ongoing involvement by the landowners in the maintenance of the land, ie in the maintenance of the water reserve. Monetary compensation does not always compensate for the loss of relationship to the land, the dignity and identity that it provides. Perhaps the compensation can be tied in some way to the role of guardianship, which can be then be passed on to the next generation. Managing the reserve as a recreational or sports area for the public has been suggested as a possible option which could return 'ownership' to the Bonriki people and perhaps generate employment and remuneration for residents (White et al. 1999). Although in some respects traditional attitudes and relationships to land may work against acquisition and use for public purposes, it may be possible to work with those values.

It is not being suggested here that private parties to a consultative or negotiating process should achieve all the conditions that they want in any water resource agreement. If all concerns are aired in advance then at least it can be stated whether or not those concerns will be attended to, and if not, why not. This reduces the likelihood of unanticipated or unacknowledged needs surfacing at a later date and causing resentments and ongoing claims for compensation, or vandalism. In the case of a water reserve, it is advisable that land is purchased outright, if possible to avoid the long term nexus of a leasing agreement. Whether the water reserve is leased or purchased, it should be emphatically stated that no agricultural, industrial or domestic activity would be permitted on the land and compensation paid accordingly. If this restriction is not likely to be observed, then activities that are allowed should be clearly specified, and the rent lowered accordingly. In some cases it more constructive and sustainable to allow productive activity to prevent inactivity and loss of self-esteem leading to agitation, and vandalism. Whatever the conditions, they should be clearly understood and accepted, as there is a positive disinclination to police any regulations that may govern activities on government reserves.

It is advisable not to allude to any possible later benefits from the agreement, such as paid work on future water resource infrastructure, as a means of persuasion for local residents. People have long memories. The mutual concrete benefits should be detailed in the agreement as a final and complete settlement.

To further prevent ongoing discontent with leasing agreements it may be advisable to pay rent in regular installments throughout the year rather than annual lump sums. In regard to practical matters the I-Kiribati live for today, and are inclined to spend all their cash at once, particularly if there is demand from many dependent relatives. If the extended family relies mainly on rent or government compensation for survival, this can mean that during the rest of the year they are in serious economic difficulty.

During the process of consultation it is important to provide graphic objective information as to the likely short term and long term environmental effects of the proposed water use.

A lesson that could be learnt from the Bonriki story, which was set in a land/ subsistence based culture, is not to overburden one community with too much demand for public sacrifice. Land for an airport and a water reserve is a lot to ask of one small island even though the two uses may be practically compatible from the government's point of view. There is no benefit from the local residents' perspective, apart from monetary compensation, which often only reaches the primary landowners. Prior to the reserve acquisition, the residents already had access to an ample supply of 'sweet' water. The airport has little relevance to residents squeezed into a reduced village area, many of who will never have the opportunity to undertake air travel.

South Tarawa is under environmental and socioeconomic stress. This has been steadily increasing over the last twenty years (Harrison 1980). The difficulties facing Tarawa go far beyond the problem of water use, although it is a critical issue. A coordinating body or Urban Management Committee is needed (Jones 1995). There is an ongoing problem with lack of communication between agencies dealing with water and land management issues. This universal problem could be exacerbated by the I-Kiribati inclination not to get caught up with other peoples' (or other bureaucracy's) business. Ideally, this Committee could also centralise and review aid projects to avoid duplication and cross purposes, and ensure relevance through consultation with local experts. To reduce the burden on government and increase community responsibility the private sector could be allowed greater involvement and investment in public works.

4.0 Common concerns in groundwater monitoring and management

4.1 Common goals in the groundwater studies

The groundwater pollution study in Tonga and the recharge study in Kiribati both aim to contribute to the sustainable management of a fragile, limited and essential resource. Both studies are also concerned with the control of groundwater pollution, as a direct focus in the Tonga study, and indirectly in the Kiribati study. In Tarawa, the strategy to protect groundwater from surface pollutants is to create a public, or government controlled reserve which restricts access and use of the land. The recharge study then focuses on maximising the use of the protected water resource by establishing the ways in which accurate estimates of recharge, and other related information, can enable water managers to more effectively estimate sustainable yields and extraction rates.

An alternative pollution control strategy, which is the focus of the Tongan study, is to allow normal access and usage of the land but then to provide guidelines to reduce the impact of human and animal activity.

Both projects relate to situations where lifestyle changes and population density has exceeded traditional parameters, and rendered traditional individual water management practices ineffective. However the consequent centralised bureaucratic intervention occurs in a context where people still consider private control over their land and its resources as an ultimate right and inherent need. These values prevail in both countries regardless of the feudal land tenure arrangements operating in Tonga.

The original design of both research projects acknowledged the existence of these critical sociocultural factors by including a social science component, but it was not fully anticipated that the conduct of the studies themselves would be so inextricably affected by the human element. In the groundwater recharge study there was insufficient time allowed to deal with the unexpected complexity of the social science involved.

One of the primary lessons to be learnt from these groundwater studies is, that in a cross-cultural multi-disciplinary project of this kind, the thorough integration of social and technical science will facilitate and maximise effective and useful research.

4.2 Common challenges and possible strategies

During the process of the two groundwater, studies certain trends and responses were experienced in both Kiribati and Tonga, despite the different focus for the research and the differences in culture, and environment. Some of these observations may be useful to keep in mind in future resource monitoring projects

4.2.1 Consultation, information and education (CIE)

When undertaking measures to protect and conserve groundwater there is a need for thorough consultation with all concerned. In the pollution study in Tonga it was apparent that there is no point in providing guidelines for siting of water supply and sanitation facilities without fully understanding the priorities, beliefs and practices of the users of those facilities. It is also essential to effectively demonstrate the value of a desired outcome if perceptions are to change.

In the more contentious context of annexing private land for the purpose of creating a government controlled water reserve, the need to fully understand the issues involved and undertake consultation with those affected has been demonstrated by the experience at Bonriki. in Kiribati. These CIE principles apply to the management strategies undertaken to conserve and protect groundwater, and to any research project which seeks to monitor and improve management.

In cross-cultural research projects such as those described in this document, the lack of shared language and/or mother tongue increases the need for appropriate communication skills in the exchange of information and training. This is not to say that applying these skills will always achieve the desired outcome, but experience has indicated that certain strategies can be more productive in the attempt to arrive at a shared understanding,

For example, to the extent that useful discussions were conducted during the recharge study, it was usually in the one-to-one context, that is, without translation by I-Kiribati personnel and not in the presence of other team members. Informal one to one or small group discussions with community members (who could speak English) were much more revealing than formal translated discussions either one-to-one or in groups. This seems to be because local people felt more comfortable making frank comments to a stranger without the presence of intervention of one of their own people, because of the complex web of local relationships and alliances.

This was also observed in the household survey conducted in Pangai-Hihifo during the groundwater pollution study. In discussions conducted without the translator, or after he had left the room, it was often discovered that the householder spoke enough English, sometimes with the assistance of mime, for a useful dialogue to be conducted. In the presence of the translator, the householder had indicated he or she spoke no English. This appears to be because of the likelihood of being teased by other Tongans if one's spoken English is not perfect. It is also understandable that people may be reluctant to discuss their hygiene habits in front of someone from their village, whereas such discussions with a stranger are less embarrassing.

There are other advantages that were experienced, in the informal one-to-one discussions, in both projects. To some degree a more relaxed familiar atmosphere could be established between two people, and also the manner of asking questions and listening to responses could be controlled. For example, if the interviewer asks a question it was done in neutral fashion, ie, the answer was not implied in the question, and if the person hesitated in their response, they were not prompted or the answer provided for them.

This basic guideline in interviewing technique seems particularly important in discussions with I-Kiribati and, in fact, many Pacific Islanders as there is a common tendency to give an answer that is assumed to be expected or desired by the questioner, particularly if the questioner is a 'guest' or foreign visitor. Also it has often been observed that people may be silent for some minutes before answering a question and if this silence is interrupted then it is unlikely one will learn what was the true content of the response. Westerners are often embarrassed by this silence and feel compelled to fill it.

The I-Kiribati and Tongans tend to avoid direct conflict particularly in formal discussions and it is important to listen carefully to what may appear to be mild comments, particularly of a negative nature. In local terms these could be interpreted as strong statements of protest or disagreement. Expatriate consultants often complain that local counterparts do not inform them of significant information at critical times. In some cases this is due to lack of attention to what might be interpreted as indecisive, disinterested or non-emphatic communications which are, in fact, presented as such out of politeness. The I-Kiribati do not usually directly question or confront authority. They sabotage or co-operate with whatever is being advocated, as they see fit (Saito 1997).

It is also worth noting that Kiribati is still a society where effective communication is primarily conducted orally and graphically. To a lesser degree this is also the case in Tonga, especially on the outer islands. The written word has limited relevance. Lengthy reports may have some usefulness for aid donors and expatriates, but the locals rarely read them. Even at a ministerial level a single page document with clearly spaced key points will have more effect than detailed communiqués. If the recipient wants to know more they will ask. Creative images and active demonstration can save hours or pages of verbosity.

Cross-cultural communication particularly of a technical nature can be hampered by the absence of suitable technical words or concepts in the local language. When preparing the presentation for the *maneaba in* Tarawa, the points that needed to be covered were first detailed in English by the expatriate specialists and then reviewed and translated into Kiribatese by the I-Kiribati technical team. The content then had to be further refined so that it was appropriately respectful to the *unimane* and the context of the *maneaba.* Translation was complicated, among other things, by the fact that there is no local word for 'evapo-transpiration' but later the team had devised a new word which means 'vapour up'. Because of the general difficulty of translation and the requirement for a particular form of address, the original content of the presentation was significantly abbreviated.

With regard to the groundwater pollution study in Tonga, and the associated composting toilet trial, it was necessary to observe strict gender related taboos when discussing sanitation issues. The taboos dictated in whose company, and in what manner, certain subjects could be discussed. This is not something that will be explained to the outsider but if the taboo is unwittingly transgressed it can become embarrassingly obvious. The Tongans have a deft way of transferring sensitive information by the use of metaphor. As previously mentioned these situations require the expatriate consultant to be receptive to subtle directives from counterparts. Unfortunately externally funded project agendas often don't allow the time or flexibility to absorb these subtleties, but they can significantly influence the success of the study both in terms of information exchange and achieving desired changes in perception and behaviour.

4.2.2 Sharing of knowledge

It cannot be assumed that information transferred to counterparts will be shared with other team members on the project, their colleagues at work or the wider community. Knowledge is power, and in Kiribati and Tonga, it did not appear to be expected that a person would pass on knowledge outside their extended family. This can be frustrating especially when undertaking multi-disciplinary research.

In terms of training it is often more effective to work on a one-to-one basis to ensure that a counterpart has understood what is being conveyed. In the presence of others there may be an inclination to feign comprehension to save face, and the embarrassment of speaking technical English could also be a deterrent. However, once individual instruction is achieved, it is then advisable to regularly discuss the outcomes in a group with each counterpart or team member presenting an aspect of the work, thus creating an ambience of common knowledge.

As soon as practical, it is advisable to have trainees conduct the work even it slows down the process or results in some errors that require repeat activities. As long as expatriate experts are responsible for the research, local counterparts are unlikely to take initiative, partly out of respect but also from lack of confidence. However, if trainees are engaged in monitoring, in the absence of the external supervisor, it is important to set up some structure that will ensure that activity and data collection will be shared. The need for individual capacity building for local personnel was experienced in both groundwater studies, but experience and training in collaboration is also a priority.

To ensure that information is passed to colleagues in their department it could be a requirement of participation in the project that an oral presentation of project outcomes is given in the workplace. As previously mentioned written reports are rarely read thoroughly, if at all. It was observed that the most effective method of dissemination was through demonstration, or where possible, through theatre or video. If respected community members participate in the dramatic presentation, it will achieve greater attention and acceptance.

4.2.3 Centralised control and individual responsibility

In both projects there was the dilemma of replacing individual responsibility with centralised control in regard to resource management. In response to the discovery of contaminated wells in Pangai-Hihifo, Tongan residents were being encouraged to close their private wells, because of likely pollution from their toilets, and consequently depend upon and pay for a centralised supply of water. (It would not be possible to rely entirely on rainwater tanks in the dry season). Once this significant aspect of independence and self reliance is removed, the incentive to adopt measures to protect the groundwater from point sources of pollution is reduced, particularly when the notion of the common good is not integral to the culture. Where regulation would support centralised control in developed countries, policing and enforcement is weak in these small island communities. Under these circumstances, it would appear to be preferable to build upon local knowledge, and traditional symbols and practices of self reliance such as the private well, and look to alternative measures to maintain an unpolluted supply of water.

Considering augmentation of water resources in any context, it is advisable to give as much attention to demand management, as to increasing supply. Establishing new sources of reticulated water supply and supportive infrastructure has immediate and obvious beneficial effect but the social disruption and cost of maintaining public water supply sources and systems can be an unseen and long term burden on community and government alike. These is particularly so in a land and resource constrained country like Kiribati, where maintenance requirements are often not attended to, or are of a low priority (Falkland 1992). It is advisable to attempt to reduce existing demand on reticulated water by whatever means possible; consumer education campaigns, rain tanks, properly constructed private wells where appropriate, leak detection and reduction, and low-flush dry and minimum discharge sanitation technology. The on-site solutions could also be more sustainable in a culture where independence and self/family reliance was a traditional value.

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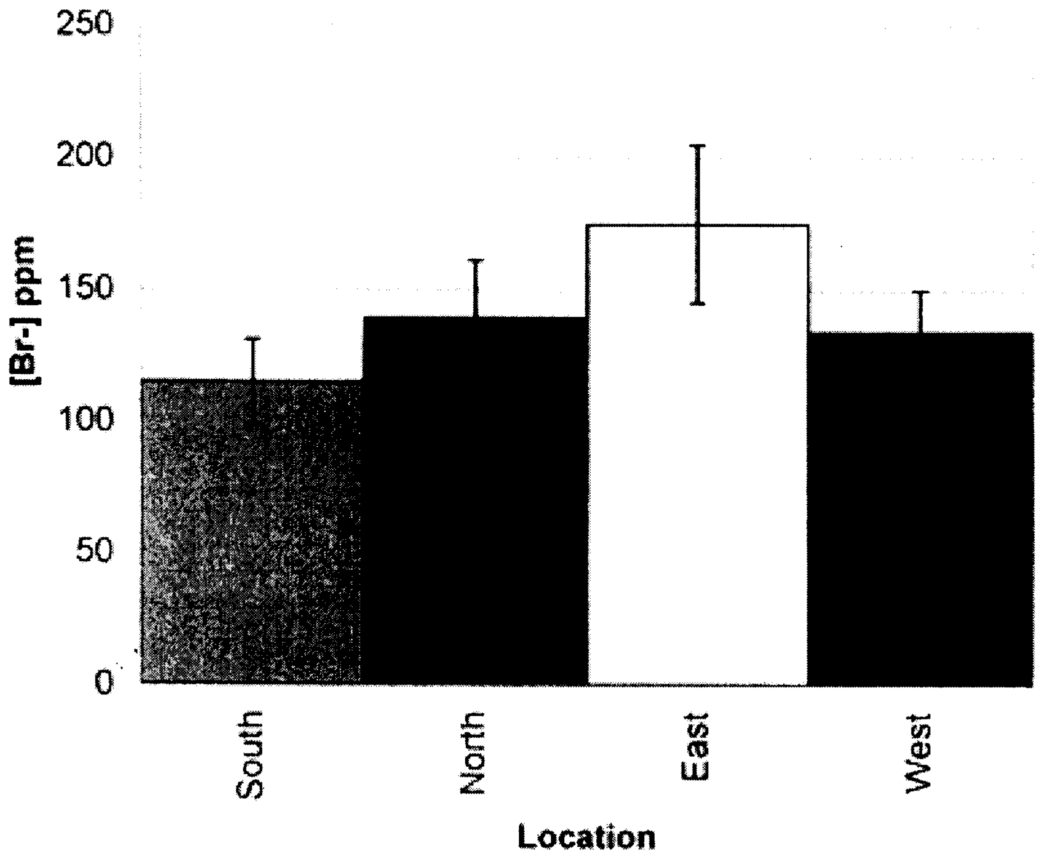
Annexes

Annex A.1

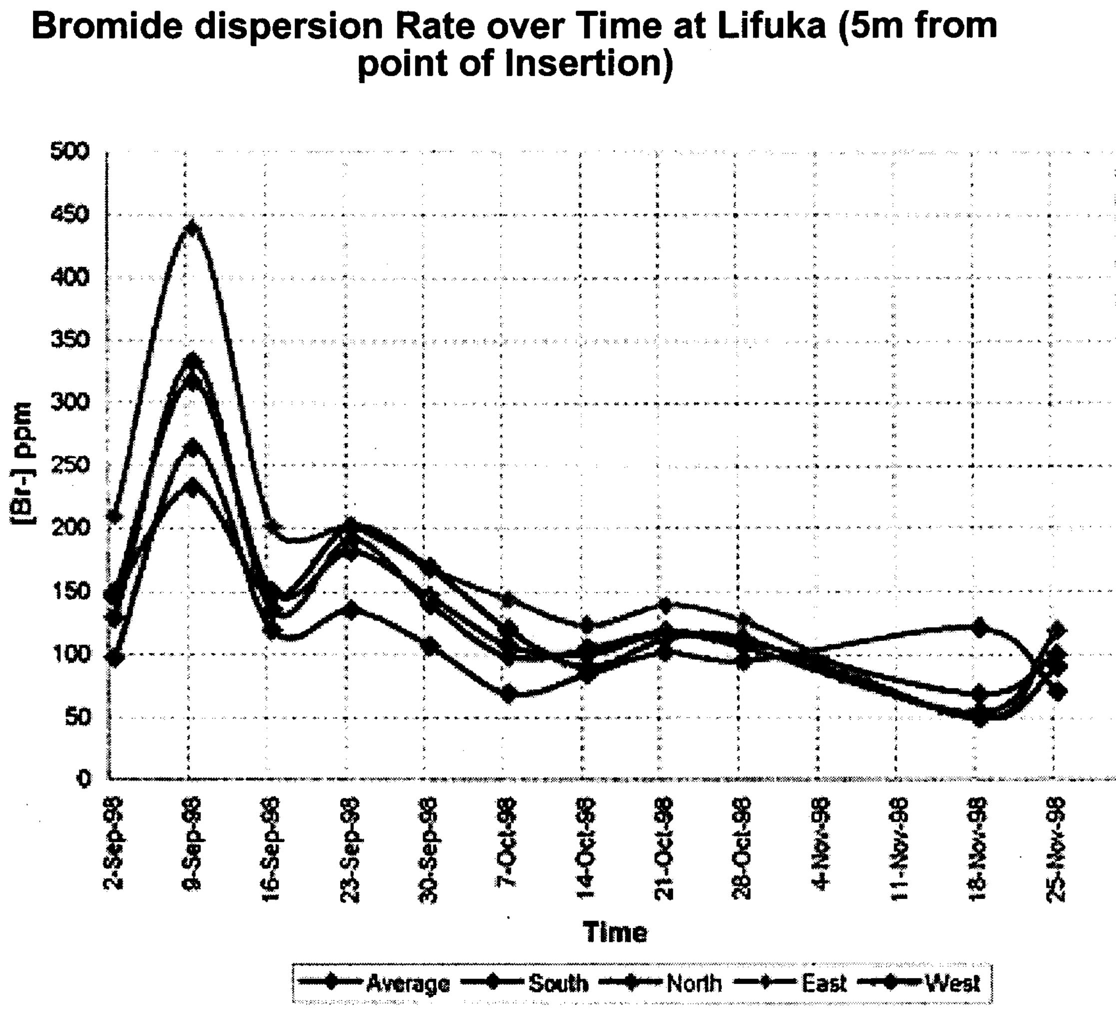
Average [BR-] Graph from the 4 Collection Points



Notes:

1. The graph shows very low spread from the average concentration
2. The highest concentration is on the eastern side or inland indicating that the flow is slightly slower in that direction.
3. Concentrations to the South and West ate lowest
4. Concentrations at collection points indicate relatively uniform diffusion of tracer in all direction with a slightly faster rate to the West

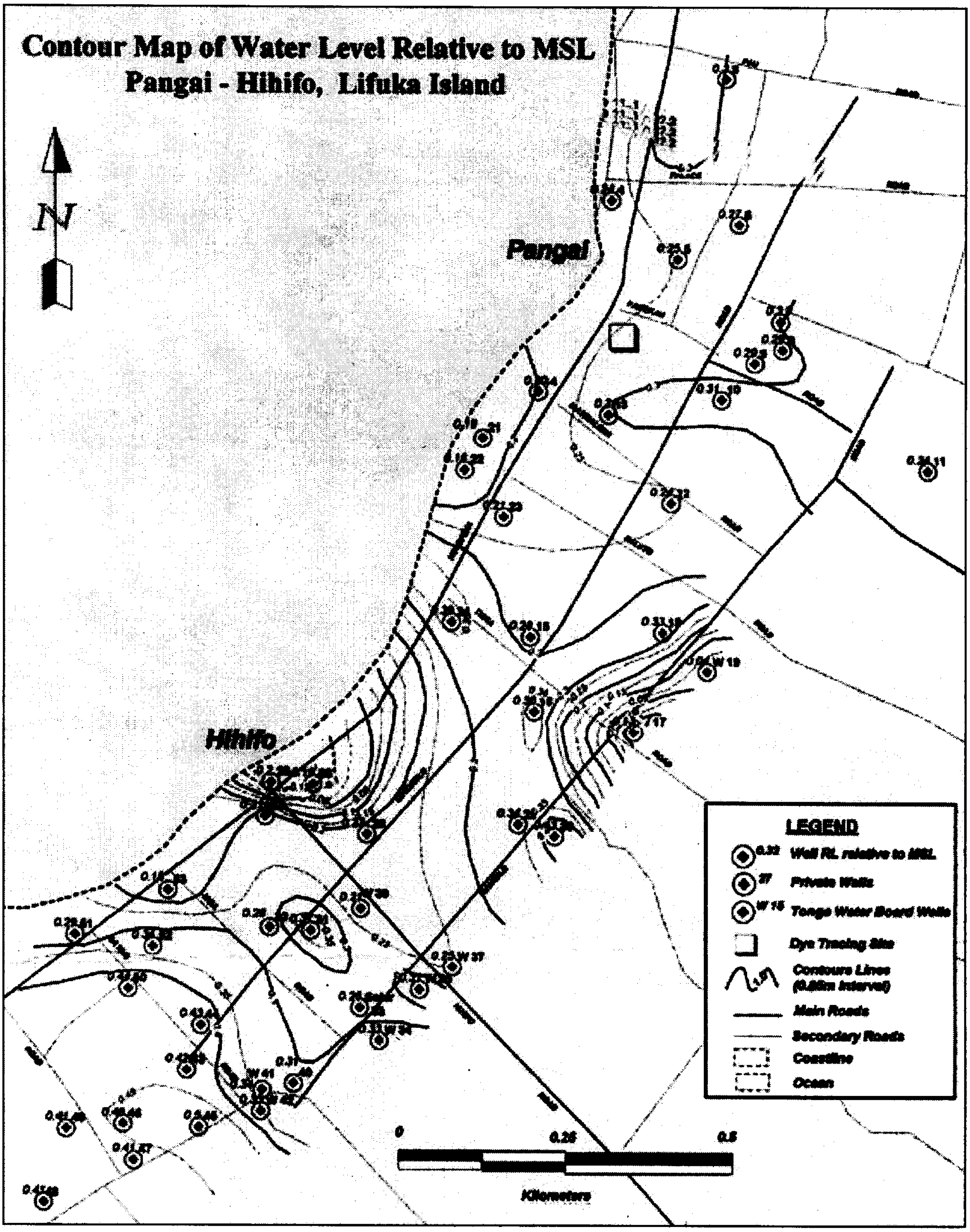
Annex A.2



Notes:

1. The tracer was inserted on August 26
2. The peak readings were determined on the 9th of September from all 4 collection points
3. Tracer concentrations id highest at the East or inland collection point
4. Tracer concentration is lowest at the South collection point
5. The salinity (sodium chloride) interference is one of the factors that was considered in the results (10ppm)
6. Concentration gradually reduced over the following two and a half months
7. A slight fall and rise occurred between 18 and 25 November that could have been due to equipment discrepancies or rainfall impact
8. Samples of the groundwater taken at the four collection points prior to insertion of Bromide registered an average of 10ppm [Br-].

Annex B.1


Contour Map of Water Level Relative to MSL
Pangai - Hihifo, Lifuka Island
N
Pangai
Hihifo
LEGEND
Dye Tracing Site
Main Roads
Secondary Roads
Coastline
Ocean
0
0.25
0.5
Kilometers

Annex B.2

Well_num	Easting	Northing	Elevatior	Well_depth	WL_R_MSL	Latitude_Sout	Longitude_West	Remarks
1	777,498.21	807,902.50	2.52	2.29	0.23	19-48-19.5	174-21-03.8	
2	777,553.10	807,877.69	2.92	2.62	0.32	19-48-19.2	174-21-02.6	
3	777,647.16	807,956.09	3.22	2.92	0.30	19-48-16.8	174-20-59.1	
4	777,475.55	807,772.25	1.76	1.52	0.24	19-48-20.0	174-21-03.2	Police station
5	777,574.60	807,682.67	2.13	1.88	0.25	19-40-28.1	174-21-01.6	
6	777,665.56	807,735.09	4.07	3.80	0.27	19-48-25.8	174-20-57.0	Evaloni Guest house
8	777,729.78	807,546.08	2.97	2.68	0.29	19-48-35.4	174-20-57.8	
9	777,688.21	807,525.49	3.25	2.96	0.29	19-48-36.2	174-20-59.9	
10	777,638.95	807,470.85	4.27	3.96	0.31	19-48-38.9	174-21-01.6	
11	777,947.46	807,364.36	6.98	6.64	0.34	19-48-40.8	174-20-50.6	Faleone prison
12	777,562.50	807,314.08	4.44	4.20	0.24	19-48-41.4	174-21-01.6	
15	777,351.85	807,111.60	4.24	3.96	0.28	19-48-43.7	174-21-07.4	
16	777,357.22	806,998.05	4.33	3.97	0.36	19-48-46.7	174-21-05.8	Finau uata
17	777,506.25	806,967.54	4.22	4.35	-0.13	19-48-49.7	174-21-05.0	TWB
18	777,549.50	807,118.28	4.33	4.00	0.33	19-48-45.3	174-21-00.4	Finau Uata Well
19	777,616.44	807,058.81	4.14	4.10	0.04	19-48-45.5	174-21-00.3	TWB well # 10
13	777,470.27	807,448.06	3.12	2.82	0.30	19-48-33.4	174-21-04.9	
14	777,364.62	807,482.59	2.67	2.47	0.20	19-48-33.4	174-21-09.9	Tailulu
21	777,280.97	807,412.88	2.34	2.15	0.19	19-48-36.5	174-21-12.3	
22	777,253.64	807,364.78	2.01	1.83	0.18	19-48-29.9	174-21-11.9	
23	777,311.92	807,293.28	2.43	2.22	0.21	19-48-40.1	174-21-09.7	
24	777,233.33	807,133.89	2.35	1.96	0.39	19-48-42.2	174-21-14.0	
25	777,025.27	806,877.24	2.04	2.23	-0.19	19-48-51.6	174-21-18.3	
26	776,962.35	806,899.77	1.78	1.98	-0.20	19-48-48.4	174-21-22.3	
27	776,953.58	806,838.30	1.82	1.61	0.21	19-48-48.3	174-21-22.3	
28	777,106.36	806,811.65	2.94	2.71	0.23	19-48-53.1	174-21-15.5	
29	777,333.36	806,826.90	2.72	2.38	0.34	19-48-56.4	174-21-11.6	
30	777,097.68	806,699.09	3.82	3.61	0.21	19-48-58.0	174-21-15.5	TWB well Hihifo Road
31	777,022.71	806,665.79	4.92	4.55	0.37	19-48-58.8	174-21-18.4	
32	777,960.87	806,669.93	3.50	3.22	0.28	19-48-59.0	174-21-20.4	
33	777,096.17	806,549.16	3.30	3.04	0.26	19-49-03.0	174-21-17.6	TWB solar pump well
34	777,125.46	806,499.80	5.47	5.14	0.33	19-49-06.0	174-21-16.3	TWB well # 6
35	777,185.85	806,576.92	4.75	4.44	0.31	19-49-01.9	174-21-12.1	TWB well # 5
37	777,234.98	806,611.08	4.70	4.45	0.25	19-49-00.9	174-21-11.8	TWB well #3
39	777,388.31	806,808.96	4.34	3.91	0.43	19-48-53.8	174-21-04.9	
40	777,996.74	806,434.76	5.37	5.06	0.31	19-49-06.7	174-21-19.0	
41	776,950.00	806,425.23	4.56	4.22	0.34	19-49-08.0	174-21-27.0	TWB well # 8
42	776,948.04	806,392.58	5.74	5.39	0.35	19-49-07.8	174-21-21.3	TWB well
43	776,837.13	806,454.17	5.42	5.00	0.42	19-49-06.4	174-21-26.1	
44	776,858.56	806,522.57	4.77	4.34	0.43	19-49-05.8	174-21-23.6	
45	776,855.15	806,368.17	5.72	5.22	0.50	19-49-07.9	174-21-23.4	
46	776,742.38	806,372.67	5.80	5.34	0.46	19-49-08.4	174-21-28.4	
47	776,758.29	806,318.86	5.46	5.05	0.41	19-49-10.3	174-21-28.3	
48	776,624.53	806,255.08	5.76	5.35	0.41	19-49-12.6	174-21-33.3	
49	776,658.29	806,365.32	5.48	5.07	0.41	19-49-09.0	174-21-32.2	
50	776,750.61	806,576.66	2.46	2.02	0.44	19-49-00.7	174-21-28.4	
51	776,670.97	806,657.68	2.28	1.99	0.29	19-48-58.9	174-21-33.1	Well at Niu'ui Hospital
52	776,790.81	806,646.35	3.19	2.85	0.34	19-48-59.8	174-21-27.8	
53	776,808.85	806,725.66	2.20	2.02	0.18	19-48-56.3	174-21-27.4	
7	777,726.62	807,588.99	4.33	4.03	0.30	19-48-31.8	174-20-58.3	FWC Hall