University of Southern Queensland

Faculty of Engineering and Surveying

INVESTIGATIONS INTO CAMBOOYA'S WATER SUPPLY PRESSURE WITH RESPECT TO LOCAL CONTRIBUTING BORES

A dissertation prepared by

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Abstract

The following document comprises of an in-depth report of how the thesis topic of "Investigations into Cambooya's water supply system with respect to local contributing bores" was completed. The problem and the solution are outlined in the project aims and objectives are defined. After this, background information on the topic and available literature are discussed. The literature section includes discussions on modeling software, council data and papers written in similar fields that are applicable to this thesis.

A methodology for this project has been included in section 3 and defines the processes involved in collecting the required data to complete the model and completing the physical data collection activities.

After the methodology section, results, discussions, recommendations and conclusions have been made. Throughout these sections it was determined that Cambooya's current water supply network is performing adequately in accordance with SEQ Water and Sewerage Guidelines. However, at periods where groundwater levels are peaking the water pressure exceeds that which is set out in these guidelines. It was recommended that a control system should be implemented to limit the George Street Bore when required, during periods of high groundwater levels.

Appendices includes in this report are:

- The course specification sheet.
- A documented risk assessment for the physical data collection activities.
- A discussion into the consequential effects of this research topic.
- Certain results tables.
- The resource requirements to complete this thesis.
- Overview of project timeline.

References are included after the appendices.

Limitations of use

University of Southern Queensland

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ENG 4111 & ENG4112 Research Project

Limitations of Use

Candidates Certification

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in the dissertation are entirely my own efforts, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically listed.

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I would like to acknowledge the assistance of a few people who have made this project possible to complete in an effective and efficient manner. Firstly, I would like to thank my supervisor, Joseph Foley for his help in understanding the task, ideas of how to go about the analyses and assistance in debugging the model. Secondly, Matthew Norman from the Toowoomba Regional Council (TRC) who has made the Bore Monitoring Report, rainfall data and Bore Register documents available. Matthew was also the one who directed me to the TRC maps site, from which, a great deal of data was gathered. Thirdly, I would like acknowledge Campbell Olsen, also from the TRC, for his help with gathering the very specific information on the bore pumps which was not at all easy to collect. Finally, I would also like to mention Damian Darr from the TRC who is the southern region's coordinator for water and sewage. Damian supplied essential information on the bores and bore pumps and offered a personal tour of the Cambooya bore pump stations and reservoirs.

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1. INTRODUCTION

1.1 Introduction

Regional and rural communities within Australia are often introducing bore water into local water supplies. This is implemented so that the drier regions of Australia still have access to a constant and sustainable water supply. However, when the bore water is being introduced into a municipal supply system, the two differences in pressure become a concern. The water supply pressure must be equal to or less than what the bore pump is producing otherwise the pump will be working inefficiently. If the pressure difference is high enough it can prevent the introduction of bore water entirely. This can lead to low water pressure throughout the network as well as higher costs due to the much more frequent requirement for maintenance and replacement pumps. In addition, the interaction of the diurnal cycle of pressure at the bore head will produce unintended consequences in regard to the delivery of bore water into the network. This diurnal issue is further compounded by the groundwater rise that has occurred in the local Toowoomba regional basin due to the recovery since the Millennium Drought.

1.2 The Solution

As water pressures vary greatly throughout the day a model must be developed to compensate accordingly. This model will emulate a section of a water network where bore water is being introduced. After the model is correctly calibrated, modifications to the model will be implemented to see what changes can be made to determine what properties have the greatest effect on the pressures within the network. These modifications will include varying groundwater levels, pipe roughness values and water demand requirements. This understanding can provide the opportunity to ensure that active bores are flowing into the water supply appropriately and when required. To check that this model is accurate, physical results will be attained via field data gathering around the location the model is replicating.

1.3 Aim

The aim of this project is to study and model the interaction of local contributing bore pumps into the Cambooya municipal water supply network. This model will then be compared to physical data to determine whether Cambooya's bores are contributing effectively around the location of analysis.

1.4 Objectives

1. Obtain background information and data relating to the water distribution network in Cambooya and the groundwater bores supplying into the water supply system.
2. Review the available hydraulic models capable of simulating the distribution network in a town like Cambooya.
3. Obtain data regarding the bore pumps that are currently supplying into the water distribution network.
4. Determine whether the local bores are working effectively in series with Cambooya's water distribution network.
5. Develop an understanding of the interaction of the ground-water recovery on the performance of the bore-hole pumps and their altered impact on distribution of water through a complex network of water supply.
6. Present results of model development, (in terms of data entry) and complexity, along with an understanding of the groundwater pumps and supply system.
7. Present results on the variation of pressure heads expected throughout the distribution network that could be expected under the current rise in groundwater levels.

2. BACKGROUND & AVAILABLE LITERATURE

2.1 Introduction

In this section the technical fields which are relevant to this thesis will be discussed. These fields include water bore characteristics, properties of water bores, specific data for Toowoomba Regional bores, relevant pump types, characteristics of the relevant pumps and the availability and performance of numerous hydraulic modeling software packages. These items are essential to this thesis as an understanding of these fields must be attained to be capable of producing accurate findings.

2.2 Water bores

In rural and regional Australia it is very common for town water supplies to include bore water. Bore water is water stored and retrieved from underground reserves known as aquifers. Aquifers can be defined as 'a body of saturated rock through which water can easily move.' (Maley 2013)

2.2.1 Types of bores

Different types of aquifers are found at different depths and therefore different bores are needed to access and retrieve from each aquifer type. Figure 1 depicts the required properties of a bore at varied drilling depths. Bores A and B are accessing aquifers at depths 60-220m and bore C is accessing an alluvial aquifer at approximately 40m deep. Alluvial aquifers make up 20 percent of Australia's bores and 60 percent of Australia's groundwater extraction (Geoscience Australia 2012). Whilst alluvials are a major resource for irrigation, town, stock and domestic uses they are susceptible to contamination and pollution due to their shallow depth (Geoscience Australia 2012).

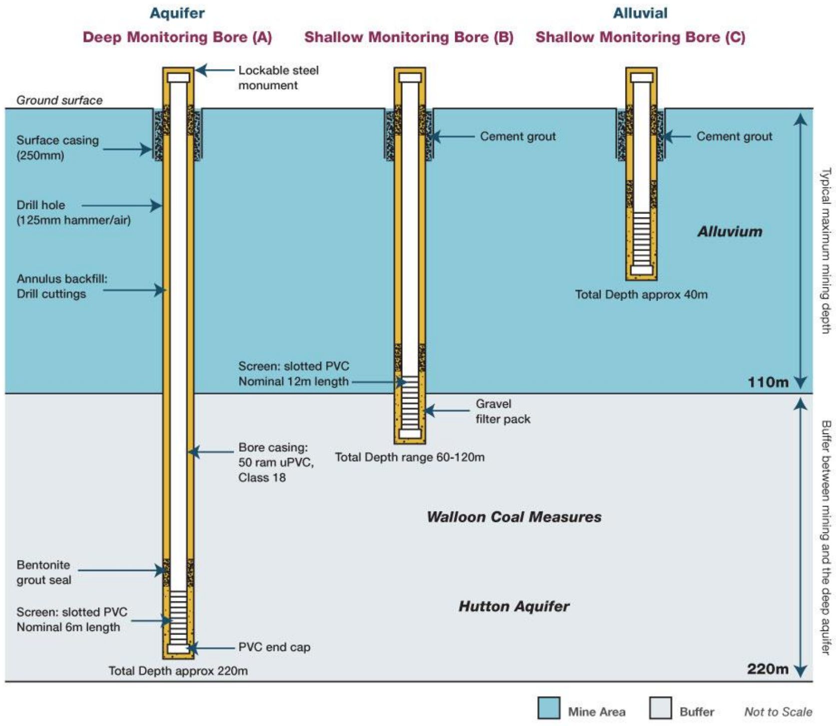


Figure 2.1: Required bore properties for aquifers at different depths. (Cockatoo Coal 2013)

2.2.2 Bore water pollution and contaminants

Before any bore water can be consumed it must first be disinfected and filtered. Raw bore water may contain microbiological, standard chemical, heavy metal and pesticide contaminants. The pesticides and standard chemicals will only be found in the shallow bores such as alluvials whilst the heavy metal and microbiological contaminants can be present irrespective of the bore depth (Australian Department of Health 2014). All of these contaminants must be filtered or decontaminated before the water can be considered potable. 'Generally, aquifers contain very limited numbers of microbiological organisms.'(Queensland Government 2014) However, various bacterial sources can be introduced into a bore during the drilling stages (Queensland Government 2014). 'In most instances these are naturally occurring bacteria, such as iron bacteria. When introduced in a bore these bacteria can flourish and cause clogging of the water delivery equipment.' (Queensland Government 2014).

2.2.3 Toowoomba Regional Bores

Up until the latest GIS data review of Toowoomba's bores it was believed that the Toowoomba region was home to over 300 bores (Toowoomba Regional Council 2012). 'Upon closer examination and field inspection, a number of the listed items were incorrectly shown. A detailed review was then conducted over a period of several months to update the bores register with missing, wrongly located and items that were not bores. The reduced total is 136 bores without including any monitoring bores at waste disposal centres or treatment plants' (Toowoomba Regional Council 2012).

Item	Count
Production	63
Decommissioned	1
Disused	1
Not in use	22
Irrigation	14
Unserviceable	1
Emergency Only	6
Observation	19
Abandoned	1
DERM Observation	5
Removed	1
Silted Up	1
Stock	1
Total	**136**

Table 2.1: Bore type counts for various uses (Toowoomba Regional Council 2012).

2.2.4 Characteristics of pumps

To fully comprehend the relationship between bores and the municipal water supply system, the characteristics and operation of pumps must be understood. The pump types that will be discussed are known as a centrifugal pumps and turbine pumps.

2.2.4.1 Centrifugal Pumps

The centrifugal pump is a pump that relies on an impeller to move fluid. "The centrifugal pump creates an increase in pressure by transferring mechanical energy from the motor to the fluid through the rotating impeller" (Grundfos 2006). "The centrifugal pump is the most used pump type in the world" (Grundfos 2006). "The principle is simple, well-described and thoroughly tested, and the pump is robust, effective and relatively inexpensive to produce" (Grundfos 2006). For this project it is mainly the impeller sizing, pump curves and pump efficiency characteristics that are of concern.

2.1.4.2 Turbine pumps

A turbine pump is essentially a vertically mounted centrifugal pump (Pump Scout 2014). The turbine pump is most commonly used to draw fluid from deep wells (Pump Scout 2014). For deeper wells, multistage systems are used. Therefore, since bore pumps are typically located up to hundreds of metres underground, the pump will have multiple stages. These stages are mathematically dealt with by multiplying the flow by the number of stages (Grundfos 2006).. A single stage pump implies that there is only one impeller i.e. an X stage pump will have X impellers (Grundfos 2006).

2.2.4.3 Impeller size

After purchase, centrifugal pumps can still be subjected to legitimate physical modification, such as impeller trimming. "Trimming reduces the impeller's tip speed, which in turn reduces the amount of energy imparted to the pumped fluid; as a result, the pump's flow rate and pressure both decrease" (United States Department of Energy 2006). "A smaller or trimmed impeller can thus be used efficiently in applications in which the current impeller is producing excessive head" (United States Department of Energy 2006). "Pump performance curves generally show performance for various impeller diameters or trims" (Satterfield 2013). It is common for Manufacturers to put several different trim curves on a pump performance curve to make pump specification easier, although this sometimes makes the pump performance curve more difficult to read (Satterfield

2013). It is now good practice to select a pump with an impeller that can be increased in size permitting a future increase in head and capacity (Satterfield 2013).

2.2.4.4 Pump Efficiency

"The overall efficiency of a centrifugal pump is the product of three individual efficiencies—mechanical, volumetric and hydraulic" (Evans 2012). "Although mechanical and volumetric losses are important components, hydraulic efficiency is the largest factor" (Evans 2012). The overall efficiency of a pump can be calculated by the ratio of the water output power to the shaft input power and is illustrated by the equation (Evans 2012):

$$E_f = P_w/P_s \qquad \text{Equation 1}$$

where:

Ef = Efficiency

Pw = the water power

Ps = the shaft power

If the water power equals the shaft power the pump would be 100% efficient. This is never the case though since there will always be losses present (Evans 2012). It is common for smaller pumps to fit within the 50-70% efficiency bracket and larger pumps to fit within the 75-93% bracket (Evans 2012).

In a practical sense pump efficiency is determined by the discharge (m^3/s) and total head (m). "The pressure head and flow that a pump is working at is called the duty" (Richards & Smith 2003). The efficiency changes with the range of possible duties for any specific pump (Richards & Smith 2003). "When you have calculated the pump duty, you can compare it to the manufacturer's specifications shown in the pump's performance curves" (Richards & Smith 2003). "By seeing the efficiency that the pump was designed to operate at, you can find out if you can improve its efficiency and thereby reduce pumping costs" (Richards & Smith 2003).

2.2.4.5 Pump Performance Curves

"A centrifugal pump performance curve is a tool that shows how a pump will perform in terms of head and flow" (Satterfield 2013). Pumps are capable of generating high volume flow rates when pumping against low-pressure head or low volume flow rates when pumping against high-pressure head (Satterfield 2013). The possible combinations of total pressure and volume flow rate for a specific pump can be plotted against one another to create a pump curve (Satterfield 2013). "The curve defines the range of possible operating conditions for the pump. Pump curves plot data on a graph with x and y axes" (Satterfield 2013). The x axis (vertical) shows the total head value (m) while the y axis (horizontal) shows the flow capacity (m^3/hr) as shown in figure 2. Also shown in figure 2 are the plotted lines for different operating speeds (rpm), the varying power requirements at different operational levels (kW), the impeller diameters (mm) and the NPSHr plots. The NPSHr lines, indicated at the bottom of the graph, define the minimum suction pressure required by a pump in order for the pump to operate without cavitation and performance deterioration (Richards & Smith 2003). The three lines indicate the NPSHr values for the shown operating speeds.

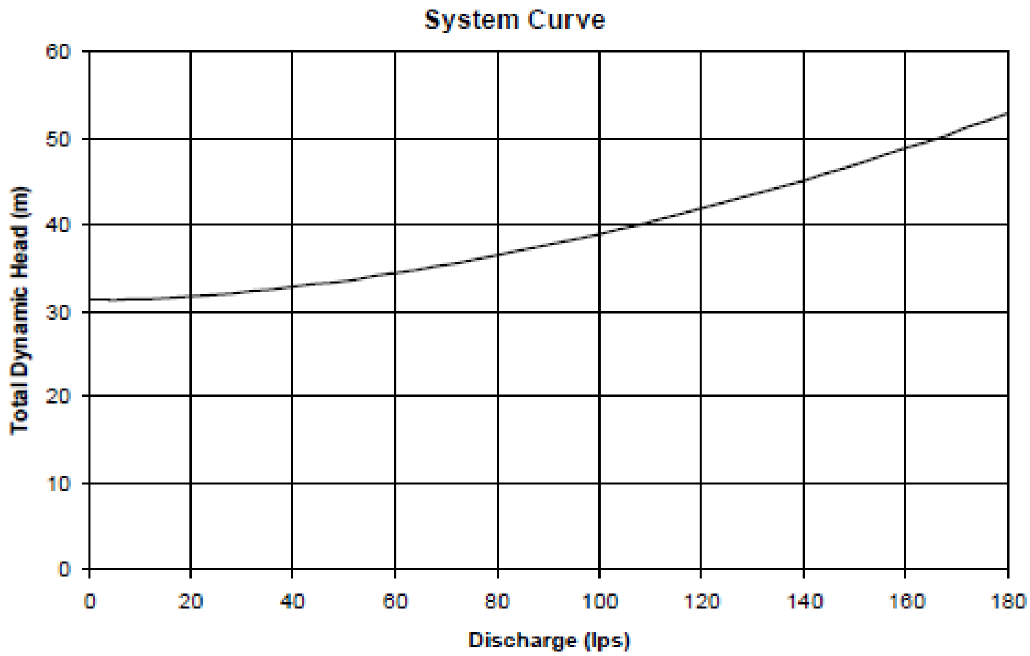


Figure 2.2: Simple pump curve for system of 30(m^3/hr) flow and 50(m) head (Pump-Flo 2014).

System curves are of a similar relationship but for the pipeline system rather than the pump. As shown in figure 3, the more water pumped into the system the greater the flow rate will be, respectively, the less water pumped into the system the smaller the flow rate will be.

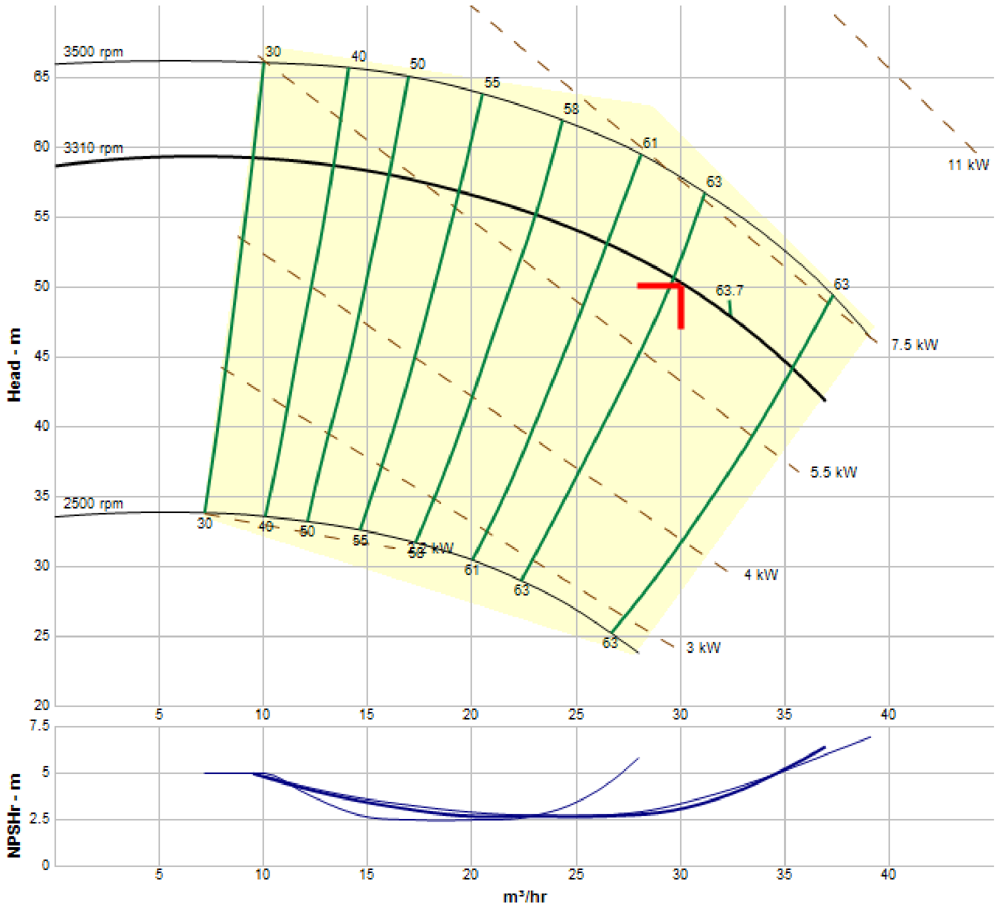


Figure 2.3: Simple system curve. (Richards & Smith 2003)

When these two curves are plotted together, the actual performance can be found. This is the point of interception between the two lines and is called the operating point, as illustrated in figure 2.3.

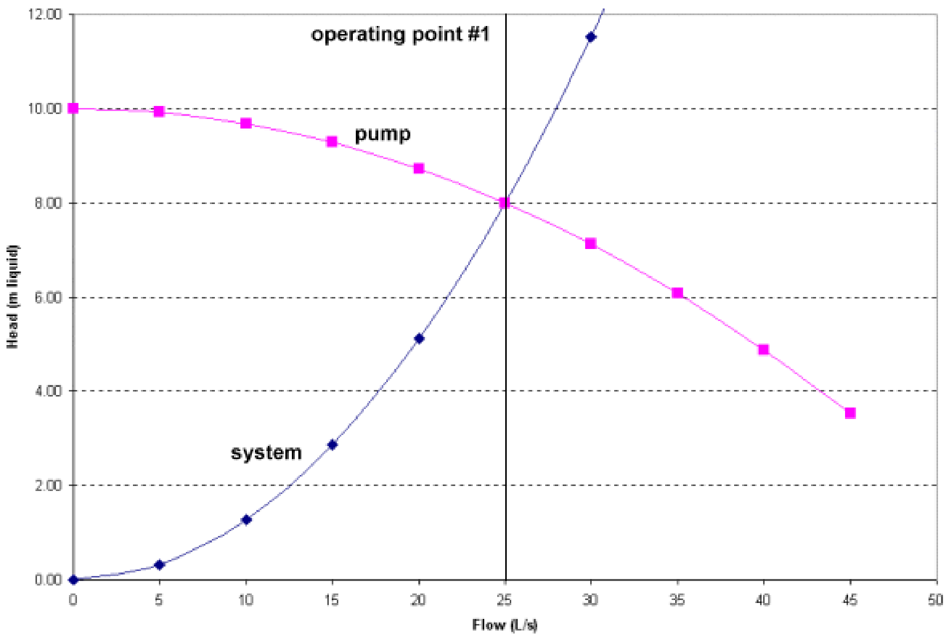


Figure 2.4: Operating Point (Spirax-Sarco 2014).

2.3 Modeling Software

To effectively model Cambooya's municipal water network, hydraulic modeling and simulation software must be investigated. As there is a large range of varied hydraulic modelers to choose from, software from both internet and database browsing efforts will be briefly analysed. This analysis will include anecdotal evidence from online reviews as well as first hand testing. The first hand testing, however, will only be performed on available freeware rather than introducing a financial requirement for products that may not be ideal for the task. If by the online reviews and advertised abilities a program with financial requirement is selected as the preferred software it will be noted in the dissertation but the most preferred freeware will be used instead so as to avoid any extra cost.

As suspected there were many different software options available. Internet searching revealed more than fifteen different options but only six of these were shortlisted into the review stage. These programs included:

- EPANET (*Free* by EPA)
- InforWater (By Innovyze)
- HydrauliCAD (By HydrauliCAD Software)
- WaterGEMS (By Bentley)
- WATSYS, also known as WaterMax (By HCP)
- WATHAM (*Free* by HCP)

Database browsing resulted in much fewer results although these programs were discussed in great depth. This type of search was very effective because the results were more valuable than that of the internet browsing results. The insight into each program at a scholarly level was more helpful than online reviews from people without any qualifications and sale pitches from software developers. The database browsing results include:

- WaterCAD (By Bentley Systems)
- EPANET (By EPA)

From both of these searches combined there were a total of eight results with seven of these being unique. The only overlapping program was EPANET.

From the seven different software options available from these searches there was a great variance in capability, usability and cost. The most relevant of these attributes is capability. The program must be capable of performing the task of modelling and running simulations for a section of the Cambooya's municipal water supply. These mandatory capabilities include:

- The program should be able to emulate pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs.
- The program will be able to track the flow of water in each pipe, the pressure at each node and the height of water in each tank throughout the network during a simulation period comprised of multiple time steps.
- The program will be able to present results in both tabular and graphical form once a full simulation is completed.

- The program will be able to upload map files so that the model can be drawn to scale. If these map files also included a three dimensional aspect, so as to include altitudes at any location, this would also be ideal.

The second most important attribute for these programs to have is usability. Usability will directly affect how long it takes to complete the construction and simulation processes. The simpler and more user friendly programs will be chosen over the difficult (but possibly more accurate) software due to the constraint of time. Therefore the requirements for usability include:

- The software must be user friendly and very easy to learn. If online tutorial videos are available online that software would become very appealing.
- The program should permit simple modification and editing throughout the construction and simulation procedures.

The final requirement that the software must meet is financial. EPANET and WATHAM were the only freeware options, whilst the others had a financial factor ranging between $50 and $300 AUD. So these were the only two programs that would be considered for the modeler of this project.

2.3.2 Further discussion on database browsing results

2.3.2.1 WaterCAD (Bentley systems)

This software was used in the scholarly article discussed later in section 3.3.2.1. In this article the software was used to make comparisons with the hydraulic model that the authors were creating. The model was being created in attempts to further evolve today's municipal water system's simulation models. There were not many comments on the WaterCAD's software performance but the use of it alone in such an advanced project is encouraging.

2.3.2.2 EPANET

This software was used in the scholarly article discussed later in section 3.3.2.3. In this article the authors were modeling the municipal water supply in Beijing city, China. The model images were very detailed and gave a good understanding of what EPANET offers. They use EPANET in parallel with a GIS .map file. This file contains all the geographical and topographical information of the desired area, making model design a much simpler task. In this report the authors also introduce water reclaiming stations which are essentially recycling stations. After water is processed through this plant it is discharged back into the system. The principle of scattered water induction into a municipal water supply is shared in this project, making EPANET a very appealing software choice.

2.4 Documentation and reports

2.4.1 Toowoomba Regional Council - Bore monitoring bore review

The bore monitoring reports for the year 2012 has been made available by the Toowoomba Region council. This annual report is based on a July – June period similar to the financial year. The report is in a report document goes into depth on the groundwater status of different aquifers around the Toowoomba Region and how they have been performing since the drought. It discusses what observation bores the Toowoomba Regional Council has and how monitoring can be improved with the existing infrastructure. The document includes:

- Rainfall and rain gauge data from the period, July 2011 to June 2012
- GIS data review
- Monitoring system review
- Monitoring bore records
- Appendices

The 'Rainfall and rain gauge data from the period, July 2011 to June 2012' includes statistical results based on record lengths extending from 73 years at the Dunmore state forest station to 138 years at the Toowoomba station. The results include a brief overview of each station's annual rainfall minimums, maximums and averages in millimeters. Whilst rainfall data is not imperative to this project, the data will give a greater understanding of the groundwater behaviour in respective areas.

The 'GIS Data Review' includes an overview of the current quantity of bores and their different roles. The document explains how this has changed over the past 12 months as there were many items that were incorrectly shown. That is, items marked as bores were missing, wrongly located or not actually bores. The GIS review itself is not required for this project but the act of the review reinforces the credibility of the data used throughout the modeling process.

As the bore population changed in that 12 month period a bore monitoring system review had to occur. In this review the Toowoomba regional council reevaluated how they were using all the bores. While the role of some bores stayed the same other bores' role changed depending on their location and aquifer type. The majority of the changes were bores that were swapped from a 'Not in use' status to an 'Observation' status and vice versa. Approximately 70% of these changes were made within the Toowoomba city. The other 30% were external to the city but within the Toowoomba region.

The millennium drought had a devastating effect upon the bores in the Toowoomba region (Toowoomba Regional Council 2012). Although there has been ground water recharge since the end of the drought, some aquifers are still yet to reach their pre drought condition. To monitor this, the Toowoomba Regional Council records the groundwater changes within the Toowoomba city. The standing water levels of Toowoomba's bores are recorded monthly into a database so that the average annual level can be calculated. This data will be imperative when including groundwater levels into the model as it will have a notable effect on the acting pump system and ultimately the discharge of the bore into the municipal water supply.

Appendices included:

- A map of the current Toowoomba region's rain gauge stations.
- A map of the average annual rainfall.
- Toowoomba's regional rain gauge data.

- Toowoomba's regional bore data.
- A multitude of maps depicting bore locations around the Toowoomba region.
- Monthly and annual graphs for each rainfall recording station around the Toowoomba region.

Of these appendices only the regional bore data and bore maps will be relevant to the modeling process. The rainfall data will be relevant to groundwater discussions but will not directly affect the results of this project.

2.4.2 Toowoomba Regional Council - Groundwater bore register – Water and Waste Strategy and Coordination (WWSC)

The groundwater bore register for 2013 has been made available by the Toowoomba regional council. This document contains information regarding the region's bores, groundwater aquifers, groundwater vulnerabilities and general land use.

2.4.2.1 Mapping

The document includes maps of bore locations, groundwater aquifers, groundwater vulnerabilities and general land use. These maps are available for the regions:

- Toowoomba Region
- Millmerran/Brookstead/Pittsworth
- Wyreema/Cambooya/Greenmount/Nobby/Clifton
- Kulpi/Haden/Goombungee/Oakey/Kingsthorpe
- Highfields
- Toowoomba City
- Cecil Plains.

All of these maps are to scale and with precise and helpful legends

2.4.2.2 Bore register

The bore register has all the information for each individual bore in the Toowoomba region. It includes valuable information such as

- **Bore and Scheme name** – When discussing the bore pumps with Toowoomba regional council representatives it will be helpful for them and myself if they knew exactly what bore/s were being discussed. This information does not have any great relevance to the topic or model.
- **Location** – The specific location of each bore will be helpful in the same way the 'Bore and Scheme name' is, but it will also assist when transferring and comparing the bore register details to the TRC online mapping application.
- **Purpose** – Each bore has a specific purpose such as 'Town Water Supply', 'Irrigation' or 'Amenities', this information is imperative in determining which bores can be used for the model and which cannot. The only bores that will be relevant in a modeling situation is those which have the sole purpose of 'Town Water Supply.' There would be no point in modeling any other bores for this project topic.
- **Status** – Bore status is also crucial in bore selection. If a bore's status is 'Decommissioned', 'Not in use', 'Emergency only', 'construction' or 'Irrigation' it will be of no use to this project. The only bores that will be shortlisted in selection will have a 'Production' status.
- **Original drill date and expiry date** – The age of the bore is also of large concern in this topic. If a bore has a relatively recent drilling date one would assume that the bore is entirely intact and running efficiently. Bores that are closer to expiry date, however, could have some faults present. These faults include, damaged filters, high chemical levels (i.e. nitrate) or damaged pipe casing. Apart from damaged or blocked filters, these faults should not have any effect on the physical testing results. The age of a bore will not be a determining factor in bore selection but if the results skew then the age of the bore may come into mention.
- **Aquifer type** – It is useful knowing the aquifer type so that the characteristics of the aquifer and groundwater in the area can be discussed.

Certain aquifers may behave differently to others and this will be noted in the discussion of results.

2.4.2.3 Bore log data

The bore log data sheets contain very similar information to the bore register but also include helpful additional data such as:

- **Bore Depth (m)** – The bore depth will be required when discussing groundwater levels and pump requirements.
- **Flow rate (L/s)** – The flow rate of the bore is required for determining the speed at which the pump is running and/or the impeller size.
- **Coal seam gas / Petroleum impacts** – Whilst this information is not relevant to the model or physical testing, it is still an issue of sustainability around this project topic.

Also attached to this document is a report on 'Groundwater vulnerability and availability - Mapping of the upper condamine river catchment.' The report is a Masters level dissertation by Allen Hansen from the University of Technology, Sydney. The dissertation focuses on climate, geology, surface water hydrology, groundwater mapping techniques and groundwater availability. Whilst, most of this report has no relevance to the topic of this project, the data gathered for the groundwater mapping techniques and the groundwater availability sections are very informative towards groundwater discussions. Information such as groundwater depths and net recharge rates are extremely relevant to this topic.

2.4.3 Evolving effective hydraulic model for municipal water supply – Wu, Zheng Y (Bentley systems)

This article has been made available by the University of Southern Queensland's articles and journals archive. The article revolves around the creation of a hydraulic simulation model for a small city's municipal water supply. This includes the mathematical decisions as well as the implementation of pipe, pump, hydrant, tank and reservoir properties that need to be made before a model can be created. Furthermore the article goes into depth about:

- Data requirement
- Calibration framework
- Implementation
- Data collection
- Calibration target, boundary and demand data
- Flow balance calibration
- Hydraulic grade calibration
- Model application

The article also discusses the use of a hydrant tagging system and Competent Darwinian Evolver software which further assists decision making.

Whilst the goal of this project is not to create a hydraulic modeler from scratch like this article describes, it gives a better understanding of what is required in creating the software that will be used and the data that will be needed before the model can be created.

2.4.4 Pipeline network modeling and simulation for intelligent monitoring and control

'A simulation model of the municipal water supply network system of a moderate-sized prairie city in North America has been described in this study. The model would be used to simulate dynamic behaviour of the system based on different pump and valve operation modes. The developed model predicts temporal flow rates and pressures at any location in the system and determines a change of water level in the reservoirs over an extended period of time.'(Kritpiphat, Tontiwachwuthikul & Chan 1998) The testing involved two different programs to simulate this behaviour; FORTRAN and MathCad. The authors concluded on their comparison between the two different programs. 'We found that the programming tools have a significant impact on the methods used to solve the problem. The FORTRAN program was found to be superior to MathCad in terms of computational and convergence speed. But the FORTRAN program requires a graphical user interface for enhancing communication between the user and the program. Since the computational time requirements for running the 28 nodes and

34 links vs the 14 nodes and 14 links model in the FORTRAN system, it does not differ significantly. Therefore the former model is used as the working model. This generates results on the dynamic change of water level in the reservoirs, which are then used as input in the expert system developed for the monitoring and control of the water supply system.'(Kritpiphat, Tontiwachwuthikul & Chan 1998) Because the software the authors chose for this analysis were programming based modellers they will not be used or discussed any further in this paper.

This paper is similar to that discussed in 3.3.3 but goes into a much greater depth mathematically. This article shows both the implemented arithmetic and discusses the different hydraulic methods that can be used rather than just being specific to the one method.

2.4.5 Hydraulic model for multi-sources reclaimed water pipe network based on EPANET and its applications in Beijing, China.

This article discusses a hydraulic simulation model that was eventually adopted by the Chinese government. Once again the authors of this article discuss the decisions that must be made prior to creating their simulation model. The large and complex network simulation also included water recycling plants that Beijing city was in need of due to their extremely high population density. The article is extremely relevant to this paper because the recycling plants will be discharging back into the municipal water supply post treatment just as the water bores in the Toowoomba region will be. In this case they chose to use the program EPANET supported by GIS software to create their simulation model. The EPANET software would construct the hydraulic pipeline and then run the simulation based upon the geographic and topographic information made available by the integrated GIS software.

3. METHODOLOGY

3.1 Introduction

In this paper, a method is proposed to increase the understanding of the relationship between a small water network's supply pressures and local contributing bores. This was possible by creating a hydraulic model of a water supply network within the Toowoomba Region and calculating the pressures at different demand periods and comparing that to results that were physically collected from the region. To accurately perform this analysis a lot of data was required.

3.2 Choosing the software

To begin this analysis the software had to be chosen. This software had to be simple and quick to learn but also fast and detailed in what it did. It would be strongly preferred if this software was capable of directly uploading '.map' files so that geographical and topographical calculations wouldn't have to be manually performed using contour maps and interpolation. It was hoped that the Toowoomba Regional council would be able to supply this '.map' file because the cost to download these from online websites requires an $80-$200 monthly subscription to a privately owned website. No other sites have been found that offer the free download of these files. It is believed that the attainment of these files would greatly reduce the time required in constructing this model. If a '.map' file could not be attained then the program would still be required to upload a map of the chosen location to the background of the modeling software. This would also assist in scaling the model. Manually interpolating on a contour map would be much more time consuming. Another viable option is to use the Toowoomba regional Council's online mapping application. This application includes 5m and 1m elevation contours. These elevations would still need to be inputted into the model but manual interpolation would be much simpler with 1m contours as an accurate guide.

After these required specifications were identified the search was narrowed down to an internet based search and a database search. As expected the internet results gave many more responses than the database results. From the internet based search there were six programs nominated for further discussion, two of these were freeware and downloadable online. In the database search there were two programs chosen, both of which were freeware and downloadable online. There was one simulator which overlapped out of the four freeware results and that was EPANET. This software was simple, free and included GIS integration which would allow the upload of '.map' files. Therefore EPANET was the chosen software for this project.

3.3 Data Requirements

In the literature discussed in section 2.3.5, it mentions the use of EPANET and the data requirement plan for a project that would be very similar to this one. Below is a network flow diagram of what data would be required and what processing the gathered data would follow in order to give an output (Kritpiphat 1998). It has been determined that this would be a fitting model for the creation of this project.

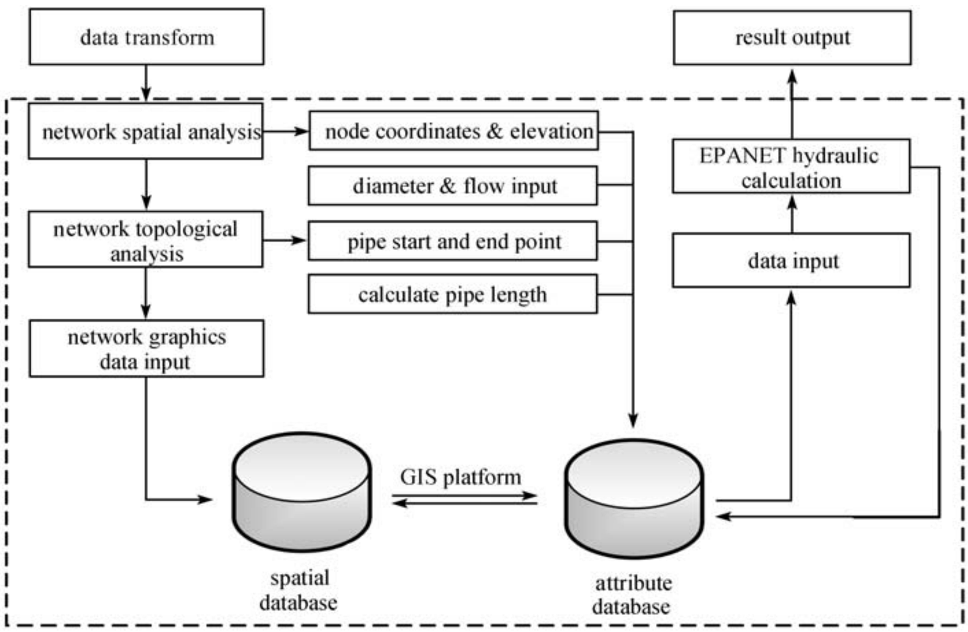


Figure 3.1: Network flow diagram (Kritpiphat 1998)

The data input would include:

- Pipe discharge.
- Pipe diameters.
- Pipe friction factor and/or minor loss coefficients.
- Water pressure at specific points (this may be calculable via the geographical data plus the present time pressure head at the gravity feeding reservoirs).
- Pump size.
- Pump Curve.
- Elevation data across the entire modeled section.
- Total head at reservoirs.
- Stagnant head of bores.
- Acting pump pressure.

All the information on pipes would be gathered from Toowoomba Regional Council's online mapping application. All pipe diameters, discharges, materials, install dates and operational statuses could be determined using the 'Identify' tool within the online application. Information on the pumps, however, is much more difficult to attain. The council does not yet have a bore pump register although they have just recently started collating data for such a document. This information would therefore be attained via Toowoomba Regional Council employees. Before this information can be gathered, however, a location must be selected.

3.4 Location

3.4.1 Location Requirements

Before any model could be created, the location of analysis had to be determined. This location had to have a reservoir and at least one bore. For a bore to be relevant in this analysis it had be an active production bore so that it is directly reticulating into the municipal water supply system. Also, to accurately map the bore pumps it was imperative that there were no booster pumps between the bore and the source as this would further complicate the analysis. It is preferred that these bores also be outside of the CBD so that discharges and water requirements are consistent and reasonably similar across the field of analysis. If the location was within the CBD, water requirements would vary greatly during the period of data collection. This is because of the variance in business types using different amounts of water depending on the time of day and the number of customers/workers present during the period of data collection. Therefore, a small amount of data from CBD areas would not necessarily accurately reflect the pressure distribution.

In residential areas water usage will be much more uniform across the area of analysis and peak times are very likely to be consistent during the week. Therefore residential areas are the preferred location of analysis. It would also be ideal if there was only one service main feeding into the area of analysis from one reservoir, this would make the analysis much simpler as water would only be feeding into the system from a single direction. If this is not possible or an area like this cannot be found then a location with the greatest possible isolation will be used.

3.4.2 Selected Location

The location that has been chosen for this project is a section within the township of Cambooya. Cambooya is approximately 30min from Toowoomba city but is still well inside the Toowoomba region. The selected location would have ideally been within the Toowoomba city, but no location fully met the analysis requirements. Cambooya has two bores, a gravity feeding reservoir and an easily isolated section that is being supplied by both the bores and the reservoir. Also, because this township does not have a central business district the results attained will be much more consistent across the network. The only major allotments that have unknown demands are the Cambooya Pub – The Bull and Barley Inn, Cambooya Primary School and the Cambooya Bowls Club. The demands of these allotments will not be taken into account and will only come into discussion to interpret any offsets between the model's results and physical results.

3.4.2.1 Location population data

There has been no population evaluation in Cambooya since 2012 therefore the councils' predictions and estimations will be used to determine a current population. The population of Cambooya has been estimated using the Council's equivalent persons (EP) estimations between 2012 and 2031 in 5 year intervals. These estimations were interpolated to derive a population for the year 2014. There is also an ultimate EP which represents the EP value when Cambooya is at a point of maximum development. The EP values from 2012-ultimate are illustrated in the table below.

Existing	2016	2021	2026	2031	Ultimate
1282 EP	1393 EP	1744 EP	1963 EP	2224 EP	2551 EP

Table 3.1: Equivalent Persons spanning from 2012 - ultimate development. (Toowoomba Regional Council 2012)

Using this data, the current population was determined to be approximately 1340 EP. This was found by interpolating between the 'existing' and 2016 EP predictions.

3.4.2.2 Cambooya Overview/Layout

Below is the overview of the section of Cambooya that is being modeled. As illustrated the reservoir is too far away from the location to show a fully scaled diagram that includes the reservoir. The image was ascertained via the TRC mapping application and edited simply in Microsoft paint.

Figure 3.2: Overview of the chosen location of analysis.

3.4.2.3 Number of residential properties (layout of area with imagery)

Knowing the total number of residential properties in the area of analysis is imperative to determining the demands throughout the system. The population will be divided among the residential lots so that an average demand per residence can be determined.

The number of residential properties was counted using the TRC mapping application. The application gives the option to show a satellite image as the background of the map. Whilst the counted number will not likely be 100% perfect due to non-residential properties or abandoned lots, it will give a reasonable number to assume as an average for the model. To most accurately count the populated allotments the driveways were considered while counting to safeguard against counting large sheds or detached garages. The following image illustrates the Cambooya overview with satellite imagery included.

Figure 3.3: Overview of the selected location with satellite imagery.

Whilst it would be near impossible to count the populated allotments from this image, the application incorporates an excellent ‘zoom in’ function. An example of this zoom (at only 90%) is shown below in figure 4.8.

Figure 3.4: Satellite image of property (90% zoom)

With this level of zoom, counting the properties, whilst time consuming, was very simple.

3.4.2.4 Diurnal pressures and demands

The existing unit demand has been calculated based on the council's historical data for water consumption across all properties connected to the Cambooya water supply network. 'The unit demand for all future planning horizons was obtained from the '*Determination of Flows for Planning Purposes across the Toowoomba Region*' report (TRC 2011) and the '*Draft Water Infrastructure Policy no. 2.3'* (TRC 2012)'(Toowoomba Regional Council 2012). 'Non-revenue water was calculated based on the actual bore production and water consumption data' (Toowoomba Regional Council 2012). Non-revenue water is applied as a constant demand (Toowoomba Regional Council). Cambooya's residential and non-residential peaking patterns and corresponding demands are shown in the images below.

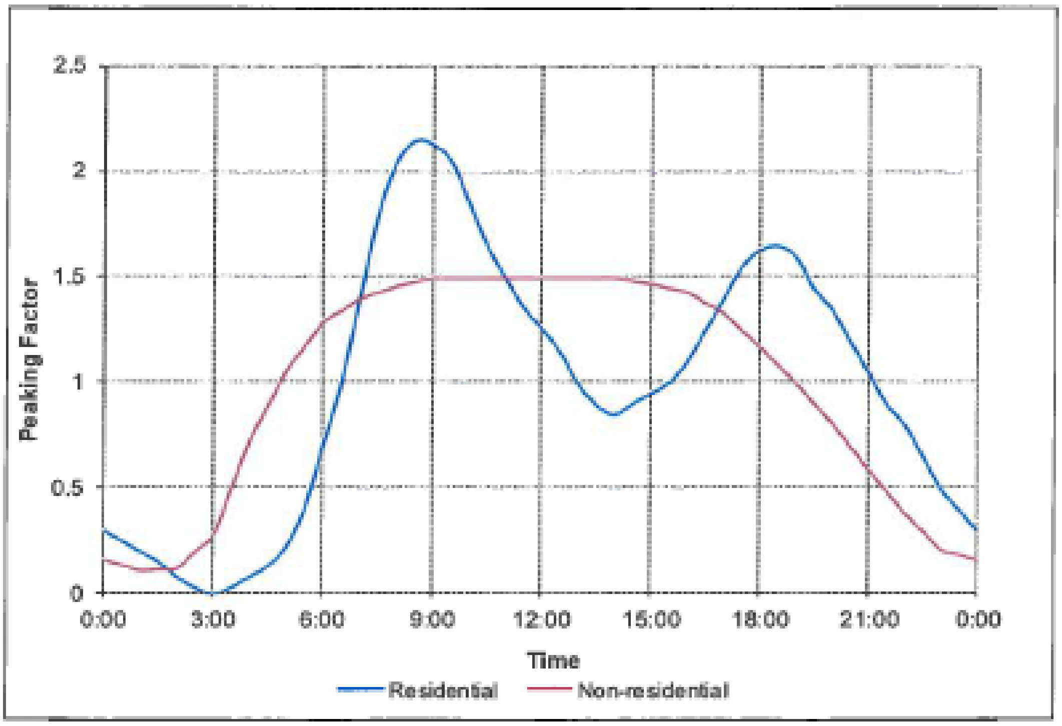


Figure 3.5: Average Cambooya water consumption – Peaking Factor vs. Time. (Toowoomba Regional Council 2012)

Planning Horizon	Total EP	AD		MDMM		PD		PH	
Existing	1288.0	2.20	L/s	3.71	L/s	5.34	L/s	11.46	L/s
		0.19	ML/d	0.32	ML/d	0.46	ML/d	0.99	ML/d
2016	1442.2	2.46	L/s	5.64	L/s	8.11	L/s	17.43	L/s
		0.29	ML/d	0.49	ML/d	0.70	ML/d	1.51	ML/d
2021	1805.5	3.08	L/s	7.06	L/s	10.16	L/s	21.82	L/s
		0.36	ML/d	0.61	ML/d	0.88	ML/d	1.88	ML/d
2026	2032.3	3.46	L/s	7.95	L/s	11.43	L/s	24.56	L/s
		0.41	ML/d	0.69	ML/d	0.99	ML/d	2.12	ML/d
2031	2302.6	3.93	L/s	9.01	L/s	12.95	L/s	27.82	L/s
		0.46	ML/d	0.78	ML/d	1.12	ML/d	2.40	ML/d
Ultimate	2641.0	4.50	L/s	10.33	L/s	14.86	L/s	31.91	L/s
		0.53	ML/d	0.89	ML/d	1.28	ML/d	2.76	ML/d

Table 3.2: Demand predictions from 2012 –ultimate development. (Toowoomba Regional Council 2012) - AD = AVG Day, MDMM = Maximum Day Mean Month, PD = Peak Day, PH = Peak Hour.

From these figures and an excel spreadsheet that replicates the process that the TRC used, the demand values for 2014 have been determined. The following table shows all 2014 demand figures that will be used in the EPANET model.

Demand data	2012	**2014**	Ultimate
Total population	1288	**1340**	2641
No. of Houses	?	**391**	?
People per house (AVG)	3.43	**3.43**	3.430
L/EP/d	147.3	**150**	200
L/EP/s	0.00170	**0.00174**	0.00231
L/s/household	0.00585	**0.00595**	0.00794
Non-revenue (L/s) (12.8%)	0.28	**0.29778**	0.50895
AD (L/s)	2.2	**2.629**	4.500
MDMM (L/s)	3.71	**3.932**	10.330
PD (L/s)	5.34	**5.653**	14.860
PH (L/s)	11.46	**12.144**	31.910

Table 3.3: 2012, 2014 and ultimate water demand data for Cambooya.

3.4.2.5 Cambooya Reservoirs

There are currently two reservoirs in Cambooya, one newly constructed and one recently retired. The two reservoirs have the following properties.

Description	Reservoir
Capacity	400 kL
Height	2.7 m
Diameter	13.73 m
Base Elevation	520.40 m
Inactive Volume	37 kL
Section	circular

Table 3.4: Retired reservoir properties (Toowoomba Regional Council 2012).

Description	New Reservoir
Capacity	1500 kL
Height	5.24 m
Diameter	19.10 m
Base Elevation	520.40 m
Inactive Volume	52 kL
Section	circular

Table 3.5: New reservoir properties (Toowoomba Regional Council 2012).

The new reservoir was constructed directly adjacent to the retired reservoir so that the same pipe line could be used with only minor modifications (Toowoomba Regional Council 2012). The site of these reservoirs was visited during a personal tour conducted by Damian Darr of the TRC. The following photos were taken at the reservoir site.

Figure 3.6: Cambooya's recently retired 400kL reservoir.

Figure 3.7: Cambooya's new 1.5ML reservoir Pt1/2.

Figure 3.8: Cambooya's new 1.5ML reservoir 2/2.

3.4.2.6 John Street Bore

The John Street bore is the lead bore for the township's supply (Toowoomba Regional Council 2012). As per tender information the duty point is 15L/s at 144m head and the pump is at a depth of 100m. All elevation data for John Street bore is shown in table 4.7.

Description	John St Bore
RL Bottom of Bore Hole	307.5 m
RL Pump	374.5 m
RL Surface Level	474.5 m

Table 3.6: John St bore elevation data (Toowoomba Regional Council 2012).

This site was also visited during the private tour with Damian Darr of the TRC. The following photos were taken at the site.

Figure 3.9: John St bore electric motor drive.

Figure 3.10: John St bore flow rate.

Figure 3.11: John St bore chlorination control unit.

Figure 3.12: John St bore chlorination concentration.

3.4.2.7 George Street Bore

The George Street bore is the auxiliary supply for Cambooya (Toowoomba Regional Council 2012). When operating, the George St bore creates a 'milky' colour in the reticulating water (Toowoomba Regional Council 2012). In order to avoid this, the council always has the John St bore activated after the George Street bore has turned off (Toowoomba Regional Council 2012). This flushes the unwanted 'milky' colour out of the reticulation (Toowoomba Regional Council 2012).

"The duty point of the George Street bore is 20L/s and 149m head" (Toowoomba Regional Council 2012). The pump is installed at a depth of 100m, the same depth as John Street (Toowoomba Regional Council 2012). All other elevation data is shown below in table 3.7.

Description	George St Bore
RL Bottom of Bore Hole	308.4 m
RL Pump	366.4 m
RL Surface Level	466.4 m

Table 3.7: George St bore elevation data (Toowoomba Regional Council 2012).

This site was also visited during the private tour with Damian Darr of the TRC. The following photos were taken at the site.

Figure 3.13: George St bore flow rate.

Figure 3.14: George St bore electric motor drive.

Figure 3.15: George St bore chlorination concentration.

3.4.2.8 Pump properties

The two bore pumps at the George and John Street pumping stations are both multistage vertical turbine pumps. The John Street pump is an Everflow 15 stage 150RM and the George St pump is an older Everflow 20 stage 6HXB. The following images are of the labels that were stamped on each pump. The labels contained important performance data and identification.

Figure 3.16: John Street bore pump label.

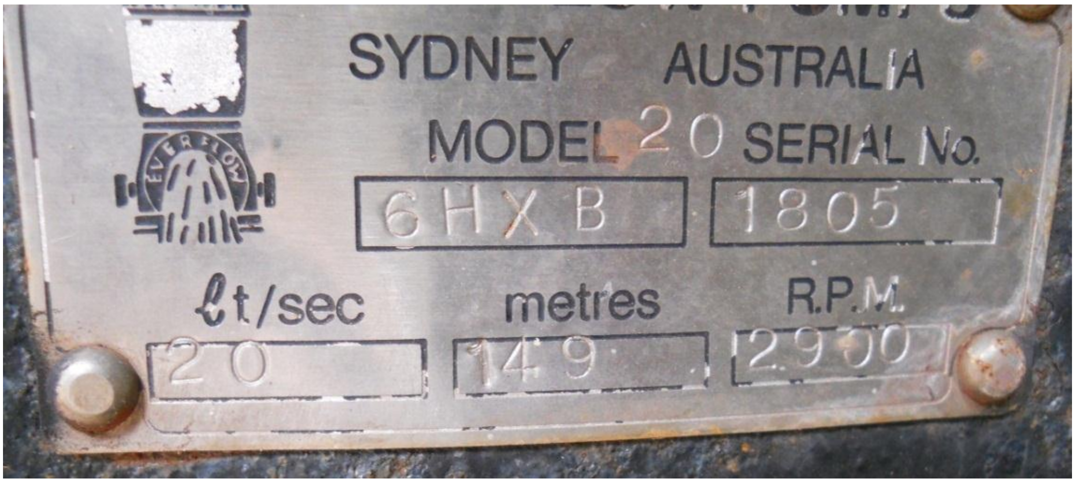


Figure 3.17: George Street bore pump label.

Unfortunately only partial pump curves were available through the TRC. Therefore the respective full curves had to be attained through Everflow Pumps Australia. However, Everflow only had the 150RM curve available since the 6HXB is such an old model. Unfortunately the 6HXB pump curve could only be found in imperial measurements, i.e. feet head and gallons per minute. Therefore to estimate the full pump curve the council's partial curve was interpolated against the tendencies of the two imperial curves found via the Peerless pump website.

The following images are of the 150 RM pump curve, the TRC's partial 6HXB curve and a larger 6HXB curve from the Peerless Pumps website.

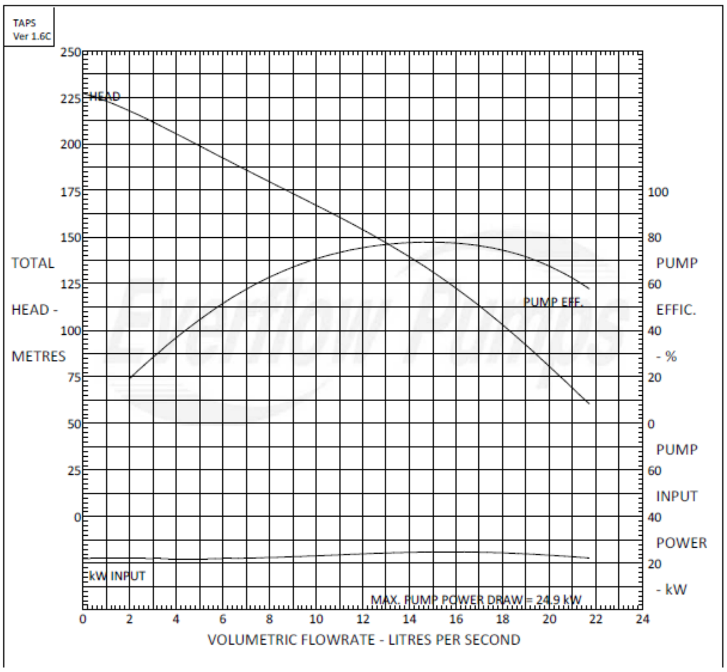


Figure 3.18: 14 Stage 150 RM Pump curve (John Street pump)

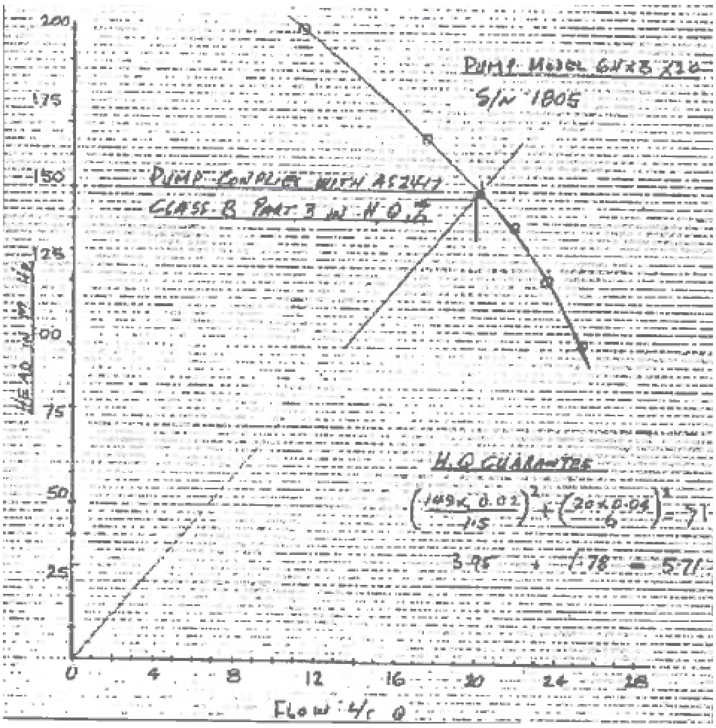


Figure 3.19: TRC's partial pump curve for 20 stage 6HXB (George St Pump).

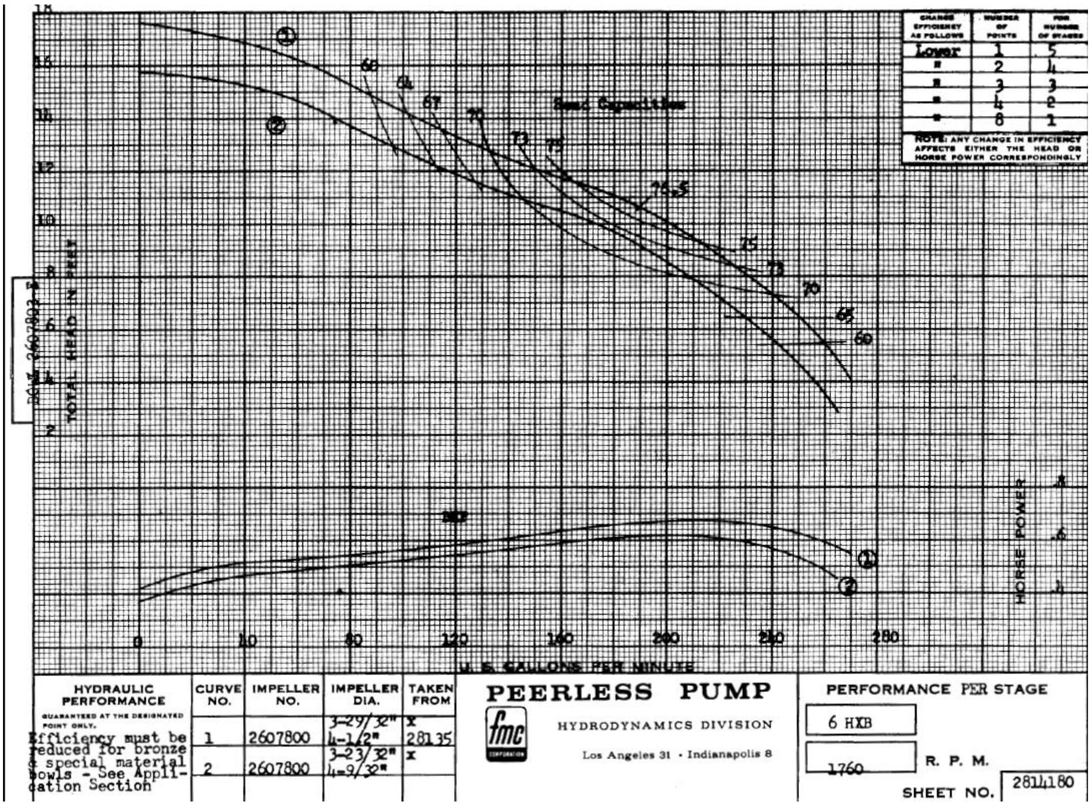


Figure 3.20: Peerless Pump's Imperial pump curve for 20 stage 6HXB (George St Pump).

From these curves the following pump data was derived. Where flow or head measurements were not given values they were approximately but carefully interpolated.

20 Stage 6HXB	
Head (m)	Flow (L/s)
230	0
225	2
200	12
165	17.5
150	20.5
137.5	22
122	23.5
100	25.5
50	27
0	28

Table 3.8: 20 Stage 6HXB pump curve in tabular form.

15 stage 150 RM	
Head (m)	Flow (L/s)
227.5	0
205	5
167.5	12.2
152.5	13.8
135	16.5
115	18.8
81.25	22
0	28

Table 3.9: 15 stage 150 RM pump curve in tabular form.

These values will be used in the EPANET model as the input data for the respective pump curves.

3.4.2.9 Pipe properties

The vast majority of pipes in the selected location are PVC-U pipes, however, there are a few iron ductile, PE100 and Blue Brute pipes scattered throughout (Toowoomba Regional Council 2014). The PE100 and Blue Brute materials have extremely similar roughness values as the PVC-U (Duronil 2007) and are therefore given the same roughness of 0.0015mm. The Iron ductile pipes have a much greater roughness value of 0.03 (Duronil 2007). Any pipes that have an unknown material will be assumed to be PVC-U pipes.

The pipe diameters vary greatly throughout the system. The 100mm and 150mm pipes are the most common sizes, but 80mm pipes and 200mm pipes are also used at low and high flow points respectively. The two pipes that attach the bores to the rest of the network have a diameter of 600mm; these pipes are considered to be detention basins for the chlorine to mix in with the water before entering the reticulation (Toowoomba Regional Council 2012).

All pipe information has been attained via the TRC mapping application. The information has been supported by TRC employees.

3.3.2.10 Cambooya's groundwater source

Cambooya's bores are extracting from an aquifer type known as 'Main Range Volcanics' (Hansen, A 1999). The Main Range Volcanics consist predominantly of tertiary basalts with various trachyte flows, breccias and truffs (Hansen, A 1999). The soil cover is dominantly black cracking clay type soils with lesser red non-cracking clay soils (Hansen, A 1999). This type of soil is present throughout Cambooya, as shown in the figure 3.21.

Figure 3.21: Cambooya soil.

The groundwater found in this type of aquifer is typically potable and yields can range from almost nothing up to 80L/s in isolated areas (Hansen, A 1999). This level of discharge occurs at the bore south of Jondaryan (Hansen, A 1999).

This particular aquifer is maintained and monitored by the Upper Hodgson Creek Groundwater Management Area 1. The Toowoomba Regional Groundwater Aquifer map is included in appendix G.

3.4.2.10.1 Recent groundwater behaviour

With the millennium drought and the 2011 floods, there has been a great variance in groundwater level activity throughout the Toowoomba region (Toowoomba Regional Council 2012). Due to the lack of historical data in the Cambooya region, groundwater levels from a Toowoomba City bore will be analysed next to the current groundwater levels of Cambooya to determine likely minimum and maximum groundwater levels. Whilst, ideally, values that represent recent groundwater level behaviour would be used, the required historical data to complete that analysis was simply unavailable as the council does not yet have any recorded data for the Cambooya area. For the purpose of this study, the levels of Freyling Park Bore, the closest monitored Toowoomba City bore to Cambooya, will be used as a reference point. This bore is also located on the same Aquifer as the two Cambooya bores. Since the data from Freyling Park bore is in percentages, maximum and minimum values can be estimated for the two Cambooya bores by comparing the groundwater levels in Cambooya next to the percentage of Freyling Park. For this comparison to be viable there must be values for Freyling Park and Cambooya from the same period. Damian Darr, from the TRC supplied Cambooya's weekly groundwater levels over a 7 week period for 2014. This would then be compared to the Freyling Park percentages from the same days. The Freyling Park data was made available by Matthew Norman of the TRC. An average of all these values will then be derived so that singular maximum and minimum groundwater levels for John and George Street bores can be determined. The values for this period are shown in table 3.10.

Determining groundwater Depth - Cambooya bores vs Freyling Park bore			
Date	Water depth (m)		Water depth (%)
	John St	George St	Freyling Park
23/06/2014	122	134	47.61
30/06/2014	122	134	47.87
7/07/2014	122	134	47.24
14/07/2014	121	133	45.96
21/07/2014	122	134	47.93
28/07/2014	122	133	47.29
4/08/2014	122	134	46.86
Average	121.86	133.71	47.25

Table 3.10: Data to determine maximum and minimum water depths for Cambooya bores.

From this data the minimum and maximum groundwater levels for John and George St have been determined. These values are illustrated in table 3.11.

Minimum and Maximum groundwater levels for Cambooya bores				
	Value	John St	George St	Percentage
Data based on period 23/06/14 - 04/08/14	Local minimum	121.00	133.00	45.96%
	AVG	121.86	133.71	47.25%
	Local maximum	122.00	134.00	47.93%
	Difference (m)	1.00	1.00	N/A
	Difference (%)	0.9918%	0.9925%	1.97%
Derived values	Minimum	98	110	1%
	Maximum	149	161	100

Table 3.11: Extreme groundwater depths in Cambooya

This data is only viable due to the assumption that groundwater levels across the aquifer share a uniform depth percentage. In reality, this would not be the case and the extreme groundwater depths would most likely differ. However, the input of these depths into the model will still give a great representation of how Cambooya's water supply pressure varies with these extreme depths.

3.4.2.11 Cambooya data collated/tabulated.

The data that will be used in the construction of the EPANET model is included in table 4.11.

Cambooya data			
Demand data	2012	**2014**	Ultimate
Total population	1288	**1340**	2641
People per house (AVG)	3.43	**3.43**	3.430
L/EP/d	147.3	**150**	200
Non-revenue (L/s) (12.8%)	0.28	**0.29778**	0.50895
AD (L/s)	2.2	**2.629**	4.500
MDMM (L/s)	3.71	**0.000**	10.330
PD (L/s)	5.34	**5.653**	14.860
PH (L/s)	11.46	**12.144**	31.910
Current Reservoir Properties			
Capacity	1500kL		
Height	5.24m		
Diameter	19.10m		
Base Elevation	520.4m		
Inactive Volume	52kL		
Section	Circular		
Bore properties			
Property		**John St**	**George St**
Bore depth (RL m)		307.5	308.4
Pump depth (RL m)		374.5	366.4
Surface level (RL m)		474.5	466.4
Water level (RL m)		396.5	400.6
Pump type		150RM	6HXB
Pump AVG Discharge rate (L/s)		15	20

Table 3.12: Collated Cambooya data for the EPANET model.

3.5 Modeling

3.5.1 Model Planning

Using the aforementioned data, the model will be constructed using EPANET, ideally with an uploaded '.map' file of the area in question. The model will include the construction of virtual pipes, nodes, pumps, reservoirs, tanks, junctions and valves that imitate a location within Cambooya's network. This will all be to topographical and geographical scale. If the '.map' file can't be attained an image of the overview of the location of analysis will be pinned to the EPANET background. The image will be made to scale and the pipeline will be drawn directly over the top of it. The altitude of each important node on the map will then be gathered and manually added to the model.

3.5.2 Model Construction

As this program had not been used before online tutorials were completed. These online tutorials gave step by step instructions of how to setup, create and run a model. Unfortunately these tutorials only included the construction of smaller, simple water networks so there was still an extensive debugging period before the model would run.

3.5.2.1 Hydraulic Options

The first step was to set the hydraulic options of the model. The main varying properties here was the flow units and head-loss formula, all other properties were left untouched. As figure 3.26 shows, the flow units were set to LPS (Litres per second) and the chosen head-loss formula was D-W (Darcy Weisbach).

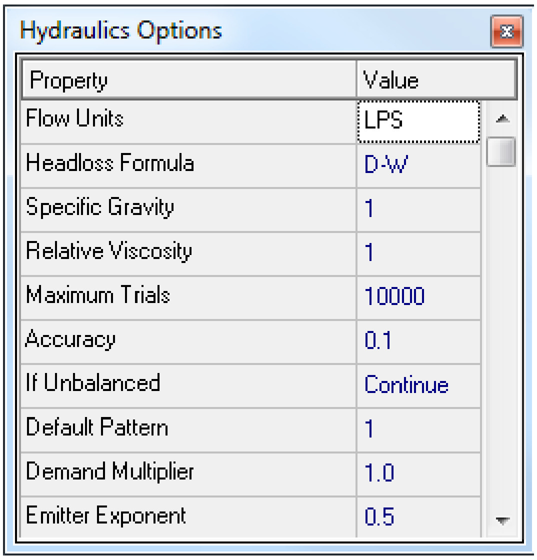


Figure 3.22: Chosen hydraulic properties for the EPANET model.

3.5.2.2 Background image scaling

The next step was to seek out a .map for the Cambooya region. As explained in 4.4.1 attaining a .map file of the Cambooya area would be extremely advantageous and significantly reduce the data input period by eliminating the requirement of inputting node elevations. This map would have also included a layout of the Cambooya pipe network so that nodes and pipes could be correctly placed. Unfortunately, however, it was not possible to attain this file.

To replace this file a screenshot was taken from the Toowoomba Regional Council's online mapping application. This image included the water network layout, but did not included transferrable elevation data. This data would have to be manually inputted at a later point during construction. Another characteristic that made this screenshot a viable image was the inclusion of a scale which illustrated a single 1km length on the map. This screenshot is shown in the following figure.

Figure 3.23: Screenshot taken from TRC online mapping application for use in scaling EPANET model.

Note the clarity of the scale and water network layout (blue lines).

The next step was to load this image as the EPANET background and create a relationship between the 1km scale in this image and the auto-lengths within EPANET. Auto-length meaning, anything drawn after setting the scale would then be to that scale. This was done by drawing 2 nodes at the absolute ends of the 1km line and then drawing a pipe between them. This pipe would then have a not-to-scale automatic length. This off length must then be divided by the actual length of 1km (1000m) to determine a length ratio. This ratio would then be multiplied by the maximum Upper X and Y coordinates in the map dimensions field. After multiplying the maximum dimension lengths by this ratio, the map would then be to scale.

3.5.2.3 Adding physical components

The next step was to place nodes at the ends of where pipes will be placed and areas of interest. The areas of interest were the positions of homes where physical data was collected from. After placing all nodes in their desired locations the pipes would be added. These pipes are simply drawn between nodes while the auto-length option is set to be 'on'. This ensures that all pipes that are drawn will be matched to the set scale size. Completing this task manually would have extended the model construction period significantly.

Since the general layout of the network had been set, it was time to add the reservoirs, tanks and pumps. A reservoir in EPANET is defined as an 'infinite source of water' (Rossman 2000). Since the volume of groundwater in the area is so substantial in comparison to the amount of water that is used, the two bores were set as reservoir nodes. Therefore, the Cambooya reservoir was not technically a reservoir in EPANET and had to be set as a tank node. A tank is 'a container of water whose dimensions can be defined' (Rossman 2000). The Cambooya tank is situated above the township and therefore does not require a pump therefore a pump has not been allocated to it in the model. The two bores, however, are both introduced into the network via their respective bore pumps and will therefore require pumps in this model also.

3.5.2.4 Component properties

Since the physical components of the network had been setup the next step was to input each component's specific properties and attributes.

3.5.2.4.1 Node properties

The information required at each node includes demand (if any) and the elevation at that point. The X and Y coordinates were automatically set with respect to the scale that was set. The Properties for node (junction) 7 are shown in figure 3.24.

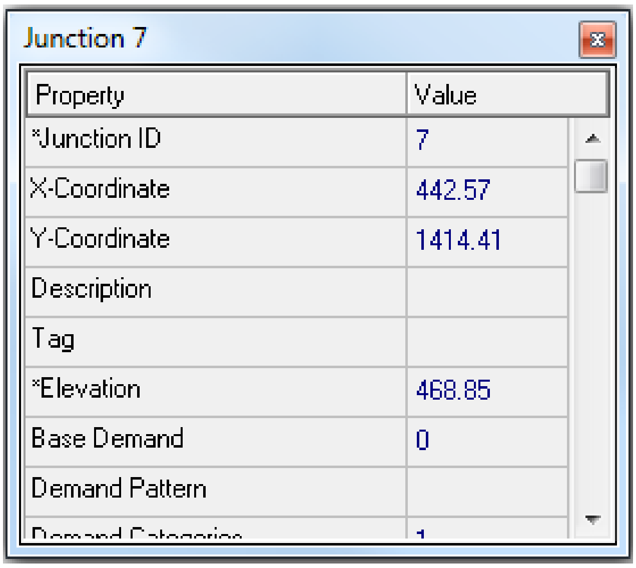


Figure 3.24: Node (junction) 7 properties.

As shown above, the elevation of this node is 468.85m; this information was gathered from the TRC online mapping application and interpolated. Also, this image shows that there is no demand at this node. This is due to the fact that only a select few nodes would have positive demand values. These demand values were applied to nodes that were situated towards the back of each city block with respect to incoming flow. This was done to reduce the time spent utting and modifying demand values across the location. Modifying demands at each individual household would not be a viable method. Therefore 1 demand per block would be calculated based on the average amount of people per home multiplied by the number of homes on that city block. A map showing the nodes with positive demands is shown in figure 3.25.

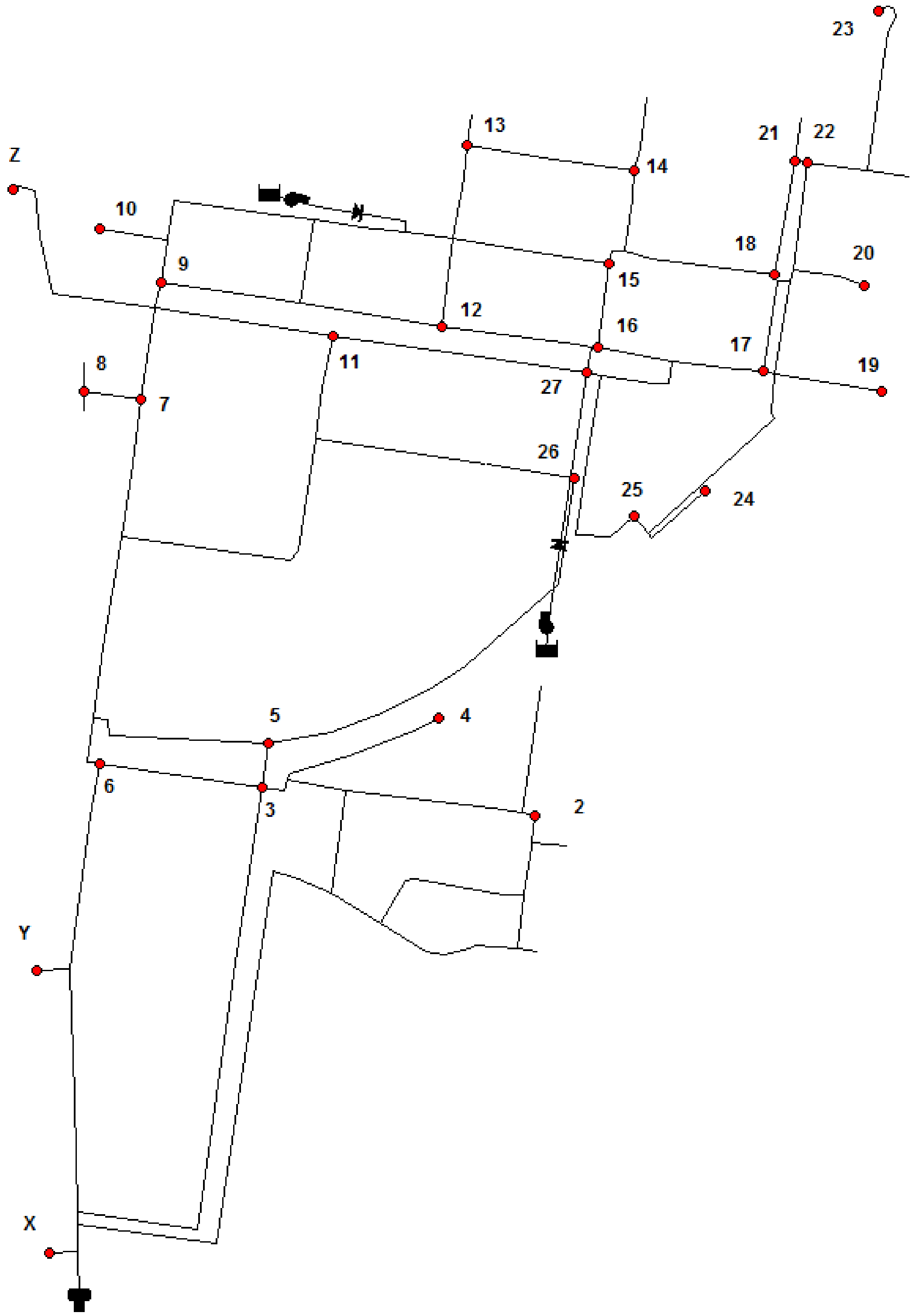


Figure 3.25: Cambooya overview showing nodes with positive demands.

These 30 nodes represent the demands for a population of 1350 people or 391 houses with approximately 3.45 people per house. In figure 3.25 the nodes have been labeled from 2 to 27 and X, Y and Z. The X, Y and Z nodes represent the portion of Cambooya that has not been included in this model. Since, in reality, this system will also be supplying to that side of Cambooya, their water requirement could not be ignored. Nodes 2-27 each represent a portion of houses in the modeled section of Cambooya. The number of houses with corresponding demand values has been collated into table 3.13. Node 1 is not present in figure 3.25 as it was used as an example in table 3.13, showing that when there are no houses in the area the demand is equal to 0. Also included in table 3.13 is the non-revenue water requirement, which, as per the Toowoomba Regional Council, is equal to 12.8% of the AD flow

Demand Position	No of houses	Demand (L/s)
1	0	0
2	5	0.029971228
3	13	0.077925192
4	4	0.023976982
5	1	0.005994246
6	14	0.083919437
7	8	0.047953964
8	7	0.041959719
9	12	0.071930946
10	3	0.017982737
11	8	0.047953964
12	12	0.071930946
13	6	0.035965473
14	20	0.11988491
15	13	0.077925192
16	9	0.05394821
17	6	0.035965473
18	5	0.029971228
19	5	0.029971228
20	7	0.041959719
21	9	0.05394821
22	4	0.023976982
23	18	0.107896419
24	3	0.017982737
25	9	0.05394821
26	16	0.095907928
27	24	0.143861893
Total right	241	1.444613171
X	40	0.239769821
Y	40	0.239769821
Z	70	0.419597187
Total left	150	0.899136829
	391	2.34375
12.8% Non-revenue	-	0.3
Absolute total	391	2.64375

Table 3.13: Calculator for Average Daily demands (AD) in Cambooya.

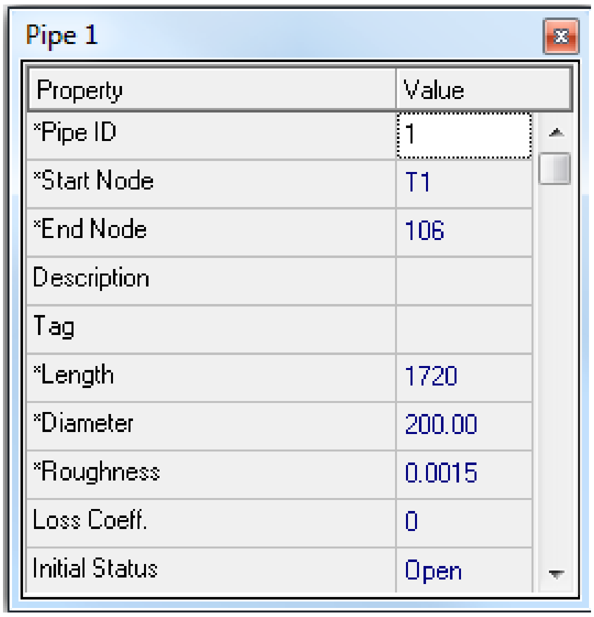
The demand values for these nodes were estimate using table 3.14. This table assumes that there is currently a population of 1350 in Cambooya this year and that each house has an average of 3.45 people. The values for the AD, MDMM, PD, PH, the Non-revenue flow requirement and the water volume per person per day were all extrapolated from the Cambooya Water Supply Scheme of 2012.

Demand data	2012	**2014**	Ultimate
Total population	1288	**1350**	2641
No. of Houses	?	**391**	?
People per house (AVG)	3.45	**3.45**	3.453
L/EP/d	147.3	**150**	200
L/EP/s	0.00170	**0.00174**	0.00231
L/s/household	0.00589	**0.00595**	0.00794
Non-revenue (L/s) (12.8%)	0.28	**0.30000**	0.50895
AD (L/s)	2.2	**2.629**	4.500
MDMM (L/s)	3.71	**4.261**	10.330
PD (L/s)	5.34	**5.653**	14.860
PH (L/s)	11.46	**12.144**	31.910

Table 3.14: Calculator for Cambooya demand averages.

3.5.2.4.2 Pipe properties

The next set of data that needed to be added to the model was the pipe properties. These properties included material, pipe roughness (DW), length, diameter and status. The pipe properties for pipe 1 can be seen in figure 3.26.


Pipe 1

Property	Value
*Pipe ID	1
*Start Node	T1
*End Node	106
Description	
Tag	
*Length	1720
*Diameter	200.00
*Roughness	0.0015
Loss Coeff.	0
Initial Status	Open

Figure 3.26: Pipe 1 properties.

The pipe material can be found using the identify tool on the TRC's online mapping application. With this pipe material, a corresponding roughness value can be found. As 95% of the pipe material in Cambooya is PVC-U the roughness was typically 0.0015mm as shown in figure 3.26 for pipe 1.

The online mapping application could also define the pipe diameters throughout the network. As shown in figure 3.26 the diameter was found to be 200mm.

Pipe length was typically not an inputted value as the scaling and auto-length function of EPANET automatically determined the lengths of each pipe. For pipe 1, however, the length was manually inputted because it is the pipe which connects the reservoir to the network. If to scale, this pipe would be a considerable distance off the page and would therefore be harder to display. To manually input this value, auto-length had to be set to 'off'. This made the length input area available to customisation.

The status of each pipe could also be modified. If a pipe was required to be closed in certain simulations to see how the model would be affected, the status could be set to 'closed'. In a typical scenario, however, the status of each pipe was set to 'open' because it is assumed that all pipes in the Cambooya Township are open flowing pipes.

3.5.2.4.3 Reservoir properties

The next properties added to the model were that of the reservoirs. These reservoirs were to emulate the George and John Street bore as closely as possible. The only property required for the reservoir is the Total Head. This value is equal to the depth of the pump plus the water level above the pump. In this instance it was 366.4m RL (Pump depth) + 34m (Water above pump). Figure 3.27 illustrates the reservoir properties of, Reservoir R2

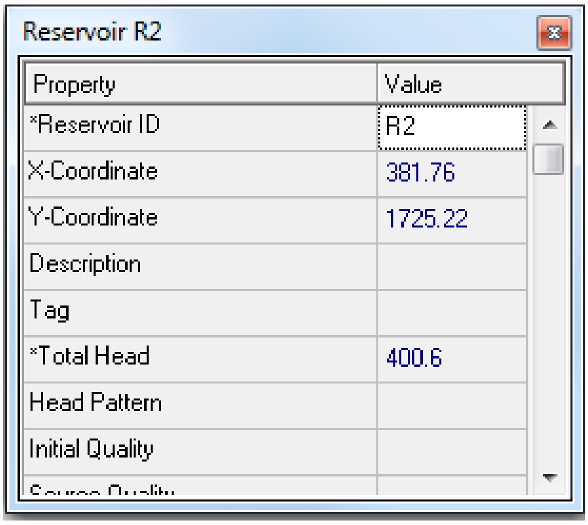


Figure 3.27: Reservoir R2 properties.

3.5.2.4.4 Tank properties

Following the data input of the reservoir was the data input for the tank i.e. the Cambooya Reservoir. The required properties for the tank included elevation, initial level, minimum level, maximum level and diameter. Like all elevation data the tank's elevation was gathered from the TRC online mapping application. The elevation value of 520.4m was also reaffirmed by council reports. Figure 3.28 was taken during the construction process and therefore only shows the round value of 520m, this was later changed to 520.4m. The initial level was more relevant for 'over time' simulations but was still a required field for this model. It represents the water level inside the reservoir at the beginning of a simulation.

This will be one of the key modifications in configuring the overall model to match the physical data. The minimum level section represents the minimum level that the reservoir can reach without shutting down. Again, this is mostly required for the 'over time' simulations but is still a required property for the model to run. The maximum level represents the height of the tank. Since the Cambooya Tank (Reservoir) is 5.24m high, the value can also be adopted for the model's tank maximum level. The diameter of the tank is shown to be 19.2m in section 3.3.2.5 of this document. Therefore this value will be adopted for the model's tank diameter also. Figure 3.28 illustrates the values for Tank T1.

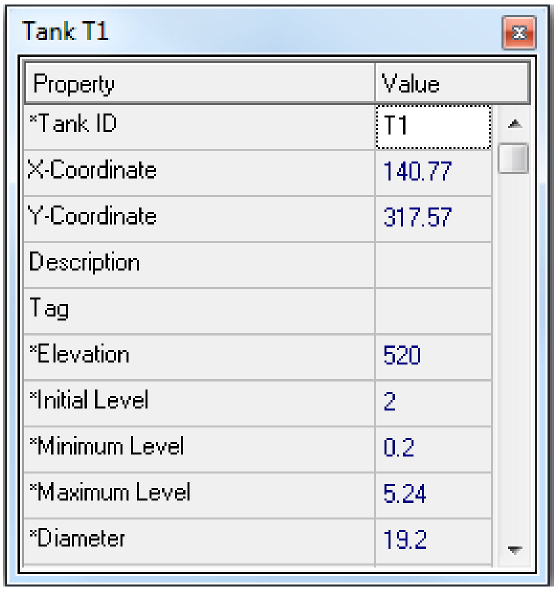


Figure 3.28: Tank T1 Properties

3.5.2.4.5 Pump properties

The final information that needed to be added to the model was that of the pumps. The data required for each modeled pump only includes the pump curve.

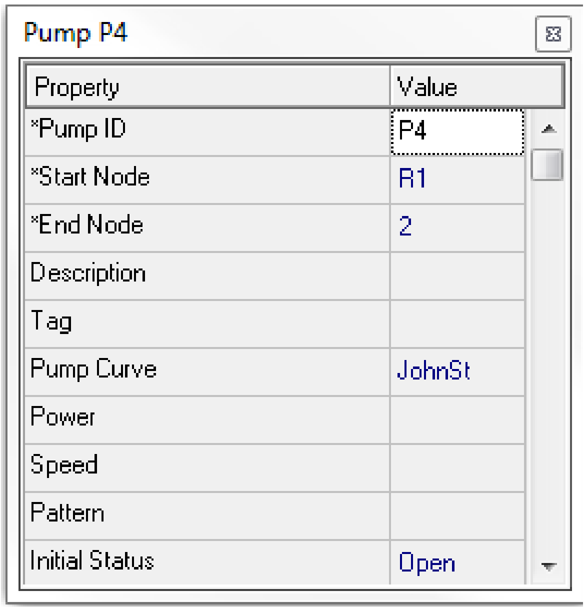


Figure 3.29: Pump P4 properties

As shown in figure 3.29, a pump curve named ‘JohnSt’ has been added into this field. This curve was created in the Edit_Curve section of EPANET. Figure 35 shows the JohnSt curve which emulates the values found in table 10 of section 3.3.2.8.

Figure 3.30: John St pump curve i.e. P4 pump curve.

The table on the left side of figure 3.30 is where the values for flow and head are added. The curve on the right is automatically drawn after the values are entered.

3.6 Assumptions

For EPANET to run models without excessive complications, assumptions had to be made within the software. The assumptions that EPANET make include:

- All pipes are full at all times (Rossman 2000).
- The pump supplies the same amount of energy, no matter what the flow is unless a pump curve is supplied (Rossman 2000).
- Water within tanks is assumed to be completely mixed (Rossman 2000).
- Any component properties that are not given a value are assumed to be 0 or the default (Rossman 2000).

The Darcy Weisbach Equation, which has been chosen within EPANET as the preferred method for dealing with pipe friction loss, also makes some assumptions. The assumptions that this equation makes include:

- For liquid flow, the density of the fluid flowing in the system is constant (ABZ 2010).
- Like EPANET, Darcy's equation assumes full pipe flow (ABZ 2010).

For this specific model to run, more assumptions still had to be made. These assumptions are not related to the software used but the scenario that is being modeled. These assumptions include.

- Neglecting non-residential water demands (i.e. school, bowls club and pub). This is because the water usage data for these locations was unavailable.
- Neglecting any minor losses that exist in the presence of valves and hydrants. These components were not included in the model due to their locations being unknown within the network.

3.7 Model Debugging

Initially, after the components of the model were all added and the specific data for each component inputted, the model would not run. There were massive negative pressures throughout the network, suggesting that the demand was not being met through the entire system. Whilst this was the only issue that the model had it was one that was not easily found and solved. Initially, it was thought that the pump data had not been entered correctly since the curve did not initially extended to 0 head and 0 flow. This was then fixed but the model would still not run. After going through the EPANET manual it was eventually discovered that the pipe size had to be entered in in millimeters. This was despite the fact that at the commencement of the project the units were set to metres. This was apparently just a selection between imperial and metric units.

3.8 Field work

3.8.1 Toowoomba Regional Council water supply system tour.

After approaching the Toowoomba Regional Council about all the required data for this thesis, a southern district Water & Sewage Operations Coordinator, Damian Darr, offered a tour of the Cambooya water infrastructure. This tour included visits to the George Street and John Street bore pump houses as well as the old and new Cambooya reservoirs. The infrastructure seen during this tour is included in section 3.3.2.5 to section 3.3.2.8.

The tour was quite relaxed with no real safety equipment being required to be onsite. As this was not known before the beginning of the tour, a high visibility vest and steel cap boots were worn as a precaution. Whilst there wasn't a large requirement for 'safe attire' the pump stations in particular covered in many 'Warning', 'Caution' and 'Safety' signs. This was mostly to do with the Chlorine basin, which was situated within the pump house. This can be seen in figure 3.31.

Figure 3.31: George St bore chlorination control unit & Sodium Hypochlorite basin.

The safety warning signs also present at the pump stations included an evacuation plan out of the single roomed building and health warnings and first aid instructions for people working within close proximity to or exposed to the Sodium Hypochlorite. These signs can be seen in figures 3.32 and 3.33.

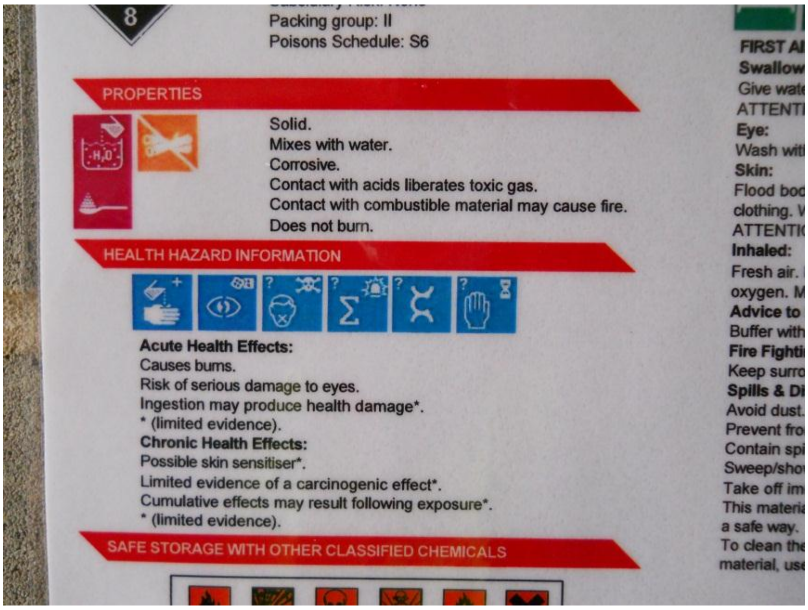


Figure 3.32: Acute & Chronic health effects of Sodium Hypochlorite.

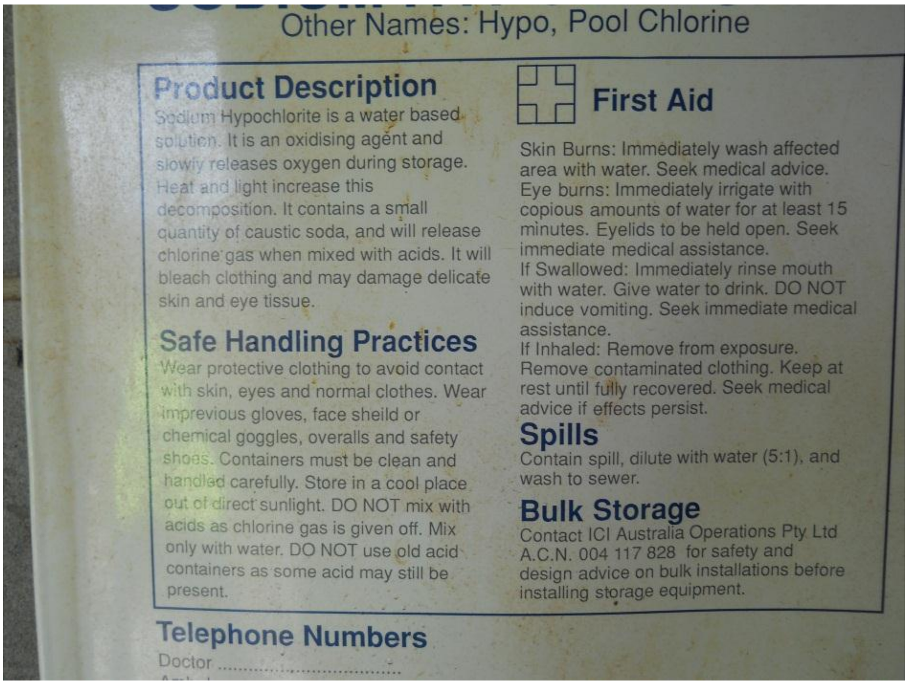


Figure 3.33: Sodium Hypochlorite First aid and handling instructions

3.8.2 Data collection plan

After the location of analysis was determined field tests were performed in the area. These field tests serve as physical results to compare against the results attained by the model. A pressure gauge would be connected to residential garden taps of 20-40 Cambooya homes at high and low demand times during the day. These readings will then be collated and used as a guide for model configuration. The results will also be graphed against the model results so that comparisons can be made. From these comparisons recommendations will be given and the effect of any assumptions will be discussed.

3.8.3 Data collection activities

All of the physical data required for this project was attained over three visits to Cambooya. Two of these activities were performed from approximately 10am-1pm during the week for the off peak /low demand period. The other visit was conducted from 6am-830am on a Saturday morning which was assumed to be a higher demand period for this location.

3.8.3.1 Off-Peak/Midday collection

Whilst conducting these activities it was important to where suitable attire. This was important not only for safety reasons but to impose a sense of professionalism to the community whilst walking from house to house. Therefore, long work trousers and a long sleeved button up shirt were worn with a high visibility TRC vest over the top. This vest was made available through Matthew Norman, a control systems engineer from the TRC. Black steel cap boots were also worn. Whilst these were not necessarily required for the task, wearing them would assist in appearing professional to the community. For protection from the sun, a hat and sunglasses were worn.

To perform the full activity, certain pieces of equipment were required. This included:

- A pressure gauge that would attach to residential outdoor taps.
- A clipboard with paper and pen for recording all the pressure readings with.
- A lanyard with USQ identification attached to increase the professional appearance.

- A Camera for taking pictures of any noteworthy experiences and important infrastructure throughout the collection activity.
- A wrench just in case the pressure gauge gets jammed on the tap (This happened on the first low demand visit and a wrench wasn't available).
- Sunscreen to prevent sunburn throughout the day.
- Mobile phone in case of any emergency
- Wallet for proof ID and incase money was required for any reason throughout the activity.

Attire and equipment were not the only requirements for this data collection activity. A reasonable considerable amount of common sense also had to be applied when making decisions while walking from house to house. The main decisions that were made revolved around house selection. Aggressive dogs were a huge issue for house visits in this area. They were the main factor that controlled the house selection process. Therefore to deem a house suitable for selection the following guidelines for dog safety were created:

- If a house had no fence or an open front fence it would be deemed safe for measurement.
- If a house had front and side fences, the front yard would be thoroughly checked for any dogs and the side fences would be checked if they were latched. If no dog was present in the front yard and side gates were latched the house would be deemed safe.
- If the owner of the house was present out the front and extended an invitation to enter the property, the house would be deemed safe. Before entering, the owner was always asked if any aggressive dogs were present.
- If the house has a high fence which cannot be seen over, the house will be deemed unsafe unless an owner is visible at the time.
- If the house has a closed front fence but no side fences the house would be deemed unsafe unless an owner was visible at the time.

Other guidelines that affected house selection were to do with present and absent house owners. These guidelines were followed so as to negate the risk of being prosecuted for trespassing.

- Once the property has been deemed safe from dogs the first thing done would be to knock on the front door to see if anyone is home. If not, only visible taps in the front yard would be available for measurement. If a measurement is taken from a front tap with nobody home, the property will be left immediately after the data is gathered.
- If, after knocking on the front door, a resident is home, the first thing that will be done was a self-introduction and the reason for the house visit. Then permission will be requested to take a pressure measurement from their outdoor garden tap. If the owner said yes, then the tap will be accessed whether it is in the front, side or back yard (assuming the owner has said that no aggressive animals were present/of any threat).
- If present home owners were to deny permission to access their tap, an apology for the intrusion was extended and their rights were immediately respected by exiting the property in a swift fashion.
- If home owners were absent but neighbours were visible they would be approached and the reason for the house visit would be explained. Typically if a neighbour was visible their house would be the more appealing option for measurement but if factors such as tap size prevented this then the neighbour was asked if they would supervise the pressure measuring from over the fence.

As briefly mentioned above tap size was another contributing factor for house selection. Unfortunately, there were two different tap sizes present in the Cambooya Township. A 28mm tap and a 32mm tap. The pressure gauge would only attach to 28mm taps or 32mm taps with 28mm conversions. This was an impacting factor when choosing the locations of where to take measurements from. The two tap types can be seen in figures 3.34 and 3.35.

Figure 3.34: 28mm tap - Suited for pressure gauge connection.

Figure 3.35: 32mm tap - Too large for pressure gauge connection.

Another process that had to be sorted prior to the data collection activity was the collection route and method of transport. It was possible to walk or drive this area and both methods would require a large amount of time to cover the whole area. It was eventually decided that it would be quicker and simpler to walk the area. Since many homes on each street had to be analysed to determine their overall suitability for measurement, it would take a larger period of time getting in and out of the car than what it would to continuously walk the route, assessing each home along the way. This would also reduce the cost of fuel required to complete the task. Figures 3.36 and 3.37 illustrate the routes taken during the low demand period in the upper and lower sections of the location.

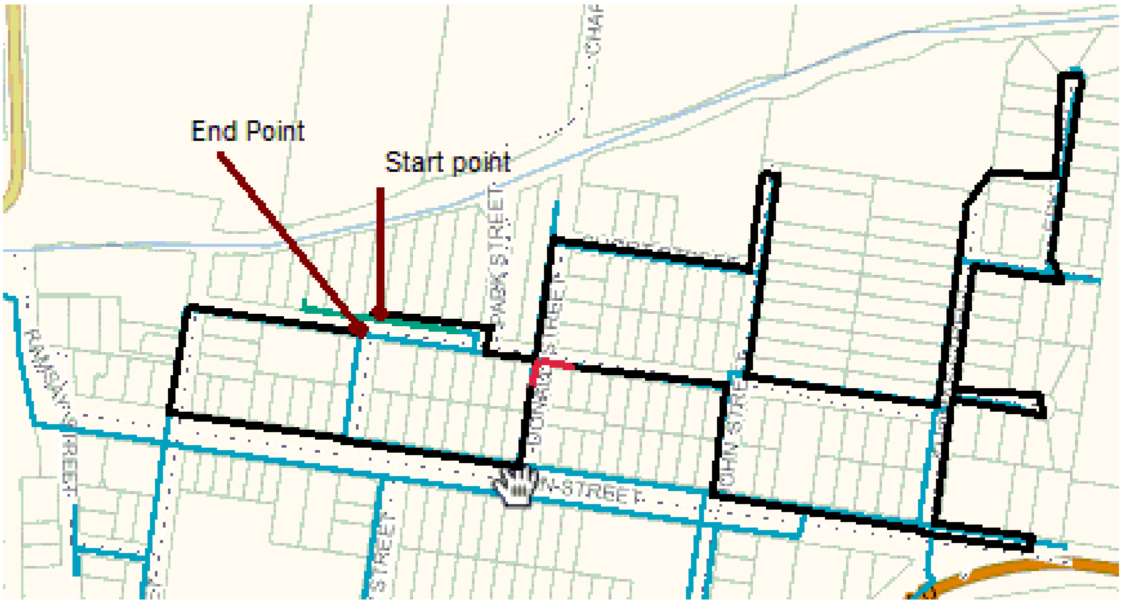


Figure 3.36: Walking route taken in the upper section during the low demand period.

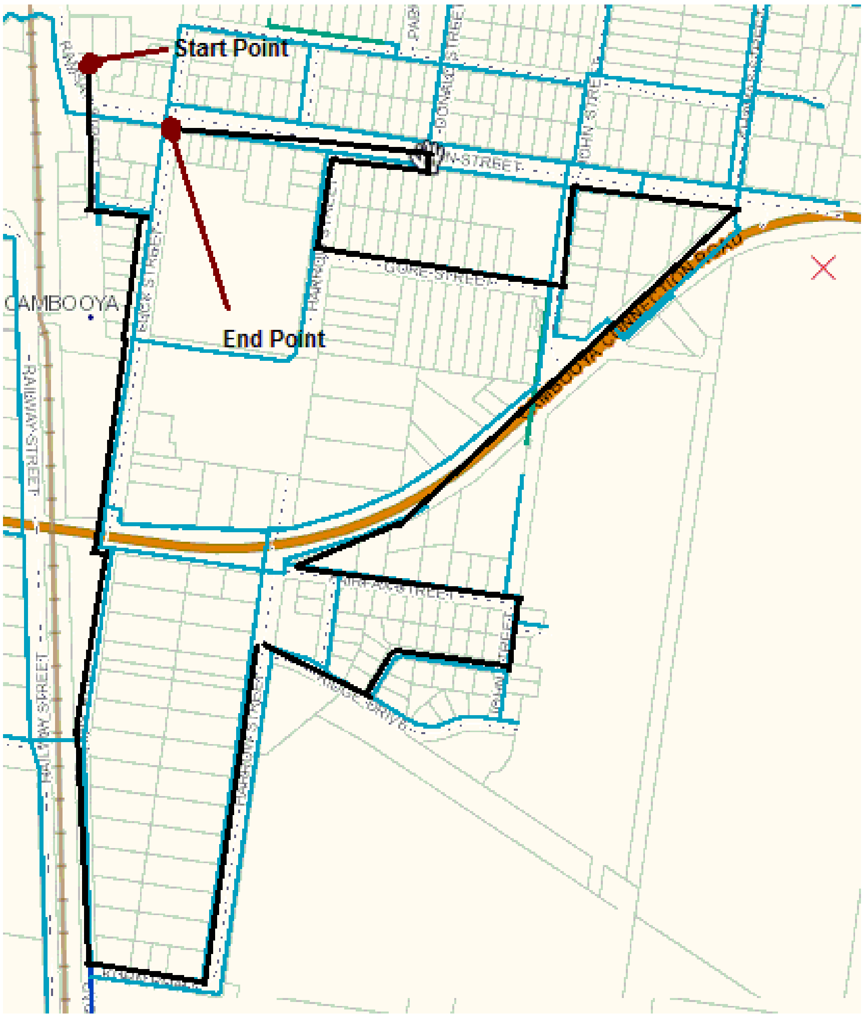


Figure 3.37: Walking route taken in the lower section during the low demand period.

3.8.3.2 On-peak/Morning data collection

The on-peak/high demand data collection activity followed the same principles as discussed in section 3.7.3.1. The only aspects of the activity that changed were the time of data collection and the method of transport. Since the highest water usage peaking factor was shown to be between 6am and 11am in figure 3.5 this would be the ideal time to seek high demand water pressures. It was also assumed that during this high demand period at least one of the bores would be running.

The only negative about conducting data collection at 6am onwards was approaching houses that early in the morning. Therefore, a guideline from the low demand data collection period had to be modified. It was determined that before

7am, rather than immediately knocking on house doors, properties would undergo a brief sound test. If any conversations or televisions could be heard from the yard, the door would be knocked on. If no noise is apparent, only visible taps in the front yard will be accessed.

The method of transport was also revised prior to the high demand data collection session. Since the houses with accessible and appropriate taps had already been determined, less searching and assessing was required. Also, for this session an acquaintance offered to drive. This would be a more efficient method because the results could be recorded during the trip between measurement locations. The combination of these two differences allowed the high demand data collection activity to be completed in one session with a total time difference of 4 hours. The route of this activity is essentially identical to that which is illustrated in figures 3.36 and 3.37.

3.9 Post results

After all of the graphing results are compared it will become apparent if the bores are currently running at an acceptable standard. Furthermore, an understanding will be gained of how the variance in groundwater levels can affect Cambooya's water distribution network. Discussions of these results will then be constructed accordingly so that accurate conclusions and recommendations can be made based on the translation of the results.

As this model concentrates on only a small portion of what the modeling software is capable of, there will be great opportunities for further work with this model. These opportunities will be briefly discussed as well.

4. RESULTS & ANALYSIS

4.1 Introduction

In this section the pressures data collected during the physical data collection activity discussed in section 3.7.3 will be compared with the pressure results that were produced by the model. The model is used to complete a multitude of analyses in situations where no bores, one bore or both bores are active. These situations were applied to the physical data, groundwater level and pipe roughness analyses so that viable comparisons could be made.

4.2 Physical Results from both on-peak and off-peak periods.

As per section 3.7.3 physical results were attained from Cambooya. These results were attained by connecting a pressure gauge to residential garden taps. The numbered nodes shown in figure 4.1 represent the houses that physical data was collected from. These property numbers correspond with the 'off-peak' and 'on-peak' demand values shown in table 4.2. Nodes that do not include numbers are merely pipe junctions or pipe ends that were required to construct the model.

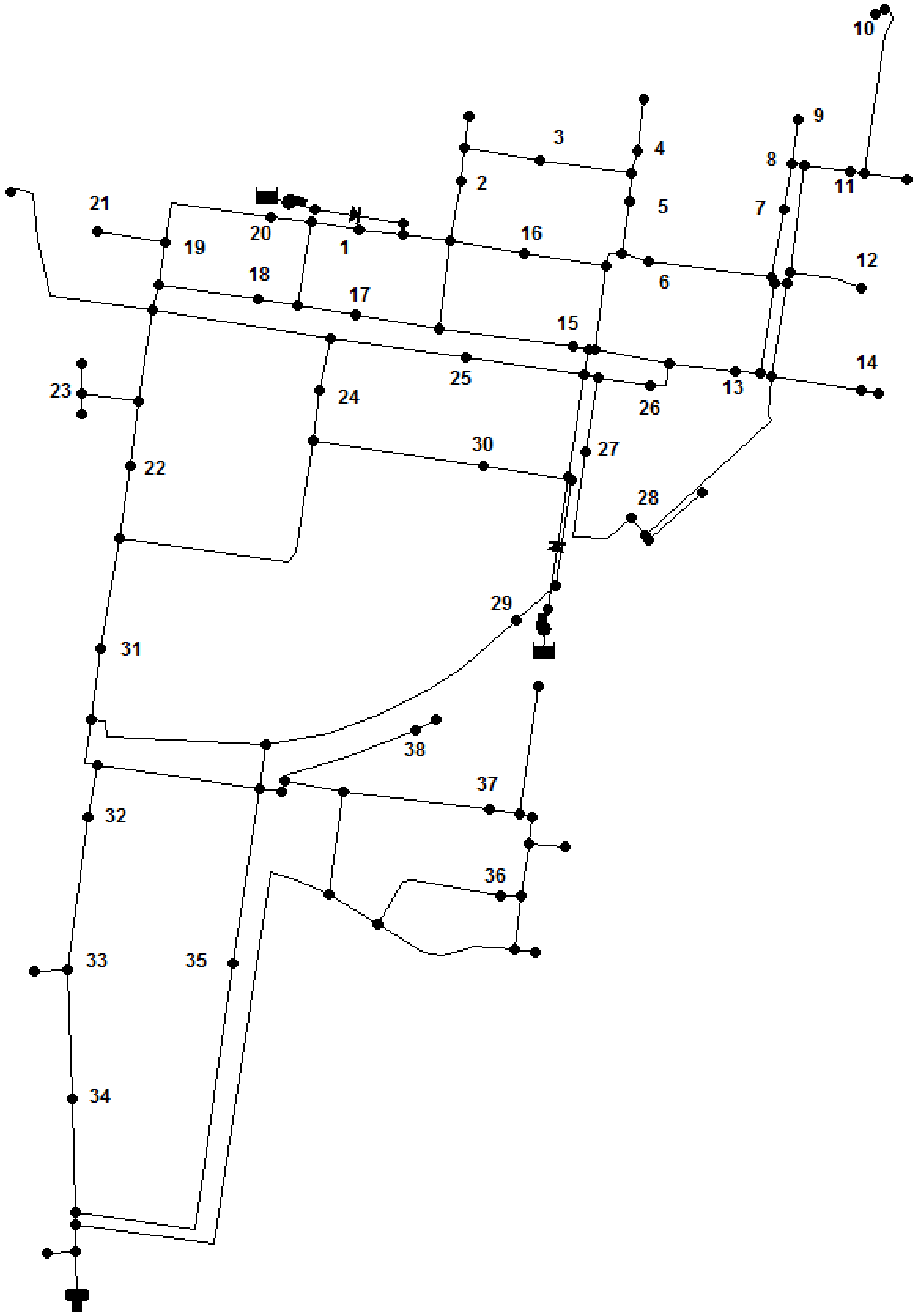


Figure 4.1: Model overview with labeled nodes where physical data was collected from.

Property #	Pressure reading (kPa)				Pressure difference
	Period	Off peak	Period	On peak	
1	9:45 - 13:15	570	6:00 - 8:30	580	-10
2		540		505	35
3		575		**N.A.**	**N.A.**
4		540		500	40
5		540		505	35
6		480		480	0
7		500		520	-20
8		520		480	40
9		520		480	40
10		500		470	30
11		520		480	40
12		500		480	20
13		500		460	40
14		460		440	20
15		460		480	-20
16		490		520	-30
17		540		520	20
18		540		560	-20
19		540		520	20
20		550		540	10
21	9:30 - 1230	540		540	0
22		520		560	-40
23		540		540	0
24		540		540	0
25		510		**N.A.**	**N.A.**
26		530		460	70
27		460		440	20
28		460		480	-20
29		480		480	0
30		510		500	10
31		540		520	20
32		530		540	-10
33		580		500	80
34		510		500	10
35		490		500	-10
36		410		420	-10
37		480		470	10
38		520		480	40

Table 4.1: Collated physical data from the 3 data collection activities (kPa).

To make this pressure data comparable to the model's pressure data, a conversion from kilopascals to metres of head needs to be made. The results of this simple conversion are shown in table 4.3.

Property #	Pressure reading (Metres head)				Pressure difference
	Period	Off peak	Period	On peak	
1	9:45 - 13:15	58.14	6:00 - 8:30	59.16	-1.02
2		55.08		51.51	3.57
3		58.65		**N.A.**	**N.A.**
4		55.08		51.00	4.08
5		55.08		51.51	3.57
6		48.96		48.96	0.00
7		51.00		53.04	-2.04
8		53.04		48.96	4.08
9		53.04		48.96	4.08
10		51.00		47.94	3.06
11		53.04		48.96	4.08
12		51.00		48.96	2.04
13		51.00		46.92	4.08
14		46.92		44.88	2.04
15		46.92		48.96	-2.04
16		49.98		53.04	-3.06
17		55.08		53.04	2.04
18		55.08		57.12	-2.04
19		55.08		53.04	2.04
20		56.10		55.08	1.02
21	9:30 - 1230	55.08		55.08	0.00
22		53.04		57.12	-4.08
23		55.08		55.08	0.00
24		55.08		55.08	0.00
25		52.02		**N.A.**	**N.A.**
26		54.06		46.92	7.14
27		46.92		44.88	2.04
28		46.92		48.96	-2.04
29		48.96		48.96	0.00
30		52.02		51.00	1.02
31		55.08		53.04	2.04
32		54.06		55.08	-1.02
33		59.16		51.00	8.16
34		52.02		51.00	1.02
35		49.98		51.00	-1.02
36		41.82		42.84	-1.02
37		48.96		47.94	1.02
38		53.04		48.96	4.08

Table 4.2: Collated physical data from the three data collection activities (Metres head).

The difference between the off-peak and on-peak pressures in the network was quite small. In some cases the pressure was actually high during the on-peak session. This could be contributed to the fact that water usage throughout the day is quite varying on a day to day basis as it is only possible to create neat demand curves over averaged out longer periods of time. Another possible contributor to these varying results could be the residential peak time being opposite to the industrial/commercial peak time. Nodes 18, 22 and 32 are some which experienced lower pressures during off-peak time compared to on-peak. However, these nodes are all located in close proximity to Cambooya’s pub, school or bowls club and would therefore have a varying peak time to areas which are entirely residential.

4.3 Analysis of Cambooya’s current water supply network with AD demands

As per the methodology discussed in section 3, the modeled results have been determined. The results that will be included are only a small portion of the results available because the only nodes that have are relevant are the nodes that are positioned where physical results were taken. Therefore only the data for 38 of the 108 nodes will be shown.

4.3.1 Comparison between modeled pressure data (no active bores) & physical data

In this section the modeled pressure outputs are representing the network pressure when both the George and John Street bores are inactive. Therefore this is a raw representation of the Cambooya network excluding the bore pressures and applying AD demands and maximum tank capacity.

These results have also been tabulated with the physical pressures collected during the field activity discussed in section 3.7.3. Note that these physical results have already been converted from kilopascals to metres of head. This allows for a neat comparison between the theoretical pressures throughout the network and the actual pressures that were manually collected. These results are then analysed within the table to determine the variance between two sets of data. This can be seen in table 4.4.

Network Table - Nodes (No active bores)						
	(Pressure in m head)					
Node ID	Model Pressure	Off-peak Pressure	On-peak Pressure	Off-peak Pressure variance	On-peak Pressure variance	Minimum Variance
Junc p1	57.1	58.14	59.16	1.04	2.06	1.04
Junc p2	56.69	55.08	51.51	-1.61	-5.18	-1.61
Junc p3	56.09	58.65	**N.A.**	2.56	**N.A.**	2.56
Junc p4	55.84	55.08	51.00	-0.76	-4.84	-0.76
Junc p5	54.19	55.08	51.51	0.89	-2.68	0.89
Junc p6	52.81	48.96	48.96	-3.85	-3.85	-3.85
Junc p7	51.89	51.00	53.04	-0.89	1.15	-0.89
Junc p8	52.99	53.04	48.96	0.05	-4.03	0.05
Junc p9	53.69	53.04	48.96	-0.65	-4.73	-0.65
Junc p10	55.09	51.00	47.94	-4.09	-7.15	-4.09
Junc p11	51.49	53.04	48.96	1.55	-2.53	1.55
Junc p12	49.09	51.00	48.96	1.91	-0.13	-0.13
Junc p13	49.19	51.00	46.92	1.81	-2.27	1.81
Junc p14	46.74	46.92	44.88	0.18	-1.86	0.18
Junc p15	52.64	46.92	48.96	-5.72	-3.68	-3.68
Junc p16	54.34	49.98	53.04	-4.36	-1.30	-1.30
Junc p17	55.9	55.08	53.04	-0.82	-2.86	-0.82
Junc p18	57.3	55.08	57.12	-2.22	-0.18	-0.18
Junc p19	58.65	55.08	53.04	-3.57	-5.61	-3.57
Junc p20	58.1	56.10	55.08	-2.00	-3.02	-2.00
Junc p21	59.1	55.08	55.08	-4.02	-4.02	-4.02
Junc p22	60.11	53.04	57.12	-7.07	-2.99	-2.99
Junc p23	60.16	55.08	55.08	-5.08	-5.08	-5.08
Junc p24	56.21	55.08	55.08	-1.13	-1.13	-1.13
Junc p25	54.1	52.02	**N.A.**	-2.08	**N.A.**	-2.08
Junc p26	50.59	54.06	46.92	3.47	-3.67	3.47
Junc p27	51.09	46.92	44.88	-4.17	-6.21	-4.17
Junc p28	49.69	46.92	48.96	-2.77	-0.73	-0.73
Junc p29	51.43	48.96	48.96	-2.47	-2.47	-2.47
Junc p30	53.22	52.02	51.00	-1.20	-2.22	-1.20
Junc p31	59.02	55.08	53.04	-3.94	-5.98	-3.94
Junc p32	57.76	54.06	55.08	-3.70	-2.68	-2.68
Junc p33	56.27	59.16	51.00	2.89	-5.27	2.89
Junc p34	54.67	52.02	51.00	-2.65	-3.67	-2.65
Junc p35	54.3	49.98	51.00	-4.32	-3.30	-3.30
Junc p36	49.66	41.82	42.84	-7.84	-6.82	-6.82
Junc p37	50.36	48.96	47.94	-1.40	-2.42	-1.40
Junc p38	52.55	53.04	48.96	0.49	-3.59	0.49

Table 4.3: Network pressure comparison (0 active bores).

From this table, it was possible to determine the minimum, maximum and average variance in pressure between the model and the physical results. These values are shown in table 4.5.

Results	Minimum	Average	Maximum
Metres head	0.05	-1.4	-6.82

Table 4.4: Important values from table 4.4.

The minimum variances were attained by determining the difference between the model output pressure and the closest of the two peak values. Doing this shows how close a modeled pressure value is to matching the physical data. Note that the sign of the value determines whether this variance is above or below the physical values. A negative value means the physical value is less than the modeled value and vice versa.

What this variance does not show is the modeled pressures that were in between the on-peak and off-peak values. There were a total of ten modeled values within the range of the two peak values. This means that the pressures at these ten locations will match the modeled pressures at certain times during the day.

Whilst the minimum and average variances of this data are encouraging results, the maximum variance is a large discrepancy. By looking into the location of this maximum variance, it was found that this node was in the new development area of Cambooya. This area does not yet have many residents yet and therefore it is very likely that the Toowoomba Regional Council has a partially closed control valve connecting this area to the network. If this value was to be neglected, the next highest pressure variances are at nodes p10, p21 and p23 with respective pressure variances of -4.09m, -4.02m and -5.08m. Nodes p21 and p23 are located near Cambooya's school, pub and bowls club. As the demands for these locations were neglected, a considerable difference between the physical and theoretical results could be expected. Node 10 is an end node located at the North most location in Cambooya and has a high demand applied to it due to its location. The combination of these characteristics could explain why this node also has such a high variance when compared to the physical results.

With the majority of the large discrepancies explained, it can be concluded that this model is a reasonably accurate representation of the Cambooya water network, especially when considering the neglected data.

4.3.2 Comparison between physical data and modeled pressure data for John St active and no bores active

In this section the modeled pressure outputs are representing the network pressure when only the John Street bore is active. Once again, AD demands and maximum tank capacity has been applied to this model.

These results have also been tabulated with the physical pressures collected during the field activity discussed in section 3.7.3. Note that these physical results have already been converted from kilopascals to metres of head. This allows for a neat comparison between the theoretical pressures throughout the network and the actual pressures that were manually collected. These results are then analysed within the table to determine the variance between two sets of data. This can be seen in table 4.5.

Comparison between node pressures - NoBores Vs. JohnStreetActive				
Node ID	(Pressure in m head)			
	Model Pressure (JohnSt bore)	Minimum Variance (from physical data)	Model Pressure (No bores)	Additional Pressure
Junc p1	59.88	-0.72	57.1	2.78
Junc p2	59.70	-4.62	56.69	3.01
Junc p3	59.15	-0.50	56.09	3.06
Junc p4	58.95	-3.87	55.84	3.11
Junc p5	57.31	-2.23	54.19	3.12
Junc p6	55.98	-7.02	52.81	3.17
Junc p7	55.13	-2.09	51.89	3.24
Junc p8	56.23	-3.19	52.99	3.24
Junc p9	56.93	-3.89	53.69	3.24
Junc p10	58.33	-7.33	55.09	3.24
Junc p11	54.73	-1.69	51.49	3.24
Junc p12	52.34	-1.34	49.09	3.25
Junc p13	52.47	-1.47	49.19	3.28
Junc p14	50.01	-3.09	46.74	3.27
Junc p15	55.88	-6.92	52.64	3.24
Junc p16	57.40	-4.36	54.34	3.06
Junc p17	58.74	-3.66	55.9	2.84
Junc p18	59.96	-2.84	57.3	2.66
Junc p19	61.14	-6.06	58.65	2.49
Junc p20	60.80	-4.70	58.1	2.70
Junc p21	61.59	-6.51	59.1	2.49
Junc p22	61.47	-4.35	60.11	1.36
Junc p23	61.70	-6.62	60.16	1.54
Junc p24	57.67	-2.59	56.21	1.46
Junc p25	57.34	-5.32	54.1	3.24
Junc p26	53.88	0.18	50.59	3.29
Junc p27	54.39	-7.47	51.09	3.30
Junc p28	52.98	-4.02	49.69	3.29
Junc p29	51.84	-2.88	51.43	0.41
Junc p30	54.09	-2.07	53.22	0.87
Junc p31	59.74	-4.66	59.02	0.72
Junc p32	56.71	-1.63	57.76	-1.05
Junc p33	54.94	-3.94	56.27	-1.33
Junc p34	53.29	-1.27	54.67	-1.38
Junc p35	53.54	-2.54	54.3	-0.76
Junc p36	48.60	-5.76	49.66	-1.06
Junc p37	49.39	-0.43	50.36	-0.97
Junc p38	51.93	1.11	52.55	-0.62

Table 4.5: Comparison between the node pressures of when no bores in the network are running to when John Street bore is running.

The average discharge out of the John Street bore is 15L/s. Applying this extra flow to the network creates an average additional pressure of 2.0m of head. The maximum and minimum additional pressures within this system are 3.30m and -1.38m respectively. This can be seen in table 4.6.

Additional pressure			
Results	Average	Minimum	Maximum
Metres of head	2.00	-1.38	3.30

Table 4.6: Additional pressure values derived from table 4.5.

Also, from table 4.5, we can see that the minimum variance from the physical data has increased. These values can be seen in table 4.7.

Minimum variance			
Results	Average	Minimum	Maximum
Metres of head	-3.48	0.18	-7.47

Table 4.7: Minimum variance values derived from table 4.5.

To compare the two scenarios (no bores active vs. John St bore active), when John Street bore is active the average minimum variance increases by 2.08m head. This is a 249% increase. Amongst these 'Minimum variance' values, only two were within the range that has been specified by the physical collection data. Furthermore, the extremes for minimum variance increase by 0.13m at the minimum and 0.65 at the maximum. These increases in model vs. physical data deviation, suggest that the physical data had mostly, if not all, been collected while John Street Bore was inactive. This also, suggests that the George St bore was inactive during this period also.

4.3.3 Comparison between physical data and modeled pressure data for both bores active and no bores active.

In this section the modeled pressure outputs are representing the network pressure when both Cambooya bores are active. Once again, AD demands and maximum tank capacity has been applied to this model.

These results have also been tabulated similarly to that seen in table 4.5. Note that the physical results have already been converted from kilopascals to metres of head. This allows for a neat comparison between the theoretical pressures throughout the network and the actual pressures that were manually collected. As these results will be in the exact format of table 4.5 the full results table for this section can be seen in appendix D. The important values derived from this table, however, are included in table 4.8 and 4.9.

Additional Pressure			
Results	**Average**	**Maximum**	**Minimum**
Metres Head	17.69	21.99	4.53

Table 4.8: Additional pressure values derived from appendix 8.5.1.

Since George Street bore produces an average discharge of 20L/s, the two bores running is series introduces an additional flow of 35L/s into the network. As shown in table 4.8, this increases the pressure throughout the network substantially. These results mean that there is a minimum and maximum increase in pressure of 4.53m and 21.99m respectively when both bores are active compared to when no bores are active. Furthermore, the George Street bore alone produces an average additional pressure of 15.69m (17.69m -2m) head to the network. In this scenario pressures are very near the 80 metres of head limit standardised by the South-East Queensland (SEQ) Water and Sewage Planning Guidelines - section A4. These results reaffirm the prediction made in section 4.3.2 – Both the John and George Street bores were inactive during the physical data collection activities.

Minimum Variance			
Results	Average	Maximum	Minimum
Metres Head	-18.96	-26.14	-1.86

Table 4.9: Minimum variance values derived from appendix 8.5.1.

Table 4.9 shows the minimum variances between two active bores and no active bores. With the additional discharge of George Street bore, the minimum, average and maximum variance values increase by 1.68m, 15.48m and 18.67m respectively. This further supports the prediction made in 4.3.2 as there are large increases in these results as well.

4.4 Analysis of Cambooya's current water supply network with future PH demands applied

To determine whether the Cambooya bore pumps are adequate for the future, an ultimate demand scenario was set up. These models would be identical to the models used in sections 4.3.1 and 4.3.3. These were the two scenarios where there were no active bores and both active bores. This will show whether the system is adequately supplying a sufficient water pressure to local residents with and without bore contributions. If the system is being adequately supplied by the reservoir alone (no bores) then there would be no need to check the system adequacy for when the bores are running.

4.4.1 Future demands applied to current water network – No active bores.

In this section the modeled pressure outputs are representing the network pressure when there are no active bores. In this scenario there will be an ultimate peaking value applied to the network, which, as per table 3.2 and 3.3, will be 31.91L/s. This value represents a PH period at ultimate development. The maximum tank capacity has also been applied to this model. The results for this comparison are shown in table 4.10. Note that the water pressure, as per the South-East Queensland (SEQ) Water and Sewage Planning Guidelines - section A4, is adequate between 22 and 80 metres of head.

Future demands - No bores				
Node ID	Future supply pressure	Current supply pressure (m)	Pressure difference (m)	Adequacy (80>X>22m)
Junc p1	42.64	57.1	14.46	Yes
Junc p2	42.08	56.69	14.61	Yes
Junc p3	41.42	56.09	14.67	Yes
Junc p4	41.14	55.84	14.7	Yes
Junc p5	39.49	54.19	14.7	Yes
Junc p6	38.1	52.81	14.71	Yes
Junc p7	37.09	51.89	14.8	Yes
Junc p8	38.17	52.99	14.82	Yes
Junc p9	38.87	53.69	14.82	Yes
Junc p10	40.12	55.09	14.97	Yes
Junc p11	36.64	51.49	14.85	Yes
Junc p12	34.31	49.09	14.78	Yes
Junc p13	34.48	49.19	14.71	Yes
Junc p14	32	46.74	14.74	Yes
Junc p15	38.01	52.64	14.63	Yes
Junc p16	39.72	54.34	14.62	Yes
Junc p17	41.41	55.9	14.49	Yes
Junc p18	42.92	57.3	14.38	Yes
Junc p19	44.35	58.65	14.3	Yes
Junc p20	43.69	58.1	14.41	Yes
Junc p21	44.8	59.1	14.3	Yes
Junc p22	47.08	60.11	13.03	Yes
Junc p23	46.77	60.16	13.39	Yes
Junc p24	43.12	56.21	13.09	Yes
Junc p25	39.49	54.1	14.61	Yes
Junc p26	35.94	50.59	14.65	Yes
Junc p27	36.42	51.09	14.67	Yes
Junc p28	34.99	49.69	14.7	Yes
Junc p29	39.92	51.43	11.51	Yes
Junc p30	40.86	53.22	12.36	Yes
Junc p31	47.2	59.02	11.82	Yes
Junc p32	49.61	57.76	8.15	Yes
Junc p33	48.75	56.27	7.52	Yes
Junc p34	47.35	54.67	7.32	Yes
Junc p35	45.48	54.3	8.82	Yes
Junc p36	41.51	49.66	8.15	Yes
Junc p37	41.97	50.36	8.39	Yes
Junc p38	43.18	52.55	9.37	Yes

Table 4.10: Comparison of future demands for 0 active bores.

Since this data shows that the system is still being adequately supplied without any active bores during a peak hour demand of an ultimate development, there is no requirement to investigate the system's future adequacy any further. The addition of the bores to the simulation would only increase the water pressure throughout the network and since all pressure readings were already determined to be greater than 22 metres, the system will perform even more adequately in the future. Also, the 80 metres of head will not be exceed since the demand in the future would decrease the maximum pressure compared to the current, and no current node experienced greater than 80 metres of head.

4.5 Effects of rising groundwater levels

In this section, the minimum and maximum groundwater levels that were determined in section 3.4.2.10.1 were applied to the model. This would enable observations of the pressure variance throughout the network when the groundwater levels are at their extremes. This scenario will closely replicate what has happened to the groundwater levels in this region in recent years due to the flash flooding and extended drought period. The results of these comparisons are illustrated in tables 4.11 and 4.12. In these tables, the pressures throughout the network for low, current and high water levels are included. A column for maximum variance is also included. This column displays the change in head throughout the network between the minimum and maximum values.

John Street Bore Active				
Node ID	Pressure (Metres head)			
	Low	Current	High	Max variance
Junc p1	57.86	59.88	61.76	3.9
Junc p2	57.61	59.7	61.65	4.04
Junc p3	57.04	59.15	61.12	4.08
Junc p4	56.82	58.95	60.92	4.1
Junc p5	55.19	57.31	59.29	4.1
Junc p6	53.84	55.98	57.97	4.13
Junc p7	52.97	55.13	57.15	4.18
Junc p8	54.07	56.23	58.25	4.18
Junc p9	54.77	56.93	58.95	4.18
Junc p10	56.17	58.33	60.35	4.18
Junc p11	52.57	54.73	56.75	4.18
Junc p12	50.17	52.34	54.36	4.19
Junc p13	50.29	52.47	54.49	4.2
Junc p14	47.84	50.01	52.04	4.2
Junc p15	53.72	55.88	57.89	4.17
Junc p16	55.3	57.4	59.36	4.06
Junc p17	56.7	58.74	60.64	3.94
Junc p18	57.98	59.96	61.8	3.82
Junc p19	59.21	61.14	62.93	3.72
Junc p20	58.8	60.8	62.65	3.85
Junc p21	59.66	61.59	63.38	3.72
Junc p22	59.92	61.47	62.92	3
Junc p23	60.09	61.7	63.2	3.11
Junc p24	56.08	57.67	59.14	3.06
Junc p25	55.17	57.34	59.35	4.18
Junc p26	51.7	53.88	55.91	4.21
Junc p27	52.21	54.39	56.42	4.21
Junc p28	50.8	52.98	55.01	4.21
Junc p29	50.6	51.84	52.99	2.39
Junc p30	52.7	54.09	55.38	2.68
Junc p31	58.4	59.74	60.99	2.59
Junc p32	55.96	56.71	57.4	1.44
Junc p33	54.29	54.94	55.56	1.27
Junc p34	52.65	53.29	53.89	1.24
Junc p35	52.7	53.54	54.32	1.62
Junc p36	47.86	48.6	49.31	1.45
Junc p37	48.61	49.39	50.11	1.5
Junc p38	51.04	51.93	52.76	1.72

Table 4.11: Network pressure with varying groundwater levels (John St bore only).

Both Bores Active				
Node ID	Pressure (Metres head)			
	Low	Current	High	Max variance
Junc p1	74.68	79.04	88.4	13.72
Junc p2	74.3	78.68	88.09	13.79
Junc p3	73.69	78.07	87.48	13.79
Junc p4	73.44	77.81	87.23	13.79
Junc p5	71.79	76.16	85.58	13.79
Junc p6	70.4	74.78	84.2	13.8
Junc p7	69.48	73.85	83.28	13.8
Junc p8	70.58	74.95	84.38	13.8
Junc p9	71.28	75.65	85.08	13.8
Junc p10	72.68	77.05	86.47	13.79
Junc p11	69.08	73.45	82.88	13.8
Junc p12	66.68	71.05	80.48	13.8
Junc p13	66.78	71.15	80.58	13.8
Junc p14	64.33	68.7	78.13	13.8
Junc p15	70.21	74.57	83.99	13.78
Junc p16	71.95	76.33	85.74	13.79
Junc p17	73.2	77.45	86.76	13.56
Junc p18	74.24	78.34	87.51	13.27
Junc p19	75.15	79.07	88.09	12.94
Junc p20	75.27	79.47	88.71	13.44
Junc p21	75.6	79.52	88.54	12.94
Junc p22	73.25	75.75	83.62	10.37
Junc p23	73.84	76.57	84.62	10.78
Junc p24	69.54	72.11	80.05	10.51
Junc p25	71.55	75.87	85.24	13.69
Junc p26	68.18	72.56	81.98	13.8
Junc p27	68.68	73.06	82.48	13.8
Junc p28	67.28	71.66	81.08	13.8
Junc p29	61.87	63.23	70.15	8.28
Junc p30	64.96	66.86	74.24	9.28
Junc p31	70.33	72.05	79.27	8.94
Junc p32	64.04	63.6	69.06	5.02
Junc p33	61.79	61.02	66.22	4.43
Junc p34	60.03	59.2	64.34	4.31
Junc p35	61.41	61.33	67.09	5.68
Junc p36	55.95	55.5	60.96	5.01
Junc p37	56.88	56.54	62.08	5.2
Junc p38	60.08	60.19	66.1	6.02

Table 4.12: Network pressure with varying groundwater levels (Both bores).

5. DISCUSSION OF RESULTS

5.1 Cambooya's current water supply network with applied current AD demands

As mentioned throughout section 4.3 the results for this section suggest that the physical data had been collected during a period where neither bores were active. Since neither bore was running during the on-peak data collection activity, it can be said that the data gathered during this period would be some of the lowest pressures that this network experiences.

As expected the pressure in the network experiences a slight increase when the John Street bore is activated. However, the results for when the George Street bore is running in series with John Street bore were not expected. The pressures that were present in this situation were 1.23-23.37m of head greater than when the John Street bore was running alone. This is a substantial increase throughout the network but is an unrealistic scenario because there would be no need for both bores to be active during an AD demand period. This pressure increase is due to the extra 20L/s flowing throughout the network. Since the demand during AD periods is only 2.63L/s, the extra 20L/s causes large back pressures in the network. In this situation water will be flowing back into the town reservoir.

5.2 Cambooya's current water supply network with applied future PH demands.

To understand the performance of Cambooya's water network in the future, peak hour demands were applied to the nodes for an ultimate development period. Only a single simulation was run because the results showed that the entire Cambooya Township still has an adequate water supply pressure without any bores running. This adequacy is due to the fact that the pressure head throughout the network was between 22 and 80 metres of head (SEQ code 2012).

Comparing the peak demands of the future to the present average demands shows that there was an average of 13.13 metres of head less in the network during the future peak. This difference was not predicted as it was assumed that the network would require active bores to maintain adequate pressure in this scenario. Fortunately this is not the case. Cambooya's water supply system will therefore not require any additional water infrastructure for years to come.

5.3 Effects of varying groundwater levels upon the network pressures.

To understand how the rise and fall of groundwater levels in the Cambooya area affect the network supply pressure, simulations with varying bore water levels were conducted. These simulations included minimum and maximum bore water levels at John St Bore for when it is active alone and at both George and John St for when they are simultaneously active. Included in these results was the pressure supplied by both of these scenarios at the current estimated groundwater levels.

When John St Bore is solely active, the average pressure difference in the network between its estimated absolute minimum and maximum groundwater levels was only 3.4 metres head. The maximum and minimum pressure differences throughout the network were 4.21 and 1.24 metres head respectively. This is not a large change upon the network considering the 51 metre difference in groundwater levels that occurs between the maximum and minimum levels.

The lowest pressure the network experienced during the minimum groundwater level simulation was 47.84 metres of head. This is still well above the adequacy limit of 22 metres of head. The highest pressure experienced in the network during the maximum groundwater level simulation was 60.09 metres of head. Once again, this is well inside the adequacy limits of 22-80metres of head.

When both bores are simultaneously running, the average pressure difference in the network between the estimated minimum and maximum groundwater levels jumped to 11.47 metres of head. This is a 8.07 metre rise from when only John St Bore was active. Also, the respective maximum and minimum pressure difference between the two groundwater level simulations are 13.8 and 4.31 metres. Again, this is a substantial increase from when only the John St Bore was active.

The lowest pressure the network experienced during the minimum groundwater level simulation was 55.95 metres of head. This was at the same node that experienced the minimum pressure in the simulation where only John St Bore was active. Also, this is still well above the adequacy limit of 22 metres of head. The highest pressure experienced in the network during the maximum groundwater level simulation was 88.71 metres of head. This maximum and 26 other node pressures, out of the 38 total nodes, were exceeding 80 metres of head. This means that this pressure is exceeding the water supply pressure limitations noted in the SEQ Water and Sewerage Planning Guidelines. Therefore, after heavy rain periods in the Cambooya area, activating George St Bore could cause a water supply pressures outside the guideline limits. This situation should seldom occur since George St Bore only activates when it is required. It could, however, occur when groundwater levels are at a maximum and a high demand period concludes. At this point the George St Bore will still be running to assist the refilling of the local reservoir. During this time, water pressures throughout the network will exceed the limitations of the SEQ water pressure guidelines.

6. CONCLUSIONS

6.1 Conclusion

The aims specified in section 1.3 of this thesis have been adequately achieved.

The majority of the required background data relating to Cambooya's water distribution network was successfully gathered. As was the data for the two bore pumps. Whilst there were portions of information that were not gathered, this was typically due to its absolute unavailability. The fact that these values had to be assumed or estimated based on trends does retract from the accuracy of these results. However, all results, whilst possibly inaccurate can be concluded on accurately as the models behaviour is still a viable representation of what occurs in the Cambooya network under the set conditions. This was verified by the similarity between the model and the physical results. The water assets department of the Toowoomba Regional Council is currently working towards expanding their records as there are many assets throughout the region that have no data record yet. When gathered, the implementation of this data could further increase the accuracy of this model.

As per section 2.3 many hydraulic models were reviewed so that the most appropriate modeler for this project could be determined. After looking at seven different modelers, EPANET was chosen due to its availability and simplicity. The option was also appealing due to the research that had been completed with this software in the past. This research is mentioned in section 2.4.5.

From these simulations it was possible to conclude that the current Cambooya municipal water supply system is adequate both now and in the future. All pressures across all simulations never dropped below 22 metres of head, meaning the pressure in the system is adequate. There were, however, findings that suggest that in some cases the pressure will actually be too high, when considering the water pressure standards mentioned in the SEQ Water and Sewerage Guidelines. This high pressure is present when groundwater levels are peaking. Whilst the pressure limit is 80 metres of head, the network experienced up to 88.71 metres of head. Not only does this mean that the presence of such high pressures is an inconvenience to locals but will also likely cause leakages throughout the network.

An investigation completed but not reported on in this document was the investigations into the effect of pipe roughness on the overall pressure of the water network. These results were not discussed because there was essentially no change throughout the system with varying pipe roughness values. For the roughness to have any effect on the network the value had to be multiplied by numbers near or greater than 100. As this was such an unrealistic roughness value, this investigation was neglected.

It is also important to note that this model's pipe roughness values and tank water height do not necessarily represent the actual property values that were present during the data collection activity. It would be an extremely hard task to determine all the pipes' actual roughness values as roughness is known to vary with age (Duronil 2007). Also, as the tank water level will vary throughout the day, a time series plot would have to be completed to determine an approximate water level at the times of measurement. It is mainly these variances that explain why the node pressures of the model were not identical to that which was attained from the physical data collection activity.

All photos that were included within this document were self-taken and therefore have not been referenced in anyway.

6.2 Further work and recommendations

As this thesis topic only presents a very specific portion of the analyses that can be applied to municipal water supply network, a large amount of work can still be completed on this hydraulic model.

As this model made many assumptions, reducing these assumptions or implementing a way of increasing the accuracy of these assumptions would be the initial stage of any continued work with this model. The inclusion of local commercial, industrial and school demands in the area would deliver the most substantial increase in accuracy for the model. These were neglected due to the lack of data, but with more time, this could most definitely be included. The assumption that all minor losses due to valves and hydrants were neglected in the network could also be removed, given more time. If the Toowoomba Regional Council could supply a map of this infrastructure than these components could quite simply be added to the network. This would remove this assumption entirely and would ultimately improve the accuracy of the model even further.

Other further work that is possible with this model is the inclusion of a time analysis. There was not enough time, for this thesis to include a diurnal simulation of how and when daily pressures peak in the system. This would also give the opportunity to the user to control when bore pumps are activated and deactivated, according to the pressure in the network or the water level in the tank. Overall this opens the gate to many more types of analyses that EPANET is capable of.

EPANET is also capable of running water quality tests and simulations. As the water being discharge from both Cambooya bores is initially raw and un-chlorinated this provides another opportunity for research. The chlorination of Cambooya's bore water occurs as it enters 600mm pipes which act as a mixing basin before it is introduced to the rest of the network (Toowoomba Regional Council 2012). How this chlorination input is controlled could also be a point of interest. If it is merely a certain volume of chlorine per hour, as shown in figure 3.12 and 3.15, then the dilution will vary with discharge. This issue would be further compounded by the rise and fall of groundwater levels in the area.

The efficiency of the bore pumps could also be investigated. The bore pumps in Cambooya are 50 and 30 years old, it is possible that there are now pumps with more suitable pump curves that could replace these pumps. To investigate this matter, an efficiency curve for each respective pump can be inputted into the model, this will determine how efficient the pumps are running throughout the day. A comparison could then be made against the efficiency of more modern pumps to see whether replacement pump are finically or otherwise viable.

In this project only average daily (AD) and peak hourly (PH) demands were applied to the model. Whilst the comparison between these two demand types provides a reasonable foundation for analysis, the model is also capable of modeling the system's behaviour in peak daily (PD) and maximum day mean month (MDMM) demand periods.

A limit of this model is the lack of consideration towards private water sources. During the data collection activities it was apparent that there were many houses that had rainwater tanks situated within their property. Some of these were extremely large. The water demand for these households would therefore be considerably less than houses without water tanks. A study to determine the percentage of rainwater consumed per day per person (or household) would be a valuable contribution to this research. If this study were to be completed it could add to the accuracy of this model.

As the Cambooya network was adequate in most circumstances, minimal recommendations need to be made. It is, however, recommended that a control system should be implemented that will limit the use of George Street Bore when the groundwater levels are peaking. This or additional pressure reducing valves throughout the system will prevent the system from exceeding the pressure limits stated in the SEQ Water and Sewerage guidelines.

7. APPENDICES

APPENDIX A - Course Specification Sheet

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **GRANT NORMAN**

TOPIC: INVESTIGATIONS INTO TOOWOOMBA'S WATER SUPPLY PRESSURE WITH RESPECT TO LOCAL CONTRIBUTING BORES.

SUPERVISOR: Joseph Foley

ENROLLMENT: ENG4111 – S1, D, 2014;

ENG4112 – S2, D, 2014;

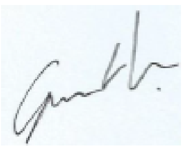
PROJECT AIM: This project seeks to investigate the varied water supply pressures throughout the day in the Toowoomba region/city and determine whether the surrounding contributing bores are being introduced efficiently (if at all) into the default water supply coming from the dams.

SPONSORSHIP:

PROGRAMME:

1. Obtain background information and data relating to the water distribution network in Toowoomba and the ground water bores supplying into the water supply system.
2. Review the available hydraulic models capable of simulating the distribution network in a city like Toowoomba.
3. Obtain data regarding the bore-hole pumps that are currently supplying into the water distribution network.
4. Simulate the interaction between a complex distribution network with existing off-takes and the addition of a number of bore-hole pumps, to understand the variation in network pressure developed over the system.
5. Develop an understanding of the interaction of the ground-water recovery on the performance of the bore-hole pumps and their altered impact on distribution of water through a complex network of water supply.
6. Present results of model development, (in terms of data entry) and complexity, along with an understanding of the groundwater pumps and supply system.
7. Present results on the variation of pressure heads expected throughout the distribution network, that could be expected under the current rise in groundwater levels.

AGREED:

 (Student) ________________________ (Supervisor) *{This was all agreed upon}*

21/2/ 2014 21/2/ 2014

APPENDIX B - Full risk assessment (pt1/4)

Health & Safety

Risk Assessment Template

Use this template to document a risk assessment to manage health and safety hazards and risks.
For more details on the risk management process refer to, *Managing Health and Safety Risks*.
Note: For risk assessments with curriculum activities refer to: *Managing Risks in School Curriculum Activities*.

Activity Description: **Data Collection from residential neighbourhood.**	
Conducted by: **Grant Norman**	Date: **18/07/14**

Step 1: Identify the Hazards

Biological (e.g. hygiene, disease, infection)		
☐ Blood / Bodily fluid	☐ Virus / Disease	☐ Food handling
Other/Details:		
Chemicals Note: Refer to the label and Safety Data Sheet (SDS) for the classification and management of all chemicals.		
☐ Non-hazardous chemical(s)	☐ 'Hazardous' chemical (Refer to a completed hazardous chemical risk assessment)	
Name of chemical(s) / Details:		
Critical Incident – resulting in:		
☐ Lockdown	☐ Evacuation	☒ Disruption
Other/Details:		
Energy Systems – incident / issues involving:		
☐ Electricity (incl. Mains and Solar)	☐ LPG Gas	☐ Gas / Pressurised containers
Other/Details:		
Environment		
☒ Sun exposure	☐ Water (creek, river, beach, dam)	☐ Sound / Noise
☒ Animals / Insects	☒ Storms / Weather	☒ Temperature (heat, cold)
Other/Details:		
Facilities / Built Environment		
☒ Buildings and fixtures	☒ Driveway / Paths	☐ Workshops / Work rooms
☐ Playground equipment	☐ Furniture	☐ Swimming pool
Other/Details:		
Machinery, Plant and Equipment		
☐ Machinery (fixed plant)	☐ Machinery (portable)	☐ Hand tools
☒ Vehicles / trailers		
Other/Details:		
Manual Tasks / Ergonomics		
☐ Manual tasks (repetitive, heavy)	☐ Working at heights	☐ Restricted space
Other/Details:		
People		
☐ Students	☐ Staff	☒ Parents / Others
☐ Physical	☐ Psychological / Stress	
Other/Details:		
Other Hazards / Details		
Possible aggressive residents in and around data collection area.		

Organisational Health
Department of Education, Training and Employment

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Page 1 of 4

APPENDIX B - Full risk assessment (pt2/4)

Step 2: Assess the Level of Risk

Consider the hazards identified in Step One and use the risk assessment matrix below as a guide to assess the risk level.

Likelihood	Consequence				
	Insignificant	Minor	Moderate	Major	Critical
Almost Certain	Medium	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Possible	Low	Medium	High	High	High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Low	Medium

Consequence	Description of Consequence
1. Insignificant	No treatment required
2. Minor	Minor injury requiring First Aid treatment (e.g. minor cuts, bruises, bumps)
3. Moderate	Injury requiring medical treatment or lost time
4. Major	Serious injury (injuries) requiring specialist medical treatment or hospitalisation
5. Critical	Loss of life, permanent disability or multiple serious injuries

Likelihood	Description of Likelihood
1. Rare	Will only occur in exceptional circumstances
2. Unlikely	Not likely to occur within the foreseeable future, or within the project lifecycle
3. Possible	May occur within the foreseeable future, or within the project lifecycle
4. Likely	Likely to occur within the foreseeable future, or within the project lifecycle
5. Almost Certain	Almost certain to occur within the foreseeable future or within the project lifecycle

Assessed Risk Level		Description of Risk Level	Actions
☒	Low	If an incident were to occur, there would be little likelihood that an injury would result.	Undertake the activity with the existing controls in place.
☐	Medium	If an incident were to occur, there would be some chance that an injury requiring First Aid would result.	Additional controls may be needed.
☐	High	If an incident were to occur, it would be likely that an injury requiring medical treatment would result.	Controls will need to be in place before the activity is undertaken.
☐	Extreme	If an incident were to occur, it would be likely that a permanent, debilitating injury or death would result.	Consider alternatives to doing the activity. Significant control measures will need to be implemented to ensure safety.

Step 3: Control the Risk

In the table below:

1. List below the hazards/risks you identified in Step One.
2. Rate their risk level (refer to information contained in Step Two to assist with this).
3. Detail the control measures you will implement to eliminate or minimise the risk.
   Note: Control measures should be implemented in accordance with the preferred **hierarchy of control**. If lower level controls (such as Administration or PPE) are to be implemented without higher level controls, it is important that the reasons are explained.

Hierarchy of Control	
Most effective (High level)	**Elimination**: remove the hazard completely from the workplace or activity
	Substitution: replace a hazard with a less dangerous one (e.g. a less hazardous chemical)
	Redesign: making a machine or work process safer (e.g. raise a bench to reduce bending)
	Isolation: separate people from the hazard (e.g. safety barrier)
	Administration: putting rules, signage or training in place to make a workplace safer (e.g. induction training, highlighting trip hazards)
Least effective (Low level)	**Personal Protective Equipment (PPE)**: Protective clothing and equipment (e.g. gloves, hats)

APPENDIX B - Full risk assessment (pt3/4)

Hazards/Risks and Control Measures

1. Description of Hazards / Risks	2. Risk Level	4. Control Measures (Note: If only Administration or PPE controls are used, please explain why.)
Environmental - Sun exposure, animals/insects, temperature, storms/weather	Low	Protective clothing suited to the weather.
Machinery - Road users	Low	Maintaining safe distance from the road at all times. High visibility clothing during periods of medium to low light.
Behaviour of local residents	Low	Introductions made and permission requested before collecting data from private property. Mobile phone to be on person at all times in case of an aggressive escalation of the patron.
Other details:		

APPENDIX B - Full risk assessment (pt4/4)

Submission	
This activity will be conducted in accordance with this risk assessment, implementing the control measures outlined in Step Three. Changes will be made to the activity, if required, to manage any emerging risks to ensure safety.	
Contact person: Grant Norman	Date: **18/07/14**
Indicate those others involved in the preparation of this risk assessment. **Nil**	

Step 4: Monitor and Review Controls

Complete during and/or after the activity.	Yes	No
1. Are the planned control measures sufficient and effective in minimising the level of risk?	☒	☐
2. Have there been any changes to the planned control measures?	☐	☒
3. Are further control measures required in future?	☐	☒
Details:		

Review completed by: Grant Norman	Designation: Student
Signature:	Date: 18/07/14

APPENDIX C - Consequential Effects

C.1 Sustainability

If this model were to be implemented on a larger scale it would theoretically save time, power and money, making this not just an efficient and environmentally friendly improvement but a financially viable option also. These improvements would be due to the model giving a greater understanding of the pressure distribution within the municipal water supply. A greater understanding of the pressure distribution would mean that pumps can be more finely tuned to the area's fluctuating requirements throughout the day. This would be to ensure that no pumps are affected by cavitation or working outside their efficiency limits in the 24 hour cycle. This would reduce the power usage of local water pumps, reduce the maintenance requirement and ultimately increase the life span of each pump.

Another concern involves the regulated input of chlorine into the municipal water supply via the bore pump sites. Quantities of Chlorine compounds are distributed into the network for the purpose of water disinfection. Any change in discharge of these sites into the network would consequentially affect the level of dilution of chlorine in the network (World Health Organisation, 1996). Whilst higher concentrations of Chlorine can have dangerous health effects, lower concentrations increase the risk of exposure to harmful bacteria (World Health Organisation, 1996). Understanding the pressure distribution network better would consequentially increase the accuracy of chlorine dilution and distribution. In addition, the hydraulic impacts on the ground water rise and network pressure also substantially alter the discharge at the pumped bore sites. Including the ground water effects in this analysis will be imperative to accurately define the relationship between the bores and the pressure distribution network.

C.2 Safety issues (Before TRC bore tour)

There are a few minor areas of safety that need to be considered for the purpose of completing this report. The first safety issue which involves the highest safety requirements is the act of visiting the bore sites and/or pump stations. If these locations have substantial height limitations or there is a requirement of any working, measuring or meter reading, people in the area must wear a high visibility vest, steel cap boots and a hard hat. As expected the high visibility vest is just to assist everyone in the work place to know each other's whereabouts. The hard hat and the steel cap boots are specifically for possible falling or dropped objects. As a council member this equipment must be worn when visiting any work site with operating infrastructure. When visiting these sites the main concern is that of electrical equipment, specifically switch boards. If anything malfunctions and needs to be changed or modified on the switch board the professional or the person getting paid to perform this task should take full responsibility for completing the action. If the area is without any probable risk these precautions are reduced to closed shoes and common sense. Also at the pump stations the bore pumps are always located underground, working in series with an above ground booster pump. Anyone visiting the underground bore pump should not suffer from claustrophobia as some of the pump stations go down hundreds of metres. This could be a very stressful situation with anyone that suffers from spatial anxiety.

A much lower risk activity that still merits a discussion is the risk involved with chronic sitting. Over the duration of this dissertation there will be many hours of sitting required while typing. There have been many articles both old and recent claiming long term or chronic sitting has a negative effect on a person's physical and mental wellbeing. All these issues can be avoided by either using a gym ball rather than a seat and by getting up and walking around at a minimum every couple of hours. There is a new piece of technology out that is specifically designed to negate the risk of chronic sitting known as a treadmill desk. As the name suggests the desk is resting at a much higher height and the user is slowly walking on a treadmill located at the desk. This would mean that the desk occupant could be both walking and working simultaneously. These desks however are worth in excess of $4000 dollars and therefore will not be considered for this project.

Another mentionable risk is in regard to legal safety. With all the hydraulic models available on the internet one must be sure that the software that is eventually used is in fact a freeware version not an illegally downloaded full version. If the full (not free) version was downloaded illegally it may bring up legal issues regarding piracy. So for the sake of legal safety and wellbeing only official freeware will be downloaded for this project.

C.2.1Risk assessment of field testing activity

There is also an understanding of safety required when gathering physical data around the selected bore site from residential housing. When walking around residential areas, it is likely that cars will be passing by often, this implies that road safety will be a constant issue during data collection. To maximize road safety, a safe distance from the road will be maintained at all times during data collection. If the data collection is occurring during times of low light, higher visibility clothes will be worn, ideally with reflectors. Closed shoes will also be worn at all times. This is to increase stability and to reduce the danger posed by any local poisonous or aggressive fauna.

Another issue of safety is that posed by unwelcoming patrons. The collection of data will require visits to private properties. Whilst, they will be notified of this presence on arrival, some residents may not be as hospitable as others. In any case where the resident becomes aggressive, they will be apologized to for any disruption and left alone. If this were to escalate further the police would be notified. See Appendix 1 for full risk assessment.

C.3 Ethical issues

The ethical issues with this project are related to all ethical issues with bores in general. Primarily bore users/monitors must make sure that they are not stealing needed water from aquifers or alluvials supplying nearby residents and especially nearby farmers. Farmers are a strong exporter of the Darling downs and stealing their irrigation water would not just have a negative effect on the individual farmer but on the economy of entire darling downs as well.

Trespassing is another ethical concern during this project. Field results will need to be gathered from residential land surrounding the bore of final choice. A student walking onto privately owned land to gather pressure data from an outdoor garden tap may not be of any concern to some residents but could be to others. This is why the courtesy of a personal introduction, purpose of visit and a request of permission to be on that resident's land will be offered to every occupant that is home at the time of data gathering. Since data will need to be gathered from the same location more than once for a greater understanding of the diurnal pressure distribution, the occupant will also be asked if it would be acceptable to return another time to repeat the data gathering without disturbing the household again. If at any time the occupant is uncomfortable with this presence or rejects it entirely, their position on the matter will be respected and the data gathering will occur elsewhere. If by chance all residents disapprove of this presence another area of analysis will be determined (assuming time allows this).

As mentioned in section 4.2, piracy is a large concern when working online and downloading research and helpful programs. Piracy is not just a safety issue but an ethical one also. Whilst the government do penalise piracy crimes it is often not enforced to everyday people, making it very easy to commit without penalty. An ethically bound person, however, will not commit a crime even if that person knows they could get away with it without a penalty. This should be the ethics employed by not only engineers but all citizens and therefore will be the mindset for this project.

In general however, engineers have an absolute ethical responsibility for controlling the earth's natural resources. Water must be must be made available and supplied by the most efficient way possible. The implementation of this model on a larger scale will make the Cambooya municipal water supply run more efficiently which will mean the bores are running more efficiently and only when required.

APPENDIX D - Results Tables

D.1 – Comparison of node pressures discussed in section 4.3.3.

Comparison between node pressures - NoBoresActive Vs. BothBoresActive				
Node ID	(Pressure in m head)			
	Model Pressure (Both bores)	Minimum Variance (from physical data)	Model Pressure (No bores)	Additional Pressure
Junc p1	79.04	-19.88	57.1	21.94
Junc p2	78.68	-23.60	56.69	21.99
Junc p3	78.07	-19.42	56.09	21.98
Junc p4	77.81	-22.73	55.84	21.97
Junc p5	76.16	-21.08	54.19	21.97
Junc p6	74.78	-25.82	52.81	21.97
Junc p7	73.85	-20.81	51.89	21.96
Junc p8	74.95	-21.91	52.99	21.96
Junc p9	75.65	-22.61	53.69	21.96
Junc p10	77.05	-26.05	55.09	21.96
Junc p11	73.45	-20.41	51.49	21.96
Junc p12	71.05	-20.05	49.09	21.96
Junc p13	71.15	-20.15	49.19	21.96
Junc p14	68.7	-21.78	46.74	21.96
Junc p15	74.57	-25.61	52.64	21.93
Junc p16	76.33	-23.29	54.34	21.99
Junc p17	77.45	-22.37	55.9	21.55
Junc p18	78.34	-21.22	57.3	21.04
Junc p19	79.07	-23.99	58.65	20.42
Junc p20	79.47	-23.37	58.1	21.37
Junc p21	79.52	-24.44	59.1	20.42
Junc p22	75.75	-18.63	60.11	15.64
Junc p23	76.57	-21.49	60.16	16.41
Junc p24	72.11	-17.03	56.21	15.9
Junc p25	75.87	-23.85	54.1	21.77
Junc p26	72.56	-18.50	50.59	21.97
Junc p27	73.06	-26.14	51.09	21.97
Junc p28	71.66	-22.70	49.69	21.97
Junc p29	63.23	-14.27	51.43	11.8
Junc p30	66.86	-14.84	53.22	13.64
Junc p31	72.05	-16.97	59.02	13.03
Junc p32	63.6	-8.52	57.76	5.84
Junc p33	61.02	-1.86	56.27	4.75
Junc p34	59.2	-7.18	54.67	4.53
Junc p35	61.33	-10.33	54.3	7.03
Junc p36	55.5	-12.66	49.66	5.84
Junc p37	56.54	-7.58	50.36	6.18
Junc p38	60.19	-7.15	52.55	7.64

APPENDIX E – Resource Requirements

E.1 Introduction

The resources that were required to complete this project in the manner described in the section 5 of this report have been listed and briefly discussed below.

E.2 EPANET

EPANET was the hydraulic modeling software used in this project. The software was available for download online and without any cost attached. The software was downloaded legally from the company's website.

E.3 Microsoft Word

Microsoft word was the reporting software used in this project. There are many other software packages available for such a task, although this software was already available and completely understood by the user. The software was attained legally prior to this project.

E.4 Internet Access

Internet access was a critical requirement of this project. It was used for research in various fields and also for constant access to the ENG4111 and ENG4112 pages within the USQ student website, uconnect.usq.edu.au. No extra cost for internet access was required since it was already available at the research and reporting location, via smart phone and at the university's computer laboratories and library.

E.5 Pump Curves

Once the pump type is defined, the respective pump curve data including varying impeller sizes, power inputs and operating speeds will be required. All of this information is required so that the EPANET model can emulate the pump as well as possible. These pump curves will either be attained from the Toowoomba Regional Council or online via the pump maker's website. This should not require any costs.

E.6 Pressure gauge

A pressure gauge will be required to record physical data from homes surrounding the bore location. The pressure gauge is a necessity to gain these physical results and so that comparisons may be made against the theoretical results from the model. For a pressure gauge to be chosen, it must be able to attach to a typical outdoor garden tap and must measure in Pascals. With this in mind the pressure gauge of choice will be a 'Holman Stainless Steel Pressure Gauge Ha3000.' This gauge fits the requirements and is available at Bunnings for a cost of $15.90.

E.7 Recording Equipment

Other equipment required for when physical data is collected will be a clip board, pen and writing pad. The pen and writing pad are for recording the physical data and the clip board is for a surface to write on no matter where the data is being collected from. All of this equipment is already available, so no extra cost will be present.

E.8 Safety Equipment

As there is no real risk apparent in any activities bar the physical data collection, not much safety apparel will be required. A few very minor precautions will still be taken to minimise risk further in the operation. Closed shoes will be worn throughout the entire data collection operation. This will minimise the risk of foot related injury, increase stabilization and reduce the danger of poisonous fauna, especially in the more rural areas. High visibility/reflective clothing will be worn if the data collection time is during low light periods or if the bore location is situated close to the road.

E.9 Microsoft excel

Microsoft excel was the program used to create spreadsheets and tables for this project. It was the preferred choice of software due to the users familiarity with the program. The program had been legally attained prior to the beginning of this project. Therefore there was no extra cost involved.

E.10 Microsoft Paint

Microsoft paint was a tool used to make minor edits to images in this project. Tasks such as creating labels and map keys were a simple enough task for Microsoft paint to complete. This software was already available as it is apart of the Microsoft Windows 7 64 bit package. This means that no extra costing was required to use this software.

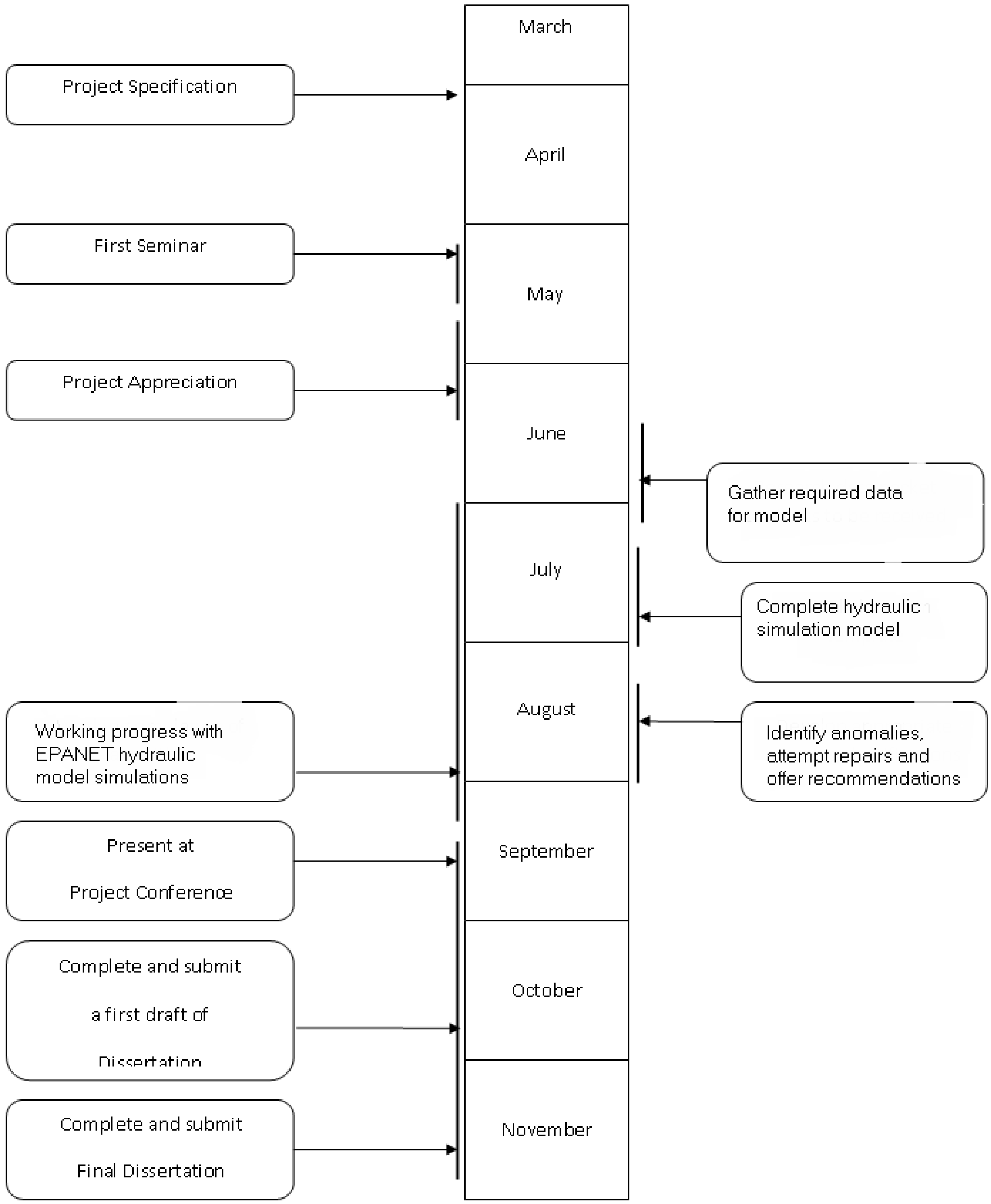
E.11 Vehicle (& fuel)

A fueled vehicle would be required during the collection of Physical data in Cambooya. Since the vehicle was already owned, it would only be the cost of fuel which would be an issue. As the site was visited 3 times and it takes approximately 25 minutes to get to and from this location about 2.3 hours' worth of driving was required. This is not including the 2.5hrs of driving required during the high demand collection activity. This required an approximate fuel cost of $50.00.

E.12 Digital Camera

Also, during the Cambooya data collection activities, many photos were taken. These photos were required for report documentation and discussion. The only requirements for this camera were for it to have a sufficient resolution and a digital connection. Scanning developed pictures would not be worth the time plus an extra cost would be involved for the development. Fortunately a digital camera with a sufficient resolution was already owned and therefore no extra cost for this item was required.

APPENDIX F - Project Timeline

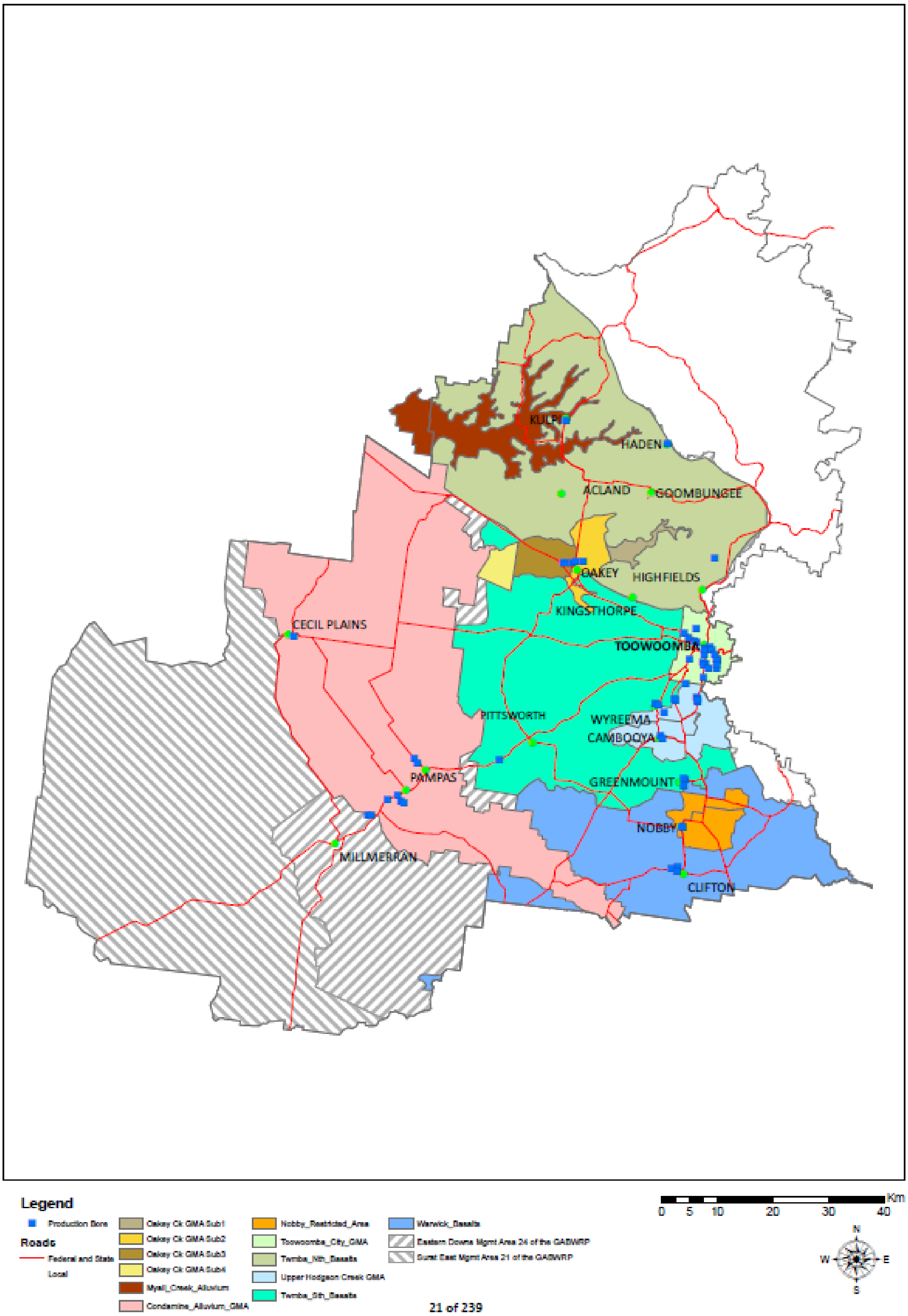


APPENDIX G - Toowoomba Region Groundwater Aquifer map

Water & Waste Services Strategy & Coordination
Integrated Management Systems

DM#5449967v3
24 May 2013

Figure B-1 Groundwater Aquifer Map



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Appendix G: TRC – Water & Waste services, strategy & coordination 2013.

References

ABZ Incorporated 2010, '*Common Assumptions Made By Other Fluid Flow Programs and The DFS Approach*', ABZ - Engineering and Managing Consulting, Chantilly, VA, Available at: http://www.abzinc.com/dfs_vs_others.php

Australian Department of Health 2014, '*Drinking Water Quality – Industry'*, Australian Department of Health, Canberra, Australian Capital Territory, Accessed 20 May 2014, Available at: http://www.health.qld.gov.au/goodhealthintnq/topics/water_industry.asp.

Bentley 2013, '*Water distribution modeling and management'* – WaterGEMS, Bentley, Accessed 21 May 2014, Available at: http://www.bentley.com/en-AU/Products/WaterGEMS/.

Cockatoo Coal 2013. '*Water - Surat Coal'*, Accessed 20 May 2014, Available at: http://www.suratcoal.com.au/index.cfm/project-info/water/.

Duronil 2007, *'PVC-U pressure pipe systems'* Plomyplas Group, Navalcamero, Madrid.

EPANET. 2013. '*What is EPANET'*, EPANET, Accessed 20 May 2014, Available at: http://safewater.supportportal.com/link/portal/23002/23015/Article/22350/What-is-EPANET.

Evans, J 2012, '*Centrifugal Pump Efficiency' – What is Efficiency*, Cahaba Media group - Pumps & Systems, viewed 15 July 2014, Available at: http://www.pump-zone.com/topics/pumps/pumps/centrifugal-pump-efficiency-what-efficiency.

Geoscience Australia 2014, '*Alluvial Aquifers',* Geoscience Australia, Accessed 20 May 2014, Available at: http://www.ga.gov.au/groundwater/groundwater-in-australia/alluvial-aquifers.html.

Grundfos 2006, '*The Centrifugal Pump'*, Grundfos Research & Technology, Bjerringbro, Denmark.

Hansen, A 1999, '*Groundwater vulnerability and availability mapping of the upper condamine river catchment*', University of Technology, Sydney.

HydrauliCAD 2013, '*AutoCAD water system hydraulic analysis software'* HydrauliCAD, Accessed 20 May 2014, Available at: http://hydraulicad.com/.

Innovyze 2013, '*Innovating for Sustainable Infrastructure'*, Innovyze, Accessed 20 May 2014, Available at: http://www.innovyze.com/products/infowater/.

Jia, H , Wei, W & Xin, K. 2008. '*Hydraulic model for multi-sources reclaimed water pipe network based on EPANET and its applications in Beijing, China'*. Front. Environ. Sci. Engin.. vol. 2, no.1, pp 57-62.

Kritpiphat,W , Tontiwachwuthikul, P & Chan, CW 1998, '*Pipeline network modeling and simulation for intelligent monitoring and control: A case study of a municipal water supply system*' *Ind. Eng. Chem. Re.*. vol. 37, no.1, pp 1033-1044.

Maley, T 2013. '*What is an Aquifer?'* Idaho geology, Accessed 20 May 2014. Available at: http://imnh.isu.edu/digitalatlas/hydr/concepts/gwater/aquifer.htm.

Pump Scout 2014, '*Turbine Pumps*' Scout Hub, Bend, Oregon, Available at: http://www.pumpscout.com/all-pump-types/turbine-pumps-ptid73.html

PUMP-FLO 2010, *'Pump Selection Catalogue'*, viewed 15 July 2014, Available at: http://ksbau.epump-flo.com/select/centrifugal/graph.aspx?

Queensland Government 2012. '*Minimum construction requirements for building a water bore in Australia'* Brisbane, Queensland. Accessed 20th May 2014, Available: http://www.nrm.qld.gov.au/water/management/pdf/minimum-const-req.pdf .

Richards, A, Smith, P 2003, '*How efficient is your pump?'*, New South Wales Department of Agriculture, AGFACTS, Ep. 5, Vol. 11, 1st edition.

Rossman, L 2000, '*EPANET 2 – USERS MANUAL*' United States Environmental Protection Agency – Water Supply and Water Resources Division, Cincinnati, Ohio.

Satterfield, Z 2013, '*Reading Centrifugal Pump Curves',* National Environmental Services Center, Tech Brief, vol. 12, no. 1, pp 3-5.

SEQ Code 2012, '*SEQ Water and Sewerage Planning Guidelines*', SEQ D& C, vol 1.0

Spirax-Sarco 2014, '*Control Valve Sizing for Water Systems',* Spirax-Sarco Limited, viewed 15 July 2014, Available at: http://www.spiraxsarco.com/resources/steam-engineering-tutorials/control-hardware-el-pn-actuation/control-valve-sizing-for-water-systems.asp

Sundaram, B, Feitz, AJ, Caritat, P, Plazinska, A, Brodie, RS, Coram, J & Ransley, T 2009, '*Groundwater Sampling and Analysis – A Field Guide',* Accessed 20th May 2014, Available: http://www.ga.gov.au/image_cache/GA15501.pdf.

Toowoomba Regional Council 2012, '*Cambooya Planning Scheme – Planning Scheme Policy No. 4, Infrastructure contributions for water supply network'*, Toowoomba, Queensland.

Toowoomba Regional Council 2012, '*Cambooya Water Supply Study – Network Planning, Strategy and Coordination'*, Toowoomba, Queensland.

Toowoomba Regional Council 2012, '*Groundwater monitoring bore review – Network Planning Strategy and Coordination'*, Toowoomba, Queensland,

Toowoomba Regional Council 2013, '*Groundwater Bore Register'*, Toowoomba, Queensland.

Toowoomba Regional Council 2014, '*Monthly bore water levels & testing record sheet'*, Toowoomba, Queensland.

United States Department of Energy 2006, '*Energy Tips – Pump Systems',* vol. 1, no. 7, pp 1-2.

WATSYS 2013, '*Water Supply System Design, Analysis and Management Software'*, Accessed 21 May 2014, Available at: http://www.technotrade.com.pk/20/WATSYS_Water_Supply_System_Design_Analysis_and_Management_Software/.

World Health Organization 1996**,** ‘*Guidelines for drinking-water quality’*, Geneva, 2nd ed. Vol.2.

Zheng, W 2009, ‘Evolving effective hydraulic model for municipal water systems’, Water Resources Management, vol. 23, no. 1, pp 117-136.