HYDRAULIC NETWORK MODELLING OF THE RAROTONGA WATER SUPPLY SYSTEM COOK ISLANDS

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Table of Contents

List of Tables

List of Figures

Executive Summary

The following report describes the work involved in creating a working hydraulic model of the Turangi section of Rarotonga's water distribution system. Work was performed both in the Cook Islands in cooperation with the Water Works Department, and at SOPAC offices in Fiji.

Objectives that were achieved during the trip to the Cook Islands include:

i) a basic familiarity with hydraulic principles, Cybernet 3.0 functions, and distribution system design methods by one member of the Rarotonga Water Works Department.
ii) a network model of the Turangi section of the Rarotonga water distribution system using data collected by the Water Works Department and other organisations.

The development of the Turangi network model involved the collection of demand, elevation and pipe layout information. In order to determine total water use (or demand) for the entire population of Rarotonga, estimates of domestic, commercial, hotel, industrial, institutional and agricultural demand were made. The following table summarises these results.

Table 1: Average Daily User Demands for Rarotonga

User Type	Average Demand
Domestic, L/d per person	300
Commercial, L/d per establishment	3,835
Hotel, L/d per hotel	13,858
Industrial, L/d per establishment	10,384
Institutional, L/d per establishment	15,792
Agricultural, L/d per plot	3,+400

These estimates are based on metered water use of specific buildings, and typical demand values.

The Turangi model reflects the proposed sectorisation of one of the five zones proposed by the Asian Development Bank infrastructure plan. Where possible, comparisons on numbers found in the ADB report were made with SOPAC-derived values, the most obvious being user demand. As can be seen in the following table, our total demand was significantly higher than the one put forth by the ADB.

Table 2: Comparison of Total Demand in Rarotonga According to SOPAC and ADB

User Type	SOPAC Estimated Demand (m3/d)	ADB Estimated Demand (m^3/d)
Domestic	3,167	2,403
Commercial	1,066	602
Hotel	1,813	899
Industrial	424	795
Institutional	362	361
Agricultural	5,241	3,775
Total	**12,073**	**8,835**

Besides evaluating total demand for Rarotonga, water use in the Turangi zone also had to be calculated. To do this, individual demands from houses, commercial properties, plantation hose cocks, etc were aggregated at certain spots or junctions. The individual demands were either based on known metered demands or typical demands for certain types of properties such as schools, office buildings and stores. In the case of agricultural demand, water use was calculated on a per-area basis. This required estimating the total area of agricultural plots in the Turangi zone.

As flow throughout the system is not constant over time, some kind of demand pattern for the Turangi system had to be determined. This was done looking at daily flow records of water being drawn from the Turangi intake. The pattern indicated that there was a peak in water use at around 7:30 am and 4 pm. Minimum water use occurred at 3 in the morning.

With all the input data as complete and as accurate as possible, calibration of the model was then performed to try and get the model to reflect measured values as they occur in the real system. The measured flow and pressure data used to evaluate the model flow and pressure results were collected by the Water Works Department. This data, collected within the past two years, reflects the isolation of the Turangi zone from the rest of Rarotonga's distribution system. The model only produced results close to the measured flow and pressure data when water use was increased by almost 3 times the estimated user demand. This translates into approximately 65% of water in the Turangi zone being unaccounted for or lost.

The only model run performed with the calibrated model was with the Matavera and Tupapa intakes taken offline, leaving the Turangi intake to supply the entire zone. This is how the zone would operate according to the ADB Infrastructure Development Report. Results indicate that the Turangi intake will not be able to supply the entire demand from this zone, as the Turangi stream simply cannot supply this amount of water. The resulting pressures throughout much of the system will also be too low for proper water distribution.

1. Introduction

1.1 General

Rarotonga's water distribution system supplies water from 12 intakes located high up in the interior of the island to a population of just over 10,000 spread around the coast. The distribution system is entirely gravity fed and operates generally at high pressures. The current water supply system is under stress, presumably from excessive and often irresponsible use by the population, and from leakage problems throughout the distribution network. Estimates of leakage range from 30-50% of the water drawn from the intakes. Water is also provided free to users in Rarotonga.

Many studies have identified the excessive demand through real consumption and water losses as the major problem of Rarotonga's water supply system. None of the suggested improvements such as water pricing as a demand regulating measure have yet been implemented.

Currently, discussions and assistance provided by the Asian Development Bank (ADB), World Health Organisation (WHO) and SOPAC that emphasised the importance of water tariffing seem to have lead to a change in political and public perception of the matter. A major public concern about water tariffing was the public notion that the Water Works "could make huge profits at the expense of its customers without improving the service". In order to be able to provide the desired service improvements Water Works has established alliances with WHO and SOPAC to drastically improve services. SOPAC provides Technical Assistance (TA) to train staff in asset managing systems (GIS) and hydraulic network modelling. WHO concentrates on leak detection and operational management (sectorisation, zone metering etc.) of the water supply system.

To implement the necessary hardware for service improvement Water Works has in the past relied mainly on New Zealand Official Development Assistance (NZODA). "Project East" was such an initiative implemented by the Water Works Department to provide upgrades to the north eastern part of Rarotonga's water distribution system ie. in the Turangi zone. The project clearly demonstrates the capability of Rarotonga's Water Works Department to undertake their water supply system upgrading work.

1.2 Scope of the Project

The work described in this report was performed during two separate visits to the Cook Islands from May 26th to June 1st 1999 and December 1st to the 11th, 1999 in cooperation with the Rarotonga Water Works Department.

The purpose of the visits was to provide hydraulic training to selected members of the Water Works staff including use of the Cybernet hydraulic modelling software, and to develop a hydraulic network model of Rarotonga's water supply system. Cybernet is a trademark software application of Haestad Methods.

The hydraulic training that was performed was aimed at enhancing the design capabilities of Water Works staff. Modelling tools such as Cybernet can be used to simulate the operation of distribution networks, in order to see how they will operate under different conditions. It is good practice for water works departments to develop a network model of their system.

Hydraulic modelling of Rarotonga's water supply system will provide:

- information on how the distribution system operates
- an inventory of the type, size and layout of the pipe network
- an indication as to whether design demands can be met by the existing system
- location of possible problems in the network ie. high/low pressure areas, leaking pipes

- knowledge on how proposed updates to the distribution network will operate

The staff member of the Water Works Department selected for hydraulic and Cybernet training was Adrian Teotahi. This choice of staff proved to be fortunate as he exhibited a high level of computer competence, an extensive knowledge of Rarotonga's existing distribution system, and an ability to absorb the information that was being imparted to him. More importantly, he was able to recognise the need for systematic and planned hydraulic modelling of Rarotonga's water distribution system, and seemed enthusiastic to get on with the work. Topics covered during the tutorials can be found in Appendix A.

The report also reflects the evaluation of the work done by other agencies, as well as new information that has been recently generated by the Water Works, WHO, ADB and SOPAC. It describes the steps for building a network model and the underlying details involved in doing so.

Though data has been gathered and summarised for the entire water supply system, this report focuses only on the modelling work of the Turangi Area ("Project East"), mainly because of time constraints and training considerations. However, the background information will enable Water Works, with assistance from SOPAC, to create similar networks for the remaining parts of their distribution system within the next six months. All the information and data collected for this report will be made available to the Rarotonga Water Works Department.

This report is intended to serve as a manual for the Water Works to proceed with the work already begun, therefore it describes relations and assumptions with more detail than generally considered necessary for a Technical Report.

2. Acknowledgments

The SOPAC Secretariat would like to thank NZODA for their financial support as part of its Water Demand Management project. The authors wish to thank all staff of Rarotonga's Water Works Department for their support and cooperation during the trip, especially Mr. Ben Parakoti, (Director) Adrian Teotahi as well as Patrick Tangapiri.

3. Development of Hydraulic Model

During a previous trip to the Cook Islands in May 1999 SOPAC Water Resources staff created a Cybernet model of Rarotonga's Water distribution system. The layout (Figure 1) of the pipe network followed the pre-Project East Master Plan and contained only roughly estimated demand information.

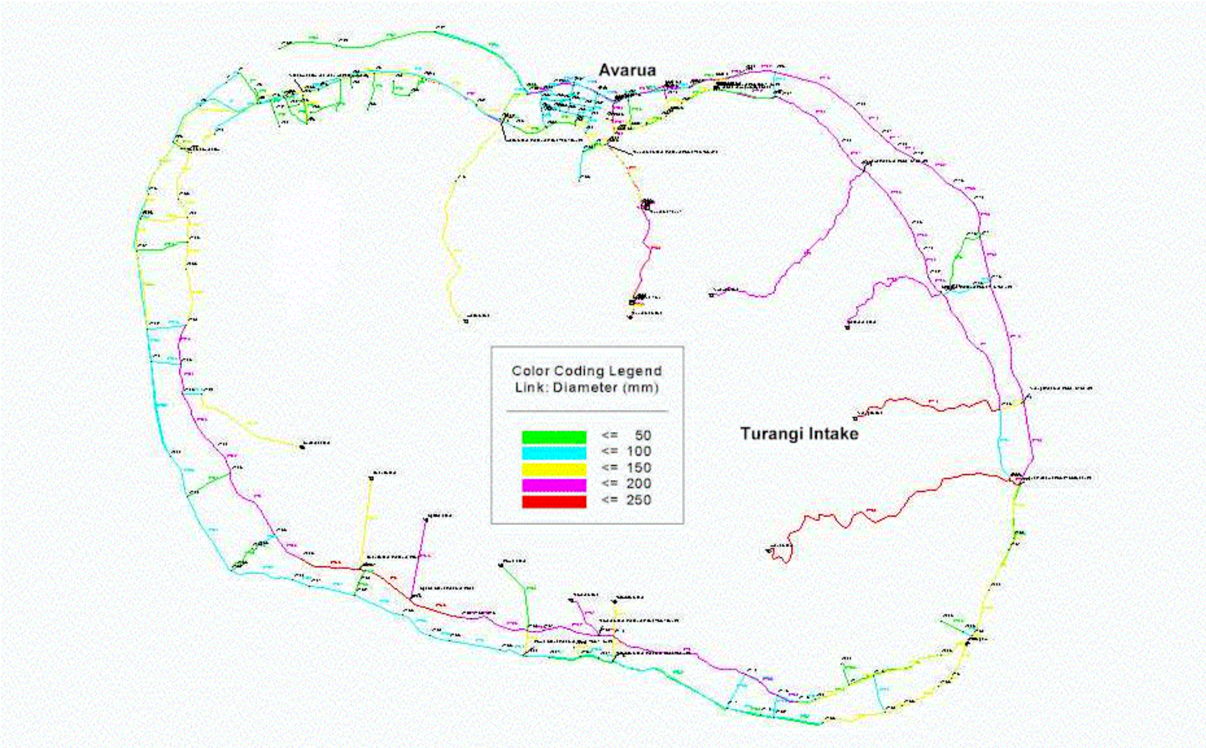

Figure 1: Hydraulic Network Model of Rarotonga without Project East Upgrades

To create a more complete and updated model various sources of information already in the possession of the Water Works Department had to be located and reviewed. This included information on updates to the pipe network layout, information on different types of user demand in Rarotonga, and elevation data.

3.1 Network Layout

The modelling that was eventually performed did not include all of Rarotonga, only the Turangi Water Supply Zone as set out in various studies (ADB, 1999; WHO 1997; Parakoti, 1998) that recommend sectorisation of the water supply system. The Turangi zone can be seen in Figure 2.

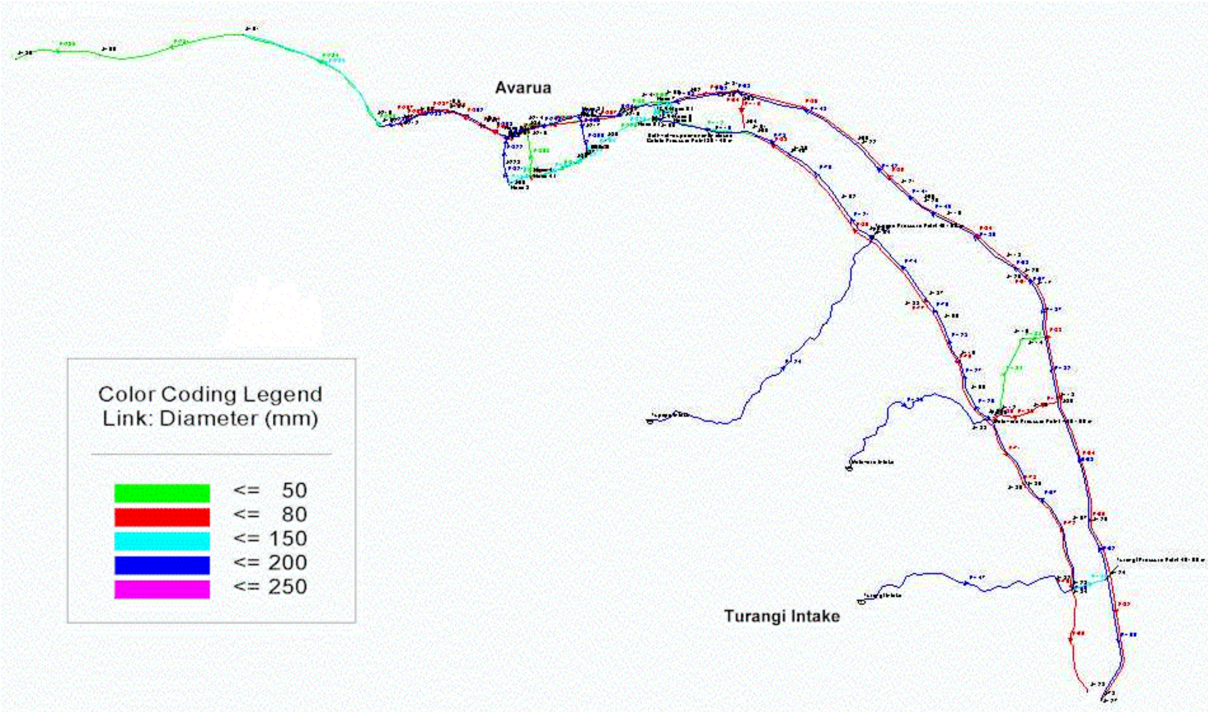

Figure 2: Hydraulic Network of Turangi Zone

This area was targeted for the following reasons:

i) In order to show members of both the Water Works Department and the ADB proposal steering committee how such zoning of the water supply system might work.
ii) To provide a useful example to members of the Water Works Department of how Cybernet as a tool could be used to enhance their capabilities and effectiveness as a department.
iii) To model updates to the distribution system performed during Project East.

The upgrading work performed during Project East included the laying of a 24 km sub-main from Avarua town in the north to Avana stream in the east on the opposite side of the road from the ring main that goes around the entire island. The purpose of this upgrade was to reduce the demand on the distribution system near the supply intakes, and to increase pressure and consequently supply in areas far from the intakes (Parakoti, 1998). A review of pipe size and materials in the network was also performed.

3.2 Elevation Data

Previous work done within the Ministry of Works, Environment, and Physical Planning (MOWEPP) resulted in the digitization of a 50-ft contour map of Rarotonga. This AutoCAD file, however, had no elevation data associated with each contour line.

To format this data into useable information, each contour line had to be turned into a separate polygon and assigned its appropriate elevation. The data was then imported into MapInfo where peak elevations, and 5 m contour lines around the coast were inserted. The end result was a Digital Terrain Model (DTM) of Rarotonga with associated elevation information held in MapInfo tables. The DTM can be seen in Figure 3.

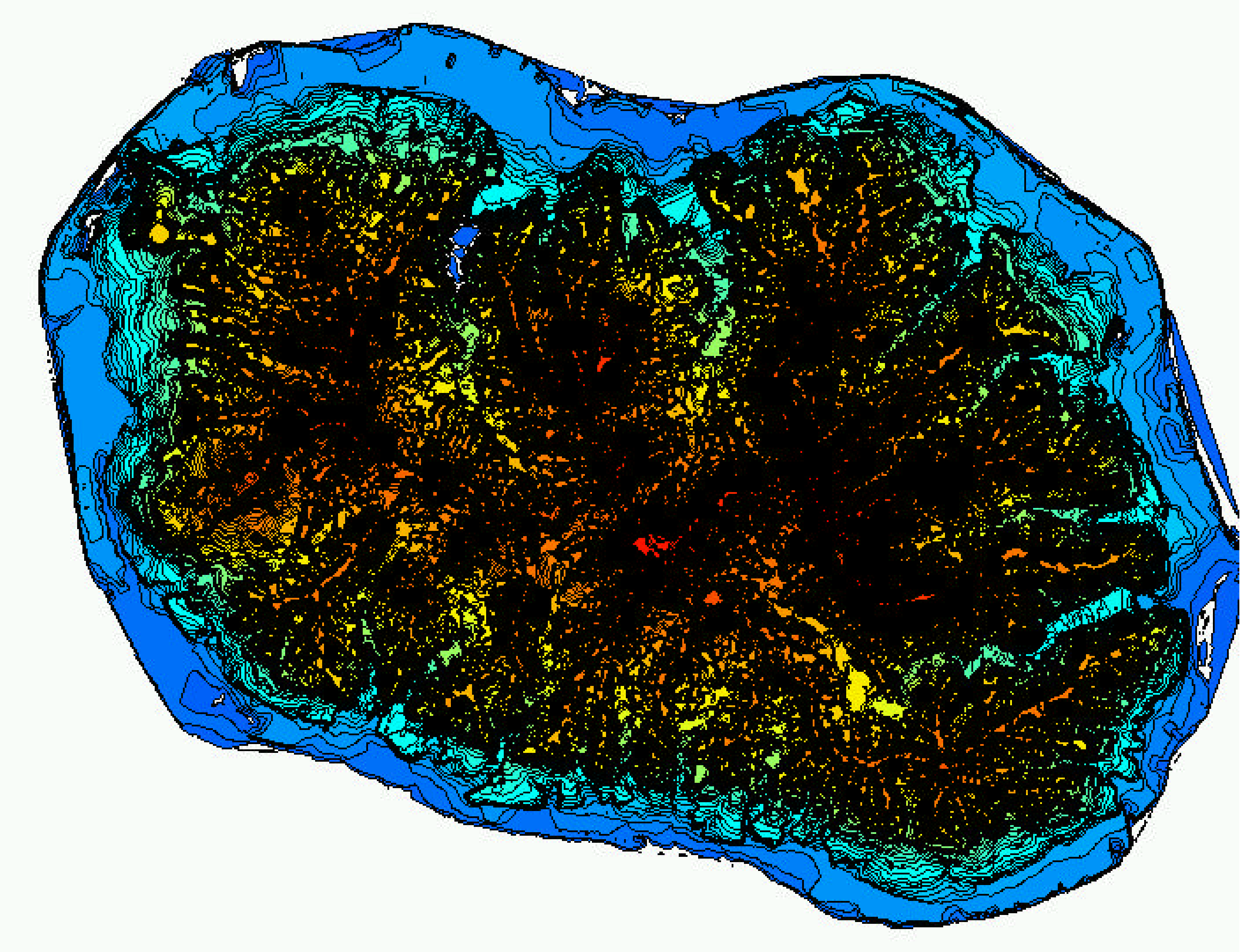

Figure 3: Digital Terrain Model of Rarotonga

Work done on the existing Rarotonga network model did not include any information on the elevation at different junctions. In order to input this information into Cybernet, the existing information in the hands of the Water Works Department had to be formatted into MapInfo tables. With this task accomplished, a database connection was established through Microsoft Access to transfer the appropriate junction elevations to Cybernet.

3.3 Demand Data

Over the past 9 years, flow data from the intakes, and meter information from specific users has been collected in a haphazard fashion. Existing information included:

- Hardcopy flow records from several intakes from 1992
- Summary information collected by a French WS project on domestic demands from 1993-94
- Summary information collected by the consultants WMI (ADB, 1999) on hotel, commercial, institutional, and agricultural demands from 1992-94
- Data from commercial, industrial, institutional, and hotel meters collected by the Water Works Department from 1993-94 and from 1996-97

First of all, meter records had to be formatted from bulk volume (L) to actual flow rates (m^3/d) and then average demand values for these extended-period records were worked out. Secondly, the records were divided into different user types: commercial, hotel, industrial and institutional. Then averages for each type of user were calculated.

Commercial, Hotel and Industrial Demand

A demand value in litres per second per establishment was worked out for commercial, hotel, and industrial use based on the collected meter records. However, it was felt that the two metered records that qualified as institutional demands did not offer a representative demand value. These records can be found in Appendix B, Tables 1-5.

Institutional Demand

Using 1996 census information on the number of people who attend church, attend university or schools, are employed by government, and are inmates in prison - institutional demands were estimated. Typical demands in L/d per unit were taken from Tchobanoglous & Schroeder, 1987. From these estimated values and the metered hospital demand, a composite institutional demand of 0.18 L/s per establishment was determined.

Agricultural Demand

Agricultural demand was estimated using two different methods. Consumptive use of water by crops was estimated using the empirical Blaney-Criddle equation. This equation takes into account climate, temperature, solar radiation, as well as plant species, and calculates the theoretical amount of water a crop will need to survive. Water consumption by individual crops was estimated theoretically to be 2655 m^3/d. Previous estimates of agricultural demand ranged from 3220-18000 m^3/d (ADB 1999). The value calculated turned out to be unrealistically low and another approach was applied.

The value for agricultural demand produced by the French consultants in 1992 was 0.04 L/s per plot, and was the average for two locations only. It was also the only metered information on agricultural demands available for Rarotonga. Census information reported that 60% of households in Rarotonga were engaged in agricultural activity. Assuming each such household had at least one plot of land, a more appropriate agricultural demand of 5241 m^3/d was determined. It is of interest to note that the amount of water generally being used for irrigation is greater than the water requirements of the individual crops according to these estimations. Calculations for agricultural demand can be found in Appendix B, Table 6.

Domestic Demand

Domestic demand data previously collected for Rarotonga ranges from 150-463 L/d per person (ADB 1999). Based on this range and the opinion of people in the Water Works Department, a domestic demand of 300 L/d per person was chosen. A summary of average demand values can be seen in Table 3. It should be noted that average demand is a flat rate, while real demands vary throughout the day as people use more water at certain times (7 in the morning) and less at others (3 in the morning).

Table 3: Typical User Demand Values Per Establishment for Rarotonga as Determined by SOPAC

User Type	Average Demand (L/s- unit)	Average Demand (L/d- unit)
Domestic, per person	0.014	300
Commercial, per establishment	0.044	3,835
Hotel, per hotel	0.16	13,858
Industrial, per establishment	0.12	10,384
Institutional, per establishment	0.18	15,792
Agricultural, per plot	0.039	3,400

Using metered information and typical demand values for certain types of users, an estimation of total demand for Rarotonga was also produced. Calculation for this can be found in Appendix B, Table 7. Numbers for certain types of establishments (eg. bakeries, petrol stations, construction companies, schools) were counted from the Rarotonga Yellow

Pages. These counted values represented approximately half of the commercial and industrial establishments present in Rarotonga according to te Aponga (Rarotongan Electricity Authority) billing records. Knowing by what percent the commercial and industrial demands were out, an appropriate scaling factor was applied to correct these values. Hotel demands were separated into small and large hotel demands, a small hotel being taken as a hostel or motel with a demand of less than 5 m^3/d per hotel. Total domestic demand was based on census population information. Institutional and agricultural total demands were determined as described above.

Table 4 shows the estimated water use for Rarotonga and the ADB proposal estimates.

Table 4: Total Estimated User Demands for Rarotonga

User Type	SOPAC Estimated Demand (m3/d)	ADB Estimated Demand (m3/d)
Domestic	3,167	2,403
Commercial	1,066	602
Hotel	1,813	899
Industrial	424	795
Institutional	362	361
Agricultural	5,241	3,775
Total	**12,073**	**8,835**

The differences in these estimates can be accounted for in the following table.

Table 5: Accounting for Differences in SOPAC and ADB Total Demands

User Type	SOPAC Estimated Demand	ADB Estimated Demand
Domestic	▪ Using 300 L/person/day ▪ Based on recommendation of Ben Parakoti, Director of Rarotonga's Water Works	▪ Using 240 L/person/day ▪ Based on ranges from French metering program, between 150-300 L/p/d
Commercial	▪ Lumping together similar establishments and using either an average metered demand or a typical demand value ▪ Using ten records from 93-97	▪ Using fixed rate of 1600 L/d for water use for all commercial properties ▪ Based on average meter readings for 3 months (Oct-Dec 96)
Hotel	▪ Working out average demands for small and big hotels from meter records, and knowing the total number of hotels ▪ Using ten records from 93-97	▪ Using 700 L/d for large hotels and 300 L/d for small hotels ▪ Based on average meter readings for 3 months (Oct-Dec 96)
Industrial	▪ Lumping together similar establishments and using either an average metered demand or a typical demand value ▪ Using ten records from 93-97	▪ Using fixed rate of 15 000 L/d for water use for all industrial properties ▪ Based on average meter readings for 3 months (Oct-Dec 96)
Institutional	▪ Using typical and metered demands for different institutions ▪ Using ten records from 93-97	▪ Estimated based on school, hospital, prison and government population
Agricultural	▪ Based on average meter readings from two agricultural plots and the percent of population involved in agricultural activity	▪ Based on crop water requirements

Total average yield from the 12 intakes supplying Rarotonga's distribution system, according to the ADB proposal report, is 18 300 m^3/d. The term yield is in this case ambiguous, and can either be interpreted as total flow in the intake streams, or as user demand - the portion of water taken from the steam for use in Rarotonga's water distribution system. If the former is the case, streamflows are not very useful data.

3.4 User Demand in Turangi

In a network model, junctions are nodes where water can leave the network to satisfy consumer demands or where water can enter the network as an inflow. Generally, junctions occur at pipe intersections and connections.

To create a more accurate representation of demand in the Turangi model, flows were disaggregated to individual junctions in the network. To do this, the location of each junction was synthesized onto the Census '96 comprehensive map of Rarotonga that details each building on the island. The number and type of user associated with each junction could then be counted. From the detailed Census information, flow data from metered locations could be input directly into the appropriate junctions and more accurate estimates of demand for other establishments could be determined based on similar known or typical demands. For example, metered information on water usage at the Enuakura Petrol Station was used for each petrol station. Typical demands were in litres per unit per day, and so some estimation of the unit - either employee, customer, parking space, seat, patient, or student was required. This information can be located in Appendix C, Table 1.

In order to include a meaningful agricultural demand at each junction, several steps had to first be performed. Using the composite satellite image of Rarotonga's coast, specific agricultural plots could be picked out, and their area determined using MapInfo. The following figure shows one such section of the Turangi zone.

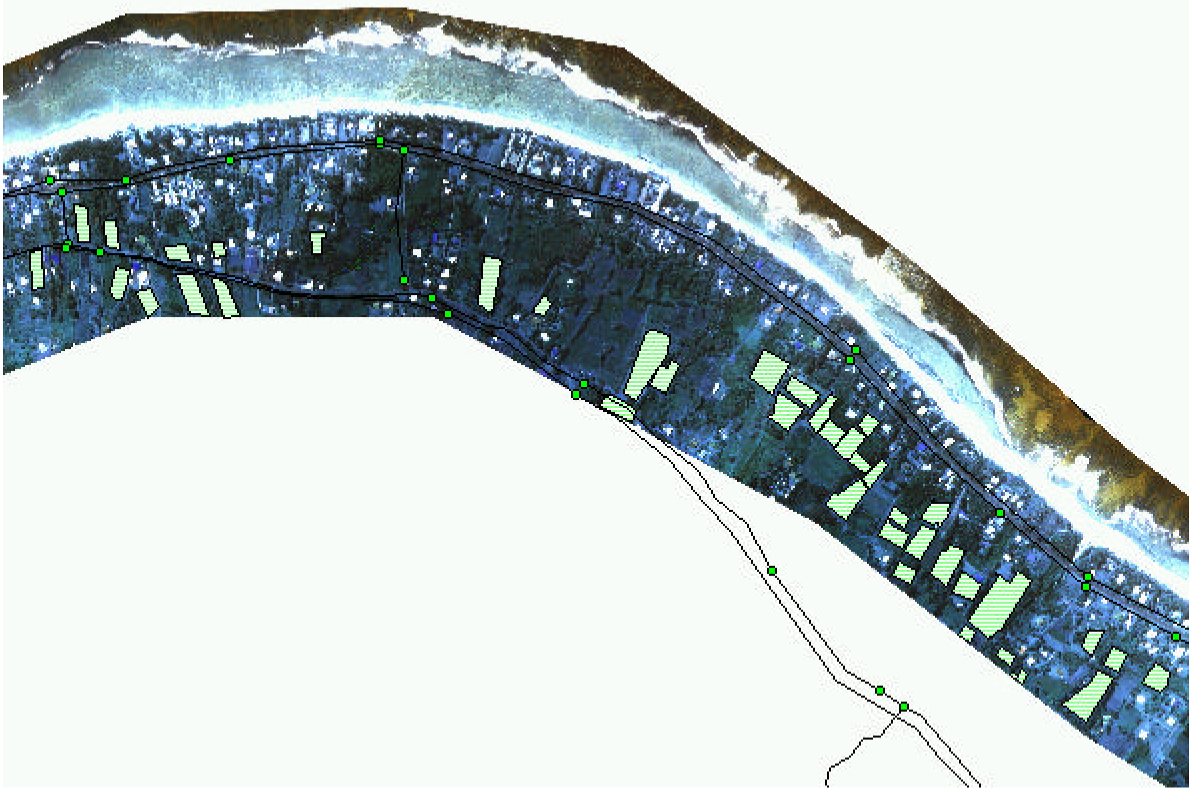

Figure 4: Agricultural Plots in a section of the Turangi Zone

Although the coastal image did not provide complete coverage of the island, complete agricultural demand for some junctions could be determined. For junctions that were not completely included in the coastal image, nearby plantation areas were picked off the 1:25000 Map of Rarotonga (Department of Survey and Land Information-NZ, 1994). Each plantation counted from the map was assumed to have the median area of the agricultural plots determined using MapInfo.

To determine agricultural demand, the total area of land used for planting was summed up for each junction. Using the metered agricultural demand value of 0.04 L/d per plot, and assuming an average plot area is the median value of 1692 m^2, usage was then calculated on a per area basis. These calculations can be found in Appendix C, Table 2. Agricultural demand was then added to the combined domestic, commercial, institutional and industrial demand.

In order to get some idea of how accurate this area-based agricultural demand method of determination was, a comparison of agricultural areas was made. The total area of agricultural plots in Rarotonga according to the Department of Agriculture was 728 460 m^2 (ADB, 1999). The area determined for this report was 744 700 m^2, a difference of 2%. This information can be found in Appendix C, Table 3.

A comparison of population in the Turangi Zone was also performed as a check on the validity of some of the information input into the model. Using Census District information compiled in MapInfo, the Turangi population was determined to be 4068. From the total number of houses associated with each junction, and knowing that on average there are 4.1 residents per household according to the Cook Islands Census of Population, an alternate population estimate of 4022 was determined. These two estimates are within 1% of each other. Calculations for this can be found in Appendix C, Table 4.

A combined-user demand pattern for the Turangi Zone was determined using the hard copy flow records from 1992. Since the demand pattern was derived from the source, it is assumed that it behaves as a composite of individual variations in domestic, commercial, hotel, industrial, institutional and agricultural demands. This assumption can be made because for all practical purposes variation at the source represents such a universal pattern. Cybernet cannot have different demand patterns for each user type, and so a universal pattern is required. The demand pattern can be seen below in Figure 5.

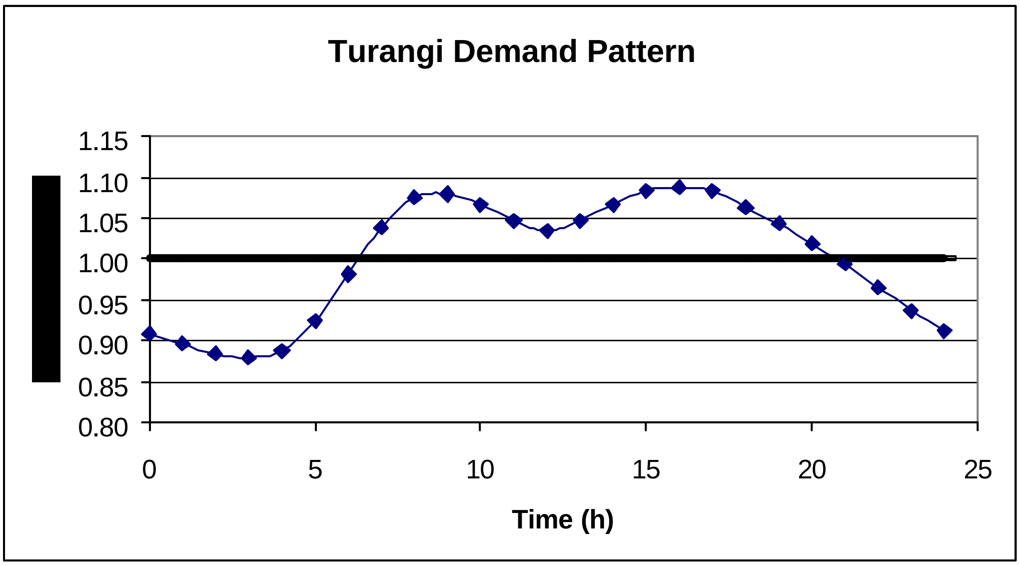

Figure 5: Demand Pattern for the Turangi Zone

To create the pattern, one flow record for each day of the week was taken over the 3-month period records were kept. These daily flow variations were then averaged, a daily average was found, and the demand pattern determined. The Turangi demand pattern was then input into the Cybernet model. Calculations for the demand pattern can be seen in Appendix C, Table 5.

3.5 Calibration of the Network Model

The hydraulic model is a simplified version of a real life system. In the real world demand is not confined to certain junctions, but is dispersed to many individual users over the entire length of the pipe. Calibrating the network model then becomes very important to see if actual pressure and flow values in the distribution system are being simulated accurately or not. Modellers call calibration the process where the idealized model is altered and varied so that it matches real world values. In the case of the Turangi model, electronic records from 1996 to the present were reviewed and used to calibrate the model.

Flow and pressure records prior to the updates performed in 1998 with Project East were discounted as they would not reflect the present day circumstances. The records also had to reflect the situation where the Turangi system is isolated from the rest of Rarotonga's distribution system. The isolation of the Turangi system, as layed out in this model, did not occur till 1998. However, records from 1996 were still used from the non-isolated system, as this was the only information available for calibration.

Firstly it was found that the calculated demand of 27 L/s did not reflect actual values from the real world system. Flows from the Turangi and Tupapa intakes were less than recorded average measured flows, and water was modelled as flowing back up into the Matavera intake. As well, pressure values throughout the system were too high – not less than 550 kPa. For conversion purposes, 1 kPa is equal to approximately 10 cm of water or pressure head.

To calibrate the model, different factors of pipe roughness and demand were tried. A fixed value of 15x the pipe roughness was found to be appropriate and was used for each calibration scenario. Roughness is just a numerical constant used to reflect the age of the pipes- the older they are, the less efficiently water traverses through them.

Different factors of demand were determined based on leakage percentages from the system. Table 6 lists the different demand factors used and the corresponding percent of water unattributed to actual demands lost from the system.

Table 6: Calibration Scenarios for the Turangi Hydraulic Model

Demand Factor	Percent of Total Demand that is Unattributed to Actual Demands (%)	Total Demand from Turangi System (L/s)
1	0	27.2
2.34	57.3	63.7
2.8	64.3	76.2
3.1	67.7	84.4
3.51	71.5	95.7

To measure how accurate each demand scenario came to representing the real Turangi distribution system, model pressures, and flows from the intakes were compared to actual values. These actual values were collected from 5 pressure points within the system for which data is regularly recorded, and from 5 locations where pressure readings had been taken on Sept 3, 1996. Minimum and maximum pressure ranges were used to compare the modelled pressure, and average and maximum flow ranges to compare the modelled flow. If the modelled flow or pressure fell within these ranges, the percent difference between the real life and modelled value was set to 0%. Otherwise, the percent difference was calculated as the minimum difference between the measured values and the one produced by the model. Summaries of each calibration scenario can be found in Appendix D, Table 1.

2.34 times the calculated Turangi demand produces 63.7 L/s, the average total flow from the Tupapa, Matavera and Turangi intakes. Using this demand factor, flow from the Tupapa intake was not within the average to maximum flow ranges. Pressures throughout the system were also found to be high, with differences in real and modelled pressures ranging from 0 to 98%.

2.8 times the accounted-for Turangi demand produces modelled flows from each intake that are within the average to maximum range. Pressures for each of the 5 pressure points are within range, but were from 48 to 77% higher than recorded values for the other 5 locations.

During extended-period simulation for this scenario, pressure head at the junction farthest from the intakes (towards the end of the airport runway, see Figure 6) approaches 0 during times of peak demand. For demand factors greater than 2.8x, pressure becomes negative at the two farthest nodes, J-189 and J-190. Although pressures below atmospheric have been observed in Rarotonga's system, the model does not accurately represent this. When pressure somewhere along a pipe network hits zero, the driving force that impels water to flow through the pressurised pipe system no longer exists at that point. There is no flow through that pipe, and demands connected to that pipe are not met. This lowers the total demand from the intake, but the model doesn't reflect this, or the fact that demands at these end nodes, where pressures are negative, are not being met.

Figure 6: Location of Turangi Network Low Pressure End Node

3.1 times the accounted-for Turangi demand also produces flows that are within the average to maximum flows from the 3 intakes. Pressures within the system are also more accurate, with errors only ranging from 37-61% from actual recorded values at the 5 locations. However, running an extended period simulation, results in negative pressures at the two end nodes. Figure 7 illustrates this problem for J-189 during extended period simulation.

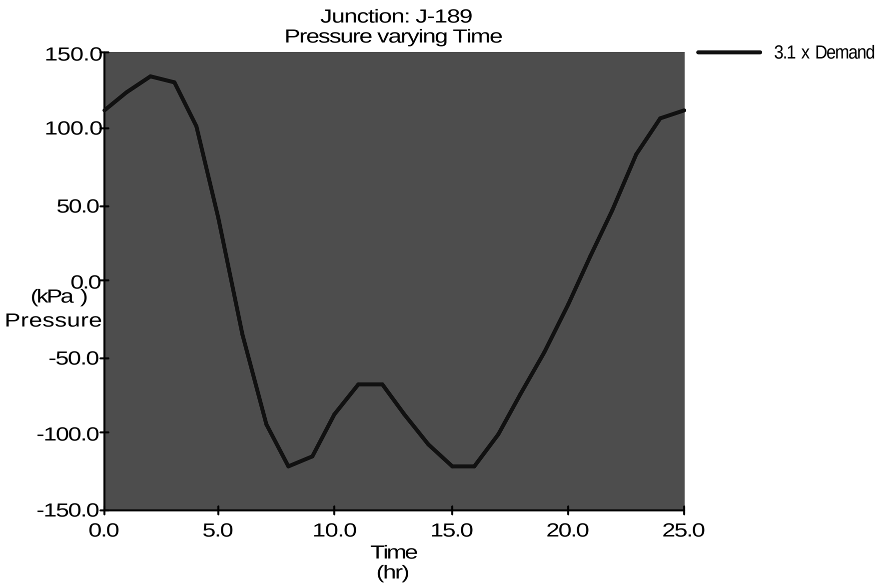

Figure 7: Pressure Variation at J-189 (End Node) for Extended Period Simulation

3.51 times the accounted-for Turangi demand produces 95.6 L/s, approximately the maximum total flow from the Tupapa, Matavera and Turangi intakes. With this demand factor, modelled flows from the Turangi and Matavera intake exceed the maximum-recorded flows from these intakes, but by less than 10%. Pressures from the 5 locations are also improved from between 2-38% error from the recorded values. However, even during a steady-state simulation, pressures at the two end nodes were negative.

The following Figure 8 illustrates how model pressures more closely match actual measured pressures as the demand factor was increased. Appendix D contains maps that show flow and pressure distribution throughout the Turangi Zone for selected demand factors.

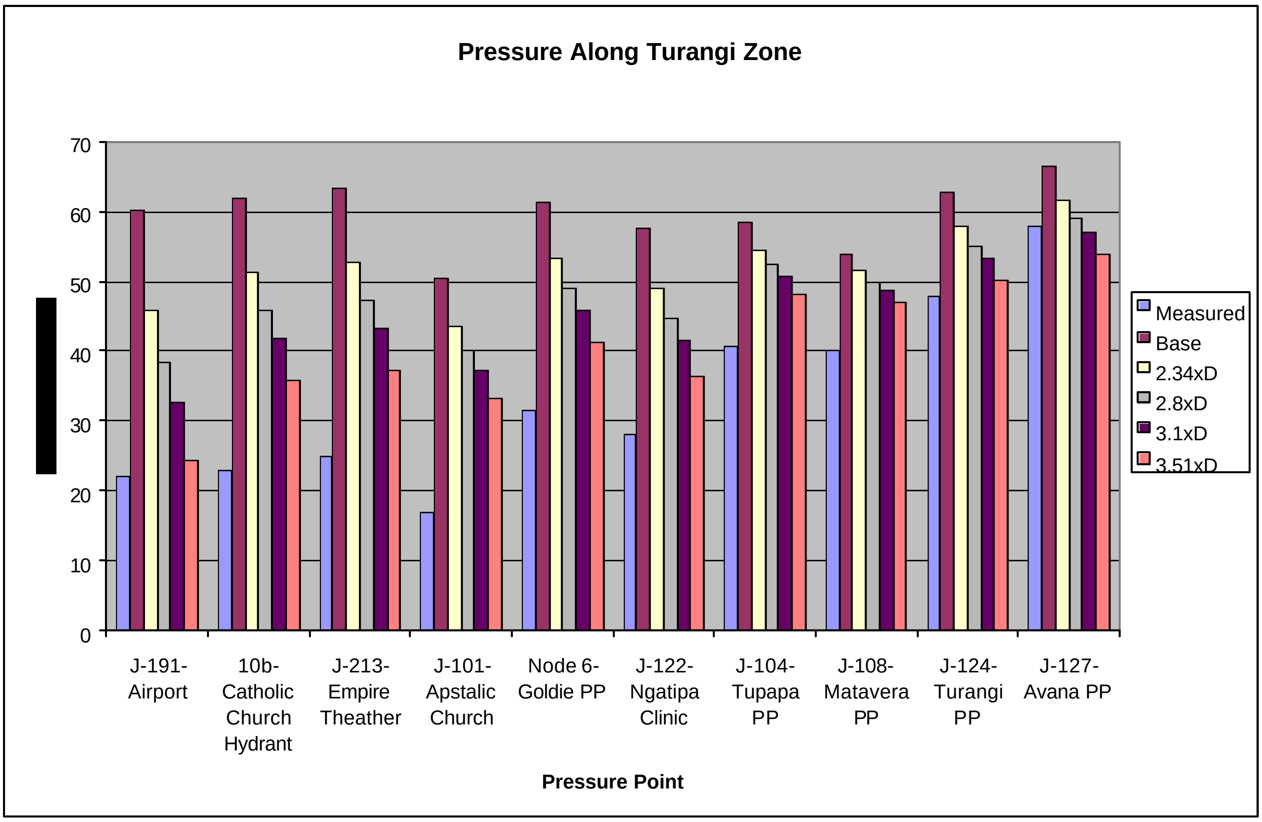

Figure 8: Variation of Pressure at Turangi Junctions with Increased Demand Factor

The calibration scenario using the 2.8 demand factor most closely matches what has been observed in the actual distribution system. For this scenario, flows from the 3 intakes were within reasonable ranges, as were pressures from the 5 regularly-recorded pressure points. At no time during extended-period simulation did pressures fall below atmospheric pressure, even at the two end nodes. Also, even though the modelled pressures for the 5 locations were not as accurate as the 3.1x and 3.48x demand factors, they were still reasonable. In calibrating the model, it was more important that flows from the intakes matched.

It is highly probable that there was already inherent error in the pressure readings for these 5 locations. For one, the readings are from 1996, before both the Project East updates and the isolation of the Turangi zone. This means that these pressure readings do not exactly reflect the system as it is modelled. Another reason for this inherent error is that the readings were taken from convenient locations above ground-fire hydrants and building hose cocks. Pressure in the model represents the pressure in the actual pipe. This results in a potential 1-2 m error in pressure head depending on how far beneath the ground the pipe is buried.

3.6 Model Runs

The calibrated Cybernet Turangi model was run for only one situation in which the Turangi intake supplies the entire zone by itself. The ADB Urban Infrastructure Report proposes that the Turangi Zone, as modelled in this report, be supplied solely by the Turangi intake, taking the Matavera and Tupapa intakes offline. The different scenario parameters, and the rationale behind running such a scenario is provided in Table 7.

Table 7: Description of Model Run

Cybernet Run	Rationale
▪ 2.8 x Demand ▪ Fixed demand pattern ▪ Without Matavera and Tupapa Intakes	The most accurate calibration of the Turangi model was for 2.8x the calculated demand. Knowing this is as close to the real life system as the Turangi model can get, inflows from the Matavera and Tupapa Intakes were taken out to see how the system proposed by ADB would behave.

Several interesting points arose from this model run. Firstly, the maximum real-world recorded flow from the Turangi intake was 36.9 L/s. It is not possible for the Turangi intake alone to meet the current total demand of 76.2 L/s for this zone. This flow rate results from the model calibration and from recorded flow at the three intakes.

Secondly, as the model assumes that the source can supply whatever demand is required of it, the total demand was taken from the Turangi intake. This resulted in low pressures throughout the network, and negative pressures at certain nodes. Within a short distance of the intake, pressures in the distribution system fall below 150 kPa, which is the minimum pressure required for adequate distribution in a typical system (McGhee, 1991). The result is that a flow of 76.2 L/s could be provided only if the pipe works were upgraded.

A map showing flow and pressure distribution throughout the Turangi zone for this model run can be found in Appendix D.

4. Conclusions and Recommendations

As with any kind of modelling, the results produced are only as good as the information being input into the model. Of the three different data inputs to the model: demand, elevation, and layout of the distribution system a different value of quality can be assigned to each. Layout and elevation information is considered to be very accurate; demand data less so.

A considerable amount of estimation was involved in determining the various junction demands. Domestic, commercial, hotel, industrial, institutional and agricultural demands were all calculated making various assumptions which include the following:

- demand from an unmetered property could be estimated using a demand from a similar type of metered property
- numbers of individuals at schools, working in offices, shops, etc. are correct
- agricultural demand based on only 2 metered plots, is representative of agricultural demand throughout Rarotonga and for all types of crops
- domestic demand is representative

Some statistics of interest that came out of this analysis are listed in Table 8.

Table 8: Statistics from the Turangi Zone

Description	Percentage, %
Percentage of Rarotonga Population in Turangi Zone	38.1
Percent Accounted for Turangi Demand is of Total Rarotonga Demand (using high estimate)	19.5
Percent Calibrated Turangi Demand is of Total Rarotonga Demand (using high estimate)	54.5
Percentage of Rarotonga Agricultural Plots in Turangi Zone	39.3
Percentage of Total Rarotonga Commercial and Industrial Premises in Turangi Zone (using total te Aponga billing records)	30.8

The Turangi model performed closest to the real-world situation with calibration factors of 1.5 x the pipe roughness and 2.8 x the accounted-for baseline Turangi demand. All other calibration scenarios either resulted in unacceptable flow or pressure values that did not reflect collected real-system values.

The only model run performed was to see how the Turangi distribution system would operate when being supplied solely by the Turangi intake. It was found that it would be impossible for the Turangi intake to meet the total demand required for this zone. Pressures throughout much of the system were also found to be lower than required in typical distribution systems.

According to the 1997 Second Water Utilites Data Book (McIntosh, et.al. 1997), a Consumer Survey came up with the following findings for Rarotonga:
- 80% claimed to have a 24-hour water supply
- 27% said their water pressure was low
- 55% said they had experienced a water-supply interruption in the month prior to the survey

The Utility Profile also noted that from 1992 to 1996, unaccounted-for water had increased to 70%. This unaccounted-for water they attribute mostly to leaks in household plumbing systems and agricultural use in residential connections.

All of the above findings from the Utilites Data Book support results produced in the calibrated Turangi model. The model was found to operate effectively using a demand that included 64.3% unaccounted-for water as opposed to 70%. Areas of low pressure were located at the end of the Turangi distribution system in the airport area, where if total demand in the system were high enough, pressures would fall below atmospheric. Such an occurrence during times of peak flow would effectively interrupt water supply.

When pressures in a pipe system are below atmospheric pressure, there is the risk of creating a vacuum where water can be drawn from the ground into the pipe. This type of inward leakage into the pipe can potentially draw contaminants from septic tanks into the water distribution system (Peralta, 1997). Such situations are undesirable and have to be avoided. The area towards the end of the airport runway is at risk for this kind of problem. System upgrades to this portion of the Turangi system should be considered.

With respect to the ADB urban infrastructure proposal, this report raises serious questions as to the technical feasibility of the system proposed. The Turangi zone, supplied by the Turangi intake alone could probably work if demand were lowered. However, there is no discussion of how to effectively lower demand in the Turangi zone in the ADB report. Upgrades are proposed to all areas of the network that were neither upgraded in 1992 by WMI nor in 1998-99 during Project East. Upgrades would definitely be required if the Turangi zone were to function as suggested in the ADB report and most probably to a greater degree than considered in the report.

It is recommended that further work in developing hydraulic models of Rarotonga's water distribution system be performed. To facilitate this, a list of tasks to be performed by the Rarotonga Water Works Department, with assistance from SOPAC, has been included in Appendix E. This further work builds upon the modelling already performed in this report.

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Appendix A:
Hydraulic Tutorial Notes

Hydraulic Training

The training provided was spread out over 6 afternoons. By date, the following topics were covered:

Dec 2→ Quantity of Water Supply

- Quantity of consumption
- Factors effecting water demand
- Types of users
- Variation in use

Dec 3→ Introduction to Cybernet Version 3.0

Dec 6→ Basic Hydraulics

- Energy principle
- Bernoulli's Equation
- Head loss

Dec 7→ Collection, Distribution and Operational Elements

- Pipes, valves, storage
- Dead ends, high points, low points and water hammer

Dec 8→ Design of a Distribution System

Dec 9→ Typical Values in the Design and Operation of a Water Distribution System

Part 1

Purpose of Water Distribution systems:

- to convey some quantity of water to the individual users

Step 1- Estimating the level of water consumption

- the amount of water you have to supply determines how big your distribution system will have to be- eg. pipe size
- in order to estimate future water use, you have to estimate the future population you are going to be supplying

Things that increase (-) or decrease (¯) water usage:

- *population*- more people use more water
- *climate*- people use more water in drier, hotter climates (eg. watering gardens)
- *economic level*- rich people use more water than poorer people
- *population density*- areas where you have high concentrations of people living have a lower water demand (eg. in apartment buildings, don't have to water lawns)
- *industry*- industrial demands tend to be high, but it depends on the type of industry
- *cost*- people who pay for their water use less
- *pressure*- distributions systems that operate under high pressures use more water
- *quality of supply*- people use less water if the quality of that water is poor
- *culture*- some cultures use more water than others (eg. keeping pigs uses a lot of water)

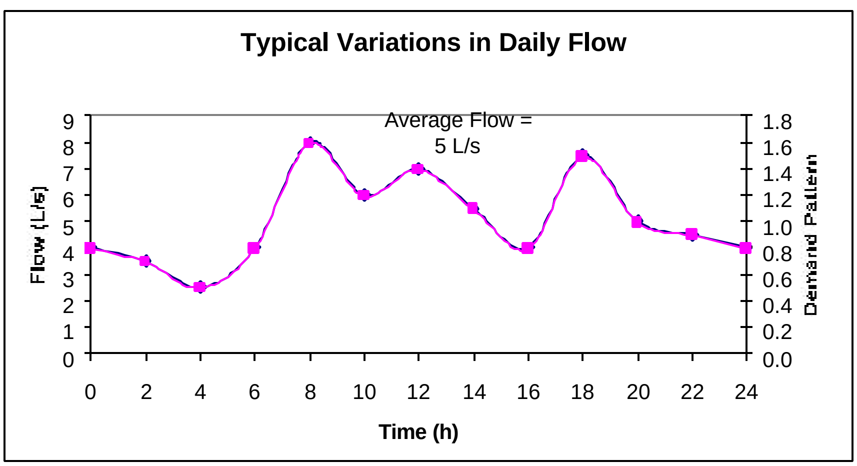
Different types of users:

- domestic
- commercial (stores, bars, restaurants, hotels)
- industrial (airports, factories)
- institutional (government buildings, schools, hospitals, prisons)
- agricultural

Total Consumption = domestic use + commercial use + public use + loss and waste

Water consumption varies during the:

- *year*- highest during the dry season
- *day*- highest around 7am in the morning when people getting up and showering, lowest from 2-4am in the morning when people are asleep



Time (h)	0	2	4	6	8	10	12	14	16	18	20	22	24
Flow (L/s)	4	3.5	2.5	4	8	6	7	5.5	4	7.5	5	4.5	4
Demand Pattern	0.8	0.7	0.5	0.8	1.6	1.2	1.4	1.1	0.8	1.5	1	0.9	0.8

The demand pattern is simply: $\dfrac{flow}{average\_flow}$

Part 2

Principle of Conservation of Energy:
- Energy can neither be created or destroyed, but can be changed from one form to another

Head (m) = Energy (J)

Bernoulli's Equation:
- Basically an energy balance from one point in a hydraulic (water distribution) system to another
- *Pressure Head*: $\dfrac{P}{g}$ Pressure is what makes pipes special→ *pressurized* closed conduits
- *Elevation Head*: z Same as Potential Energy
- *Velocity Head*: $\dfrac{v^2}{2g}$ Same as Kinetic Energy or energy due to motion
- *Head Loss*: h_L Energy lost to friction as water moves along the pipe

Minor losses→ occur in pipe fittings, bends, valves, meters, transitions, reducers, etc.

Pumps→ a pump will add head to your system

Hydraulic Grade Line (HGL):
- Sum of pressure head and elevation head
- In water open to the atmosphere (river, lake), the HGL is at the water surface
- The hydraulic gradient is the slope of the hydraulic grade line

Head Loss can be calculated using:
- *Darcy-Weisbach Equation* (use this one for pipe systems)
- Mannings Equation
- Hazen-Williams Equation

Velocity Profiles in a Pipe:
- Velocity in a pipe is greatest at the centre of the pipe
- Velocity is reduced towards the pipe wall because of friciton
- Velocity of water right at the pipe wall is 0

Note- *Look over Cybernet theory bit that was photocopied*

Part 3

Pipes→ pressurized closed conduits

Stresses Acting on Pipes:
- Pressure of water acting on the pipe (remember that the water doesn't want to be in the pipe and is always trying to force its way out)
- Forces caused by changes in the direction of flow within the pipe
- External loads like the weight of dirt on the buried pipe

- Changes in velocity

Water Hammer

- Results from the sudden stopping or slowing of flow in a pipe
- The kinetic energy of the water is transferred to the pipe wall and acts to stretch, deform and burst the pipe
- Can be avoided by closing valves slowly for example

Low Points

- Where the depth of the pipe below the ground surface is great
- High pressures may form at low points in the distribution system
- You want to break the hydraulic gradient at low points with pressure reducing valves (PRV), overflows, auxiliary reservoirs
- Place hydrants at low points in order to drain the distribution lines for maintenance purposes, and to remove sediment

High Points

- Should be kept below the HGL, otherwise you can get negative pressures in pipes which leads to the accumulation of gasses that may block the flow of water through pipes
- Negative pressures in pipes can create a vacuum that will actually suck water from the ground into your pipe→ problem if you are sucking in contaminated water from a septic tank
- Use vacuum, air relief valves, or pressure sustaining valves (PSV) to release air initially in the line or that accumulates over time, or to admit air when the line is being emptied for maintenance purposes

Valves

- Should be located at regular intervals (150-250 m) throughout the system so breaks in the pipe network can be isolated and fixed without disrupting flow to the entire system

Storage Tanks

- Used to equalize supply and demand over the long term or for emergencies such as fire
- Storage tanks placed in areas of high consumption and low pressure, and will act to increase pressure during periods of high use (7 in the morning)
- The tank will refill during the night when consumption is low and pressure high

Dead Ends

- A pipe that just terminates
- Should be avoided since supply is less certain, and lack of flow in the pipe may contribute to water quality problems

Part 4

Design of a distribution system depends on:

- *Topography*- since the water supply sources for Rarotonga are located above the level of the water users, no pumping is required → Rarotonga has a gravity distribution system
- *Users*- how much water people use determines how big your distribution system is going to have to be

Steps in designing a distribution system:

1. Flows to each section of the community must be estimated and designated to individual subareas of your system

2. A system of interlocking loops must be laid out→ this ensures continuous delivery of water even if a portion of the system is shut down for repairs
3. Flows are assigned to various nodes of the system

- The actual design of the distribution network involves determining the size of the pipes required to ensure appropriate pressures, flows, head losses and velocities in the system under a variety of design flow conditions

Design flow:
- must make sure that the system operates during the worst case scenario→ maximum daily flow + fire flow
- The design of a distribution system is based on the provision of adequate pressure for fire protection at the maximum daily flow, including fire demand

There are many solutions to the design problem of creating a distribution system→ you must optimise (adjust parameters such as pipe size to achieve the most appropriate pressures at nodes and velocities in pipes) to find the best solution.

Distribution system consists of a network of:
- nodes→ points of flow withdrawal
- links→ pipes connecting nodes

It is not reasonable to analyse a system up to every house→ individual flows can be concentrated at a smaller number of points, commonly at pipe (or road) intersections

Part 5

Design Element	***Typical Value***
Fire Flows (L/min)	1890 → min 32 400 → max
Distance between pipe on/off valves	150-250 m
Velocity in pipes to prevent deposition of sediment	0.3-0.6 m/s
Maximum velocity (@ design flow = max daily flow + fire flow)	≤1 m/s
Required pressure in distribution system	150-300 kPa
Distance between fire hydrants	60-150 m
Pipe depth in southern climates	~0.75 m
Location of pipes	Along right of way of streets

Appendix B:
Demand Data for Rarotonga

Table 1: Commercial, Industrial, Hotel and Institutional Demand in Rarotonga

	Dec93-Feb94 (m3/d)	Oct96 (m3/d)	Nov96 (m3/d)	Dec96 (m3/d)	Jan97 (m3/d)	Mar97 (m3/d)	Apr97 (m3/d)	May97 (m3/d)	Jun97 (m3/d)	Aug97 (m3/d)	Average (m3/d)
Airport Authority						15.88		16.76	17.73	45.46	23.96
ANZ Bank Building		7.25	14.13	8.10	5.59	3.20	3.27	3.15	6.80	3.00	6.05
Are Renga Motel	20.40		25.80	16.97	18.18	13.72	18.73	20.76	36.07	22.96	21.51
Ariana Bungalows		9.38	31.87	18.00	15.73	17.00	16.42	21.67	53.20	24.85	23.12
Ati's Beach Bungalows	3.26	3.13	4.00	4.03	3.09	4.40	6.42	4.00	6.80		4.35
Audtorium Water Tank		2.25	6.00	2.90	2.14	3.44	9.15	1.88	3.53	1.62	3.66
Avana Marine Condo's	3.51	1.50	4.93	2.10	5.23	1.44	3.15	1.82	5.07	4.54	3.33
B & M Heather LTD				0.69	0.59	0.48	0.42	0.30	0.47	0.31	0.47
B & M Heather LTD		4.88	16.53								10.70
Blue Pacific Laundry LTD	19.05	0.63									9.84
Concrete Structures LTD		0.50	2.67	2.76	1.09						1.75
Cook Island Bottlers LTD	1.51	70.75	33.40	15.03	16.23	14.76		12.45		9.19	21.67
CIDB Building	1.92										1.92
Cooks Conners Cafe	1.46	0.75	1.73	0.93	0.95	0.84	2.92	2.70	4.60	3.69	2.06
Cooks Conners Shopping Complex	2.76	2.00	5.20	2.59	2.41	2.88	0.92	0.94	1.80	1.08	2.26
Cultural Centre	4.13										4.13
Enuakura Petrol Station		0.63	1.07	0.62	0.91	0.68	0.69	1.06	0.33		0.75
Flame Tree Restaurant	7.23	8.88	0.07		4.00	2.72	5.46	5.12			4.78
Frangi Factory	3.42				3.59	1.76		2.24	6.40	1.38	3.13
G.L. Bergin Enterprises LTD			1.07	0.45	0.36	0.20		0.12		0.50	0.45
Hospital Water Tank	31.09		57.20	51.38	38.95			78.58		49.81	51.17
Just Burgers Takeaway							0.65	0.64	0.87	0.54	0.67
Kia Orana Factory	5.32										5.32

KiiKii Motel	1.15	1.88	2.47	0.76	1.41	1.28	0.69	0.30	1.67	1.54	1.31
KiiKii Motel	6.23	3.25	8.13	3.59	4.73	4.04	2.88	3.94	4.07	2.35	4.32
Lagoon Lodges Motel	11.75	8.50	19.87	5.76							11.47
Little Polynesian Motel	1.17		1.00	1.14	1.64	0.56	0.92	0.42	1.47	0.73	1.01
Little Polynesian Motel	6.48		19.33	2.07		1.48	0.92				6.06
Manihiki Hotel			0.07			0.08					0.07
Manuia Beach Hotel		13.50	23.40	12.83	10.14	10.08	11.04	6.61	20.67	2.73	12.33
Mataora's Flats		0.50	1.07	0.93	0.41	1.08	0.35	0.15	0.40	0.38	0.58
Mauke Hostel	3.55	0.50	3.40	1.17	1.59	1.40	2.65	0.82	0.93	0.46	1.65
Moana Sands Hotel	3.71	2.13	4.67	1.03	2.91	2.72	2.19	1.30	4.27	2.77	2.77
Muri Beachcomber Motel	37.19	65.75	58.60			9.44	59.46	61.73	70.40		51.80
Outrigger Restaurant	0.30										0.30
P & M Store		2.38	6.53	3.62	3.18	1.84	1.54	1.12	1.73	1.19	2.57
P J'S Bar & Cafe		6.25	11.80	4.97	2.41	7.52		6.67	11.93	8.27	7.48
Pacific Resort				41.69	85.64	88.52	82.12	54.09	73.20	38.46	66.25
Parliament House	0.86			0.28	0.32	0.36		0.33			0.43
Plam Grove Lodges	0.75	0.38	1.93	0.52	0.55	0.24	1.42	0.45			0.78
Plam Grove Lodges	2.57	2.25	4.60	1.93	1.82	0.48					2.28
Portofino Restaurant	7.59		3.67		9.14	7.52	1.69	1.60	3.27	3.62	4.76
Puaikura Reef Lodges	4.90	2.38	6.40	3.00		3.16	3.77	1.36	4.13		3.64
Puaikura Reef Lodges	0.01		0.33	0.45	5.14	0.16	0.12	0.42	0.20	2.73	1.06
Pukapuka Hostel	0.09	1.38	1.60	0.55	0.68	0.80	1.85	1.03	1.27	0.96	1.02
R.S.A. Club	6.61		13.40	8.52	7.14	6.32		3.09	5.47	2.31	6.61
Rarotonga Breweries LTD		14.38	39.47	22.17	13.45	14.96	12.35	12.18	13.47	7.12	16.62
Rarotonga Golf Club			16.60		5.82	6.36		3.39			8.04
Rarotongan Resort Hotel							135.23	126.06	155.67	37.23	113.55
Rarotongan Sunset Motel	9.32		11.27	1.90					0.40		5.72
Raymond Pirangi Store	5.50	10.50	13.93	4.79	8.95			5.33	10.53		8.51
Rose Flats	0.65	26.75	41.93	23.45	0.55	5.16	3.69	4.52	7.93	4.00	11.86

Rose Flats	1.84	10.00	19.87	5.17	4.59	21.32	13.65	170.91	20.87	4.35	27.26
Sailing Club	4.13										4.13
Sails Restaurant			2.93	0.24							1.59
Snowbird Laundry (Arorangi)	21.78		2.80		29.05			3.76			14.35
Snowbird Laundry (Avarua)	1.82		2.67	1.83	2.05	2.24	1.77	1.82	3.93		2.27
Sokala Villas		2.63	7.20	4.38	4.77	2.92	3.19	2.03	5.40	2.46	3.89
Squash Centre	0.34	0.88	1.53	1.00	0.36	1.00		1.18	2.13	0.50	0.99
Sunrise Beach Motel	3.17	2.50	7.20	0.97	1.14	1.48	1.04	0.79	1.60	0.50	2.04
T - Shirt Factory			0.20	0.14	0.09	0.08	0.35	0.15	0.20	0.12	0.17
Tamure Resort Hotel	3.00										3.00
Tepuka Pump Station		18.88				28.32		99.21	206.27	158.73	102.28
Tereora Pump Station		25.00	84.53	46.45	55.41						52.85
Trader Jacks	10.11	3.38	4.07								5.85
Tumunu Bar & Rest.	20.50		21.20	1.59				9.15			13.11
Tupapa Centre	0.76	2.88	5.60	9.03	5.00	6.80	3.77	3.64	1.73	3.88	4.31
Vaima Restaurant	0.80	0.75	1.87	0.69	0.73		0.58	0.42	0.73	0.15	0.75
Water Front Harbour						8.76		10.36	22.60	16.50	14.56

Table 2: Metered Commercial Demand in Rarotonga

	Dec93-Feb94 (m3/d)	Oct96 (m3/d)	Nov96 (m3/d)	Dec96 (m3/d)	Jan97 (m3/d)	Mar97 (m3/d)	Apr97 (m3/d)	May97 (m3/d)	Jun97 (m3/d)	Aug97 (m3/d)	Average (m3/d)
ANZ Bank Building		7.25	14.13	8.10	5.59	3.20	3.27	3.15	6.80	3.00	6.05
Audtorium Water Tank		2.25	6.00	2.90	2.14	3.44	9.15	1.88	3.53	1.62	3.66
CIDB Building	1.92										1.92
Cooks Conners Cafe	1.46	0.75	1.73	0.93	0.95	0.84	2.92	2.70	4.60	3.69	2.06
Cooks Conners Shopping Complex	2.76	2.00	5.20	2.59	2.41	2.88	0.92	0.94	1.80	1.08	2.26
Cultural Centre	4.13										4.13
Enuakura Petrol Station		0.63	1.07	0.62	0.91	0.68	0.69	1.06	0.33		0.75
Flame Tree Restaurant	7.23	8.88	0.07		4.00	2.72	5.46	5.12			4.78
Enterprises LTD			1.07	0.45	0.36	0.20		0.12		0.50	0.45
Just Burgers Takeaways							0.65	0.64	0.87	0.54	0.67
Outrigger Restaurant	0.30										0.30
P & M Store		2.38	6.53	3.62	3.18	1.84	1.54	1.12	1.73	1.19	2.57
P J'S Bar & Cafe		6.25	11.80	4.97	2.41	7.52		6.67	11.93	8.27	7.48
Portofino Restaurant	7.59		3.67		9.14	7.52	1.69	1.60	3.27	3.62	4.76
R.S.A. Club	6.61		13.40	8.52	7.14	6.32		3.09	5.47	2.31	6.61
Rarotonga Golf Club			16.60		5.82	6.36		3.39			8.04
Raymond Pirangi Store	5.50	10.50	13.93	4.79	8.95			5.33	10.53		8.51
Sailing Club	4.13										4.13
Sails Restaurant			2.93	0.24							1.59
Squash Centre	0.34	0.88	1.53	1.00	0.36	1.00		1.18	2.13	0.50	0.99
T - Shirt Factory			0.20	0.14	0.09	0.08	0.35	0.15	0.20	0.12	0.17
Trader Jacks	10.11	3.38	4.07								5.85
Tumunu Bar & Rest.	20.50		21.20	1.59				9.15			13.11
Tupapa Centre	0.76	2.88	5.60	9.03	5.00	6.80	3.77	3.64	1.73	3.88	4.31
Vaima Restaurant	0.80	0.75	1.87	0.69	0.73		0.58	0.42	0.73	0.15	0.75
Average Commercial Use											3.84
Average Restauraunt Use											4.13
Average Store Use											4.44

Table 3: Metered Industrial Demand in Rarotonga

	Dec93-Feb94 (m3/d)	Oct96 (m3/d)	Nov96 (m3/d)	Dec96 (m3/d)	Jan97 (m3/d)	Mar97 (m3/d)	Apr97 (m3/d)	May97 (m3/d)	Jun97 (m3/d)	Aug97 (m3/s)	Average (m3/s)
Airport Authority						15.88		16.76	17.73	45.46	23.96
B & M Heather LTD				0.69	0.59	0.48	0.42	0.30	0.47	0.31	0.47
B & M Heather LTD		4.88	16.53								10.70
Blue Pacific Laundry LTD	19.05	0.63									9.84
Concrete Structures LTD		0.50	2.67	2.76	1.09						1.75
Island Bottlers LTD	1.51	70.75	33.40	15.03	16.23	14.76		12.45		9.19	21.67
Frangi Factory	3.42				3.59	1.76		2.24	6.40	1.38	3.13
Kia Orana Factory	5.32										5.32
Rarotonga Breweries LTD		14.38	39.47	22.17	13.45	14.96	12.35	12.18	13.47	7.12	16.62
Snowbird Laundry (Arorangi)	21.78		2.80		29.05			3.76			14.35
Snowbird Laundry (Avarua)	1.82		2.67	1.83	2.05	2.24	1.77	1.82	3.93		2.27
Water Front Harbour						8.76		10.36	22.60	16.50	14.56
Average Industrial Use											10.38

Table 4: Metered Institutional Demand in Rarotonga

	Dec93-Feb94 (m3/d)	Oct96 (m3/d)	Nov96 (m3/d)	Dec96 (m3/d)	Jan97 (m3/d)	Mar97 (m3/d)	Apr97 (m3/d)	May97 (m3/d)	Jun97 (m3/d)	Aug97 (m3/d)	Average (m3/d)
Hospital Water Tank	31.09		57.20	51.38	38.95			78.58		49.81	51.17
Parliament House	0.86			0.28	0.32	0.36		0.33			0.43

Table 5: Metered Hotel Demand in Rarotonga

	Dec93-Feb94 (m3/d)	Oct96 (m3/d)	Nov96 (m3/d)	Dec96 (m3/d)	Jan97 (m3/d)	Mar97 (m3/d)	Apr97 (m3/d)	May97 (m3/d)	Jun97 (m3/d)	Aug97 (m3/s)	Average (m3/s)
Are Renga Motel	20.40		25.80	16.97	18.18	13.72	18.73	20.76	36.07	22.96	21.51
Ariana Bungalows		9.38	31.87	18.00	15.73	17.00	16.42	21.67	53.20	24.85	23.12
Ati's Beach Bungalows	3.26	3.13	4.00	4.03	3.09	4.40	6.42	4.00	6.80		4.35
Avana Marine Condo's	3.51	1.50	4.93	2.10	5.23	1.44	3.15	1.82	5.07	4.54	3.33
KiiKii Motel	1.15	1.88	2.47	0.76	1.41	1.28	0.69	0.30	1.67	1.54	1.31
KiiKii Motel	6.23	3.25	8.13	3.59	4.73	4.04	2.88	3.94	4.07	2.35	4.32
Lagoon Lodges Motel	11.75	8.50	19.87	5.76							11.47
Little Polynesian Motel	1.17		1.00	1.14	1.64	0.56	0.92	0.42	1.47	0.73	1.01
Little Polynesian Motel	6.48		19.33	2.07		1.48	0.92				6.06
Manihiki Hotel			0.07			0.08					0.07
Manuia Beach Hotel		13.50	23.40	12.83	10.14	10.08	11.04	6.61	20.67	2.73	12.33
Mataora's Flats		0.50	1.07	0.93	0.41	1.08	0.35	0.15	0.40	0.38	0.58
Mauke Hostel	3.55	0.50	3.40	1.17	1.59	1.40	2.65	0.82	0.93	0.46	1.65
Moana Sands Hotel	3.71	2.13	4.67	1.03	2.91	2.72	2.19	1.30	4.27	2.77	2.77
Muri Beachcomber Motel	37.19	65.75	58.60			9.44	59.46	61.73	70.40		51.80
Pacific Resort				41.69	85.64	88.52	82.12	54.09	73.20	38.46	66.25
Plam Grove Lodges	0.75	0.38	1.93	0.52	0.55	0.24	1.42	0.45			0.78
Plam Grove Lodges	2.57	2.25	4.60	1.93	1.82	0.48					2.28
Puaikura Reef Lodges	4.90	2.38	6.40	3.00		3.16	3.77	1.36	4.13		3.64
Puaikura Reef Lodges	0.01		0.33	0.45	5.14	0.16	0.12	0.42	0.20	2.73	1.06
Pukapuka Hostel	0.09	1.38	1.60	0.55	0.68	0.80	1.85	1.03	1.27	0.96	1.02
Rarotongan Resort Hotel							135.23	126.06	155.67	37.23	113.55
Rarotongan Sunset Motel	9.32		11.27	1.90					0.40		5.72
Rose Flats	0.65	26.75	41.93	23.45	0.55	5.16	3.69	4.52	7.93	4.00	11.86
Rose Flats	1.84	10.00	19.87	5.17	4.59	21.32	13.65	170.91	20.87	4.35	27.26
Sokala Villas		2.63	7.20	4.38	4.77	2.92	3.19	2.03	5.40	2.46	3.89
Sunrise Beach Motel	3.17	2.50	7.20	0.97	1.14	1.48	1.04	0.79	1.60	0.50	2.04
Tamure Resort Hotel	3.00										3.00
Average Hotel Use											13.86
Average Big Hotel Use (>5 m3/d)											31.90
Average Hostel Use											1.33
Average Little Hotel Use (<5m3/d)											2.18

Table 6: Determination of Agricultural Demand

Crops	Acreage	Area (m2)	Est. Plants per Acre	Total Plant Count	Kbc	Equivalent crop type for Kbc	Mean Temp-T (oC)	% of daytime hours- p	Consumptive Use (mm)	Consumptive Volume (m3)	Demand (m3/d)
Pawpaw	60	242820	800	48000	0.6	grapes	25	8.3	98	23747	779
Citrus	30	121410	430	12900	0.55	oranges	25	8.3	90	10884	357
Banana	20	80940	800	16000	0.85	corn	25	8.3	139	11214	368
Vegetable-leafy	10	40470	14500	145000	0.9	alfalfa	25	8.3	147	5937	195
Vegetable- fruits	20	80940	4800	96000	0.75	beets	25	8.3	122	9895	324
Vegetable-pulses	10	40470	14500	145000	0.7	beans	25	8.3	114	4618	151
Taro-dry	25	101175	7000	175000	0.75	potatoes	25	8.3	122	12368	406
Chilli	5	20235	4800	24000	0.7	tomatoes	25	8.3	114	2309	76
Total	180	728460							945	80972	2655

Using the Blaney-Criddle equation to determine water consumption by individual crops.

$U = 45.7\ Kbc(T + 17.8)p/100$

Comparative North American Kbc crop values were used.

Average Agricultural Demand from French records '92-'94 =	3.4 m3/plot*d
Average of 2 locations	
60	% Rarotonga households engage in agricultural activity
2569	Households on Rarotonga
1541.4	Households engaged in agriculture (# of plots)
5240.76	Agricultural demand (m3/d)
360	Counted agricultural plots from 1:25000 map of Rarotonga

Table 7: Total Demand in Rarotonga

Building Type	Number of Establishments from Raro Yellow Pgs (#)	Unit	Description of Unit	Typical Demand (L/unit*d)	Typical Demand (m3/d)	Known Metered Demand (m3/#*d)	Description of Known Demand Value	Known Demand (m3/d)	Total Demand (m3/d)	ADB Demands (m3/d)	Alternate Demands (m3/d)
Domestic	2569	10558	people	220	2323	0.3		3167	3167	2403	2640
Small Hotels (< 5m3/d)	12	901	beds	190	171	2.18	Average for <5m3 hotels	26			
Larger Hotels	56	988	beds	200	198	31.9	Average for >5m3 hotels	1787			
Hotels	*68*							1813	1813	899	-
Restaurants	20	180	meals	35	126	4.13	Average restaurant demand	83			
Car & Bike Rental	10	30	vehicles	40	12						
Boutiques	4	3	employee	40	0.48	0.17	Based on t-shirt factory	0.7			
Car Sales	4					0.45	GL Bergin car sellers	1.8			
Car Service	16	10	vehicles	40	6.4						
Cinema	1	140	seats	10	1.4						
Clubs	6	50	member	250	75	6.09	Avg of Sailing and golf club	37			
Engraver	1					5.59	Avg of B&M construction Co	5.6			
Food Stores	34					5.54	Avg of P&M and Ray's Store	188			
Jewellery	4					0.2	Based on t-shirt factory	0.8			
Liquor	6					0.2	Based on t-shirt factory	1.2			
Music Shops	8					0.2	Based on t-shirt factory	1.6			
Gas Stations	16					0.75	Enuakura gas station	12			
Arts & Crafts	16					2.02	From 3 stores in ANZ building	32			
Bakeries	7					5.54	Avg of P&M and Ray's Store	39			
Banks	6	15	employee	55	4.95	1.92	Same as CIDB	12			
Bars	17	50	customer	8	6.8	4.31	Tupapa Centre	73			
Cultural Centre	1					4.13	auditorium/library/museum	4.1			
Salons	3					3	Estimated	9			
Clothing Stores	12					2.02	From 3 stores in ANZ building	24			
Total Commercial	*192*							544.1918	1066	602	-
Actual Commercial	*376*										
Airport	1	500	passenger	10	5	24.0	Airport	24.0			
Breweries	2	10	employee	55	1.1	16.6	Rarotoga brewery	33.2			
Textiles	4					0.5	Based on t-shirt factory	2			
Glass Works	2	5	employee	55	0.55	10.7	Higher B&M construction Co	21.4			
Ice Cream Maker	1					3.1	Frangi Frozen foods	3.1			
Laundry	3	15	machines	2000	90	8.8	Avg of Laundry	26.5			
Press	1	10	employee	55	0.55		Higher B&M construction Co				
Drink Factory	2	10	employee	55	1.1	13.5	Avg of Kia Orana & CI Bottlers	27.0			
Meat Supplier	1					3.1	Frangi Frozen foods	3.1			
Shipping	1					14.6	Waterfront	14.6			
Construction Co	8	15	employee	55	6.6	5.6	Avg of B&M	44.7			
Total Industrial	*25*							200.1	424	795	-
Actual Industrial	53										
Churches	24	7239.8	people	8	58						
University	1	252	students	40	10						
Gov't Offices	19	1200	employee	55	66	0.43	Parliament building	8.2			
Hospital	1	70	beds	650	46	51.2	Hospital tank	51.2			
Prison	1	20	inmates	450	9						
Schools	9	2793	students	60	168						
Total institutional	*55*							362	362	361	-
Estimated Agricultural									5241	3775	2655
Total Demand									12073	8835	8959

Actual Commercial and Industral premises from ADB report, based on te Aponga (Rarotonga Electricity Authority) billing records.
Total are for the values in grey.

Table 8: Demand from Rarotonga's Intakes

Intakes	Average Demand from Intake (m3/d)	Avg Demand from Intake according to French (m3/d)	Elev (m)	Filtered	Comments
Turangi	2600	2074	69.1	y	best intake
Avana	2300	3400	78.4	n	
Avatiu	1650	1728	77.8	y	
Takuvaine	1650	2419	66.9	y	
Papua	2000	2160	46.8	n	
Taipara	2100	1100	47.5	y	
Ngatoe	1000		65	y	new 92
Tupapa	1000			y	new 93
Totokoitu	1000	1555	55.1	n	
Matavera	1900			y	new 94
Rutaki	400	432	48.5	y	
Muriavai	700	864	58.4	n	
Total	18300	19632			

Appendix C:
Descretized Demand Data for Turangi

Table 1: Demand at Individual Junctions in the Turangi Zone

Junction	User	Number of Users	Demand (m3/d)	Demand (L/s)	Total Demand (L/s)	Description of Demand Value
J-189	Houses	19		0.27		
	UC	1		0.01		Using domestic demand
	total demand at junction				0.29	
	demand used in the model				0.15	
J-190	Parliament		0.43	0.005		Metered location
	Frangi		3.13	0.04		Metered location
	Timber House		4.44	0.05		Same as store demand
	Cooks Corner Bus Services		1.2	0.01		Same as petrol station + G.L. Car Sellers
	Houses	19		0.27		
	Agricultural			0.15		
	total demand at junction				0.53	
	demand used in the model				0.20	
J-191	Airport		23.96	0.28		Metered location
	Mainline Office		0.55	0.01		Using typical office demand assuming 10 workers
	Old Age Home- Are Tapa'eanga			0.12		Typical rest home demand assuming 30 residents
	Blue Pacific Laundry		9.84	0.11		Metered location
	Triad		4.44	0.05		Same as store demand
	Catholic Cemetary			0.04		Same as agricultual demand
	Resene Paints		1.75	0.02		Same as Concrete Structures Ltd
	Clinic		2.6	0.03		typical hospital demand assuming 4 beds
	CIDB		1.92	0.02		Metered location
	Motor Centre		0.75	0.01		Same as Enuakura Petrol Station
	Manu Manea		0.17	0.002		Same as t-shirt factory
	Tyre Centre		0.75	0.01		Same as Enuakura Petrol Station
	Airfreight Int		0.55	0.01		Same as wearhouse demand
	Cook Is Steel Ind		10.7	0.12		Same as B&M Ltd Construction
	Houses	50		0.71		-where make blocks
	Stores	2	4.44	0.10		Average store demand
	VF	1		0		
	Agricultural			0.20		
	total				1.85	
J-192	Palm Hardware			0.003		Using typical shopping centre assuming 6 workers
J-210	Mobil		0.75	0.01		Same as Enuakura Petrol Station
	Fletcher and John Short			0.01		Typical office demand assuming 10 employees
	House of Ariki		0.43	0.005		Same as parliament
	Printing Office		0.55	0.01		From typical demands assuming 10 employees
	Taro Swamp	1		0.04		Same as agricultual demand
	Avatiu Rugby Field			0.04		Same as agricultual demand
	LDS Church		2.41	0.03		typical demands assuming 302 church/M. house attendees
	Cemetary			0.04		Same as agricultual demand
	Club House		4.13	0.05		Average bar & restaurant demand
	Tere's Bar		4.13	0.05		Average bar & restaurant demand
	Meeting House		2.41	0.03		typical demands assuming 302 church/M. house attendees
	CITC Compound		0.55	0.01		Same as wearhouse demand
	Bargan Centre		4.44	0.05		Same as store demand
	Stores	2	4.44	0.10		Average store demand
	Houses	35		0.50		
	VF	3		0		
	UC	1		0.01		Using domestic demand
	VU	1		0		
	Agricultural			0.17		
	total				1.15	50% to each junction
J-212	Warehouse		0.55	0.01		typical industrial building demand assuming 10 employees
J-47	Workshop		0.55	0.01		typical industrial building demand assuming 10 employees
	Coco Photos			0.002		Typical office demand assuming 3 workers
	Rental Cars		0.45	0.01		same as GL Bergin car sellers
	Raro Safari Tour Guides			0.01		Typical office demand assuming 10 employees
	Odds & Ends store		0.17	0.002		Same as t-shirt factory
	Meeting House		2.41	0.03		typical demands assuming 302 church/M. house attendees
	DHL		0.44	0.01		Typical office demand assuming 8 workers
	Houses	10		0.14		
	total				0.20	50% to each junction
J-193	Poly Rakei		0.17	0.002		Same as t-shirt factory
	Te Mato Tupuranga		1.1	0.01		typical office demand, assuming 20 workers
	South Seas			0.004		Typical department store demand assuming 8 workers
	Furniture Centre		4.44	0.05		Same as store demand
	Houses	16		0.23		
	UC	1		0.01		Using domestic demand
	total				0.31	
J-194	Catholic Church		2.41	0.03		typical demands assuming 302 church/M. house attendees
Node 10b	St. Joseph Hall		2.41	0.03		typical demands assuming 302 church/M. house attendees
	Budget Rental		0.45	0.01		same as GL Bergin car sellers
	Ronnies Bar/Rest		4.13	0.05		Average bar & restaurant demand
	Goldmine		0.17	0.002		Same as t-shirt factory
	Vonnia's			0.006		Typical department store demand assuming 12 workers
	Mana Court		0.17	0.002		Same as t-shirt factory
	Houses	7		0.10		
	total				0.22	75% to Node 10b, 25% to J-194
Node 10a	Island Craft		0.17	0.002		Same as t-shirt factory
Node 10ai	Westpac Bank		1.92	0.02		Same as CIDB
	Foodland		4.44	0.05		Same as average store
	Mana's Café		2.06	0.02		Same as Cook's Corner Café
	CIDB Building		1.92	0.02		Metered location
	Police Dept		2.37	0.03		same as CIDB Building and GL Bergin car sellers
	Rental Cars		0.45	0.01		same as GL Bergin car sellers
	Petrol Station		0.75	0.01		Same as Enuakura Petrol Station
	Cooks Corner		4.32	0.05		Cook's Corner + Cook's Corner Café
	Offsbank		1.92	0.02		same as CIDB Building
	CITC		6.48	0.08		typical department store demand, assuming 2 toilet rooms, 62 workers
	Houses	5		0.07		
	total				0.38	75% to Node 10ai, 25% to Node 10a
J-81	Matina Travels		0.66	0.01		Typical office demand assuming 12 workers
Node 9i	Tourist Authority			0.01		Typical office demand assuming 12 workers
Node 9	Banana Court		4.13	0.05		Average bar & restaurant demand
	Administration Block		4.125	0.05		typical office demand assuming 75 workers
	Philatelic			0.01		typical office demand assuming 10 workers
	Small Business		4.44	0.05		Same as average store
	Electrical		0.47	0.01		Same as B&M Ltd. Construction-lower value

Type of User Demand	Value	Unit
Commercial	0.044	L/est*s
Domestic	0.014	L/house*s
Hotel	0.16	L/hotel *s
Industrial	0.12	L/est*s
Institutional	0.18	L/est*s
Agricultural	0.039	L/plot*s
Turangi Clinics	2.6	m3/clinic*d
Turangi Churches	3.02	m3/church*d
Warehouse	0.55	m3/warehouse*d
Bar & Restaurant	4.13	m3/est*d
Store	4.44	m3/est*d

Conversion 0.000012 L/d into L/s
Conversion 0.011574 m3/d into L/s
Conversion 0.001 L/d into m3/d

Total number of Junctions in Turangi Zone = 88
Average Demand from Turangi Intake = 2600 m3/d

VU - Vacant, Unfit for living
VF - Vacant, Fit for living
UC - Under Construction

	Waterfront Harbour		14.56	0.17		Metered demand
	Stores	1	4.44	0.05		Average store demand
	Houses	2		0.03		
	total				0.42	40% to Node 9 amd J-81, 20% to Node 9i
J-223	Brewery		16.62	0.19		Assuming Rarotonga Brewereies- metered
	Prestige		1.75	0.02		Same as Concrete Structures Ltd.
	Cook Is News			0.01		typical office demand assuming 15 workers
	Cook Is Sports			0.01		typical office demand assuming 15 workers
	Central Motel		13.86	0.16		same as average hotel demand
	Houses	17		0.24		
	total				0.63	
J-99	Clinic		2.6	0.03		typical hospital demand assuming 4beds
Node 3	Meeting House		2.41	0.03		typical demands assuming 302 church/M. house attendees
	Stores	2	4.44	0.10		
	Houses	39		0.56		
	total				0.72	50% to each Junction
Node 4	Administration Block			0.05		typical office demand assuming 80 workers
Node 4i	Theological College			0.04		typical school demand assuming 60 students
	USP		10.08	0.12		From typical demand assuming 252 students
	Aitutaki Hostel		1.33	0.02		average hostel
	Avarua School			0.10		typical school demand assuming 150 students
	Houses	22		0.31		
	total				0.64	50% to each Junction
J-213	Are Taunga		0.17	0.002		Same as t-shirt factory
	Marine Resources			0.01		typical office demand assuming 15 workers
	Empire Theater		1.4	0.02		From typical theater demand assuming 140 seats
	Raro Records		0.17	0.002		Same as t-shirt factory
	Vanwil Agencies		4.44	0.05		typical office demand assuming 10 workers
	Stores	1	4.44	0.05		Average store demand
	Houses	3		0.04		
	total				0.18	
J-84	Para O Tane Palace			0.03		Same as domestic domand
J-215	Library		1.38	0.02		one third cultural centre value
J-214	CICC Church		2.41	0.03		typical demands assuming 302 church/M. house attendees
	Sinai Hall		2.41	0.03		typical demands assuming 302 church/M. house attendees
	Print Office		0.55	0.01		From typical demands assuming 10 employees
	Atiu Hostel		1.33	0.02		average hostel
	Houses	10		0.14		
	VU	1		0		
	total				0.26	33% to each Junction
J-86	Mani Hostel		1.33	0.02		average hostel
	Mauke Hostel		1.65	0.02		Metered location
	Mitiaro Hostel		1.33	0.02		average hostel
	Houses	14		0.20		
	Stores	1	4.44	0.05		Average store demand
	total				0.30	
J-87	Shed		0.55	0.01		Same as wearhouse demand
	Tupapa Centre		4.31	0.05		Metered location
	Mangaia Hostel		1.33	0.02		average hostel
	Houses	4		0.06		
	total				0.13	
J-98	Maraerenga Clinic		2.6	0.03		typical hospital demand assuming 4beds
Node 5	Pai Taro		0.55	0.01		Same as wearhouse demand
	Houses	4		0.06		
	total				0.09	50% to each Junction
J-216	Paradise Inn		13.86	0.16		Average hotel demand
Node 8	Meeting House		2.41	0.03		typical demands assuming 302 church/M. house attendees
Node 8i	Restaurant		4.13	0.05		Average restaurant demand
	Stores	4	4.44	0.21		Average store demand
	Houses	36		0.51		
	total				0.96	45% to J-216 and Node 8, 10% to Node 8i
J-217	Cultural Centre- Library		4.13	0.05		Metered location
	Museum, Auditorium					
	NZ Maori Hostel		1.33	0.02		average hostel
	Pukapu Hostel		1.02	0.01		Metered location
	Penr. Hostel		1.33	0.02		average hostel
	Tupapa Rugby Field			0.04		Same as agricultual demand
	Tupapa Netball Court			0.04		Same as agricultual demand
	Houses	7		0.10		
	VF	1		0		
	total				0.27	
J-218	Meeting House		2.41	0.03		typical demands assuming 302 church/M. house attendees
J-219	Dental Clinic		2.6	0.03		typical hospital demand assuming 4beds
	Out Patient		2.6	0.03		typical hospital demand assuming 4beds
	Stores	1	4.44	0.05		Average store demand
	Houses	24		0.34		
	VF	1		0		
	total				0.48	50% to each Junction
J-89	Houses	24		0.34		
	Stores	1	4.44	0.05		Average store demand
	VF	1		0		
	Agriculural			0.16		
	total				0.55	
Node 6	Old t-shirt Factory		0.17	0.002		Same as t-shirt factory
Node 6i	Aramoana Flats		11.86	0.14		Same as Rose Flats- the sans pool connection
	Houses	13		0.19		
	Agricultural			0.09		
	total				0.41	50% to each Junction
J-100	Avarua Bakery		5.54	0.06		Same as for food stores
	Triad Storage		0.55	0.01		Same as wearhouse demand
	Houses	11		0.16		
	VF	1		0		
	Agricultural			0.30		
	total				0.53	
J-141	Just Burgers		0.67	0.01		Metered location
Node 7	Houses	10		0.14		
	Stores	2	4.44	0.10		Average store demand
	VU	2		0		
	total				0.25	90% to J-141, 10% to Node 7
J-106	Clinic		2.6	0.03		typical hospital demand assuming 4beds
	Internal Affairs Office			0.01		typical office demand assuming 20 workers
	Houses	17		0.24		
	Stores	1	4.44	0.05		Average store demand

	VF	1		0		
	total				0.34	
J-92	Stores	2	4.44	0.10		Average store demand
	Houses	22		0.31		
	total				0.42	
J-131	Houses	11		0.16		
J-130	VU	1		0		
	UC	1		0.01		Using domestic demand
	total				0.17	90% to J-131, 10% to J-130
J-94	Houses	8		0.11		
	Agricultural			0.03		
	total				0.14	
J-95	APOS Church		2.41	0.03		typical demands assuming 302 church/M. house attendees
J-101	Fishing Club		4.13	0.05		Same as sailing club
	Houses	28		0.40		
	UC	2		0.03		Using domestic demand
	Agricultural			0.23		
	total				0.73	90% to J-101, 10% to J-95
J-139	Houses	15		0.21		
J-140	Agricultural			0.37		
	total				0.59	90% to J-140, 10% to J-139
J-93	Club Raro Resort		31.9	0.37		Same as big hotel demand
	Kiikii Motel		5.63	0.07		Metered location
	Punamaia Motel		13.86	0.16		Same as average hotel demand
	Houses	18		0.26		
	Stores	1	4.44	0.05		Average store demand
	VF	1		0		
	total				0.90	
J-96	Clinic		2.6	0.03		typical hospital demand assuming 4beds
J-122	Houses	34		0.49		
	VF	2		0		
	Agricultural			0.43		
	total				0.95	90% to J-96, 10% to J-122
J-102	Houses	21		0.30		
	VF	1		0		
	Agricultural			0.24		
	total				0.54	
J-103	Houses	6		0.09		
	Agricultural			0.43		
	total				0.52	
J-121	Houses	14		0.20		
	Agricultural			0.56		
	total				0.76	
J-90	Houses	4		0.06		
J-120	Clinic		2.6	0.03		typical hospital demand assuming 4beds
	Agricultural			0.20		
	total				0.29	90% to J-90, 10% to J-120
J-119	Houses	27		0.39		
	Stores	1	4.44	0.05		Average store demand
	Agricultural			0.05		
	total				0.49	
J-104	Houses	8		0.11		
	UC	1		0.01		Using domestic demand
	total				0.13	
J-138	Houses	22		0.31		
J-137	Agricultural			0.28		
	total				0.59	90% to J-138, 10% to J-137
J-118	Peasat			0.002		Typical office demand assuming 3 employees
	Houses	39		0.56		
	Stores	2	4.44	0.10		Average store demand
	Agricultural			0.26		
	total				0.92	
J-129	Matavera Primary School			0.10		typical school demand assuming 140 students
J-126	Houses	14		0.20		
	Agricultural			0.39		
	total				0.69	90% to J-129, 10% to J-126
J-105	Houses	41		0.59		
J-110	Agricultural			0.35		
	total				0.94	50% to each Junction
J-117	Houses	8		0.11		
	VU	1		0		
	Agricultural			0.02		
	total				0.11	
J-114	Packing Shed		0.55	0.01		Same as wearhouse demand
	Meeting House		2.41	0.03		typical demands assuming 302 church/M. house attendees
	Stores	2	4.44	0.10		Average store demand
	Houses	15		0.21		
	total				0.35	
J-115	Houses	10		0.14		
	VF	1		0		
	Agricultural			0.28		
	total				0.42	
J-109	Houses	9		0.13		
	VF	1		0		
	Agricultural			0.28		
	total				0.40	
J-108	Houses	7		0.10		
	total				0.10	
J-111	Houses	4		0.06		
J-133	UC	2		0.03		Using domestic demand
	total				0.09	90% to J-133, 10% to J-111
J-112	Houses	6		0.09		
	total				0.09	
J-116	Houses	6		0.09		
	Agricultural			0.20		
	total				0.20	
J-80	Catholic Church		2.41	0.03		typical demands assuming 302 church/M. house attendees
J-113	SDA Church		2.41	0.03		typical demands assuming 302 church/M. house attendees
	Clinic		2.6	0.03		typical hospital demand assuming 4beds
	Sunday School Hall		2.41	0.03		typical demands assuming 302 church/M. house attendees
	Houses	14		0.20		
	VU	1		0		
	total				0.31	90% to J-80, 10% to J-113

J-135	CICC Church		2.41	0.03		typical demands assuming 302 church/M. house attendees
J-136	Houses	24		0.34		
	VF	3		0		
	Agricultural			0.31		
	total				0.69	90% to J-135, 10% to J-136
J-125	Clinic		2.6	0.03		typical hospital demand assuming 4beds
J-107	Houses	48		0.68		
	Stores	1	4.44	0.05		Average store demand
	VF	2		0		
	total				0.77	90% to J-125, 10% to J-107
J-124	Sunrise Beach Motel		2.04	0.02		Metered location
	Houses	25		0.36		
	Stores	2	4.44	0.10		Average store demand
	VF	3		0		
	VU	1		0		
	UC	1		0.01		Using domestic demand
	Agricultural			0.08		
	total				0.58	
J-132	Houses	13		0.19		
J-123	UC	1		0.01		Using domestic demand
J-134	Agricultural			0.47		
	total				0.67	33% to each Junction
J-128	Houses	15		0.21		
	UC	1		0.01		Using domestic demand
	Agricultural			0.28		
	total				0.50	
J-127	Vaka Village			0.02		Typical demand assuming 1 public toilets
J-78	Sunday School Hall		2.41	0.03		typical demands assuming 302 church/M. house attendees
	CICC Church		2.41	0.03		typical demands assuming 302 church/M. house attendees
	Are Vaka			0.02		Typical demand assuming 1 public toilets
	Houses	31		0.44		
	VF	5		0		
	UC	1		0.01		Using domestic demand
	total				0.56	50% to each Junction
Total Turangi demand				27.22	27.22	L/s
Total Turangi demand				2351 m3/d		
Measured Flow from Turangi Intake				2600 m3/d		
Measured Flow from Turangi Intake				30.1 L/s		

Table 2: Agricultural Demand at Individual Junctions in the Turangi Zone

Junction	Area of MapInfo Plots (m2)	Additional Plots Counted 1:25000 Map	Total Area (m2)	Agricultural Demand (L/s)
J-190	1607			
	3449			
	1431			
			6487	0.151
J-191	803			
	749			
	4332			
	1119			
	1473			
			8476	0.197
J-210	2785			
	982			
	521			
	698			
	1046			
			6032	0.140
J-192	1491			
			1491	0.035
J-89		4		
			6768	0.157
Node6	1970			
	1859			
			3829	0.089
J-100	1980			
	1558			
	1453			
	1430			
	3281			
	2441			
	784			
			12927	0.301
J-94	1102			
			1102	0.026
J-101	3798			
J-95	934			
		3		
			9808	0.228
J-139	2161			
J-140	6738			
	2045			
		3		
			16020	0.373
J-96	4107			
J-122	2220			
	2085			
	1657			
	1079			
	2265			
	1023			
	1288			
	2822			
			18546	0.431
J-102	3653			
		4		
			10421	0.242
J-121	1014			
	1869			
	1962			
	2670			
	1460			
	3317			
	2212			
	8706			
	682			
			23892	0.556
J-103		11		
J-104			18612	0.433
J-90	851			
J-120	509			
	1345			
	1498			
	4503			
			8706	0.202
J-119	2124			
			2124	0.049
J-118	1052			
	1655			
	1439			

Conversion 0.011574 m3/d into L/s

Median Agricultural Plot Area = 1692 m2

	1581			
	1358			
	2207			
	585			
	1173			
			11050	0.257
J-137		7		
J-138			11844	0.275
J-105		9		
			15228	0.354
J-129	6822			
J-126		6		
			16974	0.395
J-117	805			
			805	0.019
J-115		7		
			11844	0.275
J-110		5		
			8460	0.197
J-109		2		
			3384	0.079
J-116		5		
			8460	0.197
J-135		8		
J-136			13536	0.315
J-134		12		
J-132			20304	0.472
J-123				
J-124	1425			
	2037			
			3462	0.081
J-128		7		
			11844	0.275
Total			292436	

Table 3: Determination of Total Area of Agricultural Plots in Rarotonga

Agricultural Plot	Area (m2)
1	1607
2	3449
3	803
4	749
5	1795
6	15476
7	1782
8	4332
9	1119
10	1473
11	982
12	521
13	2785
14	5117
15	616
16	891
17	1336
18	700
19	683
20	998
21	524
22	1009
23	924
24	698
25	1046
26	1491
27	589
28	392
29	392
30	361
31	1076
32	1354
33	1548
34	1541
35	1970
36	1859
37	1980
38	784
39	1102
40	6738
41	2161
42	4107
43	2220
44	2085
45	1657
46	1079
47	1023
48	2265
49	2822
50	1288
51	3653
52	1014
53	1869
54	1962
55	2670
56	1460
57	3317
58	2212
59	682
60	8706
61	851
62	509
63	1345
64	1498
65	4503
66	2124
67	2207
68	1581
69	1439
70	1358
71	1173
72	1655
73	1052
74	585
75	6822
76	805
77	1425
78	2037
79	1558
80	1431
81	1995
82	594

Median Agricultural Plot Area =	1692	m2
Average Agricultural Plot Area =	2248	m2
Total MapInfo Agricultural Area =	548432	
Additional Agricultural Plots Counted from map of Rarotonga =	116	m2
Additional Agricultural Area =	196272	m2
Total Agricultural Area =	744704	m2
Area of Agricultural Plots in Rarotonga as determined by Dept of Agriculture =	728460	%
Percent Difference =	2	

83	2045
84	1151
85	5806
86	9270
87	5367
88	882
89	2460
90	2551
91	3964
92	3672
93	3562
94	325
95	3331
96	4351
97	3183
98	6888
99	3677
100	1897
101	5808
102	4691
103	1691
104	6119
105	2389
106	2418
107	2805
108	3925
109	2759
110	1039
111	2788
112	2988
113	1612
114	3831
115	1836
116	2784
117	816
118	3686
119	2802
120	723
121	1734
122	1475
123	1186
124	11232
125	767
126	660
127	1728
128	1001
129	3440
130	2359
131	811
132	1557
133	1002
134	1361
135	770
136	3521
137	2367
138	1670
139	579
140	1002
141	2051
142	1700
143	2225
144	1244
145	1649
146	1061
147	791
148	498
149	1162
150	890
151	2008
152	1939
153	704
154	1378
155	798
156	852
157	640
158	812
159	642
160	1693
161	1117
162	4399
163	2802
164	1551
165	5454
166	4685

167	1907
168	2029
169	807
170	1440
171	1860
172	634
173	1606
174	666
175	1091
176	929
177	6472
178	4271
179	1783
180	1835
181	3109
182	1184
183	4194
184	979
185	1329
186	2567
187	2621
188	2439
189	1482
190	567
191	1873
192	1370
193	2958
194	805
195	3256
196	2456
197	1462
198	833
199	2802
200	453
201	609
202	467
203	6511
204	1964
205	3622
206	4481
207	3353
208	6170
209	1925
210	1445
211	3796
212	1800
213	2695
214	3188
215	1315
216	5556
217	2568
218	4248
219	2045
220	1364
221	1613
222	1183
223	4323
224	2028
225	811
226	3796
227	4134
228	1748
229	2163
230	1465
231	5811
232	2863
233	567
234	3880
235	1186
236	1469
237	804
238	1810
239	1453
240	1430
241	3281
242	2441
243	3798
244	934

Table 4: Estimates of Population in the Turangi Zone

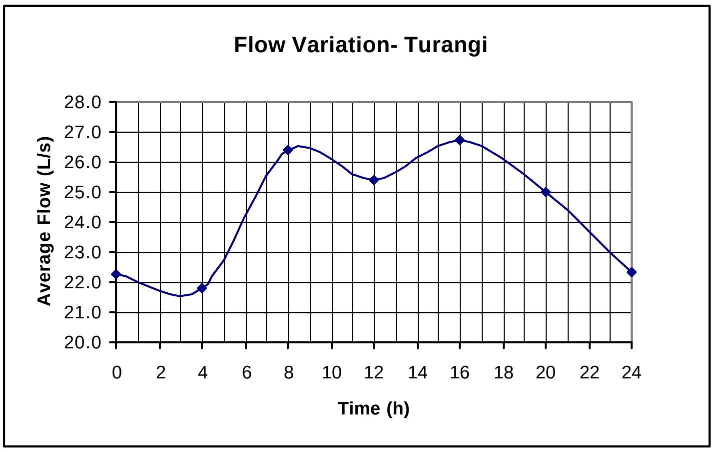
Census District Regions	Percent of Pop in Turangi District	Poputaltion	Population in Turangi
Matavera	100	762	762
Pue-Matavera	100	1096	1096
Tupapa-Maraere	100	524	524
Ngatangiia-Muri	50	939	470
Nikao-Panama	25	1269	317
Takuvaine-Parek	67	803	535
Tutakimoa-Teotu	25	390	98
Avatiu-Ruatonga	25	1066	267
Total			4068

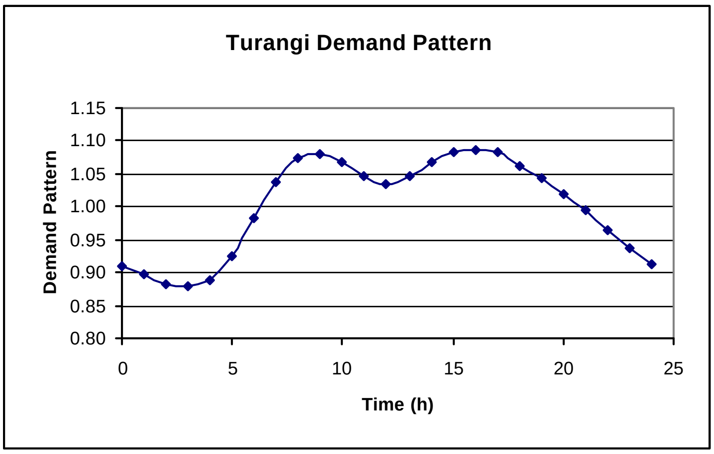
Total Houses in Turangi Zone =	981
Average Number of People per House =	4.1
Population in Turangi Zone =	4022
Percent Difference, % =	1.1

Table 5: Turangi Demand Pattern

	Flow (L/s)							
	Sun	Thur	Wed	Mon	Fri	Tues	Sat	
Time	23/08/92	27/08/92	9/9/92	7/9/92	4/9/92	27/10/92	24/10/92	Average
0	21	22.5	26	24.5	23.5	19	19.5	22.3
4	20.5	22	25	24	23	19	19	21.8
8	24.5	25	29	28.5	26.5	26	25.5	26.4
12	23.5	23.5	27	28	27	25	24	25.4
16	23	24.5	30.5	29	30	24.5	25.5	26.7
20	21	23	29.5	28	27.5	25	21	25.0
24	20	21	25	24	25	22.5	19	22.4
Average	21.9	23.1	27.4	26.6	26.1	23.0	21.9	24.3

Time	**Flow (L/s)**	**Demand Pattern**
0	22.3	0.91
1	22	0.90
2	21.7	0.88
3	21.6	0.88
4	21.8	0.89
5	22.7	0.92
6	24.1	0.98
7	25.5	1.04
8	26.4	1.08
9	26.5	1.08
10	26.2	1.07
11	25.7	1.05
12	25.4	1.03
13	25.7	1.05
14	26.2	1.07
15	26.6	1.08
16	26.7	1.09
17	26.6	1.08
18	26.1	1.06
19	25.6	1.04
20	25	1.02
21	24.4	0.99
22	23.7	0.97
23	23	0.94
24	22.4	0.91
Average	24.6	





Appendix D:
Calibration and Model Run of the Turangi Hydraulic Model

Table 1: Summary of Calibration Scenarios

Junction/ Intake	Roughness Calibration Factor	Flow Calibration Factor	Model Pressure Head (m)	Maximum Metered Pressure Head (m)	Minimum Metered Pressue Head (m)	Percent Difference (%)	Model Flow (l/s)	Average Metered Flow (L/s)	Maximum Metered Flow (L/s)	Percent Difference (%)
Turangi Intake	1	1					22.83	22.7	36.9	0
Matavera Intake	1	1					-0.62	14.7	26.5	2471
Tupapa Intake	1	1					5.31	19.6	35.6	269
J-191- Airport	1	1	60.27	24	14	151				
10b- Catholic Church Hydrant	1	1	61.92	26	18	138				
J-213- Empire Theather	1	1	63.2	30	18	111				
J-101- Apstalic Church	1	1	50.38	27	12	87				
Node 6- Goldie PP	1	1	61.33	50	24	23				
J-122- Ngatipa Clinic	1	1	57.61	30	26	92				
J-104- Tupapa PP	1	1	58.51	60	17	0				
J-108- Matavera PP	1	1	54.01	60	15	0				
J-124- Turangi PP	1	1	62.77	65	22	0				
J-127- Avana PP	1	1	66.52	70	25	0				

Junction/ Intake	Roughness Calibration Factor	Flow Calibration Factor	Model Pressure Head (m)	Maximum Metered Pressure Head (m)	Minimum Metered Pressue Head (m)	Percent Difference (%)	Model Flow (l/s)	Average Metered Flow (L/s)	Maximum Metered Flow (L/s)	Percent Difference (%)
Turangi Intake	1.5	2.34					30.6	22.7	36.9	0
Matavera Intake	1.5	2.34					16.1	14.7	26.5	0
Tupapa Intake	1.5	2.34					16.9	19.6	35.6	16
J-191- Airport	1.5	2.34	45.9	24	14	91				
10b- Catholic Church Hydrant	1.5	2.34	51.43	26	18	98				
J-213- Empire Theather	1.5	2.34	52.72	30	18	76				
J-101- Apstalic Church	1.5	2.34	43.65	27	12	62				
Node 6- Goldie PP	1.5	2.34	53.26	50	24	7				
J-122- Ngatipa Clinic	1.5	2.34	49.14	30	26	64				
J-104- Tupapa PP	1.5	2.34	54.55	60	17	0				
J-108- Matavera PP	1.5	2.34	51.56	60	15	0				
J-124- Turangi PP	1.5	2.34	57.8	65	22	0				
J-127- Avana PP	1.5	2.34	61.54	70	25	0				

Junction/ Intake	Roughness Calibration Factor	Flow Calibration Factor	Model Pressure Head (m)	Maximum Metered Pressure Head (m)	Minimum Metered Pressue Head (m)	Percent Difference (%)	Model Flow (l/s)	Average Metered Flow (L/s)	Maximum Metered Flow (L/s)	Percent Difference (%)
Turangi Intake	1.5	2.8					34.2	22.7	36.9	0
Matavera Intake	1.5	2.8					21	14.7	26.5	0
Tupapa Intake	1.5	2.8					20.9	19.6	35.6	0
J-191- Airport	1.5	2.8	38.33	24	14	60				
10b- Catholic Church Hydrant	1.5	2.8	45.98	26	18	77				
J-213- Empire Theather	1.5	2.8	47.27	30	18	58				
J-101- Apstalic Church	1.5	2.8	40.06	27	12	48				
Node 6- Goldie PP	1.5	2.8	49.02	50	24	0				
J-122- Ngatipa Clinic	1.5	2.8	44.71	30	26	49				
J-104- Tupapa PP	1.5	2.8	52.31	60	17	0				
J-108- Matavera PP	1.5	2.8	49.97	60	15	0				
J-124- Turangi PP	1.5	2.8	55.15	65	22	0				
J-127- Avana PP	1.5	2.8	58.89	70	25	0				

Junction/ Intake	Roughness Calibration Factor	Flow Calibration Factor	Model Pressure Head (m)	Maximum Metered Pressure Head (m)	Minimum Metered Pressue Head (m)	Percent Difference (%)	Model Flow (l/s)	Average Metered Flow (L/s)	Maximum Metered Flow (L/s)	Percent Difference (%)
Turangi Intake	1.5	3.1					36.7	22.7	36.9	0
Matavera Intake	1.5	3.1					24.1	14.7	26.5	0
Tupapa Intake	1.5	3.1					23.5	19.6	35.6	0
J-191- Airport	1.5	3.1	32.76	24	14	37				
10b- Catholic Church Hydrant	1.5	3.1	41.96	26	18	61				
J-213- Empire Theather	1.5	3.1	43.26	30	18	44				
J-101- Apstalic Church	1.5	3.1	37.4	27	12	39				
Node 6- Goldie PP	1.5	3.1	45.89	50	24	0				
J-122- Ngatipa Clinic	1.5	3.1	41.44	30	26	38				
J-104- Tupapa PP	1.5	3.1	50.63	60	17	0				
J-108- Matavera PP	1.5	3.1	48.76	60	15	0				
J-124- Turangi PP	1.5	3.1	53.19	65	22	0				
J-127- Avana PP	1.5	3.1	56.93	70	25	0				

Junction/ Intake	Roughness Calibration Factor	Flow Calibration Factor	Model Pressure Head (m)	Maximum Metered Pressure Head (m)	Minimum Metered Pressue Head (m)	Percent Difference (%)	Model Flow (l/s)	Average Metered Flow (L/s)	Maximum Metered Flow (L/s)	Percent Difference (%)
Turangi Intake	1.5	3.51					40.3	22.7	36.9	8
Matavera Intake	1.5	3.51					28.2	14.7	26.5	6
Tupapa Intake	1.5	3.51					27	19.6	35.6	0
J-191- Airport	1.5	3.51	24.35	24	14	1				
10b- Catholic Church Hydrant	1.5	3.51	35.88	26	18	38				
J-213- Empire Theather	1.5	3.51	37.18	30	18	24				
J-101- Apstalic Church	1.5	3.51	33.36	27	12	24				
Node 6- Goldie PP	1.5	3.51	41.14	50	24	0				
J-122- Ngatipa Clinic	1.5	3.51	36.49	30	26	22				
J-104- Tupapa PP	1.5	3.51	48.07	60	17	0				
J-108- Matavera PP	1.5	3.51	46.9	60	15	0				
J-124- Turangi PP	1.5	3.51	50.22	65	22	0				
J-127- Avana PP	1.5	3.51	53.96	70	25	0				

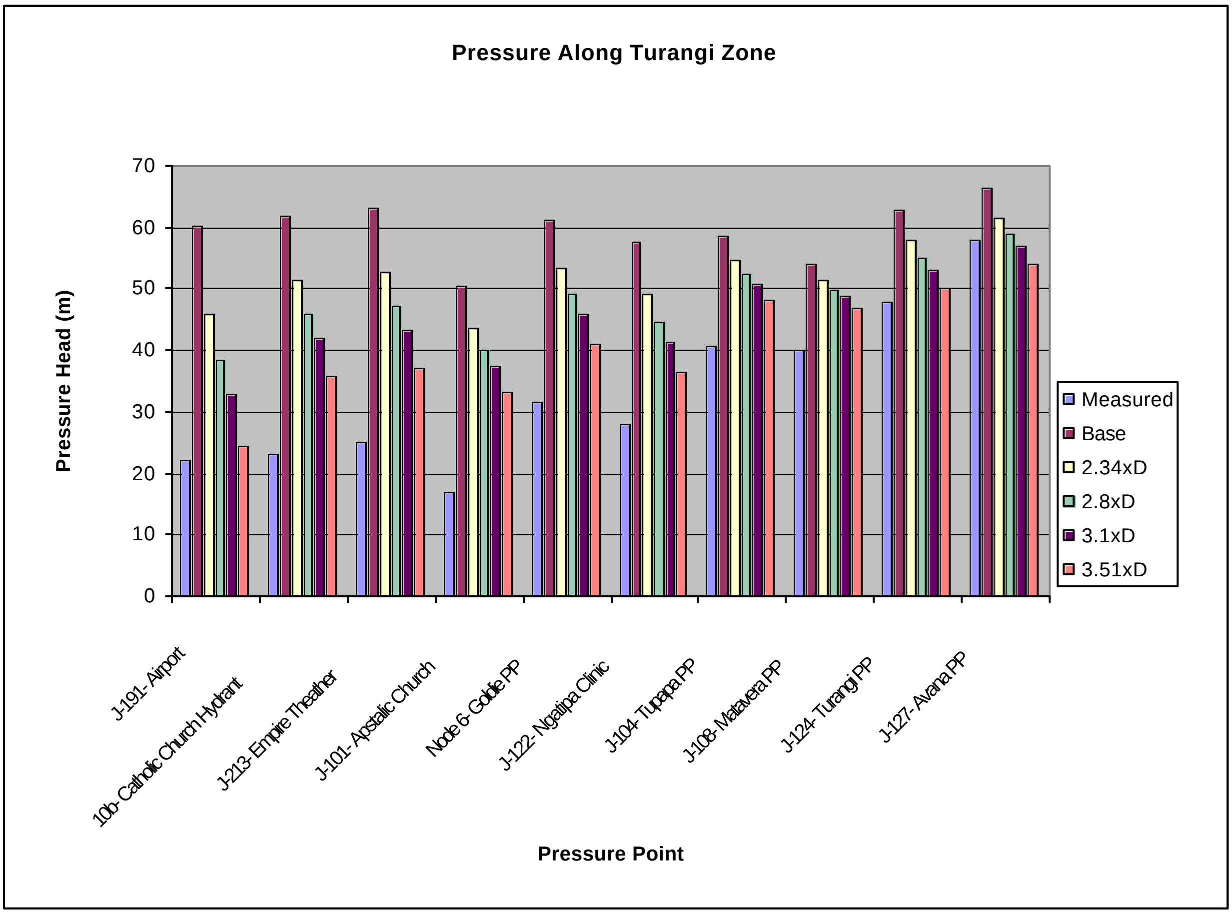
Junction/ Intake	Roughness Calibration Factor	Flow Calibration Factor	Model Pressure Head (m)	Maximum Metered Pressure Head (m)	Minimum Metered Pressue Head (m)	Percent Difference (%)	Model Flow (l/s)	Average Metered Flow (L/s)	Maximum Metered Flow (L/s)	Percent Difference (%)
Turangi Intake	1.5	3.51					40.3	22.7	36.9	8
Matavera Intake	1.5	3.51					28.2	14.7	26.5	6
Tupapa Intake	1.5	3.51					27	19.6	35.6	0
J-191- Airport	1.5	3.51	24.35	24	14	1				
10b- Catholic Church Hydrant	1.5	3.51	35.88	26	18	38				
J-213- Empire Theather	1.5	3.51	37.18	30	18	24				
J-101- Apstalic Church	1.5	3.51	33.36	27	12	24				
Node 6- Goldie PP	1.5	3.51	41.14	50	24	0				
J-122- Ngatipa Clinic	1.5	3.51	36.49	30	26	22				
J-104- Tupapa PP	1.5	3.51	48.07	60	17	0				
J-108- Matavera PP	1.5	3.51	46.9	60	15	0				
J-124- Turangi PP	1.5	3.51	50.22	65	22	0				
J-127- Avana PP	1.5	3.51	53.96	70	25	0				

Table 2: Summary of Model Run

Junction/ Intake	Roughness Calibration Factor	Flow Calibration Factor	Model Pressure Head (m)	Average Metered Pressure Head (m)	Minimum Metered Pressue Head (m)	Percent Difference (%)	Model Flow (l/s)	Average Metered Flow (L/s)	Maximum Metered Flow (L/s)	Percent Difference (%)
Turangi Intake	1.5	2.8					76.2	22.7	36.9	52
Matavera Intake	1.5	2.8					-	14.7	26.5	
Tupapa Intake	1.5	2.8					-	19.6	35.6	
J-191- Airport	1.5	2.8	-0.79	22	14	106				
10b- Catholic Church Hydrant	1.5	2.8	6.86	23	18	62				
J-213- Empire Theather	1.5	2.8	8.16	25	18	55				
J-101- Apstalic Church	1.5	2.8	-0.76	17	12	106				
Node 6- Goldie PP	1.5	2.8	9.27	27	24	66				
J-122- Ngatipa Clinic	1.5	2.8	6.95	28	26	73				
J-104- Tupapa PP	1.5	2.8	9.43	40.6	17	45				
J-108- Matavera PP	1.5	2.8	13.01	40.2	15	13				
J-124- Turangi PP	1.5	2.8	22.97	48	22	0				
J-127- Avana PP	1.5	2.8	26.71	58	25	0				

Table 3: Pressure Distribution along Turangi Zone for Different Demand Factors

Junction/ Intake	Mesured Pressure Head (m)	(Base) Model Pressure Head (m)	(2.34x) Model Pressure Head (m)	(2.8x) Model Pressure Head (m)	(3.1x) Model Pressure Head (m)	(3.51x) Model Pressure Head (m)
J-191- Airport	22	60.27	45.9	38.33	32.76	24.35
10b- Catholic Church Hydrant	23	61.92	51.43	45.98	41.96	35.88
J-213- Empire Theather	25	63.2	52.72	47.27	43.26	37.18
J-101- Apstalic Church	17	50.38	43.65	40.06	37.4	33.36
Node 6- Goldie PP	31.5	61.33	53.26	49.02	45.89	41.14
J-122- Ngatipa Clinic	28	57.61	49.14	44.71	41.44	36.49
J-104- Tupapa PP	40.6	58.51	54.55	52.31	50.63	48.07
J-108- Matavera PP	40.2	54.01	51.56	49.97	48.76	46.9
J-124- Turangi PP	48	62.77	57.8	55.15	53.19	50.22
J-127- Avana PP	58	66.52	61.54	58.89	56.93	53.96



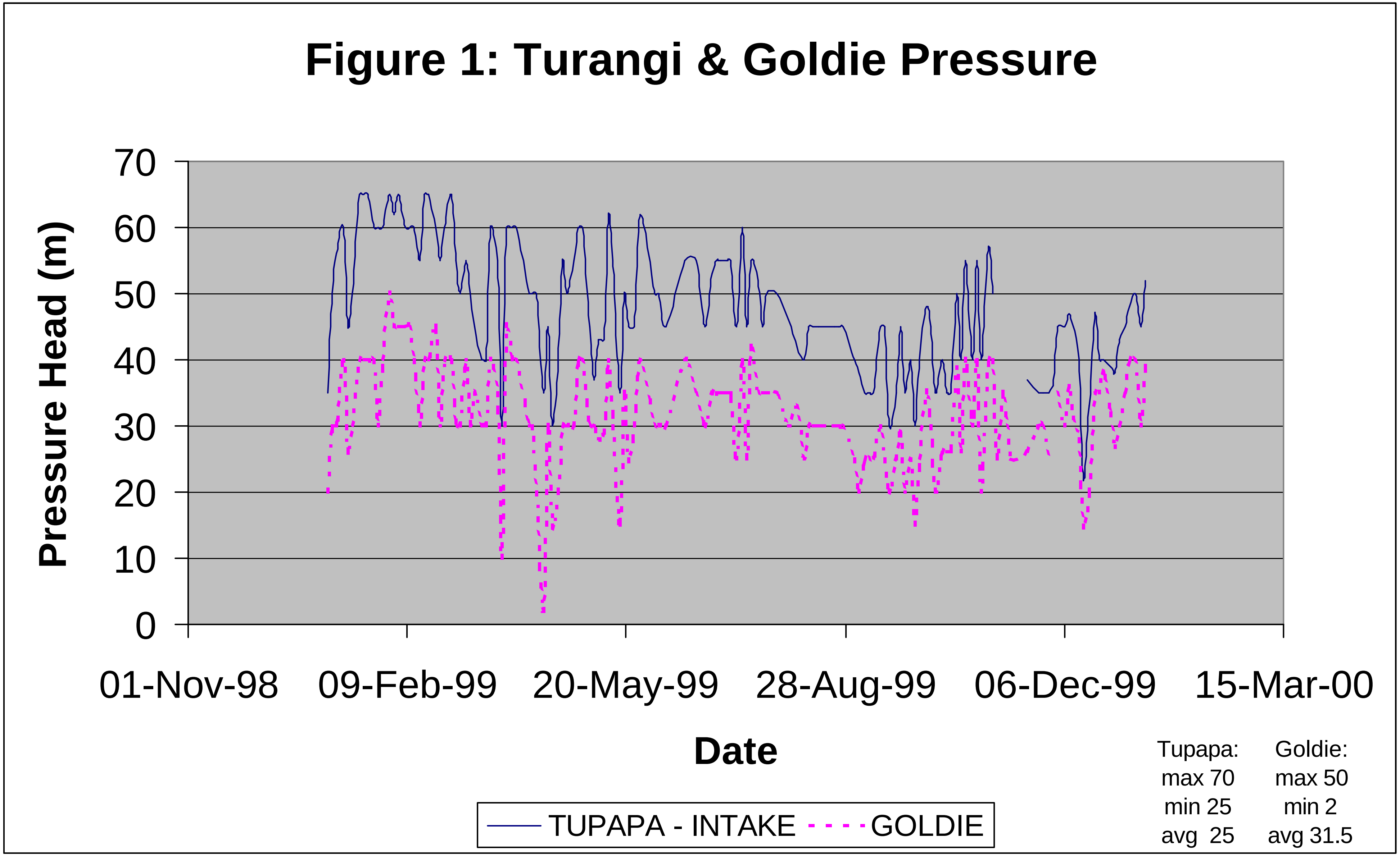


Figure 1: Turangi & Goldie Pressure
Pressure Head (m)
70
60
50
40
30
20
10
0
01-Nov-98
09-Feb-99
20-May-99
28-Aug-99
06-Dec-99
15-Mar-00
Date
Tupapa:
max 70
min 25
avg 25
Goldie:
max 50
min 2
avg 31.5
TUPAPA - INTAKE
GOLDIE

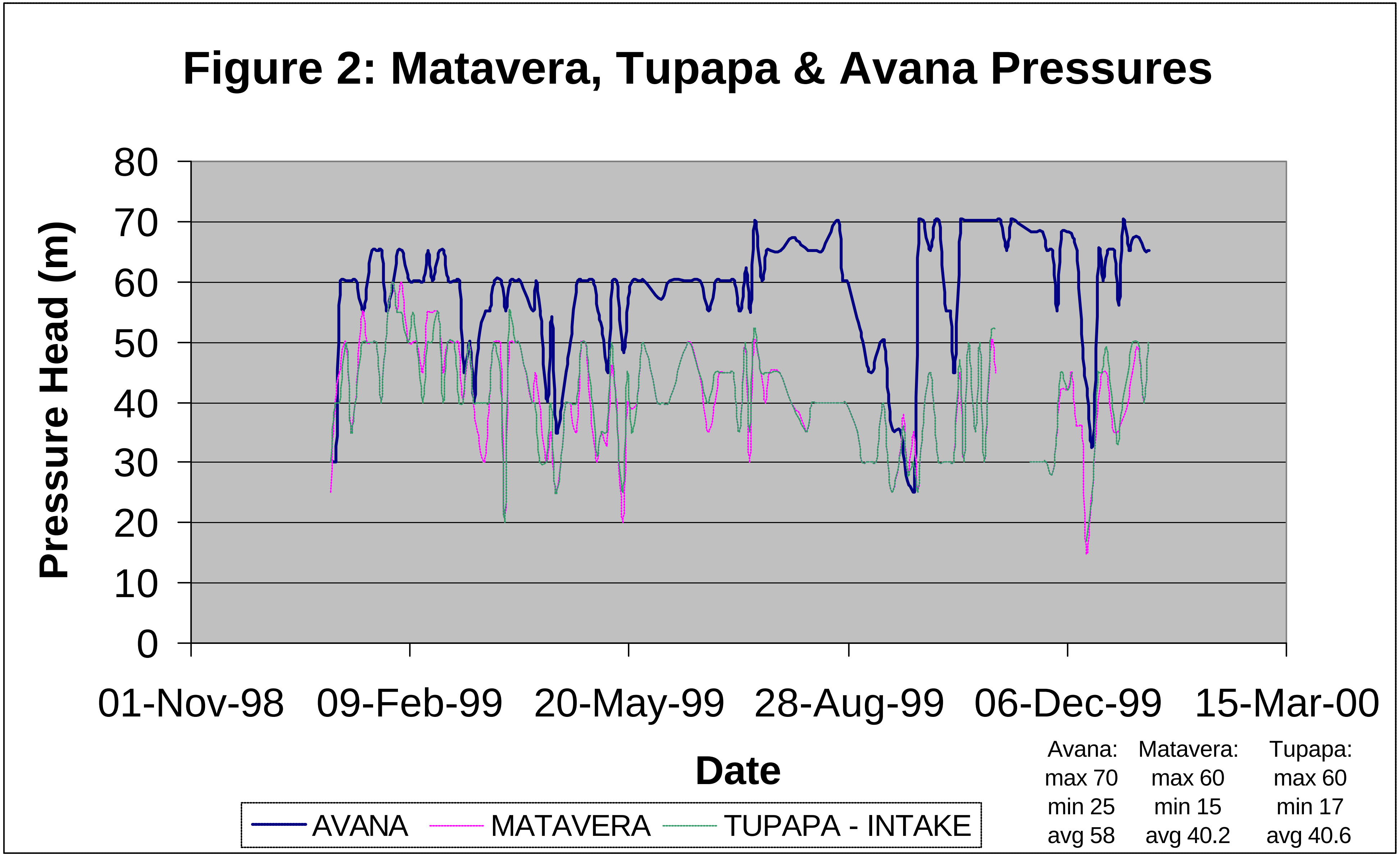


Figure 2: Matavera, Tupapa & Avana Pressures
Pressure Head (m)
80
70
60
50
40
30
20
10
0
01-Nov-98
09-Feb-99
20-May-99
28-Aug-99
06-Dec-99
15-Mar-00
Date
AVANA
MATAVERA
TUPAPA - INTAKE
Avana:
max 70
min 25
avg 58
Matavera:
max 60
min 15
avg 40.2
Tupapa:
max 60
min 17
avg 40.6

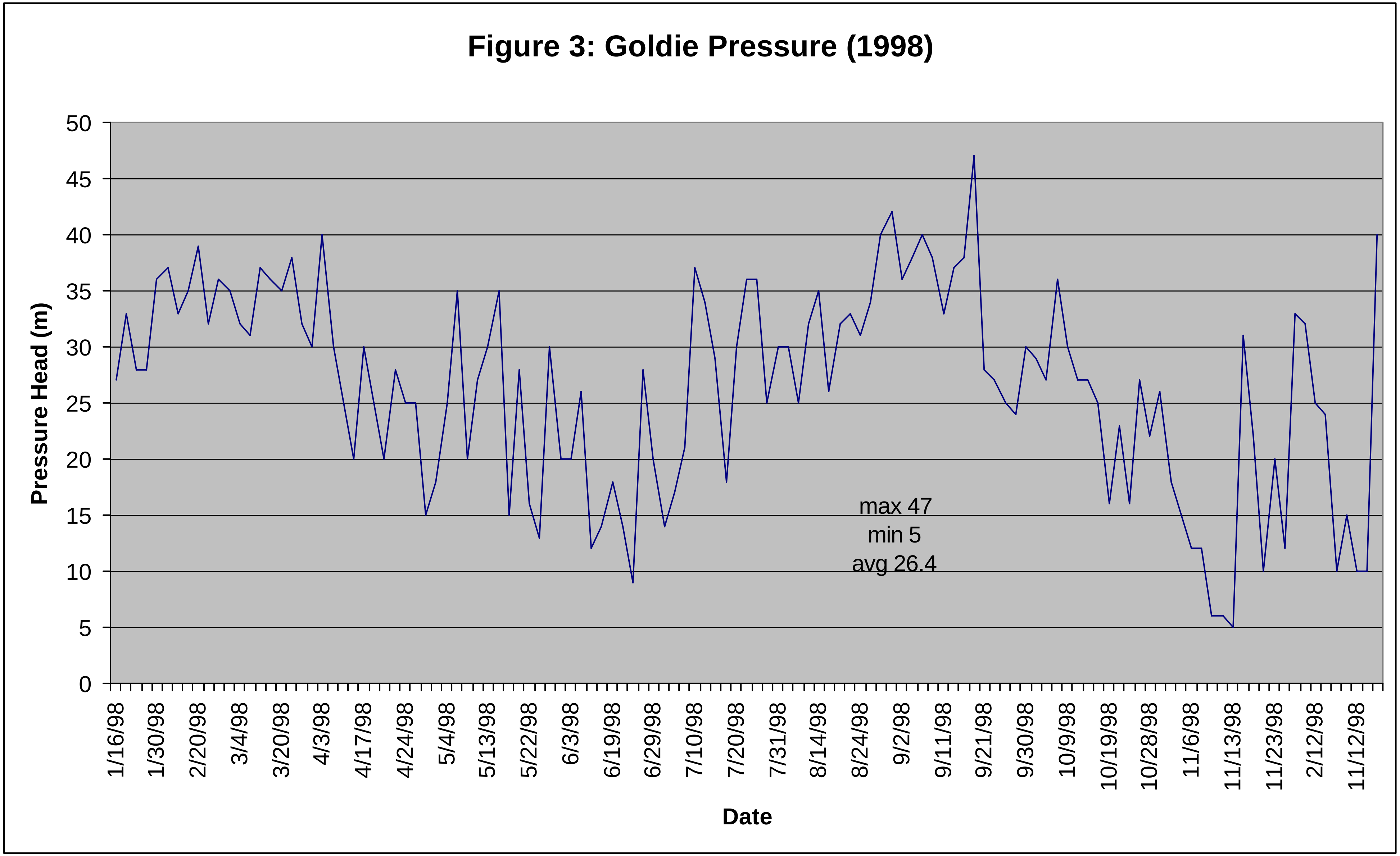


Figure 3: Goldie Pressure (1998)
Pressure Head (m)
0
5
10
15
20
25
30
35
40
45
50
max 47
min 5
avg 26.4
1/16/98
1/30/98
2/20/98
3/4/98
3/20/98
4/3/98
4/17/98
4/24/98
5/4/98
5/13/98
5/22/98
6/3/98
6/19/98
6/29/98
7/10/98
7/20/98
7/31/98
8/14/98
8/24/98
9/2/98
9/11/98
9/21/98
9/30/98
10/9/98
10/19/98
10/28/98
11/6/98
11/13/98
11/23/98
2/12/98
11/12/98
Date

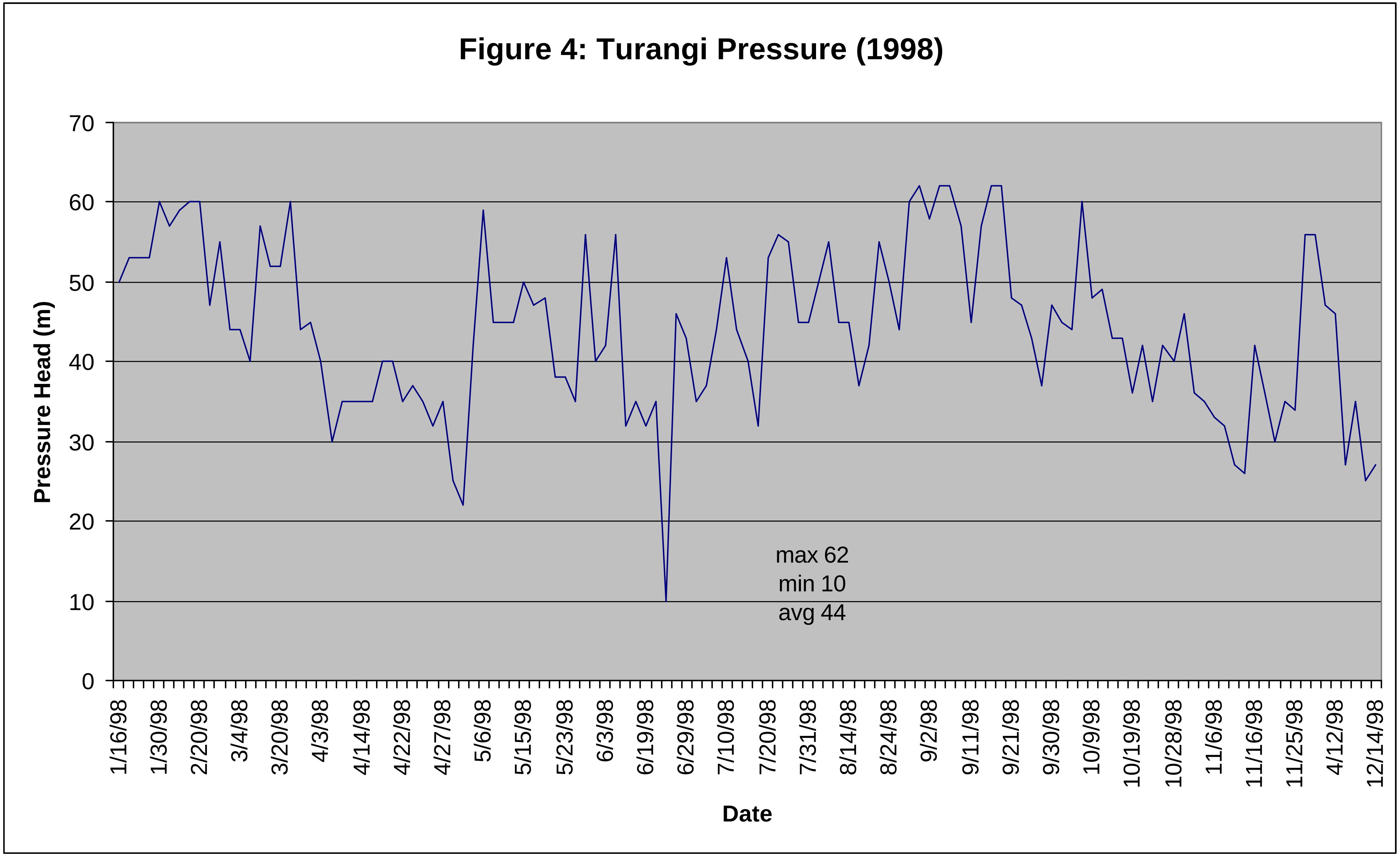


Figure 4: Turangi Pressure (1998)
Pressure Head (m)
70
60
50
40
30
20
10
0
max 62
min 10
avg 44
1/16/98
1/30/98
2/20/98
3/4/98
3/20/98
4/3/98
4/14/98
4/22/98
4/27/98
5/6/98
5/15/98
5/23/98
6/3/98
6/19/98
6/29/98
7/10/98
7/20/98
7/31/98
8/14/98
8/24/98
9/2/98
9/11/98
9/21/98
9/30/98
10/9/98
10/19/98
10/28/98
11/6/98
11/16/98
11/25/98
4/12/98
12/14/98
Date

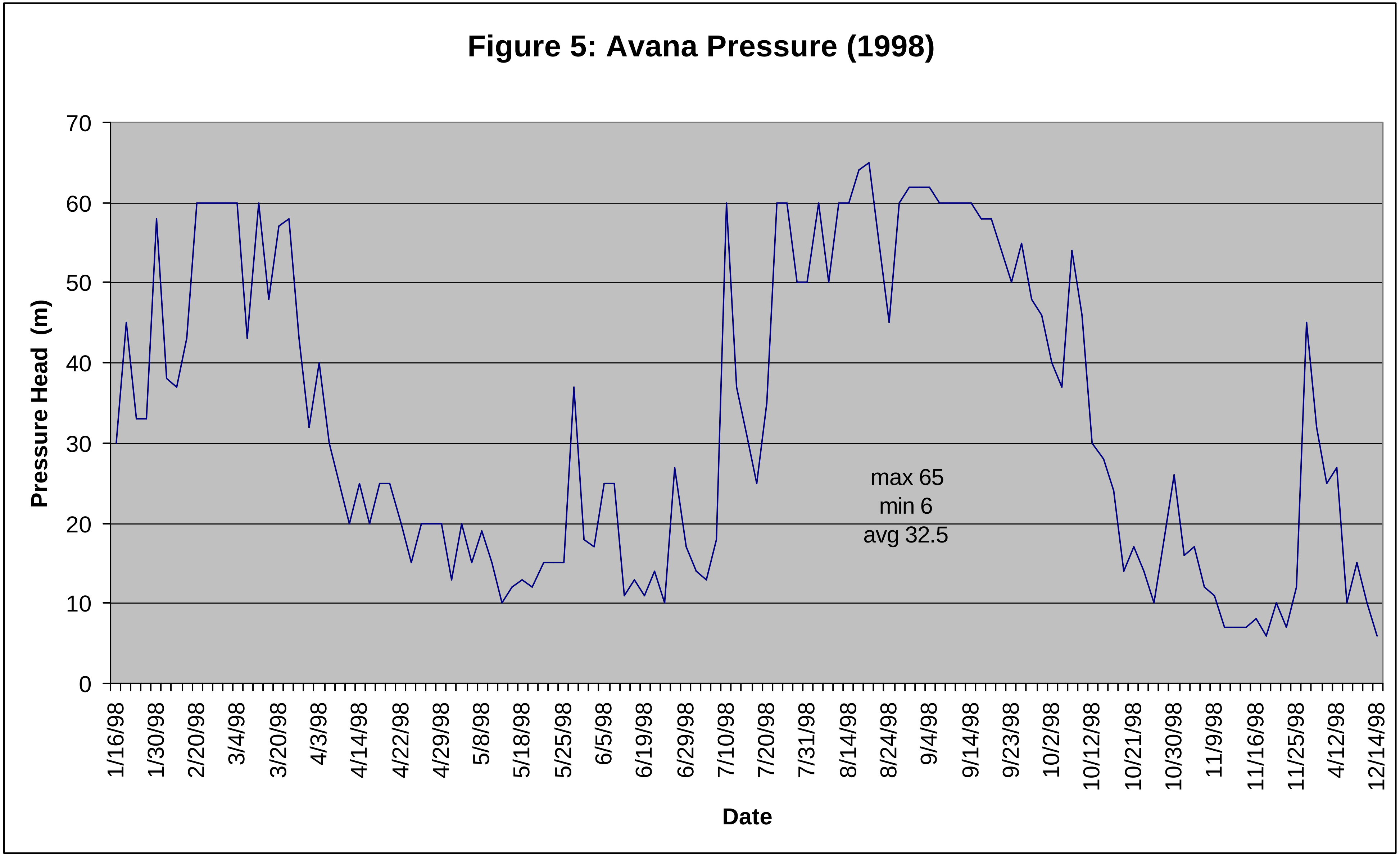


Figure 5: Avana Pressure (1998)
Pressure Head (m)
0
10
20
30
40
50
60
70
max 65
min 6
avg 32.5
1/16/98
1/30/98
2/20/98
3/4/98
3/20/98
4/3/98
4/14/98
4/22/98
4/29/98
5/8/98
5/18/98
5/25/98
6/5/98
6/19/98
6/29/98
7/10/98
7/20/98
7/31/98
8/14/98
8/24/98
9/4/98
9/14/98
9/23/98
10/2/98
10/12/98
10/21/98
10/30/98
11/9/98
11/16/98
11/25/98
4/12/98
12/14/98
Date

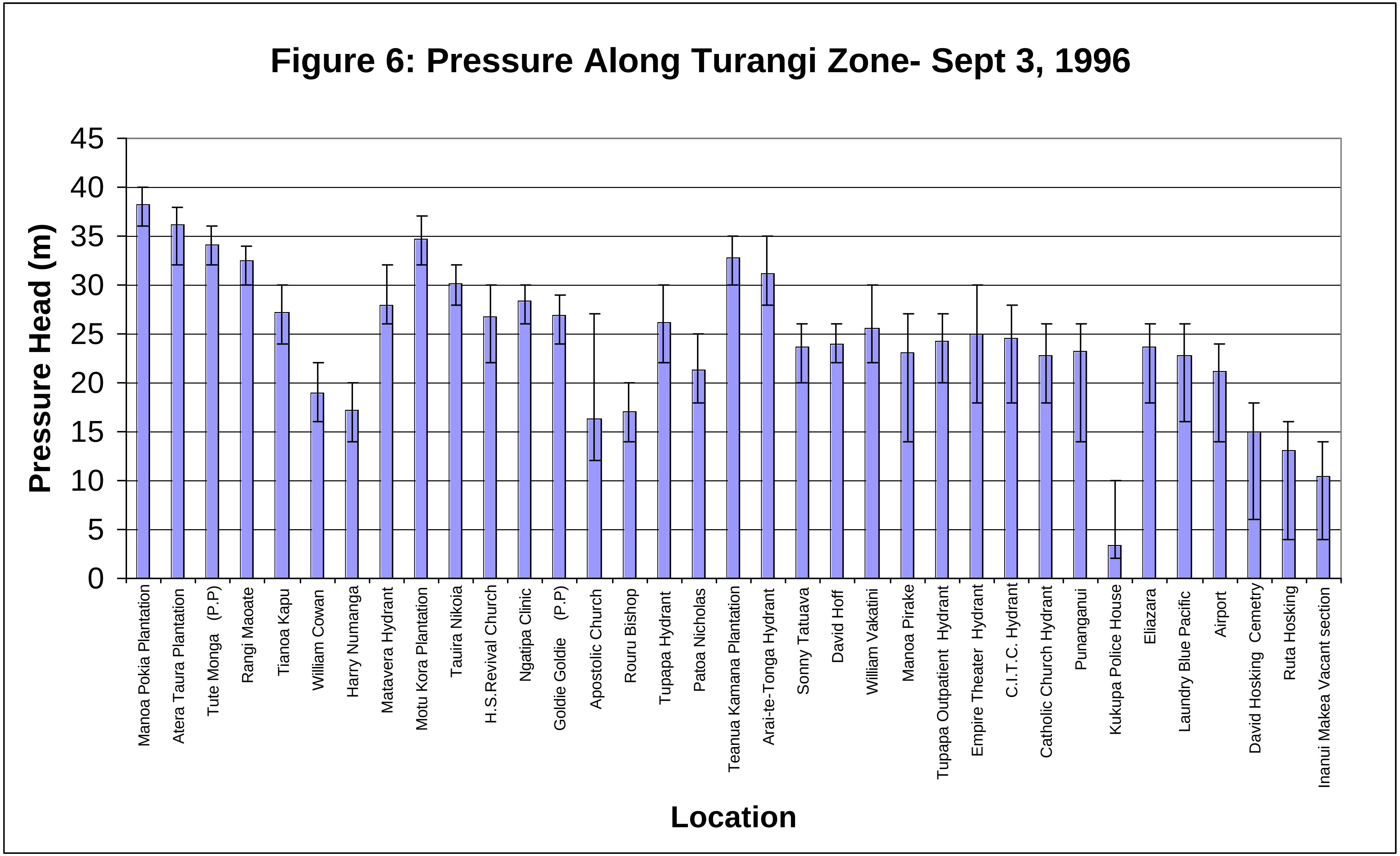


Figure 6: Pressure Along Turangi Zone- Sept 3, 1996
Pressure Head (m)
0
5
10
15
20
25
30
35
40
45
Manoa Pokia Plantation
Atera Taura Plantation
Tute Monga (P.P)
Rangi Maoate
Tianoa Kapu
William Cowan
Harry Numanga
Matavera Hydrant
Motu Kora Plantation
Tauira Nikoia
H.S.Revival Church
Ngatipa Clinic
Goldie Goldie (P.P)
Apostolic Church
Rouru Bishop
Tupapa Hydrant
Patoa Nicholas
Teanua Kamana Plantation
Arai-te-Tonga Hydrant
Sonny Tatuava
David Hoff
William Vakatini
Manoa Pirake
Tupapa Outpatient Hydrant
Empire Theater Hydrant
C.I.T.C. Hydrant
Catholic Church Hydrant
Punanganui
Kukupa Police House
Eliazara
Laundry Blue Pacific
Airport
David Hosking Cemetry
Ruta Hosking
Inanui Makea Vacant section
Location

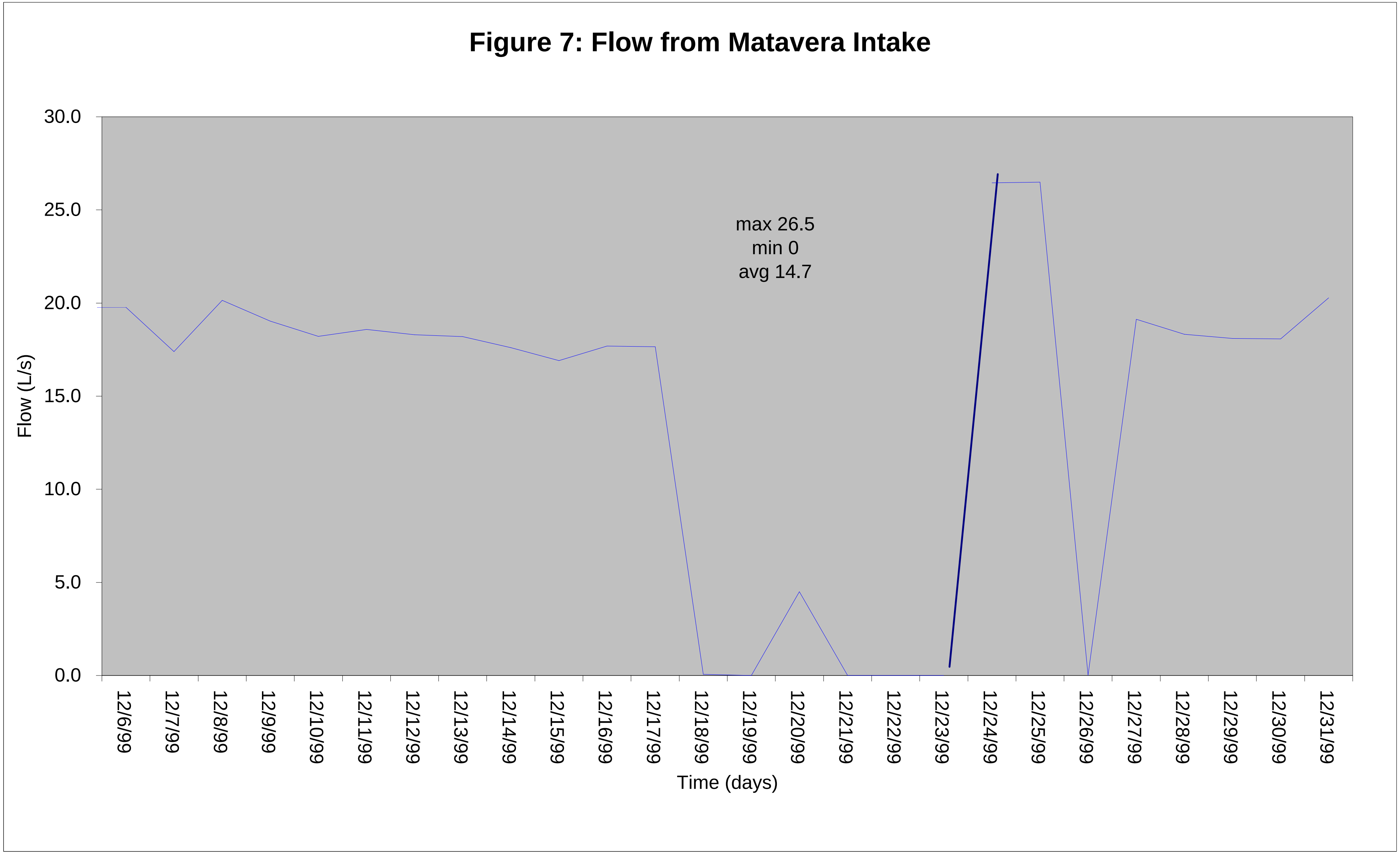


Figure 7: Flow from Matavera Intake
Flow (L/s)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
max 26.5
min 0
avg 14.7
12/6/99
12/7/99
12/8/99
12/9/99
12/10/99
12/11/99
12/12/99
12/13/99
12/14/99
12/15/99
12/16/99
12/17/99
12/18/99
12/19/99
12/20/99
12/21/99
12/22/99
12/23/99
12/24/99
12/25/99
12/26/99
12/27/99
12/28/99
12/29/99
12/30/99
12/31/99
Time (days)

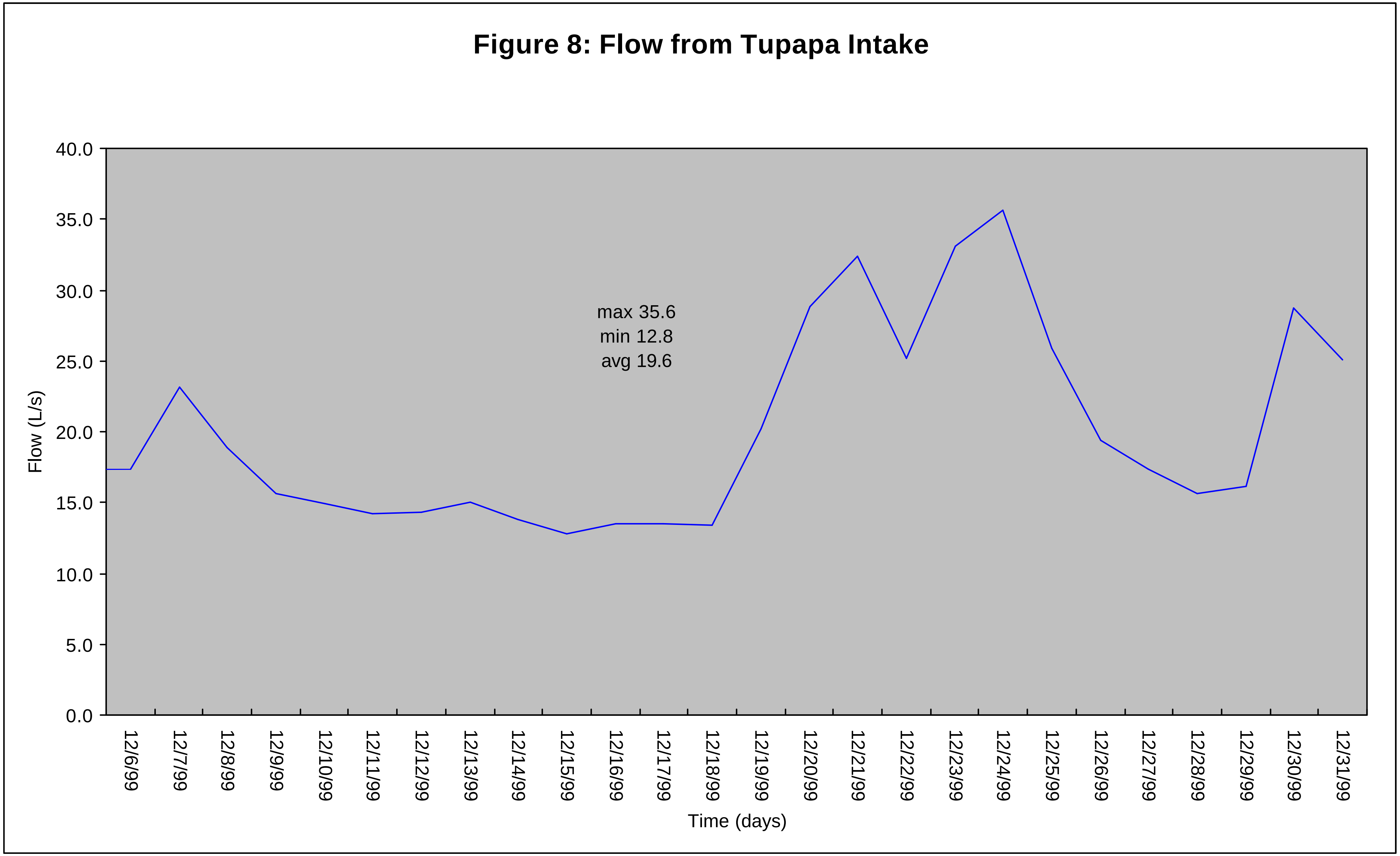


Figure 8: Flow from Tupapa Intake
Flow (L/s)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
max 35.6
min 12.8
avg 19.6
12/6/99
12/7/99
12/8/99
12/9/99
12/10/99
12/11/99
12/12/99
12/13/99
12/14/99
12/15/99
12/16/99
12/17/99
12/18/99
12/19/99
12/20/99
12/21/99
12/22/99
12/23/99
12/24/99
12/25/99
12/26/99
12/27/99
12/28/99
12/29/99
12/30/99
12/31/99
Time (days)

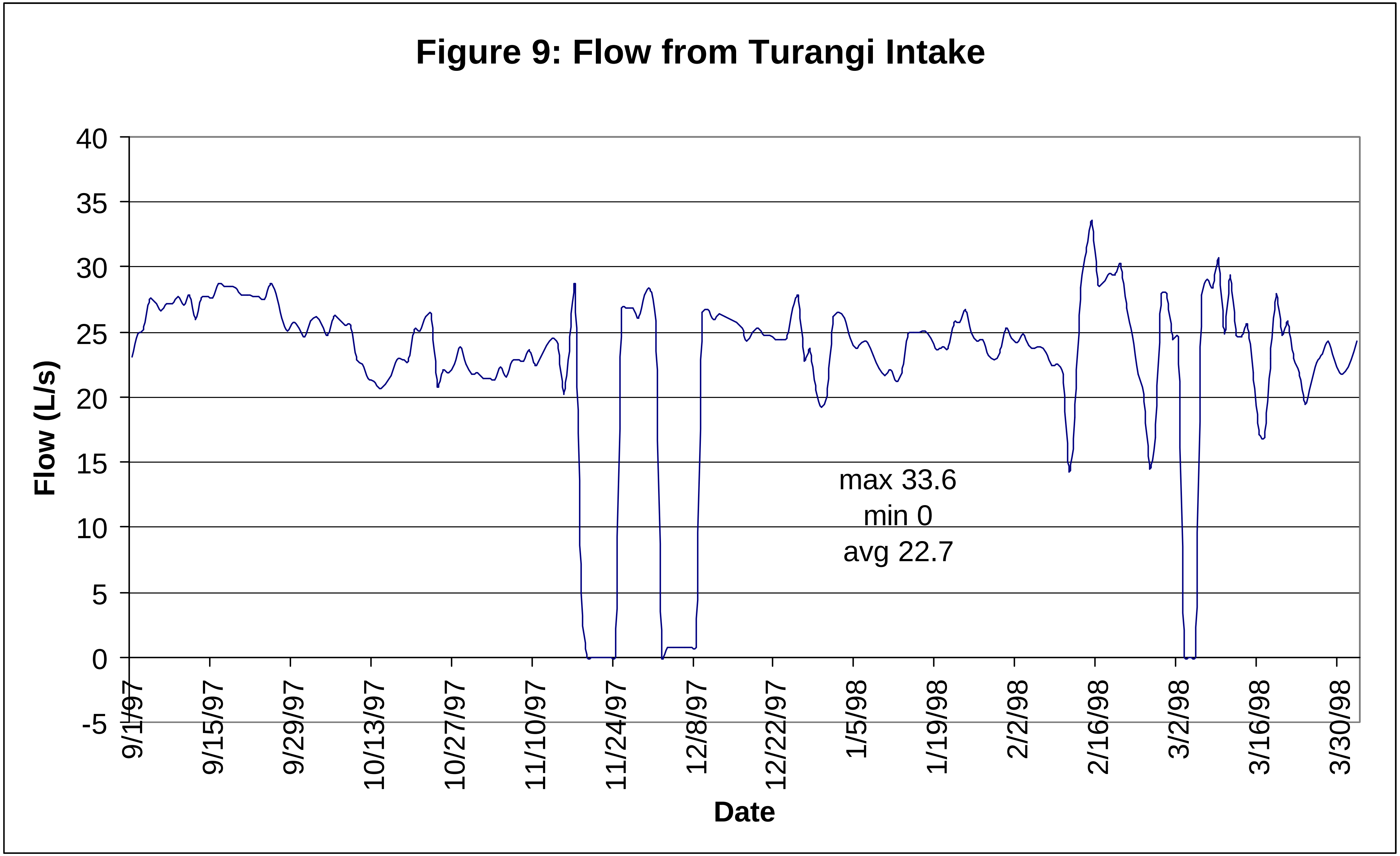


Figure 9: Flow from Turangi Intake
Flow (L/s)
40
35
30
25
20
15
10
5
0
-5
max 33.6
min 0
avg 22.7
9/1/97
9/15/97
9/29/97
10/13/97
10/27/97
11/10/97
11/24/97
12/8/97
12/22/97
1/5/98
1/19/98
2/2/98
2/16/98
3/2/98
3/16/98
3/30/98
Date

Appendix E:
List of Tasks

List of Tasks for the Rarotonga Water Works

1. Become more familiar with Cybernet by doing the tutorials.

2. Update the Cybernet master layout of Rarotonga previously done by SOPAC → check layout, pipe material and size
   - The Project East updates that were done on the Turangi model will have to be incorporated into this file
   - Master plan file is Patric:C:\waterdata\something???

3. Use MapInfo to create a database link with Cybernet in order to update the demands at each node
   - Count the number and type (domestic, industrial, commercial, institutional, hotel, agricultural) of users at each node→ because of Rarotonga's small size this could be done for each individual user

4. Metered demands from over 60 commercial, industrial and institutional locations should be input directly into their nearest respective junctions
   - Exact locations of these sites should be gathered using your GPS equipment and input into MapInfo, the demand data can then be attributed to each specific location, and this information transferred over to Cybernet

5. Create a network model for each zone as proposed by the Asian Development Bank, like the Turangi zone done in this report→ calibrate the models and see how they perform

6. Model improvements the Water Works Department are planning to make to the southwest section of the Rarotonga water distribution system→ see how it performs

7. Create a combined demand pattern for each intake. As you go through the records for each intake, keep a note of the maximum and minimum flows during this period→ these values can be used to calibrate the model. Method is the same as for the Turangi demand pattern that was created→ have data for each day of the week, don't choose records where the pattern is wacked or just a constant line

8. Find out where the valves are in your system, and how they operate→ if they're just open all the time, don't include them in the Cybernet model, but if they open and close during certain times of the day find out when, where, etc and add information to the model

9. Use GPS equipment to check exact elevations (and locations) of intakes and tanks→input information into Cybernet model

10. Go around and check all the meters in existence in Rarotonga (domestic, commercial, at intakes) and see if any of them are still working→ if they are, start collecting data, if not, see if they can be fixed and start collecting data

11. Collect flow data from intakes so you can know how much water is being used in Rarotonga→ make estimates on leakage amounts once known use is estimated

12. Collect hourly flow data (or almost hourly flow data) from different locations to develop specific user demand patterns for domestic, hotel, agricultural, industrial, institutional, and commercial users→ this could be quite easy if some of those old meters are still working

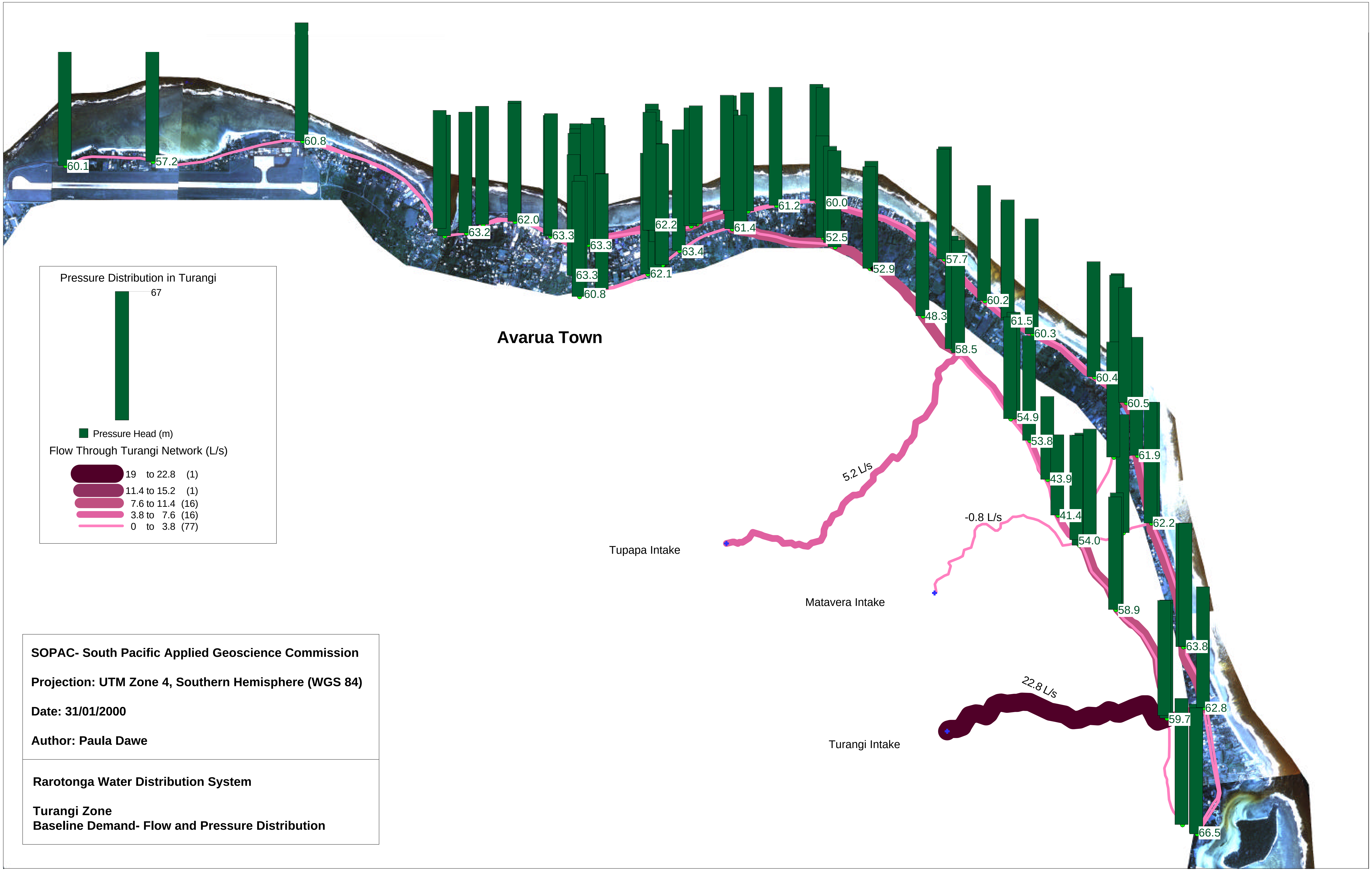
13. Run the Cybernet model once the information in it is as accurate as possible (or even before), and compare the pressure, flow, velocity, etc. values to those measured out in the field

- The model can be used as a guide to pinpoint problems, and to do checks on the distribution system
  - Checking pressures along galvanized iron pipes to see if there are leaks→ simply measure pressure at household hose cocks along the pipe line to plot the hydraulic gradient- a sudden change in the slope (reduction of pressure head) of the HGL may indicate the approximate location of a leak
  - Locating areas to put in PRV or PSV
  - Intakes that have water flowing back up to them
  - Pipes where there is no flow during peak demand, or that have negative pressures and are possibly back-drawing contaminants into the distribution system

14. If the location of pipe bends, fittings, reducers, etc. are known, the associated minor loss values can be added to the appropriate pipes in the Cybernet model (this is really refining your model)

15. Locate leaks in the system and repair→ to reduce total demand in Rarotonga

16. Input information collected into MapInfo to create a Water Utilities Data Base. Will be able to organize data, perform asset management, etc.



SOPAC- South Pacific Applied Geoscience Commission

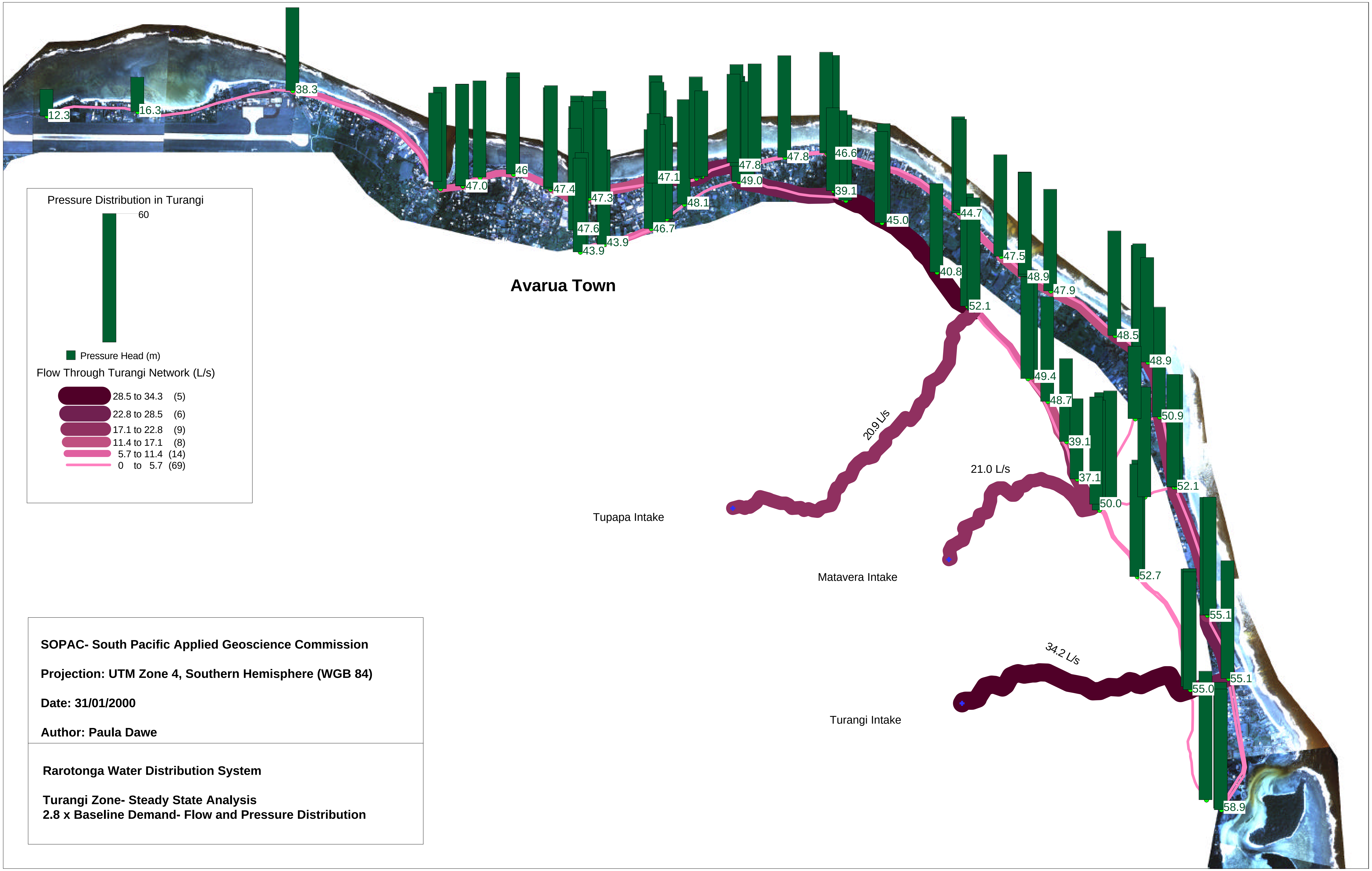
Projection: UTM Zone 4, Southern Hemisphere (WGS 84)

Date: 31/01/2000

Author: Paula Dawe

Rarotonga Water Distribution System

Turangi Zone
Baseline Demand- Flow and Pressure Distribution



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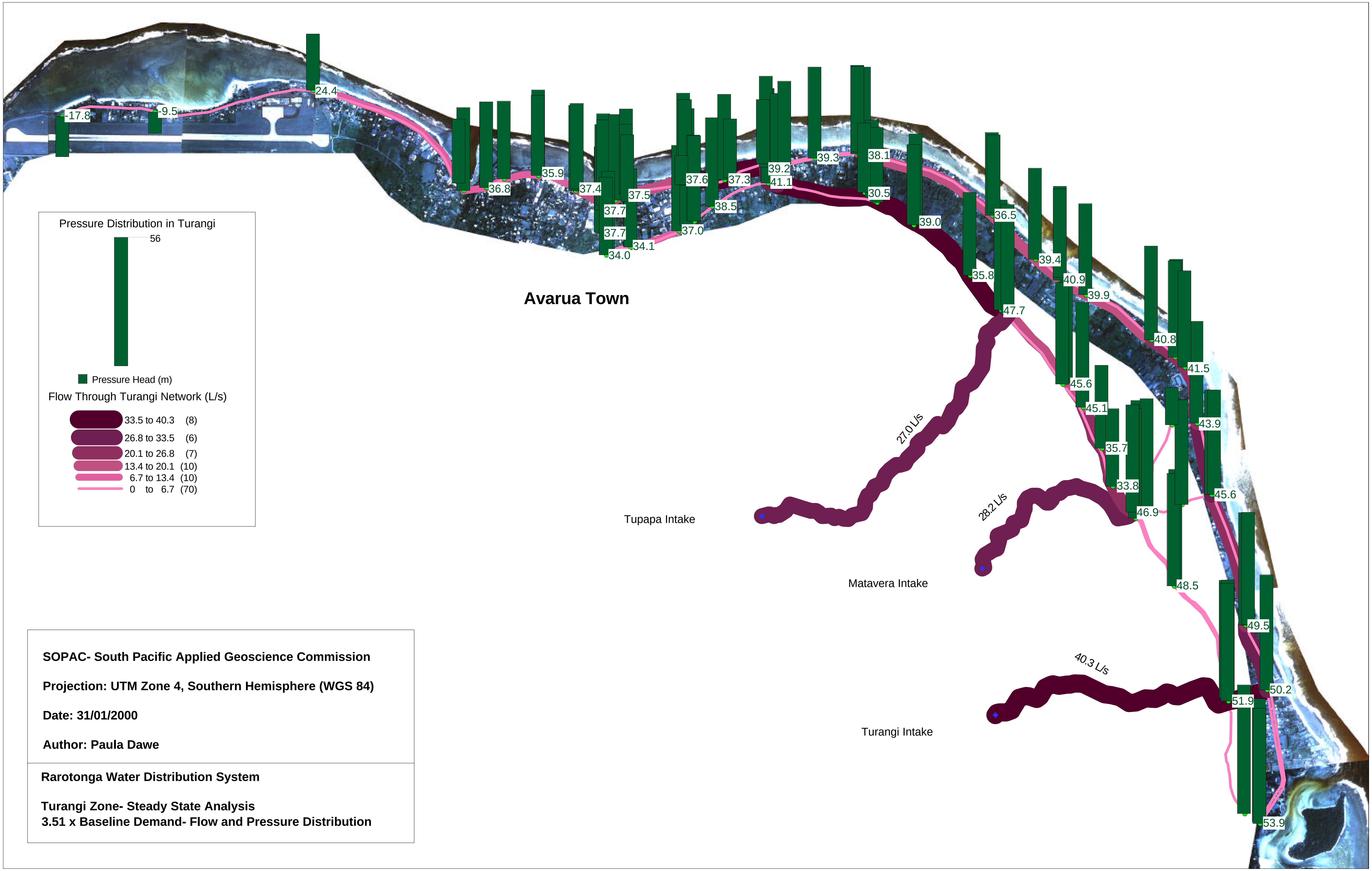
Projection: UTM Zone 4, Southern Hemisphere (WGB 84)

Date: 31/01/2000

Author: Paula Dawe

Rarotonga Water Distribution System

Turangi Zone- Steady State Analysis
2.8 x Baseline Demand- Flow and Pressure Distribution


Pressure Distribution in Turangi
56
Pressure Head (m)
Flow Through Turangi Network (L/s)
33.5 to 40.3 (8)
26.8 to 33.5 (6)
20.1 to 26.8 (7)
13.4 to 20.1 (10)
6.7 to 13.4 (10)
0 to 6.7 (70)
Avarua Town
-17.8
-9.5
24.4
36.8
35.9
37.4
37.5
37.7
37.7
34.0
34.1
37.6
37.0
37.3
38.5
39.2
41.1
39.3
38.1
30.5
39.0
36.5
35.8
47.7
39.4
40.9
39.9
40.8
41.5
45.6
45.1
35.7
33.8
46.9
43.9
45.6
48.5
49.5
50.2
51.9
53.9
27.0 L/s
28.2 L/s
40.3 L/s
Tupapa Intake
Matavera Intake
Turangi Intake
SOPAC- South Pacific Applied Geoscience Commission
Projection: UTM Zone 4, Southern Hemisphere (WGS 84)
Date: 31/01/2000
Author: Paula Dawe
Rarotonga Water Distribution System
Turangi Zone- Steady State Analysis
3.51 x Baseline Demand- Flow and Pressure Distribution

SOPAC- South Pacific Applied Geoscience Commission

Projection: UTM Zone 4, Southern Hemisphere (WGS 84)

Date: 31/01/2000

Author: Paula Dawe

Rarotonga Water Distribution System

Turangi Zone- Steady State Analysis
2.8 x Baseline Demand (Just Turangi Intake) - Flow and Pressure Distribution