TONGA WATER BOARD INSTITUTIONAL DEVELOPMENT PROJECT

REPORT ON

WATER MONITORING BOREHOLE INSTALLATION

LIFUKA, HA'APAI

25 November - 18 December 1997

Prepared by

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JANUARY 1998

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List of Abbreviations

bgl	below ground level
EC	Electrical conductivity
L/s	Litres per second (a measure of flow)
MOW	Ministry of Works
PVC	Polyvinyl chloride
TWB	Tonga Water Board
μS/cm	microsiemens per centimetre (measure of electrical conductivity, or salinity)

1. EXECUTIVE SUMMARY

1.1 Introduction

This report describes the drilling program undertaken during November and December 1997 in the Pangai – Hihifo and Koulo areas on the island of Lifuka. The purpose of the program was to:

- install seven water salinity monitoring boreholes;
- provide additional training for the Ministry of Works (MOW) drilling crew in the methods used in the installation of the monitoring system used in this program; and
- instruct the local Tonga Water Board (TWB) staff in monitoring procedures.

1.2 Summary and Conclusions

- The seven salinity-monitoring boreholes, LIF1-LIF7, requested were successfully installed in priority order. An additional two monitoring boreholes, LIF8-LIF9, were constructed at the Hihifo rugby field. Borehole locations were determined by the Technical Manager, Tont Falkland.
- A performance appraisal of the MOW drilling rig was undertaken during and at the completion of the drilling program. There are several areas where repairs need URGENT ATTENTION if the MOW drilling rig is to be seen as a viable option for similar drilling programs. A few mechanical problems were encountered with the drilling rig during the program and on-site repairs were carried out. A list of recommended repairs and other remedial work is outlined in the report.
- Training was given to the Lifuka TWB staff in borehole monitoring procedures. Physical, verbal and written instructions were given to the TWB staff in Lifuka. The verbal instructions were also reviewed by monitoring staff at the main TWB office in Tongatapu.
- Additional training was provided to the MOW drilling crew in the installation of monitoring systems and the use of polymer drilling fluids. The drilling crew is capable of constructing and installing this type of salinity monitoring borehole with some supervision.

1.3 Recommendations

- The monitors installed in this program should be pumped as much as time allows in the first quarter of 1998 to remove all residual drilling fluids in the boreholes and thus promote the sampling of representative water samples. *Priority*: 1; *Timeframe*: Immediate
- The drilling rig should be repaired in order that it be capable of further drilling work. The most essential repairs are those required to the hydraulic ram seals and the purchase of a water swivel to suit the existing drill head and pumping system. *Priority*: 1; *Timeframe*: Near Future (Note that this recommendation should be referred to the Ministry of Works).

2. INTRODUCTION

This report describes the drilling program undertaken to install water monitoring boreholes on the island of Lifuka in the Ha'apai group. This program was undertaken as part of the Tonga Water Board Institutional Development Project (the Project) and from 25 November to 18 December 1997.

2.1 Purpose

In accordance with Terms of Reference (refer Annex A), the purpose of the drilling program was to:

- install salinity monitoring systems at seven sites on Lifuka (in priority order). The monitoring systems were designed for the extraction of groundwater samples to enable salinity profiles of the lens to be developed and so design decisions can be made for future gallery construction;
- provide drilling training for MOW drilling crew in the techniques required for this work;
- provide training to TWB (Lifuka) staff in monitoring methods;
- advise on methods of completing MB2 (Mataki'eua); and
- report on progress.

2.2 Audience and Report

This report is primarily prepared for the Project's Technical Manager, Tony Falkland, and for relevant professional and technical staff of the TWB and the Project. It may also be of interest to senior management of the TWB and the Project. Aspects of the report, which deal with the condition of the drilling rig, should be of interest to the MOW who operate and maintain the rig.

The report's purpose is to:

- present the results of the drilling program; and
- recommend actions to improve the monitoring at the boreholes and to repair the drilling rig.

3. SCOPE OF WORK

The scope of work, summarised from the Terms of Reference (refer Annex A), was as follows:

- using the Ministry of Works drilling rig, assist, supervise and train the Ministry of Works driller(s) during the drilling of 7 salinity monitoring holes in priority order at nominated sites and to an agreed design. The exact sites to be provided by the Technical Manager;
- ensure as far as possible that all holes are drilled to specified design depths;
- fit each monitoring borehole with an assigned number of monitoring tubes, and backfill with suitable granular material and bentonite plugs as per the 'coral atoll' procedure used on other islands(Tarawa and Kiritimati in Kiribati; Cocos (Keeling) Islands, and Aitutaki, Cook Islands);
- finish off the top of each hole with a Gatic Cover concreted into position and locked into position with allen key bolts;
- prepare drill logs of the salinity monitoring holes; and
- report on progress and results including exit report to the Team Leader and this report.

It is noted that the sites, target depths and monitoring tube details were pre-assigned by the Project's Technical Manager Tony Falkland, on arrival at Lifuka and as the works progressed.

4. DRILLING PROGRAM

4.1 Equipment Used

The drilling equipment used to construct the water monitoring boreholes was the Walkerwell Model ASW286, operated by the MOW. The drilling rig is a top head drive rotary rig mounted on a tandem trailer. It has a 3 metre mast with 3 metre feed capacity.

The pumping unit accompanying the drilling rig is a FMC Beam Triplex pump model No L1122D. A clutch assembly mounted in the drive train of the drilling rig powers the pump.

A water tanker was hired from the Ministry of Works on Lifuka to provide a water supply during drilling operations. Although the tanker was in a dilapidated state, its use greatly increased the production rates of the drilling program.

The drill string was comprised of approx. 50 metres of 75 mm drill rod. There was also a mud tank system that had been fabricated to enable the re-circulation of drilling fluids and the mixing of drilling muds as required.

A few significant problems were encountered with the drilling rig and its associated equipment. These are outlined in section 5 together with recommended actions to remedy the problems.

4.2 Drilling Procedures

The drilling operation consisted of rotary mud drilling to construct 100 mm diameter boreholes using the 75 mm drill string provided.

Due to the strata and groundwater salinities encountered, thick drilling fluids had to be used at times. These fluids were mainly used to ensure minimal loss of drilling fluids and to ensure borehole stability.

Polymer based drilling fluids were used exclusively above and below the water table.

4.3 Drilling Program Completed

As well as the proposed seven monitoring boreholes, an additional two monitoring boreholes were completed in the time available. Each of the salinity monitoring boreholes was completed with a series of sampling tubes to specific depths. Bentonite seals were placed at intermediate spacings between the ends of the sampling tubes.

It was originally hoped to construct borehole MB2 at Mataki'eua after the drilling program on Lifuka was completed. With urgent repairs needed to the hydraulic ram seals on the drilling rig it was decided that the replacement of these seals would be a more achievable goal on the rig's return to Tongatapu which would enable borehole MB2 to be completed by the MOW drilling crew. Due to delays with the transportation of the drilling rig back to Tongatapu neither of these outcomes was possible during my visit. The MOW was requested to install the ram seals immediately after the drilling rig returned to Tongatapu.

4.4 Locations of Boreholes and Sequence of Works

The nine salinity-monitoring boreholes were completed in priority order at the following locations, as specified by the Technical Manager:

- Boreholes LIF1 and LIF2 at the Hihifo rugby field;
- Boreholes LIF3 and LIF4 at the Pangai rugby field;
- Boreholes LIF5 and LIF6 on Moa Road Hihifo;

- Borehole LIF 7 near the Lifuka Airport Koulo; and
- Boreholes LIF8 and LIF9 were completed at the Hihifo rugby field.

Locations of all boreholes are listed in Annex B. Figure 1 shows the locations of boreholes LIF1 – LIF8, all in the Pangai-Hihifo village area. LIF9 is further north at Koulo village near the airport.

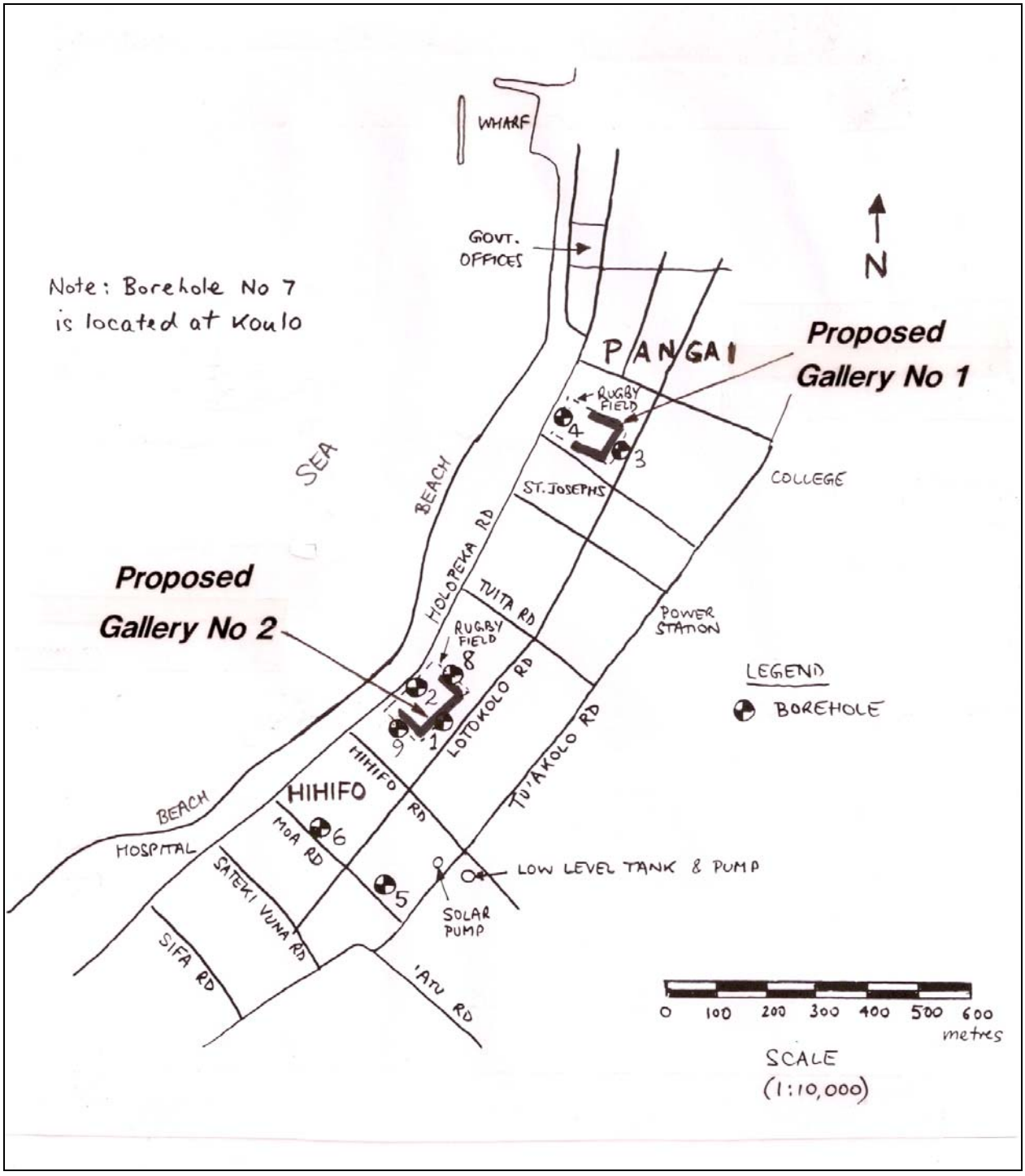

Figure 1 Locations of salinity monitoring boreholes LIF1 – LIF8 in Pangai-Hihifo area

A daily diary giving full details of the works and associated problems is provided in Annex C .

4.5 Drilling Logs

The drilling logs for all nine monitoring boreholes are provided in Annex B. These drilling logs include details of:

- geological materials (lithology);
- terminal depth of salinity monitoring tubes;
- physical data including static water level depth of stratum; and
- other relevant information including dates of drilling and personnel involved.

The drilling logs give a basic outline of the geology encountered but are not intended to be detailed geological logs.

4.6 Geological Strata

In this section, the geological strata intersected during drilling operations are discussed.

Two major strata were encountered in the Pangai – Hihifo area. These strata were evaluated based on the drill cuttings and performance of the drilling rig (i.e. torque encountered, fluid loss and ability of fluids to clear cuttings) and confirmed the results found in the report 'The Hydrology and Water Supply of The Kingdom of Tonga', February 1993 by Lindsay Furness and Saimone Helu.

The first stratum was a layer of coral limestone sands and gravels that have accumulated on the lee side of the island in recent geological times. This accretion contains discontinuous layers of volcanic ash resulting from volcanic material spread widely over the islands from nearby volcanic eruptions. This stratum is of varying depths below ground level from 19 m in borehole LIF1 to 8.5 m in borehole LIF3

The second stratum was older limestone consisting of consolidated coral reef material. This formation has various degrees of weathering and fracturing. As well as being highly permeable there are voidal zones and areas of loose and semi-consolidated materials which when drilled are unstable (as evidenced by caving). These areas were usually in the form of sand lenses, the stability of which can be controlled using drilling fluids.

Two major stratum were also encountered during the drilling of borehole LIF7 in the Kuolo area. The first was a silty clay layer of volcanic origin again resulting from volcanic material that had been spread widely over the islands as a result of nearby eruptions. This layer was comprised of highly plastic silty clay, brown to dark brown in colour. These clays were considered to be stiff to very stiff in consistency and had a moisture content usually greater than the plastic limit.

The second stratum was older limestone consisting of consolidated coral reef material identical to the limestone formations found at the Pangai-Hihifo areas.

4.7 Monitoring Systems

Three types of monitoring systems were used in the nine monitoring boreholes due to differing depth of static water level and the addition of extra boreholes to the original drilling program.

4.7.1 Type A

The main type of monitoring system installed in boreholes LIF1, LIF2, LIF3, LIF4, LIF6 and LIF8 consisted of a series of 8 mm nylon tubes set at various predetermined depths. At the base of each tube a glass-sintered filter was attached and at the surface a numbered brass snaplock fitting was installed. Between 4 and 7 nylon tubes and fittings were installed in each borehole (refer Annex B for

details). In each monitoring borehole a slotted PVC tube was placed intersecting the ground water level by approx. 500 mm. This tube can be used to ascertain static water level and to retrieve a ground water sample from the top of the freshwater lens.

Gravel was used to backfill the annulus between the monitors and surrounding formation. Approximately midway between the monitors a hydraulic seal was formed in the hole by inserting bentonite pellets to form a plug.

To protect the top of the monitoring boreholes from damage, steel Gatic covers were to be concreted into the ground. As only one of these covers had arrived on Lifuka by the time of my departure, the local TWB staff were instructed in their installation. As a temporary measure, concrete blocks were cast and placed on top of each borehole.

4.7.2 Type B

This type of monitoring system was installed in boreholes LIF5 and LIF7. The monitoring system consisted of a set of 32 mm PVC pipes ('monitoring tubes') terminating at predetermined depths. These tubes were slotted near the base and sealed with insulation tape. This type of monitoring system was used when the ground water level exceeded three metres below the ground surface.

As with 'type A' monitors, gravel was used as backfill between the monitoring tubes and intermediate bentonite seals were placed in each borehole.

The monitoring tubes were cut off at ground level and caps placed on the top of each tube. A course of bricks was concreted into the ground to enable the future placement of the Gatic covers.

4.7.3 Type C

This type of monitoring system was installed at borehole LIF9. The monitoring system consisted of a combination of types A and B as described above, in that, two nylon tubes and three PVC pipes were installed in the borehole.

As with types A and B, gravel was used as backfill and bentonite seals were placed at intermediate depths between the monitors.

4.8 Salinity Tests

4.8.1 Salinity testing during drilling

Salinity testing of groundwater during the drilling operation is desirable, but unfortunately with the large quantities of drilling fluids used and the stratum encountered, it was virtually impossible to gain any meaningful results from salinity testing.

The only means possible of ascertaining any downhole salinity would have been to test the drilling fluid return to the surface. Otherwise all drilling fluids would have had to be extracted from the borehole (endangering stability) and the borehole bailed, again not giving a water sample from any specific depth.

The best way to make any judgment on the salinity of groundwater intersected was the conditioning required of the drilling fluids used. As the salinity of the groundwater increased, the amount of drilling mud required to keep the drilling fluid at the correct viscosity increased dramatically. If drilling targets were reached, and fluid management was difficult, the boreholes were terminated at target depths.

4.8.2 Salinity testing after drilling

Near and on completion of the nine salinity-monitoring boreholes, the drilling sites were visited with the local TWB staff. They were instructed in the use of the water extraction systems provided.

The water extraction system for boreholes LIF1, LIF2, LIF3, LIF4, LIF6 and LIF8 consisted of a 'Flojet' diaphragm pump powered by a 12 volt car battery. The suction side of the pump was attached to the brass quickfit couplings at the top of each nylon monitoring tube and the pump activated.

A water extraction system for boreholes LIF5 and LIF7 was fabricated using a 15 mm brass check valve (purchased locally) attached to 13 mm diameter high-density polyethylene pipe (obtained from the TWB). This pipe was inserted into each monitoring tube and, upon reaching the base, the pipe was moved up and down. The check valve at the end of the pipe then operated to make a positive displacement pump, forcing water to the surface.

The water extraction system for borehole LIF9 consisted of a combination of the two systems above (refer Annex B for details).

A set of borehole monitoring instructions (refer Annex D) and monitoring forms indicating depths of monitors at each borehole (refer Annex E) were given to the local TWB staff

The importance of monitor development was also emphasised to the local TWB staff during the site visits and in discussion afterwards. This requires that each monitor in each borehole be bailed or pumped several times to ensure that the natural groundwater is being sampled and that the effects from the drilling operation (e.g. residual drilling fluids) are eliminated.

5. DRILLING RIG AND EQUIPMENT

5.1 Status of Equipment.

The drilling rig is in need of repair if a further drilling program is to be undertaken with any confidence of completion. It is apparent that no regular maintenance and repair program is carried out on the drilling rig.

5.2 Repairs Required

Following is a list of repairs and other remedial action required if further drilling works of a similar scale to those undertaken in the recent drilling program are required. These repairs are provided under headings of urgent repairs and other repairs.

5.2.1 Urgent repairs

Hydraulic Rams

The sets of hydraulic ram seals, procured during the drilling program, should be fitted as soon as possible. During drilling operations, the main feed hydraulic ram developed a SEVERE hydraulic oil leak. It was fortunate that these seals did not fail completely and that a 200-litre drum of hydraulic oil could be accessed. A complete set of hydraulic ram seals was procured from the drilling rig manufacturer: ***these should be fitted to all hydraulic rams on the drilling rig as a matter of urgency***.

Drill Head

The drill head should be overhauled as a matter of urgency. After drilling operations in Visit 2, the drive shaft below the main hydraulic motor was replaced. As well as this shaft and associated bearings, all bearings, seals, drive chain and drive sprockets should have been replaced.

A new drive flange from the drive head to API thread should either be purchased or manufactured.

A new air, water, mud swivel fitted to the top of the drive head is required.

Pumping System

Repair of the pumping system is required and should also be considered as a matter of urgency.

Problems with the clutch assembly driving the pump were again encountered. Clutch plates wore out and shattered. Fortunately the drilling crew had spare clutch plates. The clutch was removed and the new clutch plates installed. It is suggested that a new complete clutch assembly with control cable, to enable engagement and disengagement of the pump from the control console, be purchased.

A new relief valve should be fitted to the pump as the present unit has seized, and in its present state is a safety hazard.

New suction hoses from the mud tank to the drilling rig and from the drilling rig to the pump are also required.

5.2.2 Other necessary repairs

Power Unit

The drilling rig is powered by a Mitsubishi 6-cylinder diesel engine, which operates well. A new air cleaner and stop solenoid, to enable key operation, should be fitted and regular servicing of the unit undertaken.

Hydraulic System

The hydraulic system is in need of some repair. Most, if not all, of the hydraulic rams on the drilling rig leak in some way, and new seals for these are required as discussed earlier. It is impossible to ascertain the condition of the hydraulic pumps and motors in the system without having these pressure tested. Several hydraulic hoses on the drilling rig are in need of replacement.

Rig Controls

The control system of the machine is in need of remedial work. The only means of feed pressure adjustment at present is by physical pressure on the feed lever, rather than by micro-feed system, which is not operational. New control valves are required. Feed pressure, torque pressure and water pumping pressure gauges are not operational, and these should be replaced.

Drill String

The drill string is in a fair condition with some scaling problems. With proper management this problem can be overcome.

Mud Tanks

The mud tank system is adequate although a third tank would be desirable to enable cuttings to settle out of drilling fluids more effectively.

Winch Cable

The present winch cable is in a bad state with many burrs, kinks and generally poor condition. The cable should be replaced with 60 metres of 12 mm non-rotating crane cable.

Tools

As well as mechanical problems, the lack of hand tools supplied to the drill crew is a problem. The drill crews' ability to make on-site repairs quickly and effectively is greatly hampered. An adequate toolbox should be carried with the drilling rig at all times.

5.3 Further Comment

It should be stated that these suggested repairs were arrived at with the help and consultation with the MOW drilling crew. They are based on physical observation and a basic knowledge of the drilling rig.

6. DRILLER TRAINING

On arrival in Lifuka (28 November 1997), we proceeded to the MOW yard where the drilling rig was being stored and the drilling crew was in attendance. I was reintroduced to the MOW drilling crew:

- Mr Taniela Heimuli (Driller);
- Mr Sione Saiapa'ia (Drilling Assistant);
- Mr Himuiti Fuimaous (Drilling Assistant); and
- Mr Sione Lemeki (Drilling Assistant).

The drilling crew consisted of three officers that I had worked with during previous visits. The drilling crew were very capable with all aspects of the drilling operation including: drill set up, rod and tool handling, polymer based drilling fluid management and rig repair (providing hand tool are available) as demonstrated in previous visits.

Further on-site training was provided in drilling procedures to augment the training that had taken place on previous visits. Training consisted of reaffirmation of the procedures in the use of polymer drilling fluids and the installation of the types of monitoring systems used in the drilling program.

As in previous visits, the author has only praise and admiration for the efforts of the MOW drilling crew. It was only with their concerted efforts that the drilling program was completed within the allotted time scale. The drilling crew showed resourceful interest in all aspects of the drilling program, and although away from home base, showed a work ethic that only can be commended.

The MOW drilling crew is more than capable of constructing these types of monitoring boreholes with minimal to no supervision.

7. RECOMMENDATIONS AND ACTION PLAN

- The monitors installed in this program should be pumped as much as time allows in the first quarter of 1998 to remove all residual drilling fluids in the boreholes and thus promote the sampling of representative water samples. *Priority*: 1; *Timeframe*: Immediate
- The drilling rig should be repaired in order that it be capable of further drilling work. The most essential repairs are those required to the hydraulic ram seals and the purchase of a water swivel to suit the existing drill head and pumping system. *Priority*: 1; *Timeframe*: Near Future (Note that this recommendation should be referred to the Ministry of Works).

Bryan E. Turner, Drilling Contractor

8 Parnell St, Elsternwick

Victoria, Australia

31 January 1998

Annex A

Terms of Reference

for

Bryan Turner, Drilling Supervisor

Visit 3: 26 November - 18 December 1997

Objectives of the visit:

The objectives are:

- to successfully install salinity monitoring systems at 7 sites on Lifuka,
- to provide drilling training to Ministry of Works driller(s) in the techniques required for this work,
- to provide training to local TWB staff in method of monitoring,
- to advise on method of completing MB2 and possibly one other hole at Mataki'eua, and
- to report on progress.

Role and Function:

Accountable to the Technical Manager, the role of the Drilling Supervisor will be to ensure that the above objectives are met. The Drilling Supervisor will ensure consultative working relations with relevant Tongan agencies including the Ministry of Works and the Tonga Water Board.

Background:

The background to the requirement for salinity monitoring boreholes is provided in the Project Implementation Document and the report "Proposals for Water Supply Investigations and Improvements" March 1997 (copy attached). These boreholes will be used for long term monitoring of salinity profiles at selected sites on Lifuka.

Duties:

- using the Ministry of Works drilling rig, assist, supervise and train the Ministry of Works driller(s) during the drilling of 7 salinity monitoring holes. The exact sites will be advised on site by Tony Falkland,
- ensure, as far as practicable that all holes are drilled to the specified design depth. The design depth shall be where the salinity of the groundwater equals 80% of the salinity of seawater (measured with a well calibrated electrical conductivity meter, this is equivalent to approx. 40,000 micromhos/cm),
- fit each hole with the required number of monitoring tubes, and backfill with suitable granular material and bentonite plugs as per the 'coral atoll' procedure used on other islands (Tarawa, Kiritimati, Cocos, Aitutaki),
- finish off the top of each hole with GATIC cover concreted into position and locked down with allen key bolts,
- maintain drill logs for each hole and details of any salinity monitoring obtained during drilling,

- arrange through the Tonga Water Board or other local outlet for the purchase of miscellaneous materials (eg. cement) and acquit expenditure to Project staff in Nuku'alofa,

Project management:

This component of the TWB-IDP Project is under the management of the Technical Manager, Tony Falkland. Overall co-ordination of this component in the wider TWB-IDP Project is under the management of the Team Leader, Ray Cameron and Project Manager, Roger Dickson. On-site liaison matters should be directed through the Team Leader or Tony Falkand

Reporting:

- an **exit report** should be submitted to the Team Leader, in accordance with the required format, before leaving Tonga, and a copy to the Technical Manager on return to Australia, and
- a **visit report,** in accordance with the required format, summarising all activities and outcomes from the work and any recommended actions should be submitted to the Technical Manager within 1 week of returning to Australia.

Tony Falkland

Technical Manager

30 October 1997

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Annex B

Drilling Logs for Lifuka salinity monitoring boreholes

Summary of borehole locations

Borehole	Location
LIF 1	East side of Hihifo rugby field.
LIF 2	West side of Hihifo rugby field.
LIF 3	East side of Pangai rugby field.
LIF 4	West side of Pangai rugby field.
LIF 5	North side of Moa Road, between Lotokolo and Tu'akolo roads.
LIF 6	North side of Moa Road, between Holopeka and Lotokolo roads.
LIF 7	Koulo, West side of main road, south side of Airport gates.
LIF 8	North side of Hihifo rugby field.
LIF 9	South side of Hihifo rugby field.

Legend for Borelogs

bgl	below ground level
M	nylon monitoring tube
m/c	moisture content
PVC	PVC monitoring tube
SWL	static water level below ground level

Drilling Log for LIF1

Location:	Lifuka, Kingdom of TONGA	**Date Start:** 28/11/1997	
Site:	East side of Hihifo rugby field	**Date Finish:** 29/11/1997	
Borehole No:	**LIF 1**	**Drilling Rig :** Walkerwell ASW286	
Driller:	Taniela Heimuli	**Drill Method:** Wash Boring	
Assistants:	Sione Saipa'ia, Himuiti Fuimaous and Sione Lemeki		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m - 2.1m : SANDY SILTY CLAY (CH/CL) :** Stiff to very stiff, brown dark brown, m/c greater than plastic limit, with trace ash and plant material.		
1.5m	**1.5m – 12.2m : SILTY GRAVELLY SAND :** Fine to coarse grained, loose to medium dense, pale brown to cream, moist, becoming wet below 3.0 metres with moderate to high fluid loss below 4.0 metres	SWL 3.0mm 29/11/97	**M1: 4.5m** **M2: 6.5m**
12.0m	**12.2m – 13.0 : SILTY GRAVELLY SAND:** Fine to coarse grained, loose to medium dense, grey and cream with some ash and pumus.		**M3: 8.5m**
13.0m	**13.0m – 14.0m : GRAVELLY SILTY SAND:** Fine to coarse grained, medium dense, cream, wet. With some limestone cobbles		**M4: 10.5m**
15.0m	**14.0m – 19.0m: As Above :**With some limestone cobbles between 18.0m – 19.0m. 19.0m – 21.5m**: LIMESTONE :** Slightly to moderately weathered, highly fractured, cream, high strength, high mud loss. **END OF BOREHOLE LIF 1 AT 21.5m** **Slotted PVC Standpipe placed at 4.1m below ground level** . **Note: Borehole caved to 18.0m below ground level on withdrawal of drill string.**		**M5: 12.5m** **M6: 14.7m** **M7: 18.0m**

Drilling Log for LIF2

Location:	Lifuka, Kingdom of TONGA.	**Date Start:**	29/11/1997
Site:	West side of Hihifo rugby field.	**Date Finish:**	1/12/1997
Borehole No:	**LIF 2**	**Drilling Rig :**	Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:**	Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous and Sione Lemeki		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m – 1.9m : CLAYEY SILTY SAND:** Fine to medium grained, loose to medium dense, grey and brown moist.		
2.0m	**1.9m – 15.0m : SILTY GRAVELLY SAND :** Fine to medium grained, medium dense, grey and cream moist to wet Medium fluid loss.	SWL 1.5m 1/12/1997	**M1: 3.5m**
4.0m			**M2: 5.5m**
6.0m	With increase in silt content below 6.0m Low fluid loss below 6.5m		**M3: 7.5m**
8.0m			**M4: 9.5m**
10.0m	With trace Volcanic ash and becoming grey 10.5m – 11.1m		
12.0m	With trace Volcanic ash 12.6m – 12.8m With some Limestone (Coral) cobbles below 13.2m		**M5: 12.0m**
14.0m			
15.0m	**15.0m – 16.5m : LIMESTONE :** Highly to moderately weathered, highly fractured, cream, low to medium strength, Medium fluid loss.		**M6: 15.6m**
18.0m	**END OF BOREHOLE LIF2 AT 16.5m.** **Slotted PVC Standpipe placed at 3.0m below ground level.**		

Drilling Log for LIF3

Location:	Lifuka, Kingdom of TONGA	**Date Start:**	2/12/1997
Site:	East side of Pangai rugby field.	**Date Finish:**	3/12/1997
Borehole No:	**LIF 3**	**Drilling Rig :**	Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:**	Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous and Sione Lemeki		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m – 0.6m : SILTY SAND :** Fine to medium dense, fine to medium grained, grey and cream, moist with trace silty clay and volcanic ash		
2.0m	**0.6m – 6.4m :** SILTY GRAVELLY SAND: Fine to coarse grained, loose to medium dense, Cream. (Coral sands and Gravels with some fines)		
4.0m	**Medium fluid loss**	SWL 3.0m 2/12/97	**M1: 4.5m**
6.0m	**6.4m – 8.5m : GRAVELLY SILTY SAND :** Fine to coarse grained ,medium dense, cream with some limestone cobbles up to 600mm in diameter.		**M2: 6.5m**
8.0m	Medium fluid loss Becoming cream and brow below 8.3m.		**M3: 8.5m**
10.0m	**8.5m – 14.5m : LIMESTONE :** Highly weathered, highly fractured, cream, low strength.		**M4: 10.5m**
12.0m	Becoming highly to moderately weathered below 12.7 metres		**M5: 12.2m**
14.0m	**END OF BOREHOLE LIF3 AT 14.5m.** **Slotted PVC Standpipe placed at 4.0m below ground level**		**M6: 14.2m**

Drilling Log for LIF4

Location:	Lifuka, Kingdom of TONGA.	**Date Start:**	3/12/1997
Site:	West side of Pangai rugby field	**Date Finish:**	4/12/1997
Borehole No:	**LIF 4**	**Drilling Rig :**	Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:**	Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous and Sione Lemeki		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m – 0.6m : CLAYEY SILTY SAND :** Fine to medium grained, loose to medium dense, brown and grey moist, with trace ash and plant material. 0.6m – 8.5m : SILTY GRAVELLY SAND : Fine to medium grained, loose to medium dense, cream, moist to wet. Medium to high fluid loss 0.6m – 4.0m.	SWL 2.05m 5/12/97	**M1: 3.5m**
2.0m			
4.0m	Increase in Gravel content below 4.0m.		**M2: 4.5m**
6.0m	Increase in silt content below 5.0m. Medium to low fluid loss		**M3: 5.5m** **M4: 6.5m**
8.0m	With trace volcanic ash and becoming grey 6.5m to 7.3m.		**M5: 8.0m**
10.0m	**END OF BOREHOLE LIF4 AT 8.5m.** **Slotted PVC Standpipe placed at 2.5m below ground level.**		

Drilling Log for LIF5

Location:	Lifuka, Kingdom of TONGA	**Date Start:** 5/12/1997
Site:	Nth side Moa Road between Lotokolo and Tu'akolo roads, Hihifo.	**Date Finish:** 6/12/1997
Borehole No:	**LIF 5**	**Drilling Rig :** Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:** Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous and Sione Lemeki	

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m – 1.5m : SILTY CLAYEY SAND / SILTY SANDY CLAY :** Stiff to very stiff, brown and grey, m/c greater than plastic limit, with trace ash and plant material. Increase in sand content below 1.0m		
	1.5m – 6.3m : SILTY GRAVELLY SAND : Fine to medium grained, loose cream, moist to wet. High fluid loss.		
2.0m			
	With some limestone (coral) gravel below 4.6m	SWL 3.4m 5/12/97	**PVC1: 4.5m**
4.0m			
6.0m	**6.3m – 7.5m : LIMESTONE :** Highly weathered, moderately fractured, cream, low strength. Moderate fluid loss		**PVC2: 6.0m**
8.0m	**7.5m – 10.8m: SILTY GRAVELLY SAND :** Fine to coarse grained, loose to medium dense, cream. Moderate to high fluid loss.		**PVC3: 7.5m**
10.0m			**PVC4: 9.0m**
12.0m	**10.8m – 14.5m : LIMESTONE :** Highly weathered, moderately to highly fractured, cream, low to medium strength, with minor sand lenses, moderate fluid loss.		
14.0m	**END OF BOREHOLE LIF 5 AT 14.5M**		

Drilling Log for LIF6

Location:	Lifuka, Kingdom of TONGA.	**Date Start:**	8/12/1997
Site:	Nth side Moa Rd, between Holopeka and Lotokolo Roads, Hihifo.	**Date Finish:**	8/12/1997
Borehole No:	**LIF 6**	**Drilling Rig :**	Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:**	Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous and Sione Lemeki		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m – 0.5m : SILTY CLAY (CH) :** Stiff to very stiff, brown dark brown, m/c greater than plastic limit, with trace to some sand.		
	0.5m – 1.5m : SANDY CLAY/ CLAYEY SAND : fine to medium grained, loose to medium dense, cream and grey, moist.		
2.0m	**1.5m – 10.2m : SILTY GRAVELLY SAND :** Fine to medium grained, medium dense, cream, moist .		
		SWL	
	Becoming wet below 2.5m	2.6m	**M1: 4.0m**
4.0m		8/12/97	
			M2: 5.5m
6.0m			
			M3: 7.0m
8.0m	With trace volcanic ash and becoming grey and cream below 9.0m		
	10.2m – 12.0m : CLAYEY GRAVELLY SAND : fine to medium grained, medium dense, light grey to dark grey. (Ash layers interbedded with sand layers)		**M4: 8.5m**
10.0m			
			M5: 11.0m
	12.0m – 13.0m : SILTY CLAY : Stiff, highly plastic brown to dark brown, M/C > Plastic limit.		
12.0m			
	13.0m – 15.5m : SILTY CLAYEY SAND : Fine to medium		**M6: 13.3m**
14.0m	grained, medium dense, grey, wet , with trace volcanic ash.		
16.0m	**END OF BOREHOLE LIF6 AT 15.5m.**		
	Slotted PVC Standpipe placed at 3.0m below ground level.		

Drilling Log for LIF7

Location:	Lifuka, Kingdom of TONGA.	**Date Start:**	9/12/1997
Site:	Koulo, WST side Main Rd STH side Airport gates.	**Date Finish:**	9/12/1997
Borehole No:	**LIF 7**	**Drilling Rig :**	Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:**	Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous and Sione Lemeki		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m - 2.8m : SILTY CLAY (CH) :** Stiff to very stiff, brown dark brown, m/c greater than plastic limit, with trace ash and plant material.		
2.0m	**2.8m – 3.2m : SILTY GRAVELLY SAND :** Fine to coarse grained, loose to medium dense, cream, moist to wet. High fluid loss.		
4.0m	**3.2m – 9.5m : LIMESTONE :** Highly to moderately weathered, moderately fractured, cream, low to medium strength. (with some sand lenses) 3.7m – 3.9m : SILTY SAND (lens) : Fine to medium grained, loose to medium dense, cream, wet. 4.3m – 4.6m : SILTY SAND (lens) : Fine to medium grained, loose to medium dense, cream, wet.	SWL 4.6m 8/05/97	**PVC1: 5.0m**
6.0m	4.9m – 5.0m : SILTY SAND (lens) : Fine to medium grained, loose to medium dense, cream, wet.		**PVC2: 6.0m**
8.0m			**PVC3: 7.0m**
10.0m	**END OF BOREHOLE LIF 7 AT 9.5m.**		**PVC4: 9.0m**

Drilling Log for LIF8

Location:	Lifuka, Kingdom of TONGA.	**Date Start:**	10/12/1997
Site:	North side Hihifo rugby field.	**Date Finish:**	10/12/1997
Borehole No:	**LIF 8**	**Drilling Rig :**	Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:**	Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous and Sione Lemeki		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m – 0.5m : CLAYEY SILTY SAND :** Fine to medium grained, loose, grey to dark grey, moist.		
	0.5m – 6.0m : SILTY SAND : Fine to medium grained, loose to medium dense, grey and cream, moist.		
2.0m			
	Becoming wet below 2.3m.	SWL	
	(Very OPEN fluid return difficult to maintain 2.2m to 2.6m)	2.5m	**M1: 4.0m**
4.0m		10/12/97	
	With some coarse grained coral gravel below 5.5m		**M2: 5.0m**
6.0m	**6.0m – 9.0m : SILTY SAND :** Fine to medium grained, medium dense, grey and cream, wet with trace volcanic ash.		**M3: 6.0m**
			M4: 8.0m
8.0m			
	END OF BOREHOLE LIF8 AT 9.0m.		
10.0m			
	Slotted PVC Standpipe placed at 3.0m below ground level.		

Drilling Log for LIF9

Location:	Lifuka, Kingdom of TONGA.	**Date Start:**	
Site:	South side of Hihifo rugby field.	**Date Finish:**	
Borehole No:	**LIF 9**	**Drilling Rig :** Walkerwell ASW286	
Driller:	Taniela Heimuli	**Drill Method:** Wash Boring	
Assistants:	Sione Saipa'ia, Himuiti Fuimaous and Sione Lemeki		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m – 0.6m : CLAYEY SILTY SAND :** Fine to medium grained, loose, grey and dark grey, moist. High fluid loss. **0.6m – 4.2m : SILTY GRAVELLY SAND :** Fine to medium grained, loose to medium dense, cream, moist to wet.		
2.0m	Medium to high fluid loss.	SWL 2.3m 11/12/97	**PVC1: 2.8m**
4.0m	**4.2m - 6.2m : GRAVELLY SILTY SAND :** Fine to coarse grained, medium dense, highly to moderately weathered, slightly fractured, cream, low to medium strength. Medium fluid loss.		**PVC2: 5.0m** **PVC3: 6.0m**
6.0m	**6.2m – 9.0m : SILTY GRAVELLY SAND :** Fine to medium grained, medium dense, cream and grey. wet. With trace volcanic ash between 6.3m to 8.3m.		**M4: 7.0m**
8.0m			**M5: 8.5m**
10.0m	**END OF BOREHOLE LIF 9 AT 9.0m.**		

Annex C

Daily Diary

Visit 3: 25 November - 18 December-1997

Tue 25/11/97

- Leave Melbourne 1800hrs. Arrive Sydney 1945hrs
- Arrive Gemini Motel 2100hrs meet up with Tony Falkland.

Wed 26/11/97

- Leave Sydney 0730hrs. Arrive Auckland
- Depart Auckland. Arrive Tongatapu
- Ray Cameron picks us up from airport and go to TWB house.

Thur 27/11/97

- Leave TWB house 0730 and go to TWB office.
- Have meeting with Ray Cameron regarding work program
- Organise overtime for drilling crew if they are willing with Ray Cameron.
- Go to MOW yard and check that O/T is OK. It is.
- Go to TWB office and check with Tony F and meet Quddus
- Go to bank and change some dollars.
- Return to TWB office and help Tony with what ever I can.
- Go and purchase some fittings and WD 40.
- Ask Ray C about loan of lap top computer. OK
- 1630hrs do tour of Mataki'eua and check out new pump stations at Tongami.
- Arrive TWB house at 1730hrs

Fri 28/11/97

- Leave TWB house 0600hrs and go by taxi to airport. Leave Tongatapu at 0700hrs
- Arrive Ha'apai Lifuka 0745hrs with Tony and Saimone.
- Meet Sefili from TWB Lifuka.
- Go with Tony and Saimone to MOW yard and see drilling rig and meet with drilling crew.
- Organise water truck at $300 for our time in Lifuka.
- Organise water truck and tractor to move to first borehole location at Hihifo rugby field.
- Fill water truck, Check consumable
- Set up on first borehole and drill to 14metres

- Check with drill crew re overtime all OK
- Drill Crew finish at 1630hrs

Sat 29/11/97

- Leave Lindsay Guest house 0725 arrive drill site LIF 1 at 0730.
- Borehole caved to 8.5 meters.
- Unable to measure Static water level as boys had begun mixing mud before my arrival.
- Borehole drilled to19.2 meters mud being badly effected by saline water bore hole becoming unstable.
- Decide to terminate borehole Lif1at 19.2 meters
- Borehole caves to18.0 meters on extraction of drill string.
- Decide to install first monitor at 18.0 meters
- Monitors installed at:4.5m 6.5m 8.5m 10.5m 12.5m 14.7m 18.0m below ground level.
- Bentonite seals were placed at 1.0m 5.5m 7.5m 9.5m 11.5m 13.5m 16.2m.
- A 32mm UPVC standpipe of 4.1m length was also inserted into the borehole with the bottom 1.0m slotted at regular intervals.
- Bore hole location 95m East of HOLOPEKA, Road and 55m West of LOTOKOLO Road, 75m South of NEW PUMP, 55m North PVC pipe and 10m from corner of cyclone mesh fence.
- Move to LIF2 on west side of Hihifo Rugby field.
- Set up and drill to 2.5 meters NOTE: Centre ram for feed leaking badly, seals stuffed.
- Cut 250mm PVC and prepared LIF 1 for installation of Gatic cover.

Sun 30/11/97

- Day off

Mon 1/12/97

- HOURS Drill Crew: 8.0hrs, Drilling Rig 5.0hrs. Leave house 0745 and arrive drill site 0750
- Water truck arrives at 0800 hrs.
- Drill crew no where to be seen by 0830 go and investigate..
- Drill crew at MOW yard waiting for transport to drill site a bit hard on a pushbike.
- Drill crew arrives at 0845 and set up.
- Drill to 12 meters and find difficulty in pumping, break pump down and clean no better, decide to check suction hose , sure enough blocked! Clear and continue.
- Feed Ram leaking badly go and see Tony at low level tank and discuss.
- Decide to contact Peter Adamson of Walker Engineering and organise a new set of ram seals for the entire rig

- Return to rig and drill on to 16.5 meters. Flush borehole with fresh water before extracting drill string.
- Withdraw drill string. Bore hole caves to 16.0meters install first monitor at that depth.
- Monitors installed at 3.5m 5.5m 7.5m 9.5m 12.0m 15.6m
- Bentonite seals installed 4.5m 6.5m 8.5m 10.75 13.5m
- Install 32-mm UPVC pipe. Bottom 1.2meters was hand slotted and the base of the standpipe was at 3.0meters below existing ground level. A bentonite seal was placed from 1.5 meters to 300mm below existing ground level.
- Go to Sefili's house and cut another 150mm diam pvc length for placement tomorrow.
- Organise drill crew to cast up two 600 x 600mm concrete blocks to place over boreholes as temporary covers.
- Start monitoring LIF 1 have a bit of difficulty as drill string had to be withdrawn with drilling fluid still in bore hole. May need extensive pumping to remove

Tue 2/11/97

- Leave House 0745 meet drilling crew outside bakery.
- Drilling crew advises myself that the best course of action may be to contact MOW Tongatapu to obtain a 44-gallon drum of hydraulic fluid, I agree
- Go to rig and finish packing up. Wait on tractor it arrives at 0900.
- Show Sahi the location for LIF 3,Return to rig and install snaplock fittings and fit temporary concrete protective cover on Lif2.
- Go with Sione to MOW yard and try to phone MOW Tongatapu. No Good.
- Go to Telephone Exchange and finally get through. Organise a 44 gallon drum of Hydraulic Oil to be shipped on this evenings boat will arrive some time tonight.
- Return to drill site LIF3 drilling crew has set up but clutch on pump beginning to slip again. NEEDS A NEW CLUTCH ASSEMBLY as requested in past trips.
- Have to adjust Pump Clutch not sufficient tools on rig return to guest house and get tool box.
- Return to drill rig and finish adjusting clutch,
- Check Hydraulic oil level. It is getting low hope that Oil comes on the boat tonight!
- Decide to drill on, drill to 8.5 meters before lunch and withdraw drill string to check static water level first thing after lunch.
- Return from lunch and SWL is at 3.0meters.
- Check hydraulic oil level, Getting very low and decide to drill on for one hour.
- Drill to 11.5 meters, check oil level again and decide to shut her down till we get more hydraulic oil.
- Organise to hire the water tanker drivers privately owned truck at 10 dollars per hour.
- Go to LIF 2 pick up gravel f or LIF 3 and LIF 4 and deliver to site.
- Get materials and get drilling crew to form up and pour two more protective covers.
- Get battery from water truck and go to LIF 2 and begin to monitor borehole.

- Monitors 1 and 2 were good the rest may need back flushing and priming .
- Go to LIF 1and monitor again still a large quantity of drilling mud in hole flush with sea water to see if this will help break it down.
- pump shits itself. Return to guest house and dismantle cant see anything wrong reassemble and will have a go tomorrow.

Wed 3/12/97

- Leave house 0745 arrive rig 0750, Water truck driver at site.
- Go to find drilling crew at MOW yard and inquire if Hydraulic Oil had arrived from Tongatapu, IT HAS!
- Organise drilling crew to transport to drill site. Will take approx 1 hour.
- Go and see Tony F and see if there is anything that he requires.
- Go to Cameron Store and purchase two buckets and a pad new lock for the tide recorder on the wharf.
- Return to drill site Hydraulic Oil has been delivered and drilling crew are filling tank, put in approx 90 liters
- Send water truck off to be filled should have done it previous evening
- Went to tide gauge and removed rusted lock and freed cap for Tony F.
- Returned to drill site and commenced drilling to 14.5 meters
- Flushed borehole with fresh water and withdrew drill string, bore hole caved to 14.3meters.
- Monitors installed at4.5, 6.5, 8.5, 10.5, 12.2, 14.2 meters
- Bentonite seals placed at 2.0, 5.5, 7.5, 9.5, 11.5, 13.0 meters
- A PVC slotted pipe was inserted to 4.0meters below existing ground level.
- The drilling rig was packed up and moved to LIF4.
- Go to LIF1 and 2 and monitor these boreholes with minimal success

Thur 4/12/97

- Leave Lindsay guest house 0730hrs. Public holiday in Tonga today.
- Arrive drilling rig at 0735 Drilling crew already there.
- Set up, mudded up, and commenced drilling after doing normal start up checks and especially checking hydraulic oil level.
- Drilled to 5.5 meters, drilling fluid seem to be being effected by salinity of the ground water even at this shallow depth.
- Went to see Tony F and discuss the situation.
- It was decided to continue the bore hole to at least 9 meters and to install the monitors at that depth.
- Return to rig and tried to advance borehole, MUD PUMP SLIPPING BADLY,
- Try to adjust but discover that one clutch plate has disintegrated.

- Clutch must be removed and spare clutch plates installed.
- Return to house and get tool box.
- Remove clutch and refit plates , and reassemble .
- Test clutch works OK will probably have to fine tune in the morning.

Fri 5/12/97

- Leave house 0730 arrive drill site LIF 4 0740 water truck already on site.
- Request hire of private truck and ask driver to go and pick up drillcrew.
- Drillcrew arrives and start up, Clutch appears to be operating well.
- Checked exact sites for boreholes LIF5 and LIF6 with Tony F.
- Continued and finished drilling of LIF4 borehole at 8.5 m. Monitors placed at depths of 3.5, 4.5, 5.5, 6.5 and 8.0 m. Water level was 2 m bgl at 1500. Also installed PVC water level monitoring pipe to 2.5 m bgl.
- Drilling rig moved to borehole LIF5 (by private tractor costing $30 per tow: minimum charge).
- Started drilling at borehole LIF5 (north side of Moa Road, Hihifo, between Lotokolo Road and Tu'akolo Road). Got to approx. 8 m by 1700.

Sat 6/12/97

- Leave guest house at 0730hrs arrive LIF 5, water truck on site.
- Measure Static water level: 3.6 meters at 0730hrs
- Request hire of truck for day, ask driver to collect drill crew and collect consumables
- Talked to Tony F last evening and it was decided if SWL was lower than 3.0 meters PVC stand pipes would be installed as in Mataki'eua.
- Go to MOW yard and pay for ¼" Gravel
- Go to quarry to pick up Gravel, 1/4" gravel has far to many fines so decide to take ¾" instead.
- Return to drill site after purchasing some PVC cement.
- drilling at LIF5 completed at 14.5 m. Installed 5 PVC monitoring tubes to depths of 4.5, 6.0, 7.5, 9.5 and 12 m bgl. Lowest one short of original target owing to partial collapse of the hole.
- towed drilling rig to borehole LIF6 (north side of Moa Road, Hihifo, between Holopeka Road and Lotokolo Road).
- pumped out all monitors at boreholes LIF3 and LIF4. Most have good flow. Needed to tighten up fittings on some to improve flow. No EC tests at this stage as more water will need to be pumped to get representative values of salinity. Will do more pumping next week.
- Gave Tony F a hand to install tide gauge logger

Sun 7/12/97

- Day off

Mon 8/12/97

- Leave House 0745 arrive rig 0750
- Water truck on site. Ask if we can hire truck but am informed that it has broken down
- Another truck (better condition) passes and ask if he is willing to hire. Yes at slightly increased price $25 for eight hour day
- Drill crew arrives and sets up
- Have to go and get the consumable from low level tank
- Drill to 15.5 meters (seems tight Med to low fluid loss)
- Monitors installed at 4.0 5.5 7.0 8.5 11.0 & 13.3 meters
- Bentonite pellets installed at 1.5 4.75 6.25 7.75 9.5 & 12.0 meters
- Slotted PVC pipe installed at 3.0 meters Below Ground level, 1.0m slotted
- went with Tony F and showed Sefili monitoring procedure at LIF 2 at1400hrs
- Found store that has a car battery will purchase tomorrow.
- Arrange tractor for 0830 tomorrow to move to Kuolo
- Tractor driver wants $60 each way but get him down to $50 each way (ripped off)
- Tony F shows method of down loading Loggers from Low and high level tanks.

Tue 9/12/97

- Leave house 0730 hrs, Arrive Rig 0735 hrs
- Go and load up consumables for Koulo
- Tractor and water truck arrive at 0800 hrs
- Send Rig and water truck to LIF 7 with instructions on bore hole location.
- Fit Quick fits to LIF6.
- Arrive Koulo and rig already set up but on wrong side of road, go and check with Tony F if this is OK. It is.
- Return to drill site and commence drilling. Thick clay overlying a thin sand layer and straight onto limestone doesn't look as though there will be much fresh water.
- Drill to 9.5 meters borehole caves to9.0 meters install first PVC pipe at this depth.
- PVC tubes installed at 5.0 6.0 7.0 & 9.0 meters
- Bentonite installed at 3.0 5.5 6.5 & 7.5 meters
- Finish LIF 7 and pack up.
- Go and see Tony F get his bags and take to airport, send truck back to pick up Tony.
- Tony arrives at drill site and take him to air port
- See Tony off and return to drill site and finish packing up.
- Organise Fui to go with Tractor Driver at 0600 hrs to pick up rig and go to LIF 8 at HIHIFO

Wed 10/12/97

- Fui comes at 0700 to say that drilling rig has arrived at HIHFO.
- Tony F rings at 0730 to say: (1).Ray to send $2000.00 by Western Union today; 2. Three of Drill crew to fly home one to travel with drilling rig; 3. Take notes of monitoring procedure shown to Siua; 4. Seals for hydraulic rams on rig appear to be in Tongatapu and should be here in the next day or so; 5. Tony will try and ring tomorrow morning; 6. Monitoring sheets to be sent by Tony today.
- Arrive Rig 0730 boys there and set up, Inform them of the travel arrangements drilling crew are very happy.
- Stratum very loose and have difficulty getting return losing large quantity of drilling mud to formation, seems to tighten up 2.0 meters below water table.
- Go to see Sefili and Siua and inform them that the drilling crew have the OK to fly home and if they could change the bookings for the shipping corporation to the rig and one man.
- Go to Frisco and let them know that money transfer is coming through today.
- Return to rig and assist with top 6 meters High fluid loss.
- Take two Sione's and show them block work construction on LIF 5, will send them to LIF 7 after lunch to do same.
- Return to rig everything OK
- Go to Frisco store $2000 is there from Ray Cameron
- Pick up cash and go and pay for drill crew flights to Tongatapu
- Go to shipping corporation and pay for rig and Fui to go on ship on Friday night.
- Go to guest house and pay for my accommodation for my trip
- Return to rig and place monitors at 4.0 5.0 6.0 8.0 meters
- Bentonite at 1.5 3.5 4.5 5.5 7.0 meters
- Tractor arrives at 1230 hrs, Pack up and shift to LIF9
- Pay Tractor operator for remainder of moves and organise for him to return at 1200 hrs tomorrow and return rig to MOW.
- Commence drilling at LIF9
- Sefili arrives at drill site with Gatic cover, go with him and Sione (TWB plumber) how we want them installed, seems OK, NB Check on Ellen keys for same.
- Organise Sefili and Siewa for 1400 hrs tomorrow to go through monitoring procedure again.
- Drill LIF 9 to 8.5 meters will finish off tomorrow.

Thur 11/12/97

- Leave house at 0700 hrs arrive rig 0715 hrs
- Water truck arrives at 0800 hrs with drillcrew
- Tool up and begin drilling operations. SWL LIF9 at 0800 2.3 meters below ground level.
- Finish drilling LIF 9 at 9.0 meters but discover only 2 of the remaining 4 monitor tubes are serviceable so decide to install these at base and to install three PVC pipes as well.

- Finish monitoring and pack up rig for transport to Tongatapu
- Before rig is packed up go through equipment with drill crew for report on equipment status.
- Pour two more concrete blocks for temporary protection of boreholes, and cast in place Gatic cover on LIF1
- Tractor arrives and finish packing up
- Send tractor rig to MOW with FUI
- Go and see Sefili and make sure 1400 hrs is still OK
- Finish off LIF 9
- Finish with water truck and send him back
- Meet Siewa at LIF9 and go through monitoring procedure with him (See Attachment at end of Diary) and show him each bore hole in order from 1 to 9.
- Send drill crew to each drill location and get them to clean up as much as possible.
- Return to Hihifo and knock boys off.
- Monitoring sheets arrive late afternoon with Fin Walter. Will show Siewa tomorrow morning

Fri 12/12/97

- Leave house 0730 and go to low level tank store and organise some of the gear to be shipped back to Tongatapu.
- Return to house , drillcrew arrives at 0800hrs
- Go with drillcrew to each site and finish clean up.
- Go and see Sefili and Siewa and go through monitoring sheets and notes taken previous day with them
- Go to house and try to get Flowjet pump operational. Unsuccessful but leave pump with Sefili.
- Get bolts and mount operational pump on a timber board
- Get rest of monitoring equipment and pump bore holes 6, 8and 9
- Return with monitoring equipment and give to Safely and Siewa.
- Go and download data loggers from low and high level tanks.
- Place protective concrete blocks over LIF 8&9
- Return to house and start packing up gear
- Go with drill crew to Royal Tongan Airlines and confirm tickets
- Go and see Sefili and check that if there are any requirements from Tongatapu apart from a battery and battery charger, decide to make up another Giggler in Tongatapu and ship it to Sefili.
- Return to guest house and finish packing.

Sat 13/12/97

- Get up at 0600 and finish packing
- Truck arrives at 0645 to go to Airport.

- Go to drill crew accommodation and pick up crew and make sure Fui is OK with putting rig on ship.
- Say good buys and go to Airport.
- Leave LIFUKA and travel to Tongatapu via Vava'u
- Arrive Tongatapu 1230hrs get taxi for drill crew and myself, go to TWB house and unpack.
- Go and see David Solomon and discuss works carried out, and possibility of completion of MB2.
- Go back to TWB house and do some laundry in fresh water.
- Try to contact Tony F no good will try tomorrow.

Sun 14/12/97

- Day off

Mon 15/12/97

- Leave TWB house at 0745 and go to TWB office meet with David Solomon and say hello to rest of staff
- Go to MOW yard to see if rig has arrived.
- Am advised by MOW staff that the ship carrying the rig had been delayed in leaving Vava'u but should leave Lifuka this afternoon.
- Ring Lifuka to find out whether the spare parts ordered from Aust had arrived, Negative.
- Go to GHD office in Tongatapu to see if I can at least track them down.
- Spares are sitting in office and have been there for the past four days.
- Collect spares and take them around to MOW Yard and give them to Drilling crew to be fitted as soon as the rig arrives.
- Go to TWB house and collect data loggers and ancillary equipment and take to Quddus at TWB office
- Give him copy of data logger down load and E-mail same to Tony F.
- See David Solomon and will acquit petty cash tomorrow.

Tue 16/12/97

- Leave TWB house at 0745 and go to TWB office.
- Talk with David Solomon about plan for getting MB2 completed.
- Go to MOW workshop to see if rig has arrived and to get drill crew to fit hydraulic ram seals as soon as possible.
- Arrive at MOW and am informed that the rig was unable to be loaded in Lifuka due to there being no space available.
- Go through the list of required repairs to the drilling rig with the drilling foreman.
- Will get to LIFUKA some time next week.
- Well that shoots getting MB2 done whilst I am here.

- Return to TWB office and inform David Solomon of the situation. Not much we can do about it.
- Return to TWB house and get receipts to acquit funds back to TWB.
- Deliver receipts and acquittal sheet to David Solomon.
- Organise to go with monitoring team to Mataki'eua in the morning and check on their techniques.
- Am informed that the monitoring crew is already using an eductor tube of sorts and is able to sample all monitoring tubes.
- Go to plumbing supply store and purchase all necessary items for making up better Giggler pump to be shipped to TWB Lifuka.

Wed 17/12/97

- Leave TWB house at 0745 and go to TWB office.
- See David Solomon and discuss my duties for the day.
- Go and purchase 12 volt battery and battery charger to be shipped to LIFUKA.
- Return to TWB office and make up Giggler pump to be shipped to LIFUKA.
- Make up list of monitoring instructions for LIFUKA and go through them with the monitoring staff.
- Go to Mataki'eua and get the high-density poly hose for jiggler to be sent to Sefili.
- Return to TWB office and acquit all funds with David Solomon, no problems.
- Give David a copy of the hours for the drilling rig and crew.
- Show monitoring crew how to make up another eductor tube using the 8mm nylon tubing and fittings that were shipped to Tonga earlier in the year.
- Go to MOW yard and say my good byes and request the fitting of all spares on the arrival of the drilling rig in Tongatapu.
- Return to TWB office and say good byes
- Go to TWB house and pack up.
- Replace TWB computer in Ray Cameron's side of house as requested.

Thur 18/12/97

- Leave TWB house at 0745 and go to TWB office.
- Say final goodbyes and leave for Airport.
- Depart Tonga 1040hrs and arrive Melb 2030hrs.

Annex D

Monitoring Instructions

for

Lifuka salinity monitoring boreholes

INTRODUCTION

Following is a transcript of the verbal instructions and a copy of the notes taken during a physical demonstration of the water salinity monitoring techniques given to Tonga Water Board Staff, Lifuka on the 12 December 1997 by Bryan Turner. During this demonstration all nine boreholes were visited and requirements explained, as follows:

BOREHOLES LIF1, LIF2, LIF3, LIF4, LIF6 and LIF8

(Boreholes fitted with only Nylon Tube Monitors).

- Arrive at borehole and remove Gatic cover with allen key provided (note: only one Gatic cover has been fitted but the method of installation has been explained and demonstrated to TWB Staff Lifuka so the others can be fitted when they arrive in Tonga).
- Measure depth to Water Level with water level ('dip') meter in 32mm PVC pipe. Note time & date and water level on monitoring sheets provided.
- Attach suction side of 'Flojet' pump (see arrow indicator) to monitor (brass fitting) number 1.
- Attach Pump to Battery. **Note Well: CONNECT RED LEAD TO POSITIVE BATTERY TERMINAL**
- Pump for one minute. If no water is flowing from the delivery hose of the pump the monitor may require backflushing or priming. To do this, attach delivery hose to monitor, place suction hose in bucket of water and pump for 30 seconds. Then attach monitor to suction side of pump and resume pumping.
- Pump ½ bucket of water and take conductivity reading. Note this reading on sheet provided.
- Discard ½ bucket and repeat pumping process three times noting conductivity reading after each ½ bucket taken.
- Pumping should continue until three readings of approx same conductivity reading are taken.
- Read temperature of last conductivity reading and note on sheet provided.
- Change pump to next monitor (number 2, etc.) and repeat previous steps.
- Repeat until all monitors have been pumped and conductivity readings taken.
- Replace monitors inside plastic bag or rag, replace Gatic cover and lock with allen key bolts.
- Move to next borehole.

BOREHOLES LIF 5 and LIF7

(Boreholes fitted with only PVC pipes)

- Arrive at borehole and remove Gatic cover as above.
- Remove PVC caps fitted to PVC pipes. **NOTE: PVC PIPES ARE NUMBERED WITH NOTCHES CUT AT TOP OF PVC PIPES**
- Take water level reading in PVC pipe Number 1. Note time date and water level on monitoring sheets provided.
- Insert hand pump ('jiggler') and begin pumping.
- Pump ½ bucket of water and take conductivity reading as described in monitoring process above.
- Repeat pumping process three times noting conductivity reading after each ½ bucket taken.
- Replace all PVC caps, replace Gatic cover and lock with allen key bolts.

BOREHOLE LIF 9

(fitted with 3 PVC Tubes and 2 Nylon Tube Monitors)

- Arrive at borehole and remove Gatic cover as above.
- Remove PVC caps fitted to PVC pipes (Numbers 1 to 3) and sample from these and record results as described in sampling for boreholes LIF 5 and LIF7.
- Connect Flojet pump to nylon tube monitor Number 4 and begin pumping.
- Take water samples and note results as described in sampling for boreholes LIF1,LIF2, etc.
- Repeat procedure for nylon tube monitor Number 5
- Replace all PVC caps and monitor, replace Gatic cover and lock with allen key bolts.

GENERAL NOTES

- Once monitoring has been completed for the day go to the lagoon and take conductivity reading of SEAWATER and note: DAY, TIME, LOCATION and CONDUCTIVITY. Record this information on the Conductivity Sheets in the space provided.
- Wash conductivity probe thoroughly in rainwater at the end of each monitoring session and store in the box or case provided.

[LIFMONIT.DOC]

Annex E

Monitoring Forms
for
Lifuka salinity monitoring boreholes, LIF1 – LIF9

Borehole: **LIF1**

Location: East side of Hihifo rugby field
Type: Nylon tubes (for pumping with electric Flojet pump)
Operator(s)

Date	Time	Tube No	Tube Depth (m)	Conductivity readings (µS/cm)			Temp (ºC)	Depth to water table (m)
				1	2	3		
		PVC	4.1					
		1	4.5					
		2	6.5					
		3	8.5					
		4	10.5					
		5	12.5					
		6	14.7					
		7	18.0					

Borehole: **LIF2**

Location: West side of Hihifo rugby field
Type: Nylon tubes (for pumping with electric Flojet pump)
Operator(s):

Date	Time	Tube No	Tube Depth (m)	Conductivity readings (µS/cm)			Temp (ºC)	Depth to water table (m)
				1	2	3		
		PVC	3.0					
		1	3.5					
		2	5.5					
		3	7.5					
		4	9.5					
		5	12.0					
		6	15.6					

Borehole: **LIF3**

Location: East side of Pangai rugby field
Type: Nylon tubes (for pumping with electric Flojet pump)
Operator(s):

Date	Time	Tube No	Tube Depth (m)	Conductivity readings (µS/cm)			Temp (ºC)	Depth to water table (m)
				1	2	3		
		PVC	4.0					
		1	4.5					
		2	6.5					
		3	8.5					
		4	10.5					
		5	12.2					
		6	14.2					

Borehole: **LIF4**

Location: West side of Pangai rugby field
Type: Nylon tubes (for pumping with electric Flojet pump)
Operator(s):

Date	Time	Tube No	Tube Depth (m)	Conductivity readings (µS/cm)			Temp (ºC)	Depth to water table (m)
		PVC	2.5					
		1	3.5					
		2	4.5					
		3	5.5					
		4	6.5					
		5	8.0					

Borehole: **LIF5**

Location: north side of Moa Road, Hihifo, between Lotokolo Road and Tu'akolo Road
Type: PVC tubes with slots at base (for bailing or pumping by hand)
Operator(s):

Date	Time	Tube No	Tube Depth (m)	Conductivity readings (µS/cm)			Temp (ºC)	Depth to water table (m)
		1	4.5					
		2	6.0					
		3	7.5					
		4	9.0					
		5	12.0					

Borehole: **LIF6**

Location: north side of Moa Road, Hihifo, between Holopeka Road and Lotokolo Road
Type: Nylon tubes (for pumping with electric Flojet pump)
Operator(s):

Date	Time	Tube No	Tube Depth (m)	Conductivity readings (µS/cm)			Temp (ºC)	Depth to water table (m)
				1	2	3		
		PVC	3.0					
		1	4.0					
		2	5.5					
		3	7.0					
		4	8.5					
		5	11.0					
		6	13.3					

Borehole: **LIF7**

Location: Koulo, west side of road just south of airstrip

Type: PVC tubes with slots at base (for bailing or pumping by hand)

Operator(s):

Date	Time	Tube No	Tube Depth (m)	Conductivity readings (µS/cm)			Temp (ºC)	Depth to water table (m)
				1	2	3		
		1	5.0					
		2	6.0					
		3	7.0					
		4	9.0					

Borehole: **LIF8**

Location: North side of Hihifo rugby field

Type: Nylon tubes (for pumping with electric Flojet pump)

Operator(s):

Date	Time	Tube No	Tube Depth (m)	Conductivity readings (µS/cm)			Temp (ºC)	Depth to water table (m)
				1	2	3		
		PVC	3.0					
		1	4.0					
		2	5.0					
		3	6.0					
		4	8.0					

Borehole: **LIF9**

Location: South side of Hihifo rugby field

Type: PVC (numbers 1, 2 & 3) and nylon tubes (numbers 4 & 5)

Operator(s):

Date	Time	Tube No	Tube Depth (m)	Conductivity readings (µS/cm)			Temp (ºC)	Depth to water table (m)
				1	2	3		
		1	2.8					
		2	5.0					
		3	6.0					
		4	7.0					
		5	8.0					

Seawater

Date	Time	Location	Conductivity readings (µS/cm)		