Hydraulic Network Modelling of the Nukua'lofa Water Supply System, Kingdom of Tonga

SOPAC Technical Report 273

By Harald Schölzel

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Introduction

This technical report is the outcome of field work carried out between the 24th of November 1998 and the 1st of December in Nuku'alofa, the capital of the Kingdom of Tonga. It summarises and describes the work that has been undertaken in close co-operation with engineers of the Tonga Water Board (TWB) with respect to better understand the hydraulic performance of the existing water distribution system and find alternatives for a necessary upgrading. The upgrading of the system has been extensively and thoroughly described in the Tonga Water Supply Master Plan Project for Nuku'alofa funded by AusAID and executed by PPK Consultants Pty. Ltd. in association with Riedel & Byrne Pty. Ltd. in the early nineties. So far none of the upgrading works designed and recommended by the Masterplan have been implemented.

However, recently the Japanese government has shown serious interest in assuming financial responsibility for the implementation of the Masterplan in Nuku'alofa and a inception mission of a Japanese delegation was due to arrive in Tonga in early December 1998.

Since the Masterplan is already 7 years old TWB was concerned whether the information on which it was based upon was still valid. TWB therefore instructed SOPAC to supervise the revision of key design parameters and the hydraulic modelling for the water supply system. Hence the scope of the work was not redo the work that has been done but more to crosscheck key assumptions such as projected population and projected demand. Another concern TWB had was whether the Masterplan design would provide enough water for new developments such as canneries and hotel complexes. To be able to assess such problems a network model had to be set up.

Most of the work was finished in Tonga and was part of training on hydraulic network modelling for TWB Engineers. At the end of the field mission TWB executives were provided with expressive documentation[1] of the work, thus enabling them to provide the Japanese delegation with up-to-date information on the hydraulic performance of the Nuku'alofa water supply system and the planned upgrading. This report summarises the information already given in a presentable and comprehensive way. It also aims to highlight the benefits for hydraulic network modellers if GIS is used to generate input data and, even more important, if the GIS is used to evaluate the results.

This reports assumes that the reader is familiar with the basic terminology of hydraulic network modelling and with the Masterplan 1992.

[1] Documentation included all electronic files including an updated GIS, A1 plots and other electronic presentation material.

Acknowledgement

Special thanks should be given Samuel P. Helu, General Manager of the Tonga Water Board, Malakai Vakasiuola, Design and Planning Engineer and Vaha'akolo Palelei, Engineer, for their support and friendly reception.

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General Figures

As mentioned all general assumptions and figures have been derived from the Masterplan 1992 and only slightly amended wherever they were deemed outdated. That particularly refers to some information regarding the demand at certain locations throughout Nuku'alofa accommodating for new developments unknown at the time the Masterplan 1992 was elaborated. Reference will be made to those changes at the appropriate point.

Water Demand

Table 1Table 1 lists all average areal consumption as determined on actual consumption for 1991.

Area	**Residential**	**Inner City Commercial**	**General Commercial**	**Light Industrial**	**Schools**	**Hospital**
Areal Consumption [m^3/ha/d]	5.5	12.3	8.6	15.6	4	127.8

Table 1: Average areal consumption data for Nulu'alofa, Source: Masterplan 1992

The figures in Table 1 were derived from to accommodate

Population Projection

Year	**1989**	**1991**	**1996**	**1998**	**2001**	**2011**
Population as projected	30,500	31,245	34,116	35,300	37,038	43,653
Water Production [1000 m^3/d]	4.92	7.21	8.27	8.78	9.55	13.28

Table 2: Projected population and water production requirements

The actual population in 1998 is approx. 36,000 and fits well into the population projection. The projected water production requirements could not be met. Actual production for the month of October 1998 was 7200 m3 per day.

Demand Pattern

Three different demand patterns as described in the Masterplan 1992 were applied:

1. Residential (Annex 1.1)
2. Commercial (Annex 1.2)
3. Constant (not displayed)

The relevant multipliers can be taken from the respective Annex.

All calculations were performed using the Colebrook-White-Prandtl formula for friction loss.

Existing Water Supply System

The general approach towards modelling the existing water distribution system can be summarised as follows:

Building on the existing rudimentary GIS of the pipe system a network was created using Cybernet♥ Version 3.0 software. The updated GIS was then used to calculate an area based demand for each junction using the figures from Table 1. In order to do that the GIS recalculated the area TWB currently serves. The result was divided by the actual daily consumption of 82.8 liters per second or 7154 m^3 per day. The approach was made conservative by applying data for the month with the highest consumption. Each junction was assumed to serve a certain area considering an assumed population density based on a "lot-counting" done using the GIS. The result is an average demand for each junction based on area and population density.

All main pipes with an nominal diameter equal or greater than 50 mm were considered in the model. Roughness factors were assigned to each pipe according to its material. No allowance was made for age or actual status and no minor loss coefficients were applied[2].

Running different calibration runs within Cybernet♥ the demand at each junction was fine-tuned comparing results with actual meter readings at different times.

Annex 2.1 gives a comprehensive overview on the project inventory listing explicitly all properties of each junction and pipe. Annex 2.2 shows the model with pipe diameters, pipe material and relative demands assigned to each junction.

Hydraulic Grade Line (HGL)[3] and main flow streams a 0.00 AM are displayed in Annex 2.3. The system experiences no problems at this time of the day. Note that the booster pump is not operating at this time.

Annex 2.4 shows the same plot at 7:00 AM when presumably demand is highest. Red bars indicate "neagtive HGL". Since there is no such things like negative pressure in reality the red bars show junctions where the imposed demand can not be met. In other words the system is not working satisfactorily at that time even though the booster pump is operating. It seems that the area of impact of the booster pumps fairly limited and some areas at the far east end of the system would be better of if the pump was not running at all (not shown).

Annex 2.5 shows time series plots for the system over the 24 hours simulation. From the upper left to the lower right the plots show:

1. HGL over 24 hours for the Northwest End junction. This result is not in line with the observed pressure at this junction indicating that either demand for the area has been set to high or friction losses have been overestimated.

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[2] The reason for that was the lack of information about the pipes and the strict time limits available to complete the work.

[3] HGL is the sum of elevation and pressure referring to a datum, here mean sea level.

2. HGL at Kings Palace junction. Demand can not be met for several hours. No control could be applied for the lack of data.
3. HGL at Southeast dump. Except for some few hours at night demand ca not be met. The result is qualitatively in line with observations. The area does not receive any water during day time.
4. HGL at Mataki'eua storage facilities
5. Actual storage volume at Mataki'eua storage facilities
6. HGL at booster pump. The pump creates an HGL at about 30 m. This result is in line with pressure measurements.

Conclusions

The existing water supply system experiences serious shortcomings during high demand periods. The calculations show that during peak hours at 7:00 AM the imposed demand can not be met at any junction. This is a theoretical result and should be interpreted in the right context. Due to the algorithm and procedures hydraulic network modelling software realises the imposed demand for any junction at any "cost". That means that even highest flow rates would be "forced" through the smallest pipe. This results in negative pressure which is physically impossible. Instead it shows that the amount of water requested is too high for the system to be transported through.

In this particular case the system "demands" nearly 153 l/s. This amount is far too high to even enter the beginning of the distribution system at a "positive pressure". Since Nuku'alofa in reality gets water the conclusion is that though some parts of the water supply system such as the booster pump, the eastern end and the pipes no. 318 and 316 could be modelled fairly well the demand pattern can not reflect the real demand. As a result the calibration process of the model should go on comparing the results with bulk meter data available for several locations in Nukua'lofa.

That does not mean that the results obtained from the calulations are worthless. In contrary, the aim of the modelling procedure was to show whether or whether not a demand deemed reasonable could be supplied by the system at any time. This is not the case allowing the final conclusion that demand in Nuku'alofa is surpressed. Considering the above made assumption for demand, population and water requirements projections and the demand patters the system needs to be upgraded.

Upgrading of the Nuku'alofa Water Supply System

According to Masterplan 1992

The general approach towards modelling the water distribution system has been described in the previous chapter. In order to derive a conclusion whether the Masterplan 1992 upgrade is still meeting all requirements the "existing water supply" model has been modified according to the Masterplan.

In particular demand has been modified to accommodate water supply for new developments along the eastern waterfront (junction no. 151 and 203). On the other hand general demand has been slightly reduced compared to the Masterplan projections to take into account the reduced population increase.[4] Total average water demand amounts to about 144 liters per second or 12440 m^3 per day.

Annex 3.1 gives an comprehensive overview on the project inventory listing explicitly all properties of each junction and pipe. One new feature of the upgraded water supply system will be the provision of two local storage facilities each with a pumping station, ground level tank and high level tank. Details about the pumps and storage facilities can be found within the inventory. Annex 3.2 contains a list of all pipes to be replaced while Annex 3.3 displays a graphical overview on these pipes. The blue bars indicate a positive HGL (in contrast to the red bars in Annex 2.4). The system experiences no problems. .

Average and main flow streams together with average relative demands at 7.00 AM are displayed in Annex 3.5.

Conclusions

The upgrading of the Nuku'alofa water supply system accommodates for the projected future demand in the year 2011. Though some demand has been slightly corrected downwards it provides sufficient water at a reasonable pressure to projected new developments at the eastern waterfront.

The idea of the designers to use local storage facilities in Houma and Longolongo is nothing else but excellent and represents a very efficient solution of the pressure problem.

According to Masterplan 1992

The TWB proposal suggests that all Asbestos Cement pipes should be replaced and some bottlenecks still present in the original Masterplan 1992 upgrading should be removed. Everything else remains the same.

Annex 4.1 lists the additional pipes to be laid or replaced. Annex 4.2 shows all those pipes displayed in red. There is some overlapping with the Masterplan where the TWB suggests greater pipe diameters to be laid. The HGL that could be gained by implementing the TWB

[4] In fact population increase in Nuku'alofa even might have come to a halt due to the prevailing migration patterns.

proposal compared with the original Masterplan solution has been calculated and displayed in Annex 4.3.

Conclusions

The TWB proposal definitely further enhances the water supply situation in Nuku'alofa. Doubts remain whether this enhancement can be really justified on hydraulic grounds since the original Masterplan solution is sufficient in its design. However, since most of the pipes suggested to be replaced are made of Asbestos Cement and partly older than 30 years this report supports the proposal of the TWB. It is expected to produce a major improvement to the present and future unaccounted-for-water problems within the Nuku'alofa water supply system.

Annex 1: General Assumptions

Annex 1.1: Residential Demand Pattern

(2 pages)

Annex 1.1: Commercial Demand Pattern

(2pages)

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Annex 2.1: Supply system inventory

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Annex 3.1: Project inventory

Annex 3.2: List of all pipes to be replaced or laid.

Annex 3.3: Graphical overview on new pipes and HGL for each junction at 7:00 AM

Annex 3.4: Main flow streams and average relative demands at 7.00 AM

Annex 4: Additional upgrading as proposed by the Tonga Water Board

Annex 4.1: List of all additional pipes to be replaced or laid.

Annex 4.2: Graphical overview on new pipes

Annex 4.3: Main flow streams and HGL for each junction at 7:00 AM

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