DEMAND MANAGEMENT AND CONSERVATION INVESTIGATIONS ON THE ISLAND OF ‘EUA, KINGDOM OF TONGA

Ed Burke
SOPAC Technical Secretariat

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EXECUTIVE SUMMARY

The principle of water demand management and conservation is to assess existing water resources and distribution systems with the aim to optimise water demands, instead of developing new resources to increase the amount of water supplied. The elimination of 50% wastage within a system has the same result of increasing water supplied by 50%. Expected benefits are saving in operational costs by reducing borehole pumping, a more reliable water supply and improved environmental conditions.

The purpose of this study is to develop water demand management and conservation measures to reduce water losses and to improve the water supply system on ‘Eua. This study was requested by the Tonga Water Board.

The following demand management and conservation practices are recommended:

1. Carry out minimum night flow measurements with associated step testing to assess system losses and to identify likely areas of losses (SOPAC & TWB).

2. Repair all detected leaks and carry out minimum night flow testing again (TWB & SOPAC).

3. Campaign to fix leaks on customer side of system (i.e. leaky taps and toilets) (TWB & SOPAC).

4. Public awareness should be promoted with the public being advised of future TWB activities and given the opportunity to discuss proposals (TWB & SOPAC).

5. Install (or repair) water meters on (1) the 150mm main pipeline at the old meter location (2) on Fern Gully/Saoa’s 65mm pipeline near where it connects to the 150mm main, and (3) on the Ha’atu’a borehole pipeline. Data collected from daily reading of these meters will be used to assess water entering the water supply system (TWB).

6. TWB staff should be given the practical training and resources (equipment, tools, spare parts, fittings, and pipes) to enable them to operate and maintain the continuous and safe supply of water to its customers (TWB).

7. Both short term and long term planning is required to develop the water supply according to need and available resources (TWB & SOPAC).

8. The catchment areas that supply water for the Fern Gully and the cave sources should be protected against any activities that may adversely affect water quality and quantity (TWB).

The following conclusions and recommendations are made:

1. Development of full treatment for surface water and/or development of new groundwater wells, or a combination of both would be expensive and should be considered as long-term options.

2. Any opportunity to develop the groundwater resources should be taken to supplement surface water resources and as an emergency supply.

3. Immediate improvements to the water supply include (TWB):
   - Installation of automatic release air valves at high points of all pipelines to eliminate flow disruptions due to air locks.
   - Inspect Ana Pekepeka 150mm pipeline between the cave entrance and the Y-junction for damage and repair to get extra flow into the system to reduce borehole pumping.
   - Connect the Saoa Cave source to get extra flow into the system to reduce borehole pumping.
   - Isolate Fern Gully source from system during periods of heavy rainfall to reduce the amount of “dirty” water entering the system.

4. Data collection including pipe flows (combined 150mm pipe plus 65mm pipe from Fern Gully and Saoa Cave) turbidity from all sources and rainfall should start as soon as possible. For turbidity just noting water clarity (i.e. how “dirty”) and its duration would be useful (TWB).

5. By implementing simple improvements to existing individual rainwater catchment systems, such as upgrading and providing additional gutters and down pipes, better utilisation of rainfall and collection/storage systems should result. Regular maintenance of collection/storage systems is also recommended (TWB & local community).

6. Recommendations made in the August 1998 Draft Design Report ‘Eua Water Supply Improvement Project by Vaha’akolo Palelei and Tony Falkland (Reference 4) are generally supported (TWB).

ACKNOWLEDGEMENTS

SOPAC would like to acknowledge the assistance of Mr Holomesi Teumohenga, TWB Branch Manager of ‘Eua and his staff. The assistance and hospitality of Mr Vaha’akolo Palelei, Project Engineer, is also gratefully acknowledged.

1. INTRODUCTION

This study was undertaken as part of a Water Demand Management and Conservation Project funded by the Government of Taiwan and was requested by the Tonga Water Board (TWB). The study area is the area serviced by the TWB on the island of ‘Eua within the Kingdom of Tonga.

The purpose of the Project is to develop water demand management and conservation measures to reduce water losses and improve the water supply on ‘Eua. Information on water resources, water usage and the water supply system was collected during field investigations carried out on ‘Eua between 31 January to 8 February 1998. SOPAC Trip Report 251 (Reference 1) documents the fieldwork.

2. BACKGROUND

‘Eua lies to the south east of Tongatapu and is the only island in the Tongan archipelago that has surface water resources (see attached map for location). The formation of the island (approximately 88 km^2) is from uplifted limestone with a basaltic base. Water emanates at the contact of these two different materials through several caves as well as small streams. Some of the streams are known to dry up during drought periods.

The population of ‘Eua is approximately 4400 people who mainly rely on subsistence farming. The area serviced by TWB includes a population of approximately 4000 people.

A Master Plan for ‘Eua Water Supply was prepared as part of the Tonga Water Supply Master Plan Project in 1991 by PPK Consultants Pty Ltd (Reference 5). There is a lot of useful information about ‘Eua in this report. However most of the recommendations made in the Plan were not implemented.

Currently an AusAID funded TWB Institutional Development Project implemented by ACTEW have resources to improve the ‘Eua water supply. The intention of this report is to assist in the efforts to provide an improved water supply for the people living on ‘Eua through demand management and conservation practices.

A presentation on the principles of water demand management and conservation was made to TWB staff during the visit. Contents of the presentation is in Attachment 1.

[TR264 – Burke]

Map of Tonga showing the location of ‘Eua

3. WATER RESOURCES

3.1 Rainfall

Naturally rainfall is the source of all freshwater on ‘Eua. A daily rain gauge exists on ‘Eua however the rainfall records are incomplete and do not provide much useful information. The Nukua’lofa rainfall station on Tongatapu has a complete rainfall record dating back to 1947. It would be expected that the rainfall on ‘Eua would be greater then Tongatapu because of the higher elevation of ‘Eua. The average annual rainfall, using Nukua’lofa rainfall data, is about 1770mm with a minimum of about 838mm and a maximum of about 2655mm. January, February and March are on average the wetter months while May, June and July the drier months. Until ‘Eua has a reliable rainfall database Nukua’lofa may be used for analyses knowing results should be conservative.

3.2 Surface Water

There are several surface and underground streams on ‘Eua. The underground streams exit through limestone caves. Only streams within the Government Estate were investigated. Included were the following surface streams at Fern Gully and at Hafu plus underground streams emerging from caves known as Saoa, Ana Pekepeka and Matavai. The following flows were measured on 4-5 February 1998: (See Attachment 2 for flow measurement details)

Source	Flow (l/s)	Comments
Fern Gully Stream	1.96	Catchment area about 2.25 km^2
Hafu Stream	1.29	Catchment area about 0.7 km^2
Saoa Cave	2.18	Measured at intake
Ana Pekepeka Cave	1.27	Measured in pipeline at cave entrance
Matavai Cave	1.12	Measured in pipeline near “Y” junction

All the above sources except for Hafu and Saoa are currently used for the island water supply. Note that on the day of the measurement, the entire flow from Fern Gully Stream entered the water supply intake pipe.

It is understood that the Hafu Stream at one time was connected to the island water supply but now only supplies water for the forestry department. This stream is known to dry up during drought periods. The Saoa source intake and pipeline are susceptible to flood damage (the Saoa Cave entrance is under a 4m waterfall from the Fern Gully Stream) and has not been reconnected to the water supply after the PVC pipeline was washed away.

As a rough indication of the magnitude of the flows observed, for the 11 month period before the measurements were taken the rainfall (about 780mm) was only 50% of the long term average based on Nukua'lofa data. Note that the lowest annual rainfall recorded between 1947 and 1990 was 838mm in 1983. Thus it would be fair to say that the flows measured would be regarded as low noting that in the past the Hafu Stream is reported to have dried up.

3.3 Groundwater

Groundwater will be defined, in this report, as water taken from a borehole opposed to water flowing from a cave even though the origin of the flow may be groundwater.

The expected occurrence of groundwater on ‘Eua is in the form of a freshwater lens floating on seawater with salinities increasing with depth. Perched aquifers may exist in the volcanic materials located above sea level but may not be sustainable to due to limited storage and recharge. Groundwater investigations including drilling are required to best assess the resource.

Currently there is only one operational borehole on ‘Eua known as the Ha'atu'a borehole. The pumped flow rate measured was 2 l/s with a conductivity of about 3600 µS/cm. This indicates a moderately high salinity with 2500 µS/cm being the normally accepted upper limit.

4. EXISTING WATER SUPPIES ON ‘EUA

4.1 Water Sources

Rainwater, surface water and groundwater were all used to supply the water needs on ‘Eua during the field investigations in February 1998.

Most families on ‘Eua have access to rainwater collected from roof areas of houses and other buildings, and stored in various types of tanks. Rainwater is the preferred choice of water used for drinking, cooking, bathing and washing clothes. According to Leonie Crennan customer survey report (Reference 2), it is common for households with rainwater tanks to share their water with neighbouring households and relatives.

Reticulated water supplied by the TWB is a combination of surface water (ie Fern Gully Steam, and the underground streams intakes from caves at Ana Pekepeka, Matavai) and groundwater from the Ha'atu'a borehole. Surface sources use gravity to convey water to users 24 hours a day. Groundwater is pumped from the bore direct into the distribution system for about 8 hours per day.

The distribution system consists of mainly PVC pipes ranging in size from 150mm down to 15mm in diameter. There are no storage facilities within the system. All connections should be metered. TWB read the meters periodically and charge $1.09 TOP per 1000 litres. Some installed water meters have problems due to dirty water and debris fouling the meters (see photo 1).

4.2 Water Quality and Treatment

The piped water varies in quality. After periods of heavy rain the water becomes "dirty" and unsuitable for use. All surface sources are susceptible to pollution. Water supplied by the TWB is normally used for all needs except drinking, cooking, bathing and washing clothes for those who have access to rainwater (Reference 2).

Piped water is hard due to its contact with the limestone nature of the island. The Ha'atu'a bore water has a moderately high conductivity (3600 µS/cm) due to the mixing of fresh and saltwater. The bore water alone has a "salty" taste but because it is mixed with the surface water sources (conductivity of about 360 µS/cm) the resulting mixed water has a conductivity of about 1200 µS/cm. (See Attachment 3 for water quality measurements made during the visit).

The only water treatment carried out is at the Fern Gully source that is manually "disinfected" by spreading granular chlorine at the intake weir ponding area. Without conducting any tests this method would appear to have minimal impact on disinfecting the water supplied to customers.

4.3 Water Demand

In 1997 TWB had on average 537 metered connections supplying reticulated water to an estimated 4000 people. The following table indicates the water used based on the meter reading for 1997.

‘Eua’s 1997 Water Usage Measured by Customer Meters

Date	m^3	l/s	Connections	m^3 per Connection
Jan 97	6377	2.36	548	11.6
Feb 97	4436		544	8.2
Mar 97	4850		548	8.9
Apr 97	5580		527	10.6
May 97	3797		517	7.3
Jun 97	4328		519	8.3
Jul 97	4825		526	9.2
Aug 97	5020		538	9.3
Sep 97	4650		536	8.7
Oct 97	4469		542	8.2
Nov 97	5456		544	10.0
Dec 97	4818		549	8.8
Total Ave/month	58606 (160 m^3/day) 4883.8	 1.86	 536.5	 9.1

Based on the above data, the average daily water use in ‘Eua is 160 m^3/day with an average monthly low of 122 m^3/day to an average monthly high of 206 m^3/day. However due to faulty water meters or missing meters, the actual water usage may be higher than what was recorded but, conversely during very wet periods when the water supplied is dirty, water use would be reduced. Thus assuming that the above figures are in the correct order the average daily use of the TWB supplied water per person would be about 40 litres. This would also include non-domestic users such as the hospital and schools. Note that water used for drinking and cooking is normally taken from stored rainwater. Note that the 1991 ‘Eua Draft Master Plan (Reference 5) states an average daily consumption of 164 m^3/day based on meter readings from February through May 1990. Thus it appears that the average daily consumption for ‘Eua has been fairly constant based on the above data.

4.4 System Wastage

Due to insufficient data the exact amount of water that is lost through leakages, faulty meters and illegal connections cannot be assessed. However there is enough data to make an intelligent estimate.

Based on the measurements made (See Attachment 2) and assuming the bore pumps at 2 l/s for 8 hours a day and that surface sources contributed 3.4 l/s per day, then the average daily flow would be 351 m^3/d. Comparing this to the average daily consumption in 1997 of 160 m^3/d indicates losses of 54%.

Using the data in the 1991 'Eua Draft Master Plan suggests that the water produced by the sources averaged at 300 m^3/day (data from 150 mm flow meter when working) with an average consumption rate of 164 m^3/day, results in water losses of 45%.

In October 1997 the ACTEW team measured the minimum nightflow at 4.8 l/s with an average flow of about 6 l/s over the recorded period. This indicates a water loss of about 80% (Reference 6).

Thus it would be safe to assume that more than 50% of the water entering the reticulation cannot be accounted for.

5. FIELD OBSERVATIONS

Water quantity and quality measurements made during the field trip appear in Attachments 2 and 3.

5.1 Rainwater Systems

With rainwater being the preferred source for drinking, cooking, bathing and washing clothes, most households have access to rainwater that is stored in various types of tanks. Basically water is collected off a roof through some kind of gutter and down pipe system into a storage tank. Each system is unique being constructed with whatever material is available and/or affordable. Generally most systems observed required maintenance. (See photos 3 and 4). Often with minimum cost and effort, existing systems could be made more efficient in conveying water from roofs to the storage tanks thus providing more water from the same amount of rainfall. Roofs, gutters and down pipes generally required repairs and maintenance. Often only half the potential roof area is used to collect the rain, which otherwise could be used to generate additional water.

There is much potential to improve and better manage existing rainwater systems. It may be appropriate to run public awareness programs on the maintenance of rainwater systems and on developing management plans to conserve rainwater when water levels in tanks reach a certain level. For example when tank levels are half way, users should use water more sparingly until the tanks are replenished again.

5.2 Surface Water

The intake sources in Ana Pekepeka and Matavai caves were not visited but flows from the pipelines coming from these sources were measured at 1.27 l/s and 1.7 l/s respectively. Note that a flow of 1.27 l/s was measured in the Ana Pekepeka pipeline as it exited the cave, but zero flow was measured in the same pipeline at the Y-junction some 300m downstream. This would indicate problems with the pipeline (See photo 2).

The Saoa Cave source (measured at 2.18 l/s) could be used to provide additional gravity feed water to the system. Note that the Ha'atu'a borehole is currently pumped at 2 l/s.

The existing Hafu Stream intake is another potential surface water source that could be used in emergencies.

Both the Fern Gully and Hafu streambeds contained fine sediments and organic materials (such as leaves and sticks) that are easily stirred up and moved downstream during high flows. Thus during high flows reticulated water is often very "dirty", unusable for most usage and may cause water meters to block.

The cave sources are reported to get dirty but to a less degree then Fern Gully (personal communication with Tony Falkland, ACTEW).

5.3 Groundwater

The existing Ha'atu'a borehole provides 2 l/s of water into the reticulation system while the manually operated diesel powered pump is running. The conductivity of bore water (3600 µS/cm) indicates that brackish water is entering the well. However this is offset by mixing with the surface water sources (See Section 5.4 below).

To reduce pumping costs it would appear that the borehole is only required during peak periods of water use, low surface water flow periods and when the surface water is "dirty" following heavy rains. Alternatively the Saoa Cave source could be connected to the system noting that the observed cave flow was about the same as the borehole.

There is potential to develop the groundwater resource on the western side of 'Eua to produce better quality water than the Ha'atu'a borehole but this would require drilling new boreholes and further investigations.

5.4 Mixed Water

Conductivity of tap water from John's Guest House on 'Eua ranged between 359 µS/cm in the morning to 1290 µS/cm in the afternoon during the field work period. This is because the Ha'atu'a borehole was turned on in the morning, mixing groundwater (conductivity of about 3600 µS/cm) with the surface water (conductivity of about 350 µS/cm). Thus in the morning before the bore is operational only surface water flows in the pipeline. However by the afternoon the bore water had mixed with the surface resulting in water with a conductivity of about 1290 µS/cm. Note that the conductivity of the tap water from the Pacific Royale Hotel in Nuku'alofa was 1200 µS/cm.

5.5 Distribution System

As pointed out in Section 5.2 above, there appears to be a problem with the Ana Pekepeka 150 mm PVC pipeline between the cave and the Y-junction. This is probably due to pipe failure somewhere alone the line.

Between 19:00 on 4/2/98 and about 07:00 the next day no water was flowing in the distribution system. On inspection of the pipeline, air locks were found in the Matavai pipe just upstream of the Y-junction and in the main pipeline at the old water meter site. After air was manually expelled from the pipeline, using the valve on Matavai pipeline and old meter housing, normal flow resumed. It appears that there is a hydraulic problem with the pipeline. However the installation of air valves at all high points in the pipeline would solve the problem.

While travelling with the 'Eua TWB staff, 7 small diameter PVC broken pipe repairs and 2 water meter installations were observed. In most cases the broken pipes were caused by pigs wanting a muddy area to wallow in. Most pipe repairs observed consisted of the use of a "Tongan" pipe joint. A short piece of same diameter PVC pipe is heated up at the end and then forced over another piece of pipe thus forming a socket. Sockets are formed on both sides of the short piece of pipe, which are then glued to the broken section of pipe thus completing the repair. In some cases the repair is made underwater (See photo 5). If done properly this technique works well and is widely used in small island conditions. However it was observed that pipes have been repaired several times at the same location (see photo 6). The recurring broken pipe problem is caused because once repaired, the pipeline is not buried thus the pigs are at it again. All exposed pipes must be buried or protected in some way against breakage that results in the wastage of water.

6. COMMENTS

A decision needs to be made regarding the type of water supply services to be provided to ‘Eua by TWB. If users are content with the existing service (i.e. untreated reticulated water) supplemented by individual rain catchment systems, then only minimum upgrading works are required along with continued operation and maintenance. However if the reticulation system is to continuously supply treated water, similar to the standard being supplied by TWB for Nuku’alofa, then major capital works plus increased operation and maintenance costs would be expected.

The major options to upgrade the supply are to treat and store surface water or to develop the potential groundwater resource to provide a continuous safe water supply. A combination of both surface and groundwater is also possible.

The minimum upgrading option would include the installation of air valves, improved operation and maintenance procedures plus repair of broken pipes.

Also the recent proposal to upgrade the Fern Gully intake to provide better quality water is supported (See Reference 4).

Note that the TWB currently charge $1.09 TOP per 1000 litres of water. Based on the 1997 meter reading this would generate revenue of about $64,000 TOP per year. The current water charge is relatively high and that in itself keeps water use to a minimum.

7. OPTIONS

The following options are available:

7.1 Status Quo

Continue to use a combination of stored rainwater, groundwater and surface sources knowing that during periods of heavy rainfall that the reticulated water will be dirty.

7.2 Treatment of Surface Water

Using surface water to provide safe clean water at all times would require conventional water treatment (sedimentation, filtration and disinfection) and would cost in the order of A$280,000 according to the ACTEW team (Reference 2). Since the surface sources are all gravity fed the operational costs should be minimal mainly related to water treatment costs.

7.3 Development of Groundwater Resources

There is potential to develop groundwater resources through the construction of boreholes fitted with pumping units. The ACTEW team estimated one production well would cost $10,000 with about 5 required to supply ‘Eua (Reference 2). Site selection and pumping rates will be important to avoid high salinity as experienced at the existing Ha’atu’a borehole. It is understood that the abandoned borehole at Ohonua was producting water of low salinity (conductivity of about 1100 µS/cm). Groundwater pumped from boreholes should provide better quality water (minimal treatment) than the surface sources but with continuous pumping the operational costs would be much higher than the gravity surface supply. Also the salinity of the groundwater may increase with time thus there is a risk involved that if not constructed and operated carefully the boreholes may become like the ones at Ha’atu’a and Ohonua.

7.4 Combined Surface and Groundwater

The 1991 PPK report (Reference 5) states that for approximately 80% of the year, surface water quality is adequate to use. For the balance of the time (i.e. when the surface sources are “dirty”) groundwater could be used. This was the recommended option of the PPK Master Plan for ‘Eua, requiring drilling of a new well field, upgrading the surface water headworks and pipe reticulation system plus a storage reservoir equivalent to one day’s demand. At the time, this option was estimated to cost about A$1.6m.

The existing ‘Eua water supply system uses both surface and groundwater sources but the one borehole is not sufficient in capacity to supply the average daily demand of ‘Eua alone.

7.5 Minimum Upgrade

Installation of air valves at high points of the distribution system would bring immediate relief to flow disruptions due to air locks in the pipeline. Cave source pipeline should be inspected for leaks especially the Ana Pekepeka line for water was definitely flowing in the pipe as it left the cave but no flow was measured near the Y-junction.

The Saoa Cave source could be reconnected thus providing at least another few litres per second to the reticulation system thus not requiring water pumped from the Ha’atu’a borehole. However pipe material more robust then PVC is required. Also the cave source may provide better quality (i.e. cleaner) water then the Fern Gully stream during high rainfall conditions.

From an operational point of view the “dirtier” sources could be shut off during heavy rain and the borehole water used more. This would require TWB staff to manually turn valves and the borehole on and off as required to deliver the best quality water. Water quality of the various surface sources would have to be investigated to determine which water source deteriorates the quickest and for what duration resulting from heavy rainfalls.

7.6 Intake Improvements

A recent presentation made to TWB by Vaha’akolo Palelei (TWB) and Tony Falkland (ACTEW) (Reference 4) suggested various improvements to the ‘Eua water supply system. One was the construction of in-stream filter bed intakes to improve water clarity using the Fern Gully intake as a trial. This system has had some success in Rarotonga mainly in the removal of leaves, twigs and similar debris. Some in-stream filters performed well while others did not in Rarotonga. As discussed with Tony Falkland, care is required in constructing in-stream filters specially regarding maintenance (i.e. removal of sediments and other debris that will build up on top of the filter bed). Also the in-stream filters are susceptible to flood flows that may physically remove the filter material. A bypass is advisable to assist with construction and maintenance of the filter. These factors should be considered in designing the in-stream filters.

7.7 Pipeline Upgrading

As shown in Section 4.2 (System Wastage) at least 50% of water entering the system is lost and it is expected that actual water losses are even greater based on ACTEW October 1997 (Reference 6) minimum night flow measurements. Identifying and permanently fixing leaking pipes can be a positive and minimal cost solution to optimise water usage and water resources, increase water pressure, reduce borehole pumping requirements and is good for the environment by keeping more water in the streams and in the ground.

8. CONCLUSIONS AND RECOMMENDATIONS

The following demand management and conservation practices are recommended:

1. Carry out minimum night flow measurements with associated step testing to assess system losses and to identify likely areas of losses (SOPAC & TWB).

2. Repair all detected leaks and carry out minimum night flow testing again (TWB & SOPAC).

3. Campaign to fix leaks on customer side of system (i.e. leaky taps and toilets) (TWB & SOPAC).

4. Public awareness should be promoted with the public being advised of future TWB activities and given the opportunity to discuss proposals (TWB & SOPAC).

5. Install (or repair) water meters on (1) the 150mm main pipeline at the old meter location (2) on Fern Gully/Saoa's 65mm pipeline near where it connects to the 150mm main, and (3) on the Ha'atu'a borehole pipeline. Data collected from daily reading of these meters will be used to assess water entering the water supply system (TWB).

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7. Both short term and long term planning is required to develop the water supply according to need and available resources (TWB & SOPAC).

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The following conclusions and recommendations are made:

1. Development of full treatment for surface water and/or development of new groundwater wells, or a combination of both would be expensive and should be considered as long-term options.

2. Any opportunity to develop the groundwater resources should be taken to supplement surface water resources and as an emergency supply.

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   - Installation of automatic release air valves at high points of all pipelines to eliminate flow disruptions due to air locks.
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6. Recommendations made in the August 1998 Draft Design Report ‘Eua Water Supply Improvement Project by Vaha’akolo Palelei and Tony Falkland (Reference 4) are generally supported (TWB).

9. REFERENCES

1. Burke, E., 1998. Water Resources Investigation in ‘Eua, Tonga, Demand Management Project, 31 January – 8 February 1998. SOPAC Trip Report 251.

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ATTACHMENT 1

PRESENTATION

ATTACHMENT 2

FLOW MEASUREMENTS MADE ON ‘EUA

ATTACHMENT 3

WATER QUALITY MEASUREMENTS MADE ON ‘EUA

PHOTOS TAKEN DURING THE STUDY

Photo 1 - Typical water meter filled with debris from the distribution system.

Photo 2 – Kolo and Masi measuring pipe flow at Ana Pekepeka Cave entrance.

Photo 3 – Typical roof collection and storage system found on ‘Eua. Note with a few improvements the system would be more efficient.

Photo 4 – Special purpose built roof collection and storage system.

Photo 5 – Pipe repair being made underwater.

Photo 6 – Unprotected broken pipe. Note flow in both directions and other repairs made at the same location.