TONGA WATER BOARD INSTITUTIONAL DEVELOPMENT PROJECT

REPORT ON

WATER MONITORING BOREHOLE INSTALLATION

MATAKI'EUA and SURROUNDS, TONGATAPU

November 1996 - May 1997

prepared by

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EXECUTIVE SUMMARY

INTRODUCTION

This report describes a drilling program, undertaken over two visits in late 1996 and April-May 1997 at and near Mataki'eua on the island of Tongatapu. The purpose of the program was to install seven water salinity monitoring holes, one production hole and provide training to drillers at the Ministry of Works.

SUMMARY AND CONCLUSIONS

Six of the required seven monitoring boreholes were successfully drilled and monitoring systems were installed. A number of attempts were made to drill the seventh monitoring borehole, in the centre of Mataki'eua, but these were unsuccessful.

One production borehole was successfully drilled at the western end of Mataki'eua.

Many problems were encountered with the drilling rig during the program. The program involved two trips owing to the breakdown of the rig during the first visit in November-December 1996. The second visit was extended beyond the schedule by one week owing to additional problems with the rig and also due to adverse weather conditions.

There is an urgent need for repairs and maintenance to the rig in order for it to be used for future work. A list of recommended repairs and other remedial work is outlined in the report.

On-site training was provided to the Ministry of Works drillers and assistants in the installation of monitoring systems and the use of polymer drilling fluids. The Ministry of Works drilling crew is more than capable of constructing production boreholes with minimal to no supervision.

RECOMMENDATIONS

1. 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 drill head and pumping system;
2. To improve the method of sampling from the monitoring tubes within the salinity monitoring boreholes, trials using an eductor tube connected to a portable air compressor should be made;
3. Future salinity monitoring boreholes of the type installed during this program, should use:

    (a) PVC monitoring tubes with internal diameters equal to or greater than 38 mm, and

    (b) 'pea' (approx. 6 mm) gravel around the slotted ends of the monitoring tubes.

1. INTRODUCTION

This report describes the drilling program undertaken to install water monitoring boreholes at and near Mataki'eua on the island of Tongatapu. This program was part of the Tonga Water Board Institutional Development Project (the Project) was undertaken over two visits. The first visit was from 22 November - 3 December 1996. Completion of the works could not be accomplished during this visit due to the mechanical breakdown of the drilling rig. The second visit was undertaken from 15 April - 14 May 1997.

1.1 Purpose

The purpose of the drilling program was to

- drill seven salinity monitoring boreholes and install multi-level water salinity monitoring systems in the freshwater lens at Mataki'eua and surrounding areas. The monitoring systems were designed for the extraction of groundwater samples to enable salinity testing and thereby enable salinity profiles of the lens to be developed;
- drill one production borehole at Mataki'eua; and
- provide training to Ministry of Works drillers and assistants in the techniques used.

1.1 Audience and Report

This report is primarily written for the Project's Technical Manager and for relevant professional and technical staff of the Tonga Water Board (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 also be of interest to the Ministry of Works 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.

2. SCOPE OF WORK

The scope of work, summarised from the Terms of Reference (refer Annexes A and B), 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 and one production well at nominated sites and to an agreed design;
- fit each monitoring borehole with an assigned number of monitoring tubes, and backfill with suitable granular material and bentonite plugs;
- finish off the top of each hole with concrete slab, galvanised steel pipe with locking cap for housing, and four steel protection posts;
- prepare drill logs for each hole and details 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) and Hydrogeologist (Lindsay Furness).

3. DRILLING PROGRAM

3.1 Equipment used

The drilling equipment used to construct the water monitoring boreholes was a Walkerwell Model ASW286, operated by the Ministry of Works. 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. The pump is powered by a clutch assembly mounted in the drive train of the drilling rig.

The drill string is comprised of approx. 50 metres of 75 mm drill rod. No drill casing was located on the island although a quantity of NW or equivalent casing is reported to be present on one of the outer islands.

There is also a mud tank system that has been fabricated to enable the re-circulation of drilling fluids and the mixing of drilling muds as required.

Many problems were encountered with the drilling rig and its associated equipment. These are outlined in section 4 together with recommended actions to remedy the problems.

3.2 Drilling procedures

The drilling operation consisted of rotary mud drilling to construct 150 mm diameter boreholes using the 75 mm drill string provided.

Due to the very large annulus (size of gap between outside diameter of the drill pipe and the borehole diameter) and the stratum encountered extremely thick drilling fluids had to be used. These fluids had to not only ensure minimal loss of drilling fluids to the stratum but to give sufficient fluid viscosity with available annular velocity to lift drilling cuttings to the mud tanks at the surface.

Bentonite based drilling fluids were used, where required, in the stratum above the existing water table. Polymer based drilling fluids were used in stratum below the water table.

3.3 Drilling program completed

Six of the proposed seven monitoring boreholes were completed.

The seventh monitoring borehole (MB2 near pump station 105) had to be abandoned due to massive fluid losses at depth and the near exhaustion of supplies of polymer drilling mud. Attempts were made at three positions in the vicinity of the pump station to drill this hole but the target depth could not be reached.

The first production well was commenced on 10 May 1997 and completed on 13 May, the day of my departure to Australia.

Locations of all holes are shown in Figure 1 and listed in Annex C.

3.4 Sequence of works

Borehole MB3 was drilled and monitoring tubes installed (refer Annex D for details) during the first visit. Borehole MB2 was also started during the first visit. It was drilled to about 12 m when the rig failed (refer section 4.2).

During the second visit, two boreholes in the Mataki'eua area (MB4, MB1) were initially drilled. Due to rain and poor access at the time the third borehole in this area (MB2) was postponed, and it was decided to drill MB7 near the Hihifo Road. This was followed by borehole MB5 adjacent to well 129 at Tongami. Borehole MB6 in the Fualu quarry was then drilled. Finally, the rig was returned to borehole MB2 at Mataki'eua with the assistance of the Ministry of Works 4x4 backhoe.

The first of the production holes (at the site of the former pump station No 118, Mataki'eua) was completed after the monitoring boreholes.

Daily diaries giving full details of the works and associated problems are provided in Annex E (Visit 1) and Annex F (Visit 2).

3.5 Drilling logs

The drilling logs for all seven monitoring boreholes are provided in Annex C. 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, and were not, intended to be detailed geological logs.

3.6 Geological strata

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

Two major strata were encountered during drilling operations. 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).

The first stratum was a silty clay layer of volcanic origin (resulting from volcanic material that had been spread widely over the islands in recent geological times as a result of nearby eruptions). This layer was comprised of a 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 depth of this stratum varied from 0.0m in the already excavated quarry area MB6 to 3.4m in boreholes MB1 and 7, the other boreholes had a coverage of approx. 2.0 meters.

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 (caving). These areas were usually in the form of sand lenses, the stability of which can be controlled using drilling fluids. In some circumstances where a voidal area is encountered massive fluid loss is encountered being much more difficult to control.

3.7 Monitoring systems

The monitoring system used at each of the six completed monitoring holes consisted of a set of PVC pipes ('monitoring tubes') terminating at different depths. These tubes were slotted near the base and heated to form a seal at the very base. Between 5 and 7 pipes were installed at each borehole (refer Annex D). Annex D also shows the base of each monitoring tube.

Sand was used to backfill the annulus between the tube(s) and surrounding formation. Approximately midway between the base ends of adjacent tubes a hydraulic seal was formed in the hole by inserting bentonite pellets to form a plug.

The diameter of the PVC pipes used at the first borehole (MB3) had an internal diameter of 21 mm. Such diameter pipe could be bailed with a small diameter bailer. The 5 later boreholes used larger PVC pipes (internal diameters of 38 mm) to provide for alternative methods of water sampling (refer below). Use of the larger pipes meant that the insertion of packing sands and bentonite seals had to be done with extra care to ensure their correct placement.

To protect the top of the monitoring boreholes from damage, steel pipe was used to house the monitoring tubes. The height of each steel standpipe above ground level is shown in Annex D. The top of the tubes is at the same level. Concrete bases and four steel corner posts were installed for added protection.

3.8 Salinity tests

3.8.1 Salinity testing during drilling

Salinity testing of groundwater during the drilling operation is desirable, but unfortunately with the drilling methods 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.

With the large quantities of drilling fluids used it was considered totally inadequate to test return fluids to give any meaningful salinity level.

The best way found 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.

3.8.2 Salinity testing after drilling

On completion of the six salinity monitoring boreholes, the drilling sites were visited with Kutusi Fielea (Senior Technical Officer, TWB). He was instructed in the use of the water extraction system made up while drilling operations proceeded.

A water extraction system for boreholes MB1, MB4, MB5, MB6 and MB7 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. It was later detected (refer visit report by Tony Falkland, June 1997) that ingress of sand caused the foot valve to jam open at a number of monitoring tubes.

The pipe and foot valve system was not suitable for borehole MB3 which had narrower monitoring tubes. Problems were also found using the small diameter bailers with some of the monitoring tubes at MB3; the bailer would become stuck presumably due to curvature of the pipe. Later monitoring (refer visit report by Tony Falkland, June 1997) has shown that all but one monitoring tube at this borehole can be bailed. Because of the problems found with this borehole, larger diameter PVC pipes were used in all the other boreholes.

The best means for the extraction of water samples from borehole MB3 is probably the use of an air eductor tube With this method, a small diameter tube would be lowered to the base of the monitoring tube and compressed air is passed through the eductor tube which physically lifting the water from the pipe, where it can be collected for salinity testing. A relatively small amount of compressed air would be required for this operation and could be delivered by a small electric operated compressor available to the Tonga Water Board. It is recommended that this method be trialled. This method of sampling might also prove more effective at the other boreholes.

The importance of monitor development was also emphasised to Kutusi during the site visit 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.

4. DRILLING RIG AND EQUIPMENT

4.1 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. The size and depth of boreholes drilled in the recent drilling program takes the Ministry of Works drilling equipment to the limit of its capability.

4.2 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.

4.2.1 Urgent repairs

Drill Head

The drill head should be overhauled as a matter of urgency. During drilling operations in Visit 2 the drive shaft below the main hydraulic motor, giving all torque to the drill head, sheared. On-site welding of the shaft was undertaken allowing drilling operations to continue. While these stop-gap repairs were done, it was noticed that all bearing and seals in the drill head were in need of immediate replacement.

Pumping System

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

During Visit 1 a major problem arose with the pumping system. The clutch assembly driving the pump was worn out with no further adjustment possible and the clutch slipped continuously. The clutch was removed. It was suggested that a new clutch assembly be purchased with new valves, valve seats, and valve springs for the pump unit. The Ministry of Works decided to obtain only new clutch plates and refit the unit. After the refit, the pumping unit worked to a limited degree, in that the pump was not able to be engaged or dis-engaged from the control console, as designed, and had to be run continuously if the pump was put under any load.

New valve, valve seats and valve springs as well as spares should be purchased immediately. 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.

4.2.1 Other necessary repairs

Power Unit

The drilling rig is powered by a Mitsubishi 6 cylinder diesel engine which operates well. A new air cleaner 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. 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. The fact that no drill casing accompanied the drilling rig is a problem especially where very high fluid loss situations may occur at depth. There are no drill collars with the drilling equipment, the presence of which would greatly increase annular velocity and therefore assist drilling operations.

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.

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 tool box should be carried with the drilling rig at all times.

4.3 Further comment

With repairs to the pumping system and the drilling head, works on a smaller scale to those completed in this drilling program could be undertaken.

5. TRAINING

On arrival (25 November 1996), I was introduced to the Ministry of Works drilling crew:

Mr Sioeli Latu (Drilling Foreman);

Mr Taniela Heimuli (Driller);

Mr Sione Sapa'ia (Drilling Assistant);

Mr Himuiti Fuimaous (Drilling Assistant);

Mr Sisi Atuaki (Water Tanker Driver); and

Mr Asta (Tractor Operator).

It was obvious from the first meeting that the drilling crew had been previously trained. The drilling crew were very capable with all aspects of the drilling operation including: drill set up, rod and tool handling, bentonite based drilling fluid management, rig repair (if tools and spares available) and identification of local strata.

On-site training was carried out in new procedures, primarily the use of polymer drilling fluids and the installation of monitoring tubes.

It is noted that the author not only trained the drilling crew in these functions but in return learnt quite a deal from the drilling crew, especially in their management of massive fluid losses in local conditions with the limited equipment available. The author regarded it as a privilege to work with a team, which had machinery that needed constant attention and less than favourable drilling and weather conditions, and still showed genuine interest in the drilling program and the benefit it will be for their community.

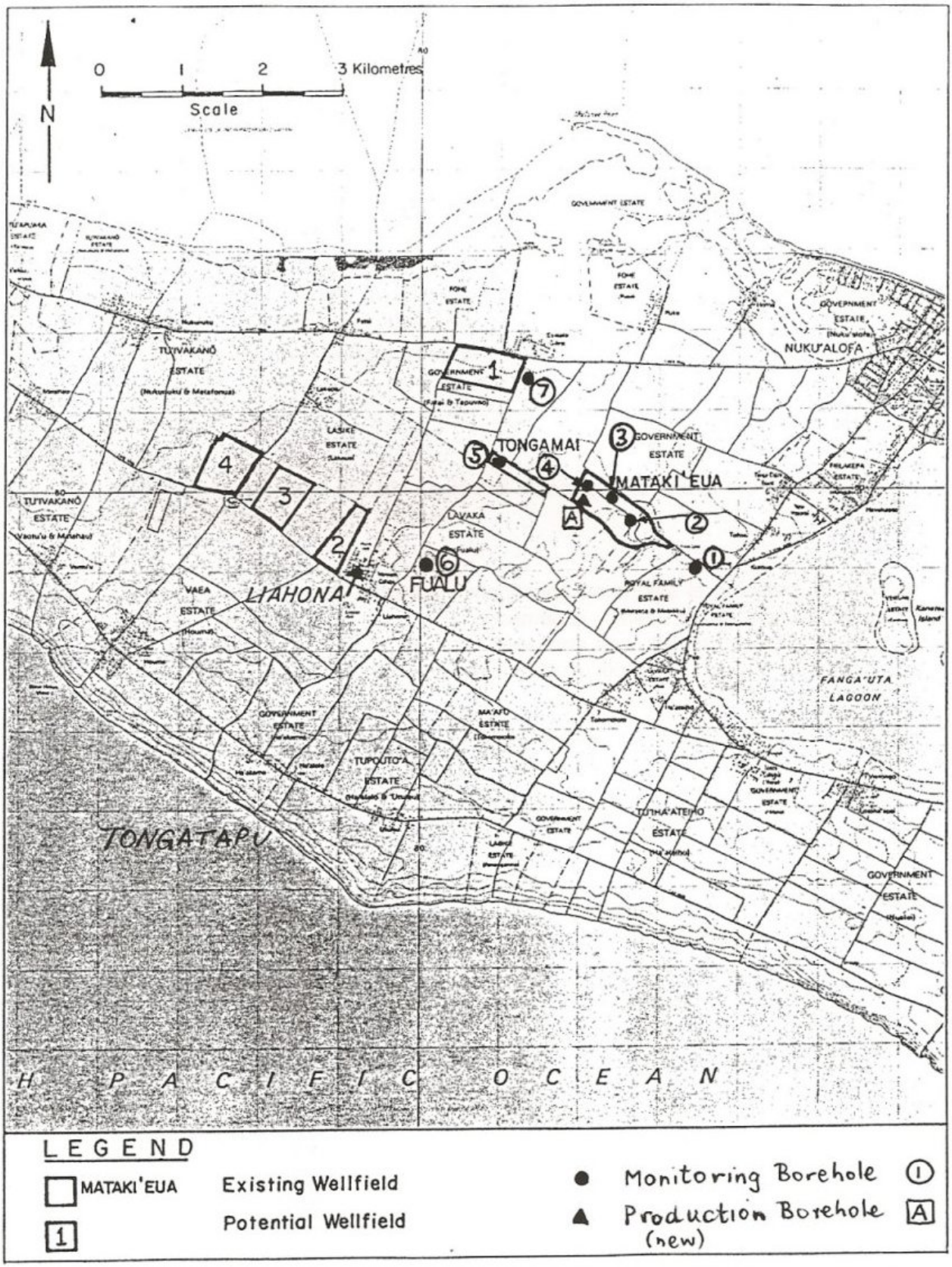
The Ministry of Works drilling crew is more than capable of constructing production boreholes with minimal to no supervision.

6. SUMMARY OF RECOMMENDATIONS

1. 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 drill head and pumping system;
2. To improve the method of sampling from the monitoring tubes within the salinity monitoring boreholes, trials using an eductor tube connected to a portable air compressor should be made;

3. Future salinity monitoring boreholes of the type installed during this program, should use:
   (a) PVC monitoring tubes with internal diameters equal to or greater than 38 mm, and
   (b) 'pea' (approx. 6 mm) gravel around the slotted ends of the monitoring tubes.

Figure 1
Location of boreholes (at and near Mataki'eua)



This drawing is based on Drawing 1 of Furness L. (1996). Report on Visit to Tonga, 8-16 May 1996, prepared for ACTEW Corporation, Douglas Partners, June 1996.

Annex A

Terms of Reference, Visit 1

for

Bryan Turner, Drilling Supervisor: Visit 1

22 November - 19 December 1996

Objectives of the visit:

The objectives are:

- to successfully install salinity monitoring systems at 7 sites at and near the Mataki'eua/Tongamai wellfield on Tongatapu,
- to provide drilling training to Ministry of Works driller(s) in the techniques required for this work, and
- to report on progress.

Role and Function:

Accountable to the Hydrogeologist and the Technical Manager, the role of the Drilling Supervisor will to ensure that the above objectives are met.

Background:

The background to the requirement for salinity monitoring boreholes is provided in the Project Implementation Document and other preceding documents. These boreholes will be used for long term monitoring of salinity profiles at selected sites from near the Fanga'uta Lagoon to west of the current wellfield used for pumping groundwater to Nuku'alofa.

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 and design for these holes will be specified in detail by the Hydrogeologist (Mr Lindsay Furness) who will be in attendance for the drilling of the first hole. Preliminary details are provided in the attached figures,
- 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 to the satisfaction of the Hydrogeologist,
- finish off the top of each hole with concrete slab, galvanised steel pipe with locking cap for housing, and four steel protection posts to the satisfaction of the Hydrogeologist,
- ensure that at the end of drilling each hole the top of the hole is sealed (to prevent tampering) by a lockable steel cap,
- maintain drill logs for each hole and details of the salinity monitoring holes to the satisfaction of the Hydrogeologist. Send drill logs at the completion of each hole to the Hydrogeologist and Technical Manager,
- after the departure of the Hydrogeologist, arrange through the Tonga Water Board (contact David Salomon, Chief Engineer) for the supply of necessary materials (e.g. PVC pipes, steel pipes and cement),
- maintain liaison with the Hydrogeologist and nominate in advance any additional material requirements that are not available locally.

- organise progress reports (from the drilling supervisor) to be sent by fax to the Technical Manager,
- before leaving the site, prepare a brief report on the overall drilling program including training aspects and recommendations about further needs if future similar drilling is undertaken. Submit this report by fax to the Hydrogeologist and the Technical Manager.

Further details:

- details of the site locations and preliminary designs for monitoring tube installations and details of above-ground protective works are shown in the attached figures. These will be conformed and modified, as necessary, by the Hydrogeologist, and
- the nominated Hydrogeologist is Lindsay Furness (phone: 07 3252 1236; fax: 3252 4684).

Principles of Service:

- the Drilling Supervisor will ensure consultative working relations with relevant Tongan agencies including the Ministry of Works and the Tonga Water Board.

Tony Falkland

17 November 1996

Annex B

Terms of Reference, Visit 2

for

Bryan Turner, Drilling Supervisor: Visit 1

15 April - 6 May 1997

Objectives of the visit:

The objectives are:

- to successfully install salinity monitoring systems at 6 sites at and near the Mataki'eua/Tongamai wellfield on Tongatapu, noting that one has already been installed,
- to assist with the drilling of the first production borehole at Mataki'eua,
- to provide drilling training to Ministry of Works driller(s) in the techniques required for this work, 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 other preceding documents. These boreholes will be used for long term monitoring of salinity profiles at selected sites from near the Fanga'uta Lagoon to west of the current wellfield used for pumping groundwater to Nuku'alofa.

Duties:

- using the Ministry of Works drilling rig, assist, supervise and train the Ministry of Works driller(s) during the drilling of 6 salinity monitoring holes and one production borehole. The exact sites and design for these holes have previously been specified in detail by the Hydrogeologist (Mr Lindsay Furness),
- 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 procedure for the first borehole drilled in November 1996,
- finish off the top of each hole with concrete slab, galvanised steel pipe with locking cap for housing, and four steel protection posts to the satisfaction of the Hydrogeologist,
- ensure that at the end of drilling each hole the top of the hole is sealed (to prevent tampering) by a lockable steel cap,
- maintain drill logs for each hole and details of the salinity monitoring. Send drill logs at the completion of each hole to the Technical Manager (fax 616 285 7224),
- assist with the drilling of one production hole at Mataki'eua,
- arrange through the Tonga Water Board (contact David Salomon, Chief Engineer) for the supply of necessary materials (e.g. PVC pipes, steel pipes and cement),

- maintain liaison with the Technical Manager and nominate in advance any additional material requirements that are not available locally.
- before leaving the site, prepare a brief report on the overall drilling program including training aspects and recommendations about further needs if future similar drilling is undertaken. Submit this report by hand to the Team Leader of the Tonga Water Board Project, Ray Cameron and by fax to the Technical Manager.

Further details:

- details of the site locations and preliminary designs for monitoring tube installations and details of above-ground protective works have been previously supplied
- there should be 3 x 25 Litre Quikmud and 12 x 50 lb buckets of bentonite pellets with the Tonga Water Board. A further order of Quikmud and bentonite pellets is on the ship to Tonga arriving in early May (the latter will be required for drilling at Neiafu and Lifuka).

Tony Falkland

11 April 1997

Annex C

Drilling Logs for boreholes MB 1 - MB 7

Summary of borehole locations

Borehole	Location
MB 1	At old site 222, (between lagoon and Mataki'eua) on south side of road.
MB 2	Adjacent to well 105, Mataki'eua. Not completed.
MB 3	Adjacent to well 115, Mataki'eua
MB 4	Adjacent to well 116, Mataki'eua
MB 5	Adjacent to well 129, Tongamai
MB 6	North side of entry ramp, at base of Fualu quarry
MB 7	Approx. 150 metres south of Hihifo Rd opposite the Sia'atoutai Theological College, east side of road (100 metres south of location shown by Mr L Furness during visit 1).

Legend for Borelogs

bgl	Below ground level
m/c	Moisture content
SWL	Static water level below ground level

Drilling Log

Location:	Tonga tapu , Kingdom of TONGA	**Date Start:** 23/04/1997	
Site:	At old site 222	**Date Finish:** 24/04/1997	
Borehole No:	**MB 1**	**Drilling Rig :** Walkerwell ASW286	
Driller:	Taniela Heimuli	**Drill Method:** Wash Boring	
Assistants:	Sione Saipa'ia, Himuiti Fuimaous		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0 m - 3.4m :SILTY CLAY (CH)** , stiff to very stiff, brown - dark brown, m/c greater than plastic limit, (friable).		
2.0m	With trace limestone gravel and becoming pale brown below 2.2m.		
4.0m	**3.4m - 4.3m : LIMESTONE :** Completely weathered, highly fractured, low strength, cream and pale brown.		
	4.3m - 9.8m :LIMESTONE : Highly to moderately weathered cream, low strength.		
6.0m			
	With some minor sand lenses below 6.6m (caving slightly)	SWL	
8.0m		6.2M	
	Becoming highly weathered below 9.3m	0915HRS	
	9.8m - 10.8m : LIMESTONE : Moderately to slightly weathered, slightly fractured, cream , medium to high strength.	24/04/97	**M5: 8.45m**
10.0m			
	10.8m - 16.4m : LIMESTONE : Highly weathered, cream, low strength, moderate to low mud loss.		**M4: 10.55m**
12.0m			
14.0m			
16.0m	**16.4m - 17.2m : LIMESTONE :** Slightly weathered, cream, high strength, low mud loss.		**M3: 16.06m**
18.0m	**17.2m - 21.6m : LIMESTONE :** Highly to moderately weathered, cream, low to medium strength, moderate mud loss.		**M2: 21.05m**
20.0m			
22.0m	**21.6m - 26.0m : LIMESTONE :** Highly weathered, cream and pale brown, low strength, with sand lenses to 100mm in thickness. Severe mud loss.		
24.00m			**M1: 23.65m**
	Bore hole caving unable to clear sand and cuttings		
26.0m	**END OF BOREHOLE MB1 AT 26.0m.**		

Drilling Log

Location:	Tonga tapu , Kingdom of TONGA	**Date Start:**	07/05/1997
Site:	Adjacent to well 105 Mataki'eua	**Date Finish:**	10/05/1997
Borehole No:	**MB 2**	**Drilling Rig :**	Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:**	Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m - 2.1m : SILTY CLAY (CH) :** Stiff to very stiff, brown dark brown, m/c greater than plastic limit, with trace ash and plant material.		
2.0m	**2.1m - 4.6m : LIMESTONE :** Highly weathered, slightly fractured, brown and cream, low strength.		
4.0m	**4.6m - 6.0m : LIMESTONE :** Highly to moderately weathered, slightly fractured, cream, low to medium strength.		
6.0m	**6.0m - 12.4m : LIMESTONE :** Slightly to moderately weathered, cream, medium to high strength.		
8.0m			
10.0m			
12.0m	**12.4m - 21.1m : LIMESTONE :** Highly to moderately weathered, moderately fractured, cream, low to medium strength, with minor sand lenses, moderate mud loss.		
14.0m		SWL	
16.0m		14.8m	
		8/05/97	
18.0m			
20.0m	**21.1m - 25.0m : LIMESTONE :** Slightly to moderately weathered, highly fractured, cream, high strength, high mud loss.		
22.0m			
24.00m	**END OF BOREHOLE MB2 AT 26.0m.**		
26.0m	**Note: Massive mud loss at 24.5m and 25.0m after grouting at 24.5, and 25.0m VOIDAL. Borehole abandoned due to supply of drilling fluids**		

Drilling Log

Location:	Tonga tapu , Kingdom of TONGA	**Date Start:**	25/11/1996
Site:	Adjacent to well 116, Mataki'eua	**Date Finish:**	29/11/1996
Borehole No:	**MB 3**	**Drilling Rig :**	Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:**	Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m - 2.1m : SILTY CLAY (CH) :** Stiff to very stiff, highly plastic, brown dark brown, m/c greater than plastic limit.		
2.0m	**2.1m - 7.2m : LIMESTONE :** Highly weathered, highly fractured, brown and cream, low strength.		
4.0m	Cream below 3.5m		
6.0m	**7.2m - 12.3m : LIMESTONE :** Highly to moderately weathered, moderately to highly fractured, cream, medium to		
8.0m	low strength.		
10.0m	Becoming moderately weathered below 10.m		
12.0m	**12.3m - 18.7m : LIMESTONE :** Slightly to moderately weathered, moderately fractured, cream, medium to high strength, medium mud loss.	SWL 12.0m 0900hrs 26/11/96	**M7: 13.0m**
14.0m			**M6: 14.5m**
16.0m			**M5: 17.0m**
18.0m	**18.7m - 22.3m : LIMESTONE :** Moderately weathered,		
20.0m	slightly fractured, cream, medium strength.		
22.0m			**M4: 22.0m**
24.0m	**22.3m - 30.3m : LIMESTONE :** Moderately to slightly weathered, slightly fractured, cream, medium to high strength.		
26.0m			
28.0m			**M3: 27.0m**
30.0m	**30.3 m - 36.5m : LIMESTONE :** Slightly weathered, slightly fractured, cream, high strength.		
32.0m			**M2: 32.0m**
34.0m			**M1: 35.5m**
36.0m	**END OF BOREHOLE MB 3 AT 36.5m**		
38.0m			

Drilling Log

Location:	Tonga tapu , Kingdom of TONGA	**Date Start:**	16/04/1997
Site:	Adjacent to well 116, Mataki'eua	**Date Finish:**	21/04/1997
Borehole No:	**MB 4**	**Drilling Rig :**	Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:**	Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m - 2.3m : SILTY CLAY (CH) :** Stiff to very stiff, brown to dark brown, m/c greater than plastic limit with trace organic material and ash to 1.3m.		
2.0m	with trace limestone gravel below 2.0m **2.3m - 7.0m : LIMESTONE :** Highly weathered, highly fractured, pale cream, low strength, loss of drilling fluid at 2.8m.		
4.0m			
6.0m			
8.0m	**7.0m - 9.0m : LIMESTONE :** Moderately to highly weathered, moderately fractured, cream, low strength, with some minor sand lenses.		
10.0m	**9.0m - 10.0m : LIMESTONE :** Slightly to moderately weathered, lightly fractured, cream, medium to high strength.	SWL 11.3m 0900rs 19/04/97	
12.0m	**10.0m - 21.2m : LIMESTONE :** AS Above		
14.0m			**M6: 15.7m**
16.0m			
18.0m			**M5: 18.6m**
20.0m			
22.0m	**21.2m -29.4m : SANDY GRAVEL / GRAVELLY SAND :** Fine to medium grained, loose to medium dense, cream, severe fluid loss at 27.5m. (unconsolidated coral sands and gravels)		**M4: 23.2m**
24.0m			
26.0m			**M3: 27.9m**
28.0m			
30.0m	**29.4m - 32.1m : LIMESTONE :** Highly weathered, highly fractured, cream, low strength, with some sand and gravel lenses.		**M2: 30.8m**
32.0m	**32.1m - 38.0m : LIMESTONE :** Slightly weathered slightly to moderately fractured, cream, medium to high strength.		
34.0m			**M1: 34.1m**
36.0m	Borehole caving slightly.		
38.0m	**END OF BOREHOLE MB4 AT 38.0m**		

Drilling Log

Location:	Tonga tapu , Kingdom of TONGA	**Date Start:**	29/04/1997
Site:	Adjacent to well 129, Tongamai	**Date Finish:**	30/04/1997
Borehole No:	**MB 5**	**Drilling Rig :**	Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:**	Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m - 2.1m : SILTY CLAY (CH) :** Stiff to very stiff, highly plastic, brown dark brown, m/c greater than plastic limit becoming pale brown with some limestone gravel below 1.4m.		
2.0m	**2.1m - 7.4m : SANDY GRAVEL/GRAVELLY SAND:** Fine to coarse grained, medium dense slightly cemented in areas, cream, low mud loss.		
4.0m			
6.0m	**7.4m - 13.5m : LIMESTONE :** Moderately to highly weathered, slightly fractured, cream, low strength, low to		
8.0m	medium mud loss.		
10.0m		SWL 11.3m 0900rs 19/04/97	
12.0m			**M6: 10.4m**
14.0m	**13.5m - 14.5m : LIMESTONE :** Highly to completely weathered, cream, low strength, with unconsolidated sand lenses.		**M5: 13.0m**
16.0m	**14.5m - 21.2m : LIMESTONE :** Moderately weathered, moderately fractured, cream, low to medium strength. minimal mud loss, hard to clear cuttings.		**M4: 17.9m**
18.0m			
20.0m	**21.2m - 29.6m : LIMESTONE :** Highly weathered,		
22.0m	moderately fractured, cream and pale brown, low strength, with some sand lenses.		**M3: 22.9m**
24.0m			
26.0m			**M2: 27.4m**
28.0m			
30.0m	**29.6m - 34.0m : LIMESTONE :** Moderately to slightly weathered , slightly to moderately fractured, cream, high strength.		
32.0m	Mud being attacked by groundwater require large amounts to condition mud to lift cuttings.		**M1: 31.8m**
34.0m	**END OF BOREHOLE MB5 AT 34.0m**		
36.0m			

Drilling Log

Location:	Tonga tapu , Kingdom of TONGA	**Date Start:**	2/05/1997
Site:	On north side of ramp base of Fuala quarry	**Date Finish:**	4/05/1997
Borehole No:	MB 6	**Drilling Rig :**	Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:**	Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m - 3.3m : LIMESTONE :** Moderately to slightly weathered, Highly fractured, cream, medium to high strength. Massive fluid loss to stratum at 0.6m and 2.4m. Grout in lockable casing.	SWL 1.3m 1000rs	
2.0m		03/05/97	
4.0m	**3.3m - 6.0m : LIMESTONE :** Moderately weathered, moderately fractured, cream, medium strength. Minor fluid loss Some sand lenses below 4.8m		**M6: 3.8m**
6.0m	**6.0m - 8.6m : LIMESTONE :** Highly to completely weathered, slightly to moderately weathered, cream, low strength, minimal fluid loss.		**M5: 6.4m**
8.0m	**8.6m - 16.2m : LIMESTONE :** Moderately weathered, moderately fractured, cream, medium strength, moderate fluid loss.		
10.0m			**M4: 10.9m**
12.0m			
14.0m			**M3: 15.4m**
16.0m	**16.2m - 24.6m : LIMESTONE :** Highly to moderately weathered moderately fractured, cream, low to medium strength.		
18.0m			
20.0m			**M2: 20.9m**
22.0m			
24.0m	**24.6m - 29.5m : LIMESTONE :** Moderately weathered slightly to moderately fractured, cream, medium strength		
26.0m	with some minor sand lenses.		
28.0m			**M1: 28.5m**
	END OF BOREHOLE MB5 AT 29.5m		
30.0m			

Drilling Log

Location:	Tonga tapu , Kingdom of TONGA	**Date Start:**	26/04/1997
Site:	Approx 150m south of Hihifo Rd in wellfield 1	**Date Finish:**	28/04/1997
Borehole No:	**MB 7**	**Drilling Rig :**	Walkerwell ASW286
Driller:	Taniela Heimuli	**Drill Method:**	Wash Boring
Assistants:	Sione Saipa'ia, Himuiti Fuimaous		

Depth (m)	Material (Lithology)	Other Tests	Monitors (m bgl)
0.0m	**0.0m - 3.4m : SILTY CLAY (CH) :** Stiff to very stiff, highly plastic, brown dark brown, with trace ash, m/c greater than plastic limit.		
2.0m		SWL 3.0m 28/04/97	
4.0m	**3.4m -8.8m : LIMESTONE :** Highly to completely weathered, moderately fractured, pale brown, low strength, with some sand lenses. **Becoming cream below 4.6m**		
6.0m			
8.0m	**8.8m - 12.3m : LIMESTONE :** Moderately to highly weathered, moderately fractured, cream, with sand 20 to 50mm thick, low strength.		
10.0m			**M6: 10.5m**
12.0m	**12.3m - 16.2m : LIMESTONE :** Moderately to slightly		**M5: 12.8m**
14.0m	weathered, slightly to moderately fractured, cream, medium to high strength.		
16.0m	**16.2m - 22.5m : LIMESTONE :** Highly to moderately weathered, moderately to highly fractured, cream, medium to		**M4: 16.6m**
18.0m	low strength, fluid loss throughout.		
20.0m			
22.0m	**22.5m - 26.8m : LIMESTONE :** As Above with some unconsolidated sand lenses up to 200mm thick.		**M3: 22.7m**
24.0m	hard to cleat hole of cuttings (caving slightly)		
26.0m	**26.8m - 34.2m : LIMESTONE :** Highly weathered,		**M2: 27.1m**
28.0m	moderately fractured, cream, low strength, Fluid loss hard to control.		
30.0m			
32.0m			**M1: 32.3m**
34.0m	**END OF BOREHOLE MB7 AT 34.2m**		
36.0m			

Annex D

Borehole Monitor Table

Bore Hole Number	Height of Standpipe above ground level	Total Depth of Monitor Below Top of Casing						
		Monitor No 1	**Monitor No 2**	**Monitor No 3**	**Monitor No 4**	**Monitor No 5**	**Monitor No 6**	**Monitor No 7**
MB 1	+ 950mm	24.6m	22.0m	17.0m	11.5m	9.4m		
MB 2	**NOT COMPLETED**							
MB 3	+ 1.0m	36.5m	33.0m	28.0m	23.0m	18.0m	15.5m	14.0m
MB 4	+ 870mm	35.2m	31.7m	28.8m	24.1m	19.5m	16.6m	
MB 5	+ 900 mm	32.7m	28.3m	23.8m	18.8m	13.9m	11.3m	
MB 6	+ 700mm	29.2m	21.6m	16.1m	11.6m	7.1m	4.5m	
MB 7	+ 900mm	33.2m	28.0m	23.6m	17.5m	13.7m	11.4m	

Annex E

Daily Diary, Visit 1

22 November - 3 December 1996

Fri 22 November
- 1100-2300: fly from Melbourne for Tonga via NZ
- 2300: meet Lindsay Furness

Sat 23 November
- meet Roger Dickson
- day off to see Tongatapu

Sun 24 November
- day off: Fafa island

Mon 25 November
- inspect drill sites at 0730.
- to Ministry of Works (MOW) at 0800: inspect rig and meet personnel.
- establish rig on site at MB3 (near PS115). Tractor U/S. Pump clutch is also U/s.
- drill to approx. 10 m. Pump suction valve broken. Remove and send to MOW workshop for manufacture. Should be back drilling tomorrow.

Tue 26 November
- to MOW at 0800. Pick up new suction valve: good workmanship.
- arrive on site at 0915. Start up rig and reassemble pump. Start drilling: had to adjust clutch on pump 3 times - slipping badly. New thrust bearing required.
- drill to 22 metres. Limestone (seawater?) attacking polymer mud.
- send water tank for refill at 1500 due to power failure and low level in tanks on site. Tanker orders to town to refill by TWB.

Wed 27 November
- 0800: speak to Chris, workshop manager, at MOW re trying to find new thrust bearing. After extensive search - no go.
- speak to welder regarding protective caps.
- start drilling: drill to approx 32 m. Pump: slipping clutch problems with drill string sealing - not much can be done. Pump clutch out of adjustment decide to weld the clutch with straps.
- assembled PVC tubes for first installation - hopefully tomorrow.

Thur 28 November
- arrive MOW at 0745.
- organise welder to go on site. Weld up clutch: seems to work.
- continue drilling to 39 m
- flush mud from borehole with water at end.
- withdraw drill string. Cuttings present in borehole and bottom is 1.5 m short: decided to install at that depth.
- installed remainder of monitors.
- moved rig to next borehole (BH2): end at 1630.

Fri 29 November
- arrive MOW at 0800. Check on water truck and fuel. Good start.

- drillers have to be back at yard at 1500 for party for Chris.
- drill to 24 m at BH2. Pump broke down: welded bars on clutch broke.
- return to yard to organise welder for Monday.
- transport steel standpipe to MB3 site: will concrete the steel standpipe at first (MB3) borehole tomorrow.
- met Brian McKenzie, Royco regarding quarry site borehole (MB6): agreed to meet on site a day or so before to locate exact position.

Sat 30 November
- meet drillers on site at 0830
- transport protective cover and install. Work to 1200.

Sun 1 December
- day off

Mon 2 December
- to MOW at 0800: see Kupa regarding welder. He decides clutch needs proper repair. Fair enough.
- go to drill site (MB2) and pick up rig
- return to MOW yard. Remove and pull down clutch.
- contact Walker Engineering, Victoria (manufacturer of rig) re necessary repairs to clutch assembly.
- inform David Salomon and Tony Falkland of situation: decided to return on next available flight owing to the situation. Can get flight tomorrow.

Tue 3 December
- leave Tonga; fly via Auckland to Melbourne.

Annex F

Daily Diary, Visit 2

15 April - 14 May 1997

Tue 15 April

- Fly Sydney NZ100 to Auckland. Fly Auckland NZ35 to Tongatapu.
- Met by David Solomon at Airport. Will go directly to MOW Workshop and meet drillers in morning

Wed 16 April

- Leave TWB House at 8.00am and meet Kupa (Workshop manager, MOW) at 8.30am. Organize Drilling Rig and crew, water tanker for approx. lunch time
- Inspect drill sites at Mataki'eua. Wet and Slippery
- Meet with David Solomon at 9.15am. Go through MOW billing from last trip and approve.
- Locate drilling supplies and consumables
- David Solomon requests a status report on the MOW (Walkerwell) Drilling Rig before large scale production program on outer islands is undertaken.
- Rig and personnel ready 11.00am. Leave for MB4 adjacent to Pump station 116.
- Rig and tractor cannot travel on track inside Bore Farm. We have to cut fence on roadway adjacent to MB4 to west.
- Set up rig and adjust pump clutch in operating position drill to 10m.
- Site visit by David Solomon
- Notice tear in flex coupling rubber. Partially remove (need 14mm open end spanner, not on rig) and find spare in MOW workshop LUCKY.
- Will complete refit in morning.
- Try to arrange longer working hours for drill crew. David Solomon and Kupa to organize hopefully
- Rig time 11.00am -3.30pm. Down time 3.30pm - 4.30pm.

Thur 17 April

- Leave house 8.15am arrive MOW yard 8.30am. Pick up drill crew and tools and leave for site.
- Remove torn flex coupling and fit spare, tricky with lack of tools on rig but get there.
- Commence drilling at 10.30am. Drill to 16 meters.
- Shaft in drill head shears. Loose all head torque. Pull back 6 meters and effect repairs.
- Pull head cover off. Shaft below hydraulic motor sheared. Had been previously welded.
- Go to MOW workshop and organize welder with Kupa
- Go to quarry and pick up welder, tow to near airport and decide to get tractor to pick up due to tow hitch on car and tow ring on welder incompatible. Tractor goes to pick up welder but runs out of fuel. MOW organize fuel and welder arrives on site at 4.00pm. Effect repairs.
- New Shaft Required. ENTIRE DRILL HEAD NEEDS OVERHAUL. All visible bearings and seals need replacement.
- Leave site at 4.45pm
- Inform David Solomon of situation at approx 1.30pm
- Overtime has been organized will see Kupa in morning
- Rig time 10.30am - 11.30am. Down time 8.30am - 10.30am, 11.30am - 4.45pm.

Fri 18 April

- Leave house 8.15am arrive, MOW yard 8.30am

- See Kupa regarding over time for drill crew. MOW to pay O/T and bill TWB
- Arrive site 9.00am and replace guard on drill head
- Start drilling at 9.30am
- Drill to 24 meters, out of water send water truck for refill
- Run drill crew back to MOW yard to pick up pay and lunch
- See David Solomon regarding supply of 32mm PVC standpipes rather than 25mm. David to chase up local supply.
- Purchase garden hose for extra water from pump stations
- Pick up drill crew at 1.15pm and return to site
- Commence drilling at 1.30pm. Bit blocks with rust at 26 meters, trip out and clear, drill crew directed to try and de-scale rods before placing them in drill string. (drill string in BAD condition).
- Trip in, lose water pressure, partial bit blockage and pump not building pressure
- Rod sticks with suspended cuttings falling back and unstable bore hole wall from 21 meters
- Free rod by surging LUCKY
- Trip out and unblock bit
- Pull down pump. One Valve stuck
- Return to MOW workshop to get hook nose circlip pliers to effect repairs.
- Knock drill crew off at 4.30pm and return to drill site to free stuck valve
- Valve is bronze i.e. the valves, valve seats and valve springs have not been replaced as requested on my last trip. The current valves were only a stop gap solution to the problems encountered on the last trip. The current valves tend to bell at the face where they contact the valve seat and cause the valves to stick. Hope drill crew have kept spare bronze valves manufactured last trip. WHAT A DAY
- Drill time 9.30am - 3.00pm. Down time 8.30am - 9.30am, 3.00pm - 4.30pm.

Sat 19 April

- Leave house at 7.45am arrive MOW yard at 8.00am, pick up drill crew and leave for site.
- Find spare valve. Pull all valves and check (fair). Replace stuck valve
- Start drilling at 9.30am
- Bore hole has collapsed to 24.2 meters. Mud up and redrill
- Pump working OK, reach 27.5 meters. Holding bolt on top of water swivel lets go mud everywhere
- Pull back 6 meters an effect repair 15 minutes. Pump working OK went off with a bang
- Bore caving to 25 meters. Mud up and redrill
- Drill to 28 meters loose circulation completely. Pull back and mud right up, unable to regain circulation. (Oh for some casing!). It appears to be a combination of the stratigraphy being loose to medium dense fine to medium grained sands and gravels and the inability of the drilling fluid to stabilize this formation.
- It was decided to cement grout the base of the bore hole and attempt to regain circulation using a bentonite plug in this formation.
- Finish grouting and drop drill crew at there villages
- Drill time 9.30am - 12.30am. Down time 8.00am - 9.30am.

Sun 20 April

- Sleep in, do diary

Mon 21 April

- Leave house 8.15am arrive MOW workshop 8.30am. See Kupa regarding bentonite powder
- See Sioeli (foreman driller MOW) if any other techniques are used locally in this situation? Negative and wishes ourselves good luck.
- Pick up Bentonite and Guar Gum from storeman and leave for site at 9.00am

- Arrive site at 9.30am and mud up with bentonite and guar gum bore hole grouted to 20.5meteres
- Proceed to re drill caving formations, reach 29 meters with minimal loss of drilling fluids.
- Drill to 32 meters using bentonite then switch back to Polymer mud.
- Drill to 38 meters (Got There!).
- Bore seems to be caving slightly. Mud right up. Am unsure what will happen once bit is removed. Possibly cave back to 20 odd meters. TRIP OUT.
- Bore hole caved slightly, to 36 meters. Decide to install Base standpipe at this Depth.
- Must clear MUD from borehole but fear further caving. Decide to place standpipe to depth and then trip into the hole with smaller bit on string (carefully). Works well enough.
- Attempt to backfill borehole to next Bentonite seal depth but not enough back fill sand left.
- Will see David Solomon and organize
- Decide to hang standpipes to 24 meters and tie them in position just in case of major caving overnight.
- Go back to MOW yard pick up tanker driver and drive crew home (Last bus has left)
- Return to TWB house and inform David Solomon of situation. Will organize more back fill in morning.
- At last some PVC in the ground.
- Down time 8.30 am - 9.00am. Drill time 9.00am - 5.30pm (no lunch)

Tue 22 April

- Leave house 8.15am arrive MOW workshop 8.30am see drill crew and request tractor for towage of drill rig
- See David Solomon regarding back fill material, suggests to see Kupa and to if MOW will supply
- See Kupa he suggests that TWB supply as it is their site.
- Go to supplier and determine price.
- Return to David and am given funds to purchase the back fill and also organizes for its pick up and delivery.
- Go to Dept. of Lands and Survey to pay for material and receive order form to give to workers at stockpile.
- Return to TWB office give David receipt and change and thought I had organized the truck driver to pick up the back fill and deliver it to site.
- Return to drill site where drill crew are packing up all equipment not essential in the continuation of the monitoring process.
- Use what back fill was left from the previous day and wait for truck!
- Raining since this morning. Give it twenty minutes and decide to look for truck.
- Go to material supplier had not been sighted there, go to TWB store and speak to storeman, wires crossed somewhere, he organizes immediate pick up and delivery but decide to follow anyway
- Pick up what is considered sufficient and return to site.
- Place remaining standpipes in position. Note: unable to position last standpipe due to tightness in bore hole
- Bring back fill to within a couple of meters of and decide to let bore hole settle down before installing the lockable cover.
- Finish packing rig and move to next borehole
- Had previously inspected site and was deemed suitable for access by the rig and not favourable at the time the rig would be reversed out and another of the drilling sites would be employed !!
- Tractor lost traction within a few meters of the site and it was decided to reverse and either try again or move to another site.

- Whilst reversing the trailer mounted drilling rig became bogged. We're stuck!
- After several attempts at freeing the trailer it was obvious that our efforts were futile with the equipment that we had available.
- Return with tractor to MOW workshop and organize with Kupa to get the tractor and Backhoe up there first thing in the morning.
- Inform David Solomon of situation.
- Still Raining
- Rig Time no drilling but rig required over hole till monitoring completed.

Wed 23 April

- Left house 8:15am arrive MOW yard 8:30am. See Kupa regarding Backhoe to help extract rig from bog.
- Kupa organizes Backhoe as soon as operator can be found.
- Leave MOW yard 9"00am with Backhoe and tractor for Mataki'eua to pull rig to new location MB1
- After considerable pulling, pushing and bush clearing the rig is moved to the roadway
- The Backhoe also cleared an area for the drilling rig at MB 1
- Sent tractor and Backhoe to MOW and requested the water tanker be sent to site whilst we set the rig up.
- Set rig up and water tanker arrived.
- Drilled to 20 meters without too many problems, only had to strip pump once and clear bit twice.
- At last a fair day
- Rig Time 10:00am - 5:30pm. Downtime 8:30am - 10:00am

Thur 24 April

- Leave house 8:00am arrive MOW yard at 8:15am.
- Organize drill crew and see Kupa regarding drill crew overtime. All OK for ANZAC day and Saturday.
- Saw David Solomon regarding getting some more 32mm PVC pipe out onto site. Not a problem.
- Went back to MOW yard everything ready. Left the site at 9:00am.
- Arrive site and drill to 26 meters. Getting severe fluid loss below 21 meters due to stratum and water salinity attacking polymer mud.
- Tried a little Bentonite but only flocculates in the saline fluid.
- Unable to clear cutting from base of borehole! Pump valve sticking.
- Decide to pull back 9 meters and pull pump down. One valve on suction side badly belled. Will take back to MOW yard and grind back into shape over lunch time. Also send water tanker back to yard to refill.
- Check water tanker is ready and return back to site.
- Wash pump out and replace ground valve. Seems to work well.
- Clean out mud tanks and mud up.
- Run bit to base of borehole, fair return but not many cuttings coming to surface.
- Loosing a significant amount of drilling fluid even though it is as thick as ....
- Decide to place 500ml of polymer mud directly into drill stem, to see if we can lift cuttings. Very limited success, saline water attacking mud, can't get enough annular velocity.
- Trip out and see how deep hole ends up.
- Borehole ends up at 24.6 meters. Will install first monitor at that depth.
- Storeman has not delivered PVC at this stage. Will chase up.
- On way to TWB office met David Solomon who explains there has been a stuff up with the supplier but it will be delivered directly.

- Return to drill site the pipe has been delivered. Pickup some more packing sand and return to drill site
- Install monitors to 12 meters, will complete monitoring operation in morning.
- Rig time 8.30am - 5.30pm. Down time Negligible

Fri 25 April

- Attend dawn ANZAC day service at Aust. High Comm.
- Leave house 7.45am arrive MOW yard 8.00am. Pick up drill crew water tanker and tractor and leave for site.
- Arrive site and complete monitoring in MB1.
- Place lockable steel casing over and pack up rig.
- Move rig to MB7 and set up.
- Drill to 5.4 meters and have massive fluid loss. Try to control with Bentonite but useless
- Site visit by Doug and Ray, they bring lunch. Have lunch and discuss condition of rig.
- Decide to Grout bore hole. Mix 2 bags of cement and place at base of bore hole.
- Grout extending up bore hole 1.3 meters from base. Should seal. Redrill tomorrow.
- Send tractor back straight after lunch and water tanker back as soon as grouting operation was completed and wash up finished approx. 3.00pm
- Return to MB4 finish off backfilling, final 2 meters from surface and place lockable casing over standpipes. Box out for concreting. Unable to concrete at this stage as protective pipes are still in storage
- Return to MB1 and box out ready for concreting.
- Rig time 8.00 am to 1.00pm. Drill crew 8.00am to 4.30pm

Sat 26 April

- Leave house 8.15 arrive MOW at 8.30. Leave for site with drill crew water tanker and tractor (just in case)
- Arrive site set up, mud up, depth of bore hole at 4.2 meters.
- Re drill to 5.4 meters grout works! Continue drilling reach 6.2 meters and have another massive fluid loss, decide to cut losses and move.
- Moved west approx. 100 meters and set up again.
- Drill crew show concern that we may not be on the same land owners property.
- Go and see original landowner and he travels back to site with me to look at the positioning first hand. The drilling rig is still positioned on his land every thing OK.
- Drill to 20.6 meters with some fluid loss at approx 6 meters, mud up and continue.
- Hose from mud pump to mud mixer splits mud everywhere
- Send water tank back for refill and go to MOW workshop to use vice to repair hose.
- Rig time: 8.30am - 4.00.pm. Water tanker: all day Tractor: 8.30am to 1.00pm.

Sun 27 April

- Day off. Sleep in. Relax

Mon 28 April

- Left house 8.00am arrive MOW yard 8.15am. Organize drill crew water tanker and mud
- Leave for site 8.45am
- Arrive site, greased rig, cleaned mud tank mudded up and drilled to 30 meters. (borehole had collapsed to 14.5 meters).
- Valve sticking again in mud pump, pull mud pump down and replace with spare.
- Return grease gun to MOW workshop and grind valve as spare again.
- Drill to 34 meters (significant fluid loss in areas, could only control with mixture of polymer and bentonite).
- Reach target depth and flush with fresh water to remove mud.

- Go to TWB yard at Mataki'eua and collect remaining 50mm PVC pipe and transport to drill site.
- Collect rest of backfill and transport to drill site.
- Install monitors to 12 meters (all going well)
- Packing up, ask water tanker to return to yard!!! Water tanker bogged AHHH! Unable to free, need assistance
- Return to MOW yard and ask Fui (licensed to operate tractor) and watchman if the tractor could be used to extricate the truck from the bog.
- The watchman is unable to give OK without written permission from the plant foreman.
- Go to plant Supervisor house and gain written permission. Return to MOW yard and gain access to tractor.
- Return to drill site and extract truck from bog.
- Pack up and drive drill crew home after returning water tanker and tractor to MOW yard.
- Drill time 8.30am to 6.30pm.

Tue 29 April

- Leave house 8.00am arrive MOW 8.15am and organize drill crew, water tanker and tractor. Leave for site.
- Arrive site and install last monitor after going to get more backfill from MB2.
- Pack up and move to MB6.
- Set up at MB6 and commence drilling.
- Go to E.M.Jones store and find supply of 32 mm waste PVC pipe.
- Go to TWB and inform Roger Dickson of the supplier and ask that this info could be passed onto David Solomon.
- Return to drill site drill crew have drilled to 6 meters.(no problems)
- Drill to 20 meters. WAY TO GO.
- Drill time 10.00am - 5.30pm. Down time 8.30am - 10.00pm

Wed 30 April

- Leave house 7.45 am arrive MOW yard 8.00 am. Fill water tanker and organize drill crew, fuel etc
- Drop project lap top computer off at water board office and return to MOW yard.
- Drill crew ready, see Kupa and deliver cheque for first two weeks drilling. Went through account everything OK.
- Arrive at drill site MB6 and clean out mud tanks and commence drilling. The borehole had caved slightly overnight to 18.5 meters.
- Redrilled to 20 meters and continued
- Previous night David Solomon had given me a cheque to purchase 32mm PVC waste pipe.
- Went to bank and cashed cheque, went to E.M.Jones and purchased pipe only organizing TWB truck to transport it to Mataki'eua.
- Found check valve small enough to fit inside 32mm PVC pipe now all I need is some 1/2" or 3/4" tubing suitable.
- Had to go through the purchasing of more backfill again.
- Returned to drill site. Drill crew had advanced bore to 30 meters having some difficulty with maintaining circulation. Pump slipping slightly and mud breaking down,
- Hard to clear hole of cuttings. Had to use an excessive amount to clear them.
- Found connecting adaptor for sampler and gave it a go using garden hose as rising tube. Got some water out but a semi-rigid tube would be a lot better. Will try and purchase when get a chance.
- Go and see Manager ROYCO batching plant and organize site visit for 7.30am tomorrow.

Thur 1 May

- Leave house 7.15am arrive ROYCO office and travel to quarry and pick suitable site.
- Leave quarry and travel back to ROYCO office. Arrive MOW yard at 8.00am and organize drill crew.
- Arrive site and check pump, mud up and continue drilling.
- Formation had caved slightly, redrill and continue to 34 meters.
- Finding it very hard to maintain annular velocity, salinity attacking drilling fluid
- Finally achieve target depth but have had to use an excessive amount of polymer mud.
- Clear bore hole of drilling fluid and install monitors.
- Speak to Kupa regarding overtime for drill crew for Saturday and Monday. All OK.
- Drill time: 8.30 - 4.30

Fri 2 May

- Leave house 7.45am arrive MOW yard 8.00am organize water truck and tractor.
- Arrive drill site and install lockable steel casing.
- Pack up rig and leave for quarry site MB6.
- Arrive quarry site and enter have to use water tanker as brake for trailer mounted drilling rig slope for entry to quarry quite steep.
- Run drill crew back to MOW yard at lunchtime to pick up their pay.
- Set up rig. Rock at surface, have to grout mud tank to surface to enable fluid return.
- Grout mud tank with cement and bentonite grout, go to ROYCO batching plant and gain access to quarry for Saturday and Monday (public holiday)
- Unable to locate steel cut to size, last trip, for protective barriers fore bore holes, speak to storeman and am able to use 100 mm scrap PVC pipe. (will suffice).
- Concrete MB1 and leave for home.

Sat 3 May

- Leave house 7.45am arrive MOW yard 8.00am and organize water tanker and drill crew when they arrived not to bad especially after a PAY DAY.
- Arrive quarry and set up and mud up drill past grouted section and loose circulation
- Try to mud up but cannot be controlled
- Loose circulation completely but drill on to 3.5 meters. Grout at this stage and hopefully this will solve circulation problems.
- Strip pump down to check valves, the are not sealing. So remove to grind at a later stage.
- Leave drill site and organize gear to concrete up MB5.
- Go to TWB at Mataki'eua and cut 100 mm PVC pipe for guards.
- Deliver this to MB5 and concrete
- Return to MOW yard and gain permission from the watchman to gain access to workshop and so their bench grinder and grind pump valves.
- Drill time 8.30 - 9.30. Water tanker all day

Sun 4 May

- Day off, go to Pangimotu

Mon 5 May

- Leave house 7.45 am arrive MOW yard 8.00am. Organize drill crew and leave for site.
- Arrive site and mud up drill past grouted section and proceed.
- Every thing OK
- Drill to 29 meters without any hassle.
- Flush borehole with fresh water and trip out.
- Send Fui to Mataki'eua to pick up residual PVC pipe

- Unable to obtain bentonite pellets from main store at TWB so installed 1st monitor and leave it at that.
- Drill time 8.30.- 4.00

Tue 6 May

- Leave house 7.00am and deliver key for quarry back to manager ROYCO batching plant and return to house.
- Leave house 7.45 am, arrive MOW yard 8.00 am. Weather TERRIBLE. Rain and wind, tropical depression off Fiji.
- Organize drill crew and make sure water tanker filled. Organize tractor and backhoe for after lunch, organize to see Kupa to OK plant before lunch.
- Go to drill site and install monitors. Still raining ,drill crew not enjoying their days work!!
- Stop for lunch and dry off.
- Return to MOW yard just before lunch and make sure the plant will be on site just after lunch.
- Kupa said if plant had not arrived by 2.00pm to come and organize something.
- Still raining!!! Doubt whether the track will be passable even with the 4*4 backhoe at our disposal.
- Goes 2.15pm and decide to go to MOW yard and see what has happened to the backhoe.
- Arrive MOW yard and hardly any person to be seen, gleen from plant supervisor that operator thought that it was too wet to work (Fair call)
- No backhoe for this afternoon so not much will be accomplished
- Return to drill site and finish packing up
- Drill time:1.00hr to lay mast down and pack gear. Pay labour to 4.30pm

Wed 7 May

- Leave house 7.45am, arrive MOW yard 8.00am. Organize water tanker, tractor and backhoe.
- Leave MOW yard and proceed to Quarry site to remove rig.
- Gate locked at 9.15am. Return to ROYCO office and get key from batching plant manager, agree to drop key with bulldozer driver in quarry.
- Return to quarry open gate and remove rig, need backhoe to push rig up ramp. STILL RAINING.
- Travel to MB2. Slippery as all get out but the rig up there. Takes quite a bit to manoeuvring rig over old bore hole but with some pushing and pulling with the backhoe finally get there
- Set up, mud up. Borehole is open to 24.6 meters.
- Drill to 27.4 meters. Massive mud loss.
- Trip out and grout base of bore hole.
- Have to go and buy 10 bags of cement, none left of old supply.
- Finish grouting MB2 return to quarry to cement MB6. Decide not to place concrete base and bollards as there is exposed lime stone at surface at this location security for the stand pipe which has been concreted to the surface rock will be provided by the placement of large limestone boulders around the borehole.
- Drill time 11.00am - 3.00pm. Drill crew pay to 4.30 pm.

Thur 8 May

- Leave house 7.45am arrive MOW yard 8.00am. Check water tanker, drill crew, pick up more bentonite and see Kupa and give him cheque for last invoice.
- Arrive drill site, set up mud up.
- Drill past grouted base of borehole - looks good! Advance borehole another 1.25 meters and another huge mud loss (spoke too soon!!). Decide to cut losses and move borehole as a substantial void is evident in that the drill string could be advanced an additional 500mm

where the loss was first encountered. (casing please).

- Move borehole 20 meters to the East. Other side of pump station.
- Have to return to MOW yard and organize tractor
- Follow tractor back to site where drill crew have packed up and waiting.
- Go to TWB store and find there is a considerable length of 3/4" high density poly pipe that would be suitable as a sampling tube if I can attach it adequately to the 3/4" check valve.
- Move rig and set up again. Rig is at a slightly lower R/L estimated at approx 1.3 meters.
- Similar over burden profile to original hole
- Drill to 24 meters. No problems. Getting some loss as borehole is advance slowly
- Massive fluid toss at 24.5 meters
- Grout borehole base will see how we go in the morning
- Inform David Solomon and Ray Cameron of situation. Will see how we go in the morning.
- Drill time: 9.00am - 4.00pm

Fri 9 May

- Leave house 7.45 am arrive MOW yard 8.00am. Organise water tanker drill crew more bentonite and see Kupa regarding overtime on Saturday for drill crew.
- Arrive drill site and set up and mud up again.
- Drill to 24.5 meters and continue site visit by guys from Kinhill construction. Give them run down of what was going on.
- Drill to 25 meters an again a massive mud loss. The guys from Kinhills quite impressed, wish me luck and depart.
- It's Decision Time. Go to see David Solomon to inform him of situation. Arrive TWB office and was informed that he had gone to Mataki'eua. Return to drill site and David arrives.
- Discuss situation with David and it is decided that considering the limited amount of polymer drilling mud left (approx 2.5 litres), that one more attempt at grouting the base of the borehole will be attempted. If unsuccessful, the borehole will be abandoned and we will move to the first of the production holes
- Grout base of bore hole and pack up gear for tomorrow. Raining again.
- Find more timber for formwork and finally concrete off the last of the protective concrete pads.
- Drill time: 9.00am - 11.00am. Pay drill crew to 4.30pm.

Sat 10 May

- Leave house 7.45am arrive MOW yard 8.00am. Organise water truck, tractor and drill crew.
- Arrive drill site and set up, mud up and give it another go. Drill again to 25 meters and another massive loss.
- Bite the bullet and pull off. Pack up
- Will go to first production well site
- Should be interesting as there has been a lot of rain overnight but see how we go.
- Inside track is just passable! A couple of times have to unhook tractor to unbog water truck and likewise have to use water truck to assist drill rig to traverse some slippery patches but get there.
- Set up, mud up and commence drilling.
- Water table is measured at 13.0 meters from the abandoned well head. Borehole to be terminated at 3 meters into the existing water table that is total depth 16.0 meters.
- Drill 175mm bore hole to accommodate 150mm PVC bore casing
- Drill to 5.3 meters and experience fluid loss problems. Lose circulation completely but decide to drill blind to 6.0 meters then to grout.
- Grout borehole and secure for the day.
- Drill time: 9.00am - 4.00pm. Drill crew paid to 4.00pm.

Sun 11 May

- Get up late, do diary, start brief report to Ray Cameron, prepare some forms for Kutusi

Mon 12 May

- Leave house 7.45am, arrive MOW yard 8.00am, check on drill crew to see they have everything needed.
- Go to TWB office and check borehole design for production well with David Solomon.
- Return to MOW yard to make sure drill crew is aware of target depth and casing or borehole design all OK
- Return to TWB office and discuss with Kutusi the monitoring program as in means of extraction, importance of monitor development, system of sampling and supply of additional sampling equipment from Australia.
- Visited each monitor site with Kutusi and demonstrated the operation of the jiggler that had been made up.
- Also showed Kutusi MB3 where the use of an air lift system will have to be used
- Called in to see drill crew progressing nicely
- Returned to TWB office with Kutusi and gave him full set of keys for lockable caps
- Engraved borehole numbers and tagged remaining keys and left them with David Solomon.
- Returned to drill site of production bore which had reached target depth
- Cuttings had to clear flush as much as possible. Trying to use as little mud as possible.
- Leave 1 meter sump at base of screen and slot 2 meters as per Lindsay's instructions.
- Go to Air NZ to confirm flights have to pick up tickets at airport.
- Go to bank. Money from Marie has not arrived see Ray Cameron and get $100 petty cash advance.
- Return to drill site. Small amount of cuttings at base of borehole will clear in morning.
- Return to MOW office and see Kupa who gives me new invoice to complete monitoring.
- Go to house and clean vehicle
- Will go and say good bye to drill crew in morning

Tue 13 May

- Leave house 8.00am go to TWB office and drop rest of monitoring gear on Kutusi's desk
- Go to bank and pick up cash and return to pay Ray Cameron petty cash advance
- Go to MOW yard check on drill crew and say my good byes
- Return to house finish packing and leave for airport
- Exit Tonga
- Arrive Melbourne