UNESCO-IHP/SOPAC Groundwater Pollution Study
Pangai-Hihifo, Lifuka
Kingdom of Tonga

Report on the Completion of Phase Two
(August - December 1998)

by

Dr Leonie Crennan
Ecological Sanitation
Dunbar St, Stockton 2295, Australia
Fax: 61-2-49284082

Tevita Fatai
Geology and Hydrogeology Unit
Ministry of Lands, Survey and Natural Resources
Nuku'alofa, Tonga.
Fax: 676-23216

Timote Fakatava
Head Chemist, Tonga Water Board
Nuku'alofa Tonga
Fax: 676-27518

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UNESCO/SOPAC IHP Groundwater Pollution Study, Lifuka, Tonga

Completion of Phase Two

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1.0 INTRODUCTION

1.1 Context of Report

In December 1998, Phase Two of the groundwater pollution study in Tonga was completed. This Report summarises the activities undertaken to complete the study and presents the outcomes. The Report relates to the conclusion of field studies commenced in June 1997 that were not completed at that time due to lack of funds. Field studies, laboratory work and preparation of the results for this completion of the Phase Two were conducted between August and December 1998.

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

During 1996-1997 sampling and testing of 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 wells on three occasions over a twelve month period for E-coli, Faecal Coliform and Total Coliform, in both the First and Second Phases (Crennan 1996) (Furness 1996). Over the period of testing the pollution levels appeared to be gradually increasing.

In 1997, Phase Two field work was conducted by Mr. Tevita Fatai, Assistant Hydrogeologist, of the Ministry of Lands, Survey and Natural Resources (MLSNR), 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.

1.2 Scope of Work

Dr Leonie Crennan was contracted to undertake the following work for the completion of Phase Two of the study:

> " Within the framework of the UNESCO International Hydrological Programme Humid Tropics Programme and the UNESCO project on Environment and development in coastal regions and in small islands (CSI), and in order to achieve the completion of the first and second phase of the Groundwater Pollution Study carried out in Lifuka Island, Tonga, in accordance with the updated version of the outline approved by the UNESCO Water Resources Workshop, USP Suva, Fiji, July 1997, attached as Annex 1 of this contract,
>
> 1. act as team leader for the completion of the study
>
> 2. be responsible for the preparation of a report by the study team, presenting and integrating the technical and social science results of the study in a form suitable for publication as a

UNESCO technical document and in academic journals, paying particular attention to principles which may be of broad applicability, and serve as a basis of "wise practices" for communities and water resource managers in similar situations.

3. submit to the UNESCO Office for the Pacific States, Apia a budget for expenditure associated with the work described in articles I.1 & I.2.

4. submit to the UNESCO Office for the Pacific States, Apia the report described in article I.2 and a financial statement on the use of funds provided under this contract"

"Problem statement: There is 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 potential for pollution of groundwater in Pacific and small island countries.

Development rationale: Fresh clean water is essential for human health. This study can provide information that will review the current promotion of guidelines that may be contributing to groundwater pollution especially on small islands.

Beneficiaries: Community of Ha'apai at Tonga - communities in the Pacific region with similar geological conditions and water and sanitation concerns - health regulators - health and hygiene educators, institutions concerned with setting internationally applied sanitation facility guidelines.

Goals: Sustainable use of groundwater and reduction of water-borne disease. Increase public awareness and responsibility for sustainable management of groundwater. Guidelines for CIE on conducting a study of this nature.

Purpose: To complete current stage of study - specifically: monitoring and sampling of Bromide and Rhodamine dye tracing experiments - to include rainfall data in analysis - test well water samples for nitrates. Correct errors in groundwater measurements.

Expected results and evaluation indicators: More comprehensive evidence of rate and direction of flow of groundwater, degree of pollution, where pollution is coming from. 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. Preparation and publication of results of study. Change in perception by community regarding these issues. "

1.3 Activities to Complete Phase Two

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

- Re-collect Bromide tracer samples
- Test tracer samples.
- Monitoring of 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
- Prepare information for publication for a number of audiences.
- Involvement of community in monitoring process.

1.4 Resources/inputs.

The design of the study assumed time and co-operation 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).

2.0 METHODOLOGY AND DISCUSSION

The methodology adopted in this study was intended to be transferable to other islands with similar conditions and problems. Phase Two 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 the Completion of Phase Two are described in this Section.

2.1 Re-collection of Bromide Tracer Samples.

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. It was not intended to repeat the Small Scale Bromide tracing experiment during the completion of Phase Two.

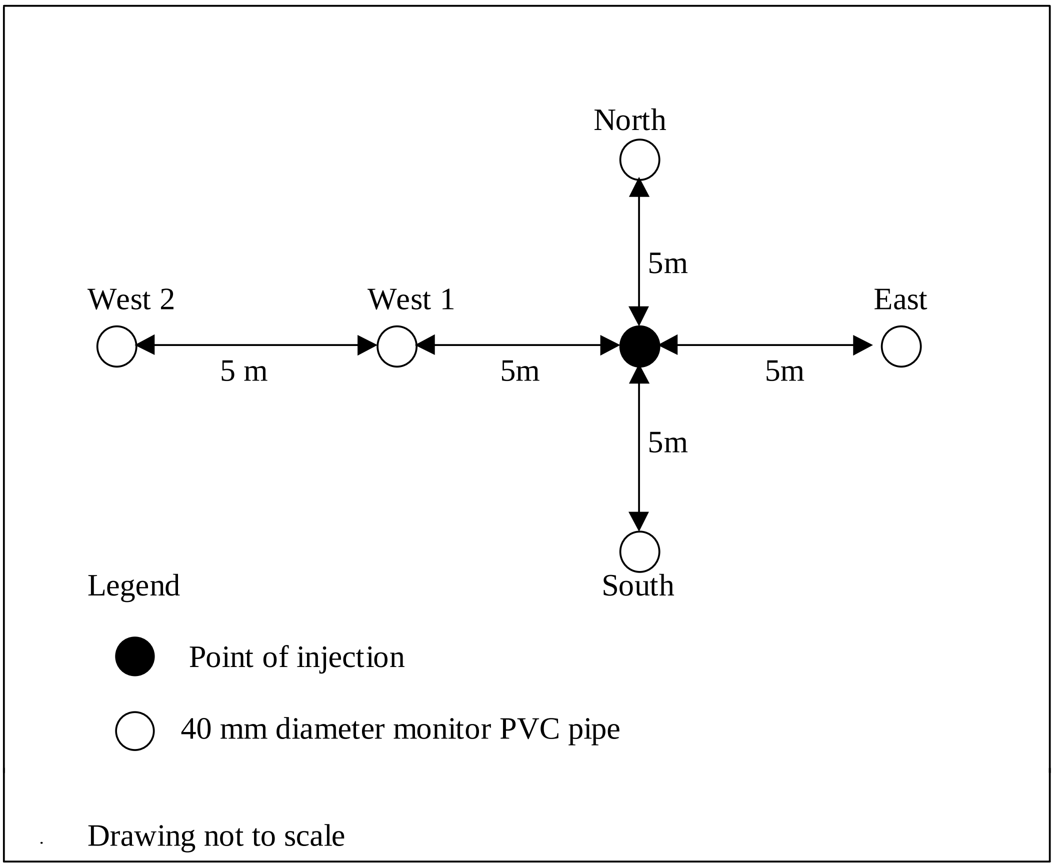
2.1.1 Method for Small Scale Tracing

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 6 meters square was dug approximately 2 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.

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.

Figure 2.1: Plan View of Small Scale Tracing Experiment



2.1.2 Method for Large Scale Tracing

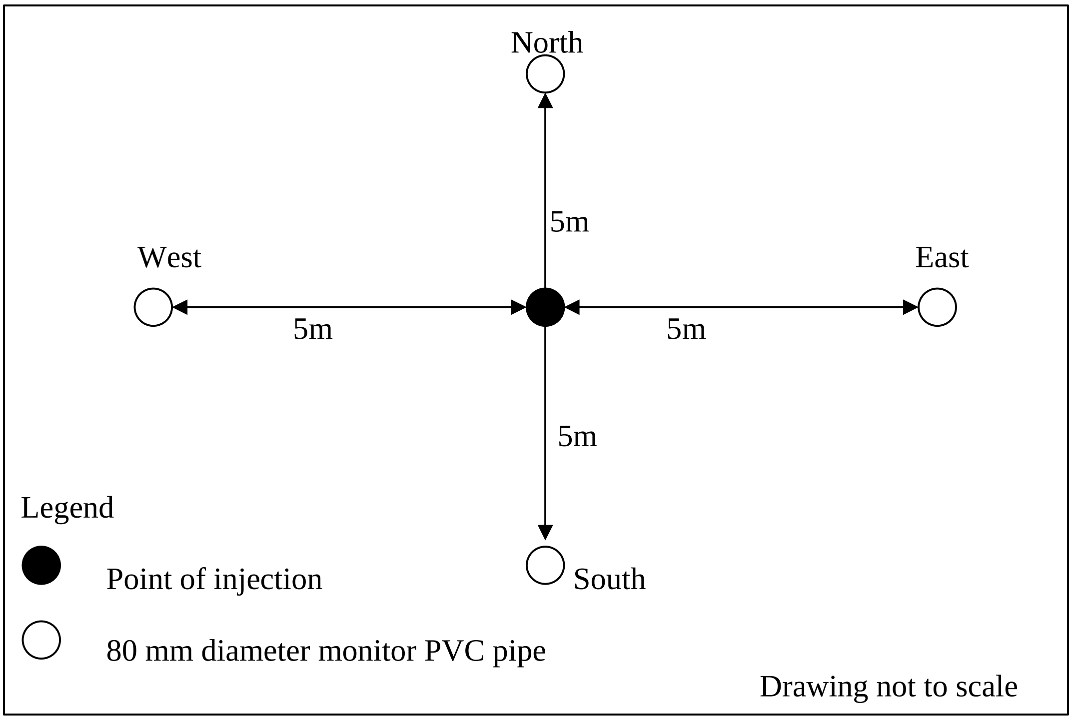
Five boreholes of about 100mm diameter were dug approximately two meters to the water table and into the water table by about 0.8 – 1.0m. Slotted PVC pipes (80mm diameter) were inserted. The layout of the piezometers was in a shape of a cross. (See .Figure 2.2). A central piezometer was used to introduce 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 vandalized.

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.

2.1.3 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 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 been un-used 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 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.

2.2 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-S102, an Intermediate Junction Reference Electrode (4mm plug), and a Temperature/ACT Probe.

2.2.1 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* + 100ml distilled water = 1mg/L *Bromide S*
- 1ml of 10mg/L *Bromide S* + 100ml distilled water = .1mg/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 1mg/L *Bromide S* was mixed with 2ml of ISAB, and for the Secondary Standard 75 ml of .1mg/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.

2.2.1 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 also12 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.

2.2.2 Testing of 1998 Bromide Tracer Samples

As mentioned in 2.1, 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 Annexure 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 Annexure 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 2.3.1

2.3 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 consultant 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.

It was not intended to repeat the use of Rhodamine as a tracer in this completion stage of Phase Two, but only to integrate the results from the two tracers.

<u>2.3.1 Small Scale Dye Tracing using Rhodamine</u>

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 5 ml 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 a 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.

2.3.2 Comparison of the Rhodamine-WT and Bromide Tracers

The dye appeared to move much slower than the bromide tracer does. 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 entirely 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 behavior 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.

2.3.3 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 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).

2.3.4 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 wellwater. Mosese also agreed to visit the householders once a month to check the well water himself. The Health Inspector went on leave 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.

Figure 2.3 Plan View of Large Scale Dye Tracing, SITE 1

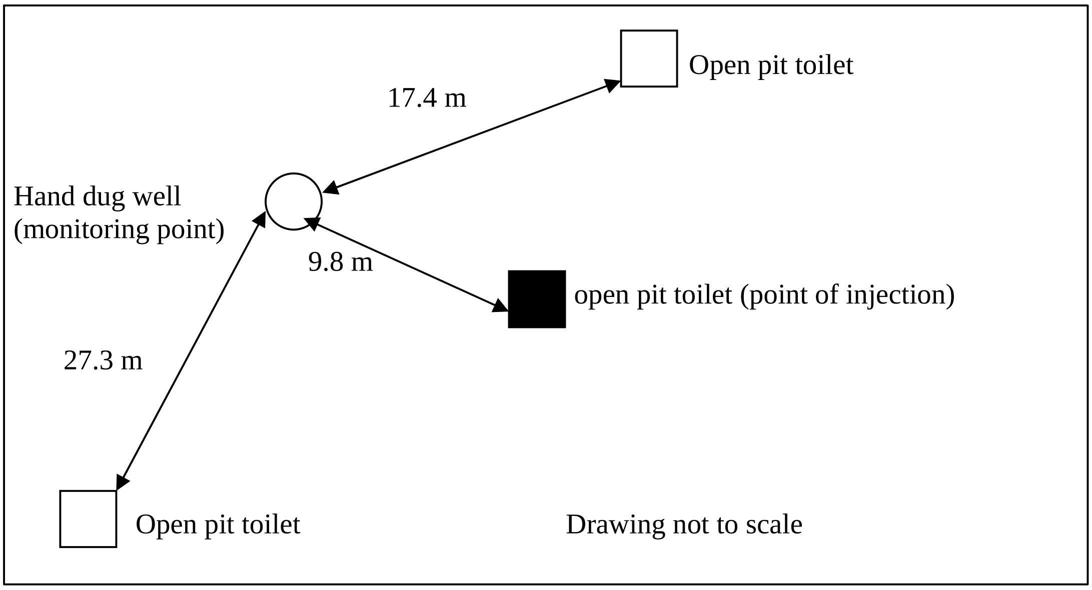
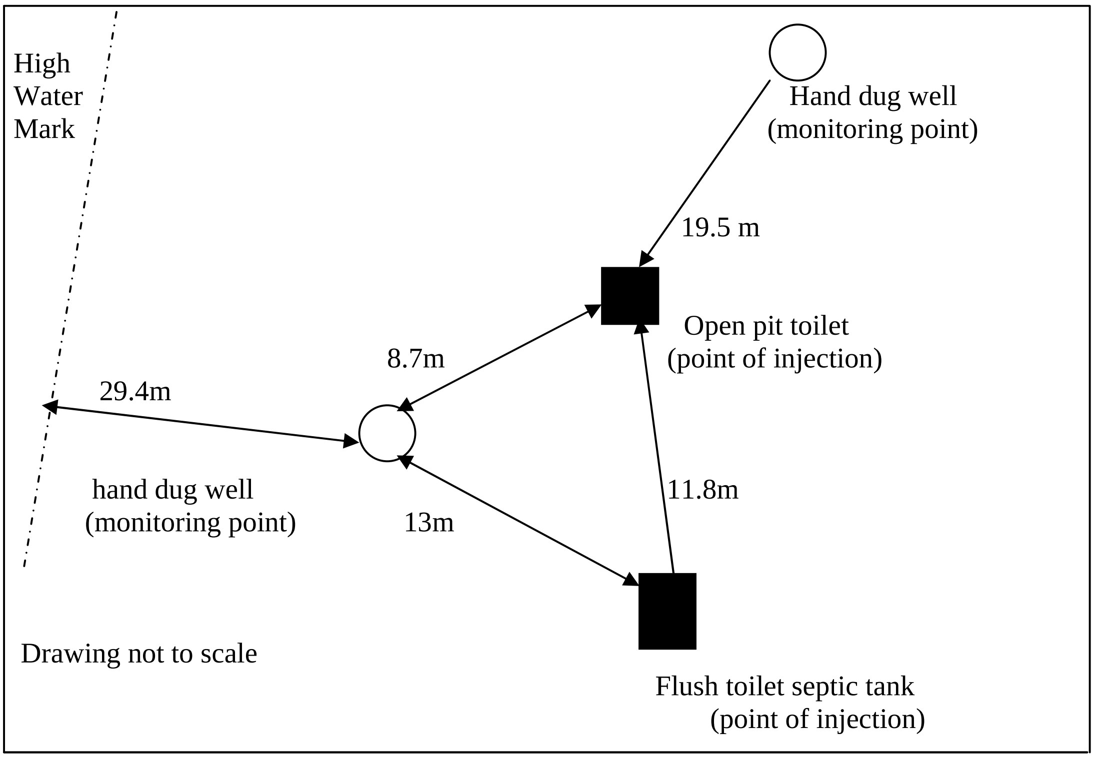


Figure 2.4 Plan View of Large Scale Dye Tracing, SITE 2



If this experiment was to be repeated it would need to be conducted in a more controlled environment, such as the school where a number of people are responsible for monitoring.

2. 4 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 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 the Completion Phase, 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 Annexure B.1 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 southeastern area. From analyzing 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.

2.4.1 Geology of Lifuka

The island of Lifuka is situated at 19^{0}48'S and 174^{0}21'W with an area of 11.5 square km. 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). See front pages of this Report for Location Maps.

2.5 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 Annexure 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.

2.6 Testing for Nitrates in Private 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 pathogen 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 and concentration of pollution in the samples. However the necessary re-agents 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 Phase the samples had been thrown out by laboratory staff.

2.7 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 community survey summarised in Section 3 of this report.

2.7.1. Location of test sites

The Principal of Joseph's School was approached to allow the main study to be 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 vandals)

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, Mr Lomano Hausia, with collection of samples
- Students and staff observed the appearance of dye in the Small Scale experiment.
- Students and staff participated in a workshop given by Tevita Fatai 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

2.7.2 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, Tevita Fatai from MLSNR. It appeared that some local people were not aware of the extent and nature of the acquifer, 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 2.2.1 of this Report).

2.7.3. Personnel Involved in the Study

In the planning for the experiment, 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 multi-disciplinary 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.

<u>2.7.4 Associated Activities</u>

During the two year period of the UNESCO 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 solid ‘waste’ 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 fertliser (Crennan 1996-1998, 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 Joseph’s 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.

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.

2.8 Preparation of Information for Publication

This report was prepared by the research team December 7-17,1998 to provide a description of the process and outcomes of Phase Two of the study in secular language, which can be understood and used by personnel involved in water and sanitation management. 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.

Extra technical detail, and data used in analysis is provided in the Annexures for inclusion in any scientific publication or review that may arise out of the study. The suggestion to use Bromide as a tracer came from a number of sources (Dillon 1996), but a literature search did not reveal much practical information on monitoring relevant to this 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 contexts.

The Summary and Conclusions (Section 4.0 of this Report) 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 water quality.

An educational video was being made that describes the process and findings of the UNESCO project and its links with the Tonga Water Board Composting Toilet Trial mentioned in Section 2.7.4 of this report. The staff and students of St Joseph’s School, other community members and UNESCO team personnel also participated in the scripting and shooting of the Tonga Water Board video in Tongan language. The video will be distributed throughout Tonga and a subtitled version could be made available for wider distribution.

3.0 SOCIAL SCIENCE COMPONENT

The social science component in Phase Two was integrated with the physical science activities as described in Section 2.7 of this Report, and the description of that process provides guidelines for CIE on conducting a study of this nature.

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, and the findings are summarised in Section 3.1.

3.1 Phase One Household Survey

The 1996 household survey contributed to understanding of potential groundwater pollution by providing information on the following practices experiences, and priorities. Full details were provided in Crennan 1996 (UNESCO).

Types and 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.

Types and reason for choice and use of wells, and other water supply collection facilities?
The water from the Tonga Water Board was preferred for convenience as it was reticulated, rainwater was preferred for quality (purity and taste) and affordability, and well water was preferred for affordability, reliability, quality (no chlorine, not so hard, inconsistent or salty as the Tonga Water Board supply), and having an established history of usage.

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.

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 then burned. If they had a pit toilet the refuse was disposed in the toilet.

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.

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.

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.

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 wallow outside kitchen for pigs to frequent.

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 diarrhea. 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.

3.2 Change in Community Perceptions
During Phase Two 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 wells in close proximity to toilets, or closure of pit toilets in close proximity to wells. Widespread interest in the composting toilets and reduced use of flush toilets also indicated that people were making the necessary links between water resources and sanitation facilities. Personnel from the Tonga Water Board, the Ministry of Health and the Ministry of Land Survey and Natural Resources had certainly become more aware of the threats to water resources from current siting and use of toilet facilities. Students teachers and community members who participated in the study more fully understood the nature and movement of the freshwater lens.

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 behavior 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 source control.

4.0 SUMMARY and CONCLUSIONS
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. So 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 acquifers. In 1977 the Environment Protection Agency in the USA designated areas with a septic tank density greater than 15 septic tanks per square kilometers 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 3000 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 acquifer.
12. Strategies to protect public and environmental health must address local beliefs and priorities to enable change in perceptions and behavior
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 repairing 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 acquifer 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 should 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.

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ANNEXURES

A.1 Average Graph from the 4 Collection Points
A.2 Bromide Dispersion Rate over Time
B.1 Contour Map of Water Level Relative to MSL
B.2 Data from Groundwater Survey

Authors

Dr Leonie Crennan
Ecological Sanitation
85 Dunbar St, Stockton, Australia
Fax: 61-2-49284082

Tevita Fatai
Assistant Hydrogeologist
Geology and Hydrogeology Unit
Ministry of Lands, Survey and Natural Resources
Nuku'alofa, Tonga.
Fax: 676-23216

Timote Fakatava
Head Chemist, Tonga Water Board
Nuku'alofa Tonga
Fax: 676-27518