Melbourne Water model validation – identifying and reducing system uncertainty.

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ABSTRACT

In 2010 Melbourne Water and Opus International Consultants undertook the validation of the Melbourne Water bulk water transfer model. This paper presents a case study of the project, focusing on the development of a robust methodology for validating a large and complex system that included setting realistic expectations for the validation and development of a field test plan.

This project involved the systematic recording of network information to identify, quantify and reduce data gaps to improve the model accuracy. Key to this process was the development of a system schematic. The use of this schematic enhanced the recording of data gaps and validation results whilst viewing the network on a single sheet of paper. This enabled an appreciation of the interaction of the various parts of the network, and allowed potential solutions for issues to be identified.

The systematic development of reservoir and trunk main balances gave a thorough audit of over 300 permanent flow meters that were used for the validation. Data gaps and inconsistencies identified through these balances provided guidance to the expected level of validation possible for the model.

A field test plan was developed based on the validation results. The anomalies and uncertainties identified in the validation directed the field test planning. The field test data will be used for calibration.

This case study presents the methodology used to achieve the model validation and the development of current and future peak day scenarios, and the field test plan. The role of the schematic and novel approaches to developing simple model representations of real life operations are presented. This case study will be of interest to modellers dealing with large networks and their managers, and will show a realistic pragmatic approach to model validation, field test planning and the simulation of a large and complex network.

KEYWORDS

Water Model, Validation, Calibration, Field Test Plan, Anomalies

1 INTRODUCTION

In November 2010 Melbourne Water (MW) commissioned Opus International Consultants (Opus) to proceed with the Water Network Model Improvement Project. The project implements the Network Model Management Strategy to improve the accuracy of and confidence in the bulk water supply model.

The project has two stages: Stage 1 model validation/future scenario development and Stage 2 preparation of a field test plan. In Stage 1 an existing model of the Melbourne water network was validated for a historic summer day using data recorded on the 22/01/2006. The validation steps lead naturally to the development of the field test plan (Stage 2), and subsequent calibration, with the model validation providing a good platform to understand the system and operation and model representation of the network. The data gaps and anomalies identified in the validation have been used to guide the development of the field test plan.

2 SCOPE AND OBJECTIVES

The scope of this project is to develop a summer flow validation of the model using the available SCADA data, develop future scenarios and a field test plan (FTP). The coverage and quality of the SCADA data has been established, which guides the validation result expectations. The validation has demonstrated how representative the model is of the system. The SCADA review and model validation has enabled an appreciation of the confidence in the data/model describing the system, with the objectives of; quantifying the level of confidence in the system knowledge and model representation. The exercise serves to generally decrease the level of uncertainty in the model, and increase the confidence in both its use and the interpretation of SCADA data.

The validation comprises 7 steps as summarised below:

1. System and model review
2. Model update
3. SCADA data download
4. Trunk and reservoir balances
5. Model setup
6. Validation
7. Anomaly identification and system confidence assessment

These steps lead naturally to field test planning, which comprises the development of a testing methodology, the identification of existing and additional (new) monitoring sites and the development of a programme and cost estimate to undertake the work. This is a desktop study to define an initial field test plan, which will be refined through input from Melbourne Water Operations and Planning staff, consultation with Monitoring Contractors and assessment of site practicalities.

3 MELBOURNE WATER - BACKGROUND

Melbourne Water manages Melbourne's water supply catchments, removes and treats most of Melbourne's sewage, and manages rivers and creeks and major drainage systems throughout the Port Phillip and Westernport region. It is owned by the Victorian Government, with an independent Board of Directors responsible for governance. The responsible Minister is the Minister for Water.

Melbourne Water is a significant business, responsible for managing $9.4 billion in water supply, sewerage and drainage assets, and is committed to looking after these in a way that protects and improves their environmental, social and financial values. Melbourne Water's annual operating revenue of more than $900 million is earned from water supply and sewage treatment charges, and drainage rates. It is used to fund operations and infrastructure projects including water, sewerage and drainage upgrades and water recycling schemes as well as works to improve and protect Melbourne's rivers, creeks, wetlands and bays.

Melbourne Water's customers are the metropolitan retail water businesses – City West Water, South East Water and Yarra Valley Water – as well as other water authorities, local councils, land developers and businesses that divert river water. Other partners include the Port Phillip and Westernport Catchment Management Authority, the Municipal Association of Victoria, Sustainability Victoria and the University of Melbourne. Melbourne Water works closely with research organisations to assess long-term impacts on Melbourne's water resources. Community engagement encourages the support and involvement of many community stakeholders.

Sustainability is the cornerstone at Melbourne Water to ensure a 'sustainable water future' through the Strategic Framework - achieving sustainable business outcomes. Melbourne Water is committed to addressing, implementing and maximising financial, environmental and social outcomes across all operations and creating an environmentally aware and innovative work culture. The Strategic Framework formalises Melbourne Water's long term vision of 'working together to ensure a sustainable water future'. The Strategic Framework underpins all strategies and policies and guides the five year Water Plan, three year Corporate Plan and 20 year Capital Plan and provides the context for Melbourne Water's planning processes ensuring social, environmental and economic impacts are considered in all aspects of business operations.

Network modelling is an essential element of Melbourne Water's strategic planning for the following reasons:

- It provides tools to plan, build, operate and manage our assets efficiently, innovatively and in the most sustainable manner;
- It provides a simple way to demonstrate the robust planning process to stakeholders;.
- It provides a simple way to demonstrate effective and efficient financial and risk management;
- It provides a simple way to develop our people and support our workplace culture, and
- It provides a simple way to promote a culture of learning, sharing of information and continual improvement.

Melbourne Water has made significant investment in network modelling over the past ten years. There is an ongoing need for network models to support capital investment decisions and the growing need for hydraulic network information from numerous internal and external stakeholders and customers.

The current network modelling practice and business priorities aim to ensure that network modelling in Melbourne Water provides value for money and makes hydraulic network data more accessible for internal and external stakeholders and customers. To achieve this the current Network Model Management Strategy defines a targeted approach to improve and then maintain the accuracy of the water and sewer network models, highlight best practice, identify the investment required and maximise the use of network modelling

4 PROJECT PROCESS

Validation and field test planning for a network of this size is a significant undertaking. Successful completion has required a mix of back to basics and innovative thinking. Coming to grips with the network layout and functioning required the development of the network schematic, which is the central document developed and used throughout this project. The schematic is described and shown in the following section of this paper, but in essence it is the entire reticulation shown on a single sheet of paper.

The process of validation, field testing and calibration are interlinked and iterative. The further the process is taken, the greater the confidence in the model. The expected model accuracy and potential uses of the model as a result of increasing model calibration has been made, as shown in Table 1. As validation, field testing and calibration are essentially investigations, it was not possible to finalise the FTP. Rather an incremental process has been established with milestones along the way, where the progress can be evaluated, options for further work considered and the way forward established. Some initial activities are considered essential (e.g. Data downloading, reservoir and trunk main balances, addressing unmetered off takes and anomaly resolution) while some future activities may not be required depending on the outcome of previous work. These activities and their relationship are shown in Figure 1.

Table 1 Expected model accuracy for increasing levels of calibration

Activity	Expected Model Accuracy and use	Pros	Cons
Existing summer validation As reported in Stage 1 of this project	60% High level strategic planning only	• Uses existing SCADA • Relatively straightforward • Has been completed	• Limited model accuracy • Anomalies identified but not resolved
Address Unmetered Offtakes	65% High level strategic planning only	• Desktop exercise • Retailer involvement	• Limited model accuracy • Need to keep up to date with offtake status
Resolve Anomalies	75% Planning and limited operations use	• Improved understanding of system for Planners and Operators • Improves chance that calibration data will be useable	• Will take significant effort/cost • Co-ordination of participants • Risk that anomaly cannot be resolved • Requires some flow meter/pressure logger installation
Gather field test data for calibration	85-+ using SCADA system only Planning and Operations use only	• Minimal field enabling work to obtain data • Audit and improvement of SCADA system	• Recalibration of some SCADA sites likely to be required • Greater reliance on Operation inputs
	95%+ using SCADA and loggers Optimisation of design and ready for water quality calibration	• Maximum possible reliability of data gathered • Not subject to radio outages or SCADA calibration factors • Optimal locations for calibration data gathering selected • Independent set of data from SCADA may improve SCADA system	• Significant field work required; costly • Required enabling works will delay project • Will require tapping into some SCADA points

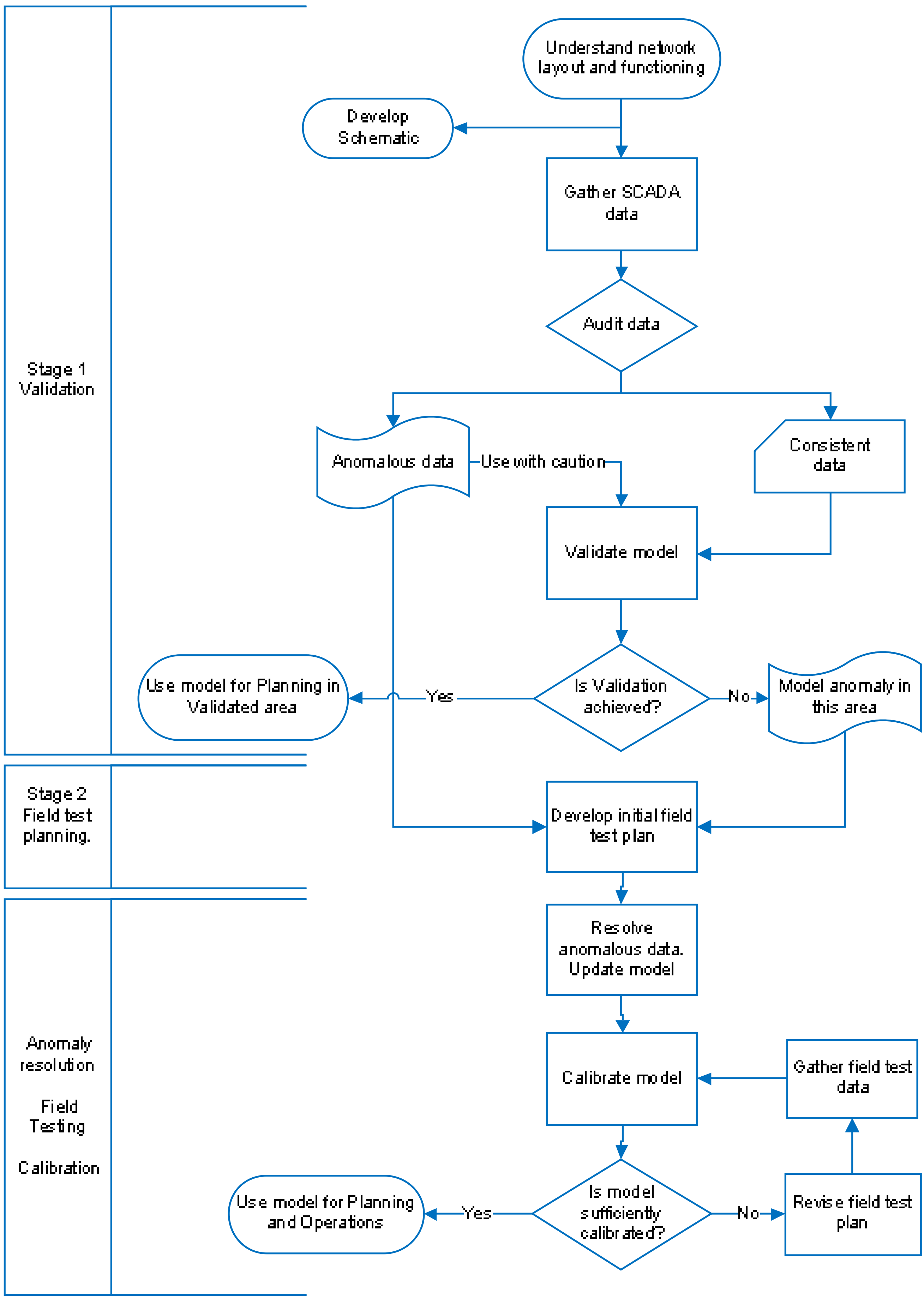


Figure 1 Project Process

5 THE SCHEMATIC AND DEVELOPING SYSTEM KNOWLEDGE

The schematic is the key document developed and used in this project. On a single sheet of paper the entire treated water network has been laid out. It shows the water sources, pipelines, pumpstations, control valves, demand points and reticulation connectivity that make up the bulk supply network. See Figure 2. Copies of the schematic have been overlaid with information to show validation day flows, the results of the data audit, the results of the validation and the field testing monitoring locations. As the whole network is viewable at a glance, a appreciation can be developed of the inter-relation of the components that make up the reticulation. A balance of clarity with detail has been struck using colour and symbols to maximize the knowledge available from the schematic. Developing the schematic proceeded in parallel with establishing knowledge of the system and an understanding of its functioning. Extensive interviews were held with Planning and Operations staff to confirm the understanding developed, and their input into developing the schematic was invaluable. Additionally a Functional Description of the operation of the network was developed that captured the key operational protocols used to direct the flow around the network. Together the Schematic and Functional Decsription recorded the system knowledge developed and were referenced throughout the project. This was crucial for updating the model and interpreting model results.

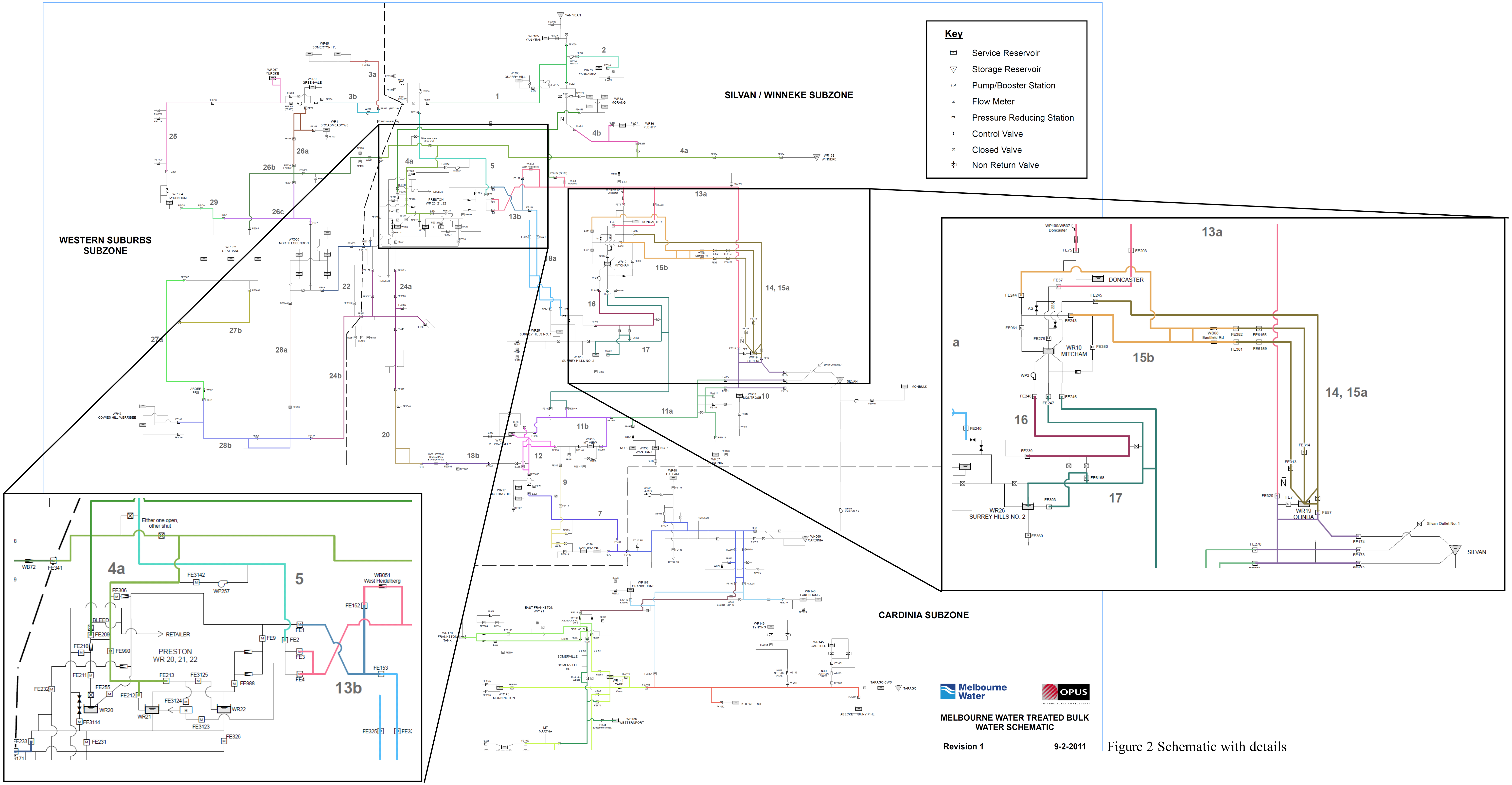


Figure 2 Schematic with details

6 SCADA DOWNLOAD AND RESERVOIR BALANCES

The SCADA records of flow, pressure and reservoir water level were extracted for the validation day (22 January 2006). These were used to develop the demands in the model, for reservoir and trunk main balances and to check the validation result. They were extracted for a 24 hour period from midnight to midnight at a 6 minute interval. All records were averaged over the six minute interval. Where data was not available from SCADA for that day, either an adjacent trunk or reservoir balance was used to derive the missing data if possible or another similar demand day was chosen to complete the reservoir and trunk main balances.

The reservoir balances are a mass balance check of the flow and reservoir water level SCADA data. They consider the flow into and out of the reservoir and the change in water level. They are based on 24 hours of data and the balance is done at 6 minute intervals. This allows the reservoir level to be derived throughout the 24 hour period, and the derived level (based on inflow – outflow and reservoir size) has been compared with the measured level. This is represented graphically in the reservoir balances, see Figure 3. This allows a quick check that the flow meter and reservoir levels are consistent at a site, and the sensitivity of the balance to flow meter accuracy can be established.

Three possible reasons for not achieving the reservoir balance were developed; reservoir shape, flow meter error and reservoir leakage. The balance calculation has assumed the reservoirs are prismatic (i.e. that the walls are parallel and for a given change in water depth the volume change is the same at all levels in the reservoir). Reservoirs where this is not the case will affect the results of the balance. This may be observed as the reservoir either filling and/or emptying too quickly or slowly.

Similarly, flow meter errors and reservoir leakage have been considered where a good balance has not been achieved. In some locations adjusting a metered inflow and/or outflow by up to 8% has resulted in a very good balance and an error of this magnitude wouldn't be considered unusual for an older flow meter, see Figure 4. Leakage is only considered a possibility where the flow balance indicates a higher water level than measured.

The reservoir balance has been assessed as Very Good (within 100 mm), Good (from 100mm to 400mm) or Fair (over 400mm). This is a subjective assessment developed as the project progressed and an appreciation of the limits of data accuracy was developed. It is useful to prioritise the investigation of reservoirs during calibration, and may not be applicable to other systems.

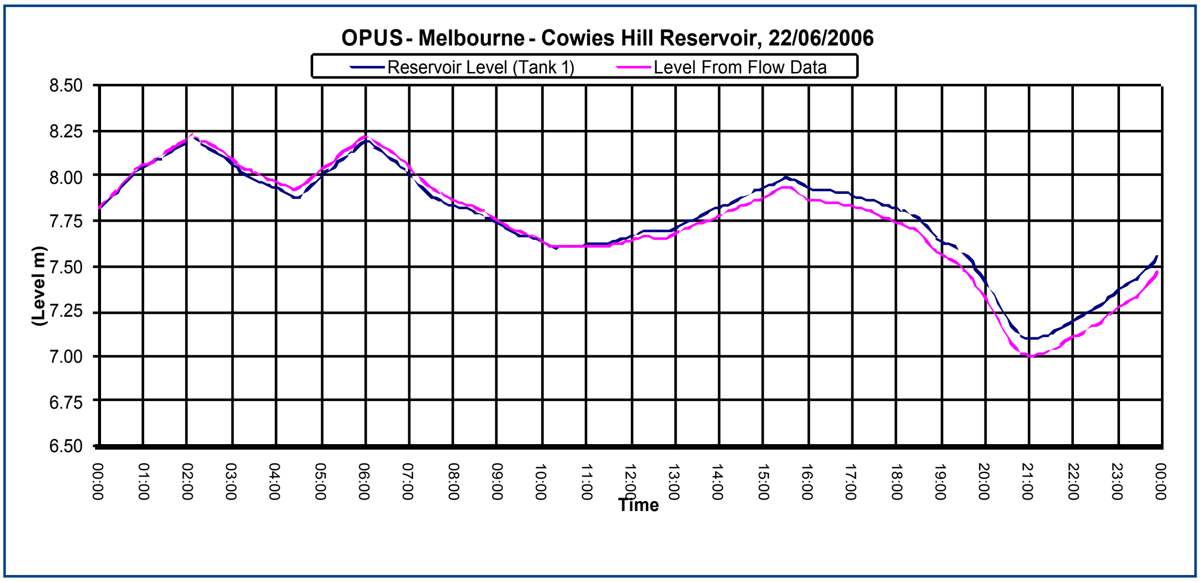


Figure 3 Cowees Hill reservoir balance

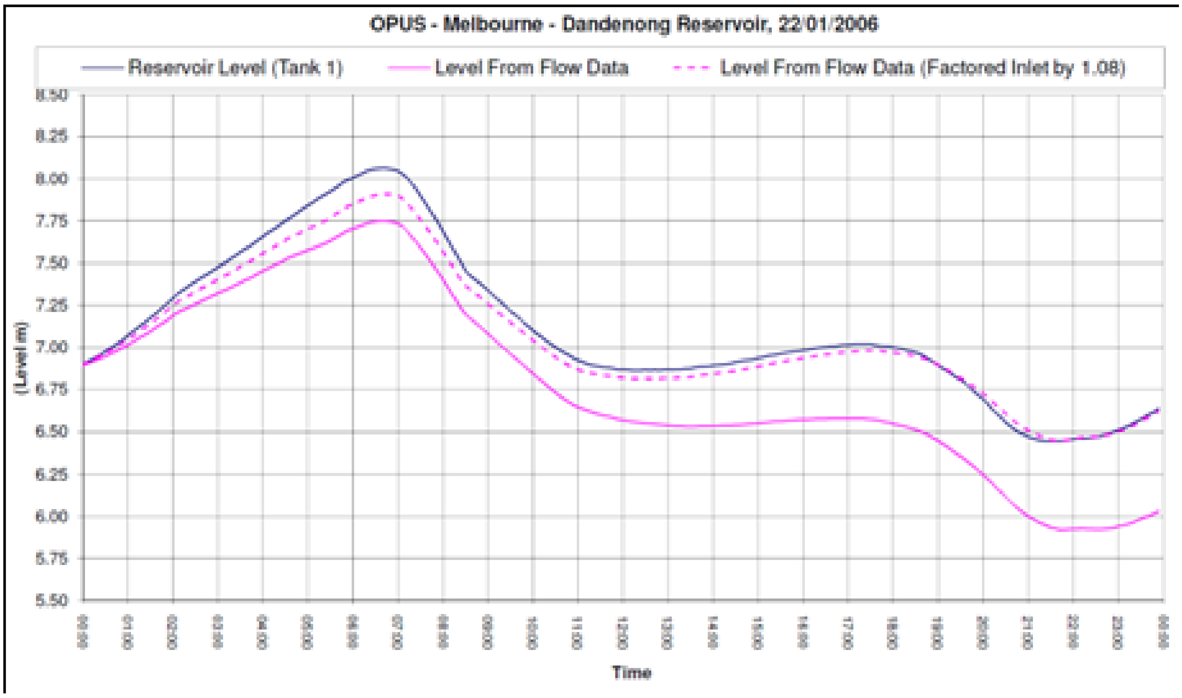


Figure 4 Dandenong reservoir balance

7 TRUNK MAIN BALANCES

The trunk main balances consider a subset of the network where all inflow and outflow is measured. The network was split into 48 individual "lines" which were individually considered in the trunk main balance process. The metered flows over the 24 hour validation day have been used to check the mass balance. Where there is an imbalance this indicates either demand, leakage or flow meter error. There are a number of unmetered off takes from the Melbourne Water system to the Retailers. Flow through these off takes was calculated using the adjacent flow meters.

An example of a typical diurnal demand derived from a trunk main balance is given in Figure 5. Care was required when interpreting trunk main balances, as occasionally they required the subtraction of two large flows, which leads to the error in these flows being added. This can result in inconclusive balances being obtained (see Figure 6), which had to be used with caution in the validation.

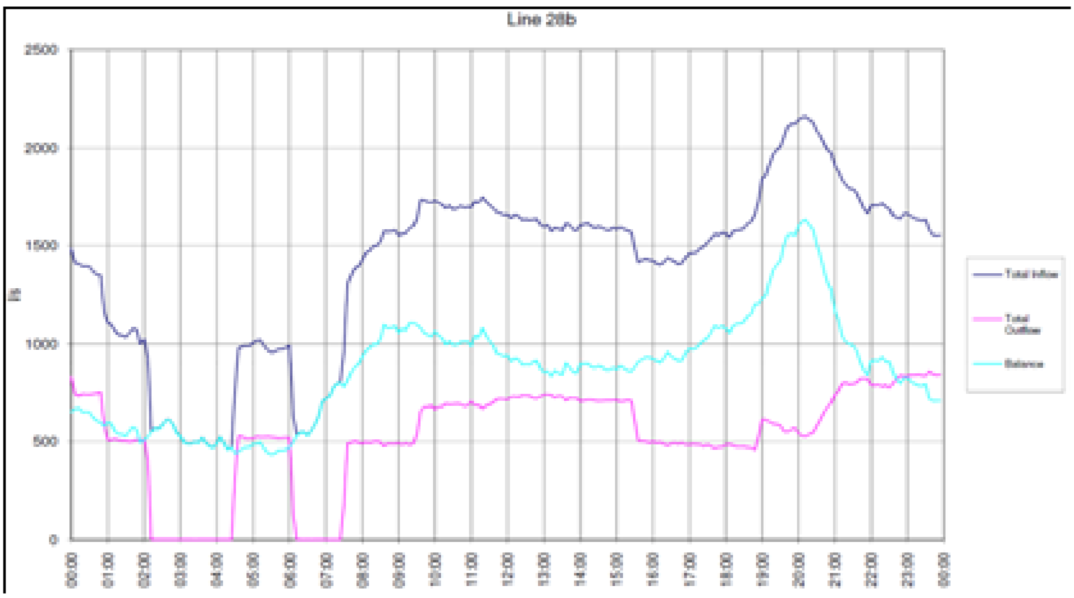


Figure 5 Trunk main balance showing a typical diurnal demand balance

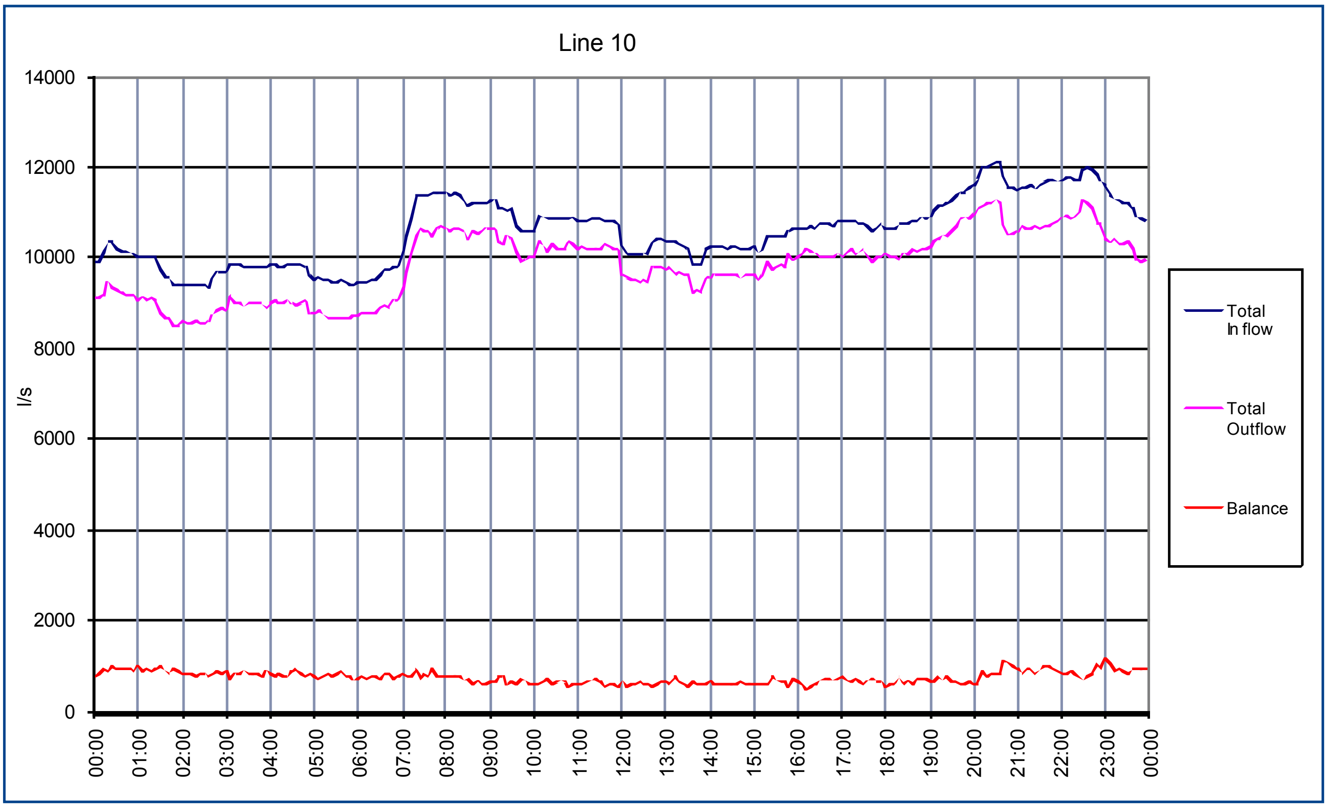


Figure 6 Trunk main balance showing effect of subtracting two large flows. Inconclusive result.

8 MODEL UPDATE AND SETUP

8.1 MODEL UPDATE

The model was updated to include Retailer pipelines that form part of the network but were not included in the original model. The Retailers (customers of Melbourne Water) have an extensive reticulation connected to the bulk system, which in some cases links different parts of the Melbourne Water network together. A small number of Retailer reticulation pipes have been included in the model, as these are significant diameter pipes (600mm and above) which may affect the bulk system operation. These pipes have been identified through discussions with Melbourne Water planning and operations staff and added to the model as active elements..

8.2 MODEL SETUP

The model setup for validation used the updated model and the demands and controls were revised to reflect those measured on the validation day. The demands were calculated from metered flows and trunk main balances and the resulting demand allocated to specified nodes in the model.

The controls that alter the flows within the model have a significant effect on the system operation. They have been taken from the functional description of the system and translated into standard controls which have been applied to the model. Whilst the modelling software (H2OMap) is capable of simulating logic controls to emulate a Programmed Logic Controller (PLC), a simple approach using standard controls was adopted, as it makes the future use and checking of the model easier.

8.3 LIVE DATA

In addition to the demands and controls input into the model, a further input is the live data (SCADA record of reservoir water levels, flows and pressures). This data has been reformatted and input into the validation scenario and appears as a background trace on the comparison graphs of these parameters. This enables a speedy evaluation of the validation and aids revision of the model as the validation proceeds.

9 MODEL VALIDATION

9.1 VALIDATION AND ANOMALY IDENTIFICATION

The validation was an iterative process of revising the model controls and demands initially input to improve the match between the live data and model outputs. It followed the same general sequence as the reservoir and trunk main balances, starting at the reservoir sites and then moving through the trunk system to cover the entire network. Live data (SCADA records of flow, pressure and reservoir water level) was used to graphically compare against the model outputs and to guide the validation and present the final results.

The system was broken down into smaller subsets where the boundary conditions are known, e.g. a reservoir complex where the in/out flow meters, pressure sensors and reservoir levels define the water movement through the complex, or a section of trunk main where the inflows and outflows are known and pressures recorded. The SCADA record of the boundary conditions of each of these smaller areas was validated previously in the trunk main and reservoir balances (described in Sections 6 and 7). This shows the confidence in the boundary conditions and indicates the expected validation result in this area, i.e. a good trunk main balance indicates the model should validate in that area, and an imbalance indicates the validation will be difficult to achieve in that area.

Firstly the peripheral reservoirs were validated driving from a fixed measured head and checking the flows. The system was adjusted until the flows give a reasonable match, using control adjustments and imposing reasonable minor losses. If this is not possible (because, for example, an unrealistic minor loss is required) the area has been noted as an anomaly. A record of all adjustments to the model was made. The areas were progressively opened up until the model as a whole functions.

The outcome of this process was a listing of the alterations made to the model and areas that are anomalous. It gives a documentation of the confidence in the SCADA data and model representation of the system. The exercise served to generally decrease the level of uncertainty in the model, identify anomalous areas and increase the confidence in both the model use and the interpretation of SCADA data.

9.2 VALIDATION CONTROLS

The base model used for the validation included the standard and rule based controls applied in the previous winter validation model. As a starting point each of the rule based controls were assessed and consequently disabled for this validation. Most of the standard controls were also disabled and the controls identified from the functional description of the system were translated into updated standard controls. This approach was taken because of the use of standard controls within the model makes the model more “user friendly” for future use and checking of the model controls.

The functional description of the system highlighted a number of locations where valves in the trunk main network had either been operated manually or controlled in a manner that required fixing in the model, for example where the weather is used as a predictor of demand and the system operated accordingly. At these locations the flow was fixed to represent the actual flow through the valve on the validation date. By fixing the flow the actual headloss across that valve on the validation date has been simulated. As the validation proceeded the fixed flows imposed were able to be removed, because the other parts of the model were functioning correctly. The number of places where the flow was fixed was reduced to seven across the entire network.

9.3 VALIDATION RESULTS

Plots showing the validation achieved at each of the reservoir, flow meter and pressure gauge locations were developed. Examples are shown in Figure 7, Figure 8 and Figure 9. The validation results for each site have been categorized into Good (within 10%), Fair (10% to 25%) and Poor (over 25%), and plotted onto the schematic, along with the SCADA data availability at each measuring site. See Figure 10 for two examples of validation results. This allowed an overall appreciation of the model validation to be developed, taking into account the SCADA data upon which the validation was based.

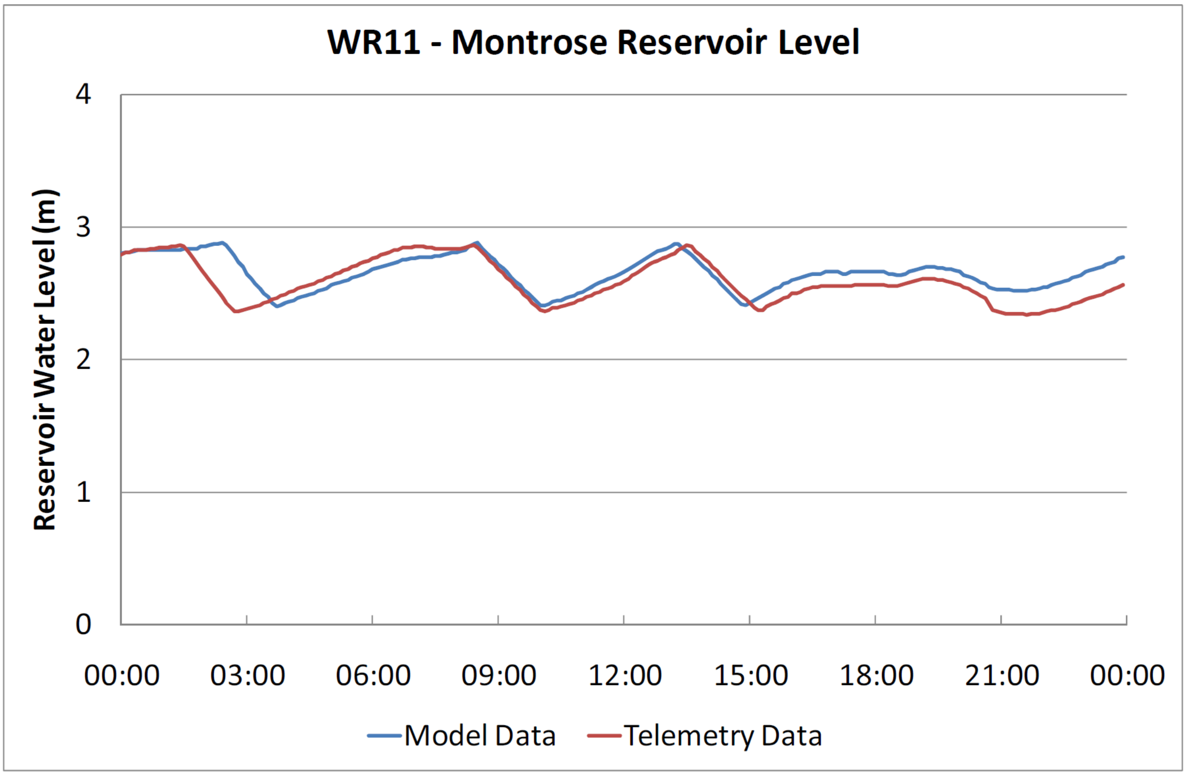


Figure 7 Reservoir water level validation result

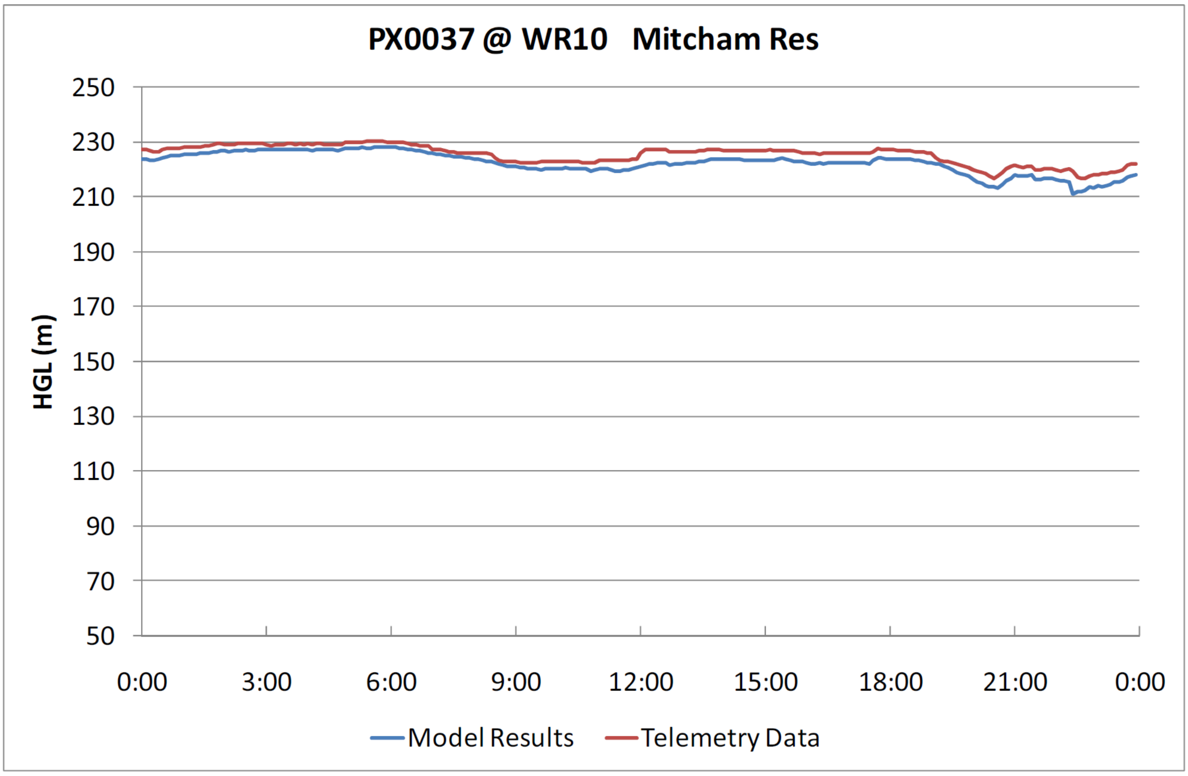


Figure 8 Pressure gauge validation result

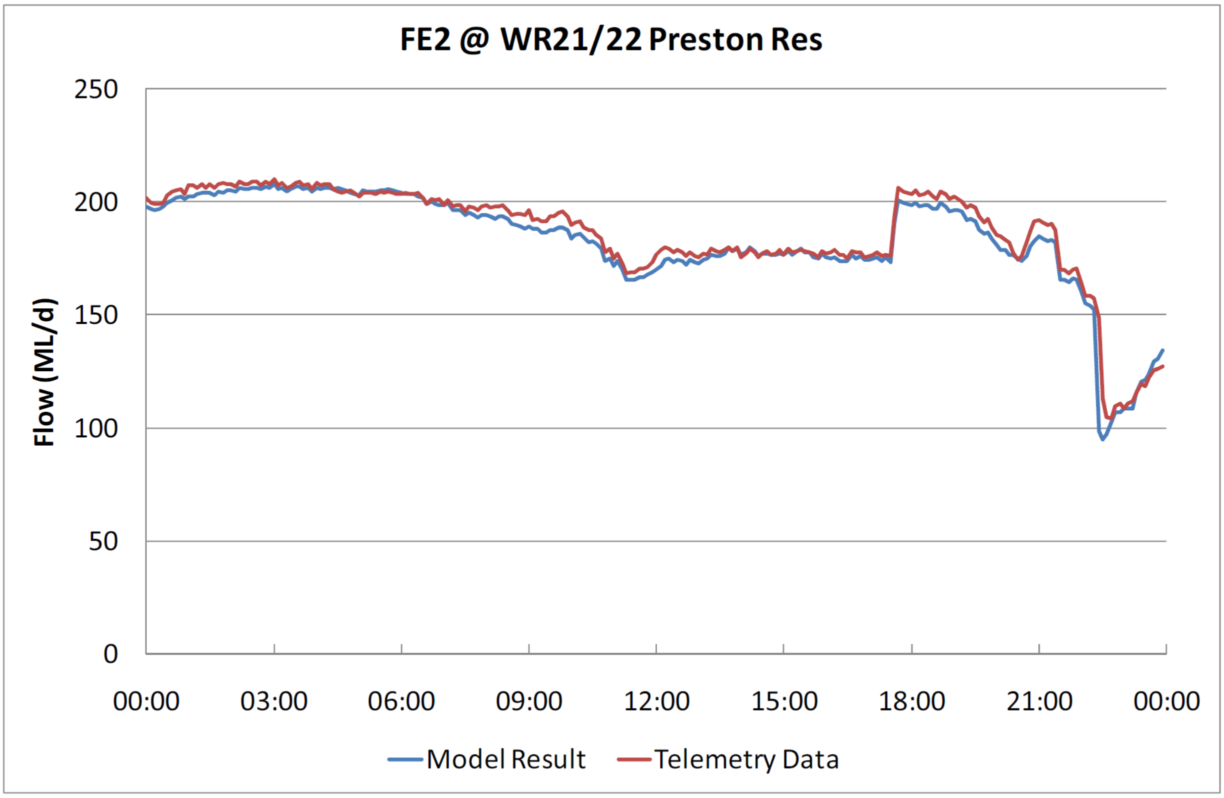


Figure 9 Flow meter validation result

The validation result categories of < 10%, < 25% and > 25% have been applied using the following criteria:

Category	Criteria

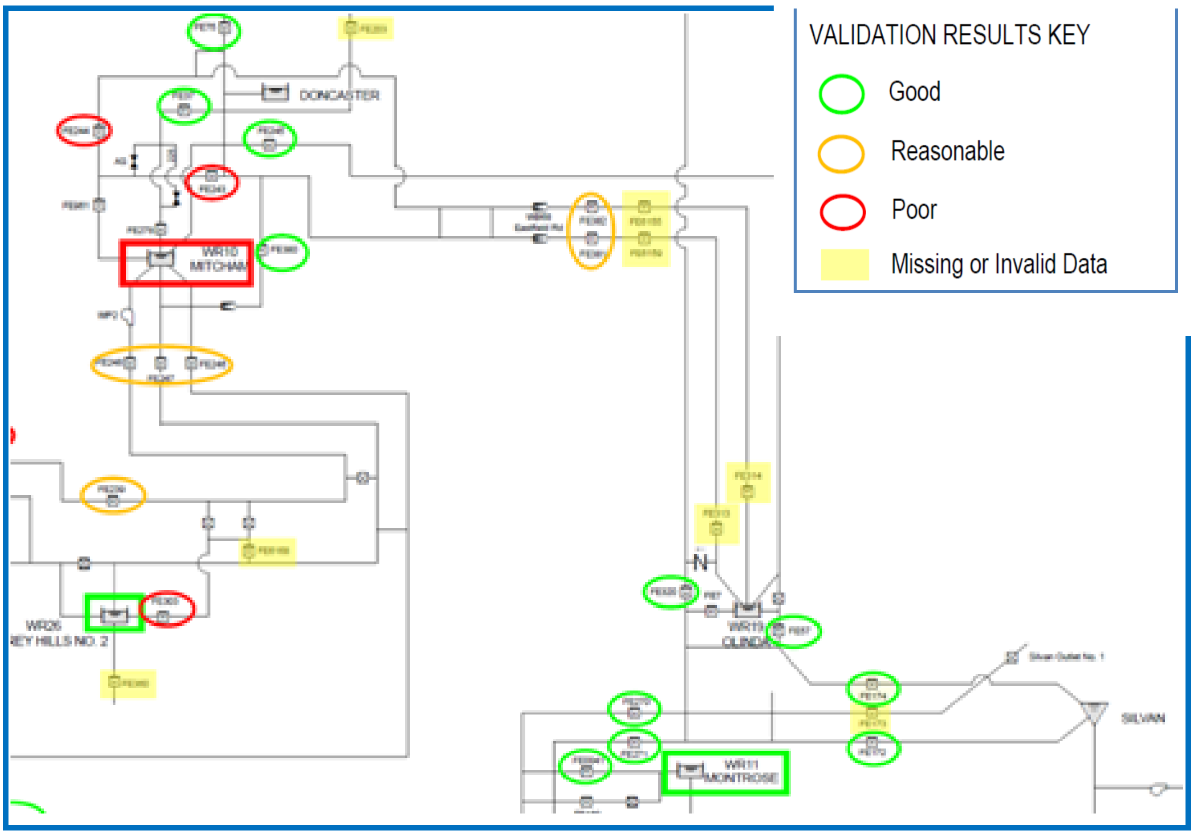
<10%	Model results within 10% of the SCADA values for each timestep
<25%	Model results within 10 – 25% of the SCADA values for each timestep
>25%	At any timestep the model result is greater than 25% different to the SCADA values

These criteria have been developed by Melbourne Water to give an indication of the validation results and to highlight those areas which require further investigation during the field test and calibration stages. Using this approach the maximum difference between the SCADA and model result (for any timestep) determines the category for that site location and therefore the pattern is not taken into account. A summary of the number of reservoir depth, flow meter and pressure gauge locations using the categorisation described above is provided below.

Parameter	< 10%	< 25%	>25%	Total
Flow	54	13	43	110
Reservoir water depth	20	5	1	26
Pressure	41	10	1	52

At the flow monitoring sites where SCADA data was available for the validation date, approximately 40% of the sites are considered not well correlated (> 25%) based on the criteria specified. It should also be noted that included within the 54 sites with good flow correlation (<10%), there are 7 sites where the flow was fixed to match the telemetry data and 22 sites where a demand was applied immediately downstream of the flow meter equal to the flow meter data.

It should be noted that the tolerances for calibration would likely be stricter than the categories above, particularly for the reservoir depth and pressure gauge sites.



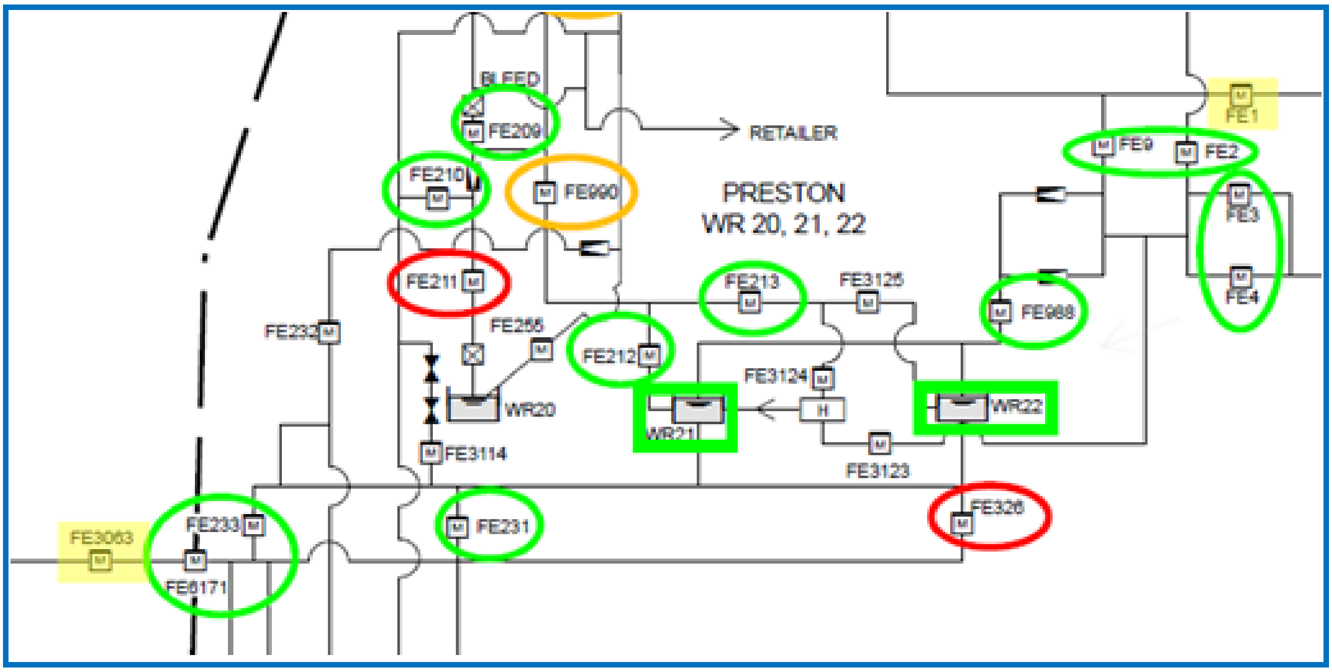


Figure 10 Validation results

10 ANOMALIES

Areas where it was not possible to achieve a good or fair match were defined as anomalies. These anomalies have been discussed and generally confirmed with Melbourne Water Operations staff as known areas of uncertainty in the system operation. The anomalies were documented and displayed on the schematic to provide a further layer of understanding. A detail of this is shown in Figure 11. The anomalies form an important input into the field testing planning, as particular attention will be paid to the anomalous areas to improve the understanding at these locations.

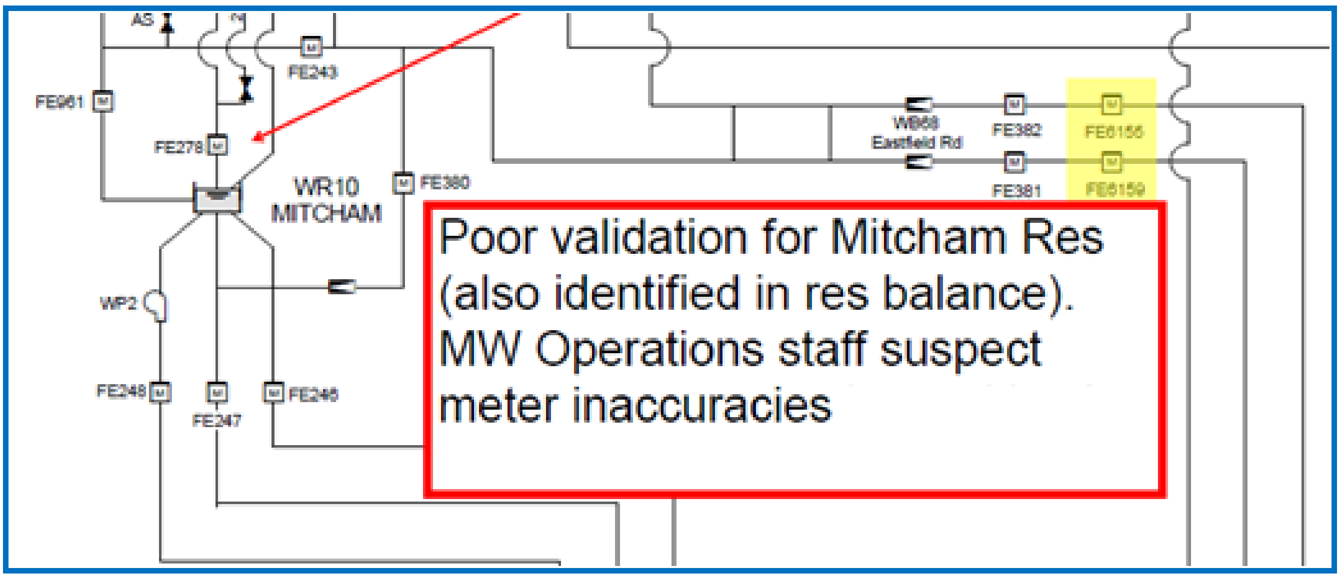


Figure 11 Validation anomaly and comment

11 FIELD TESTING

11.1 FIELD TEST PLANNING

This section describes the proposed plan to gather the calibration data. The water network is significant, with over 1000 km of pipe up to 2m in diameter, and potentially over 1000 monitoring locations. To make the field test and calibration a manageable exercise, a staged sequential field test was proposed – using the understanding of the system and its anomalies gained from the validation to target the monitoring. The stages of the field testing are shown in Table 2.

The network was split into 5 areas, each to be separately monitored for 2 weeks. 1 week has been allowed for establishment and disestablishment of the monitoring equipment which gives a total monitoring period of 16 weeks over the summer period. It is planned for 2013/2014. A number of loggers would remain at key points in the network for the entire logging period to provide continuity and boundary conditions between each area.

The field test will be a significant undertaking. A One Team approach of Operations staff, Planners/Modellers, Consultants, Logging Contractors and Retailers will be adopted to enable the sense of a shared goal, and to ensure buy in and responsibility from all parties in the field test. It will be advantageous if the system is operated in as "normal" a manner as possible over the logging period to minimise the impact of unusual operation on the calibration data gathered. This includes minimising the shut downs and planned maintenance over the logging period.

Table 2 Stages of the Field Test

Stage	Description	Phase
1	Develop initial FTP	Planning
2	Address unmetered off takes	
3	Investigate and where possible resolve anomalies	
4	Finalise field test	
5	Undertake enabling works	
6	Monitor system – over a summer (peak) demand period	Execution
7	Audit and prepare monitoring data for calibration	Finalisation

The validation highlighted a number of anomalous areas of the system – where the operation and flows are unclear, unknown or contradictory to the best understanding of the system. It is proposed that these anomalies are investigated and resolved prior to the field testing to improve the consistency of the data gathered. This is an important step in the calibration process. It will reduce the risk of completing the field test and not being able to calibrate the model, due to contradictions in the data gathered brought about by the anomalies. It will also give the immediate gain of increased system understanding.

The monitoring locations will be confirmed taking into account site conditions and the required enabling works finalised. These will primarily consist of the installation of flow meters and pressure tapping points. The monitoring will take place over a peak demand period. This will capture the operation of the system while it is delivering the maximum annual flows. The data will be checked and audited during and immediately following the monitoring period to assure consistency and that the best data has been obtained.

11.2 DATA GATHERING USING SCADA AND LOGGING

Data will be gathered using the extensive SCADA system, augmented with logging at selected sites. The data validity of key SCADA sites will need to be confirmed prior to data gathering to ensure scaling factors, reduced levels and signal transmission is of a standard appropriate for model calibration. This standard is often higher than that required to operate the network. Data from new monitoring locations will be obtained by logging at these sites. The latest generation of loggers are GSM enabled for remote read back of data which will be considered on a site by site basis to simplify the field testing process. Where cell signal is not available the data will be logged and manually downloaded.

11.3 FIELD TEST PLAN DEVELOPMENT

This section outlines the development of the field test plan. The steps undertaken in this process are as follows:

- Identification of existing monitoring sites
- Identification of unmetered off takes
- Identification of new monitoring sites
- Split the network into manageable sized areas to reduce the data gathering risk

Existing Monitoring Sites

The first step in developing a field test plan was the identification of all existing monitoring sites in the network. This was undertaken using the schematic developed in Stage 1 of the study (model validation), detailed plans of the network and SCADA data and schematics. These were discussed with Operations staff to confirm the understanding of the system.

To break the system down into manageable areas the 48 trunk line numbers used for the Stage 1 model validation (and previous studies) were adopted and each of these lines assessed individually. Once the lines were completed, reservoir and other asset sites (such as pressure reducing stations, valve complexes and pump stations) were assessed to pick up any additional existing monitoring points in the network.

This assessment identified 270 flow and 198 pressure monitoring points that exist in the network. It should be noted that the status of each of these sites was not investigated as part of this study. Each of these sites should be reviewed to verify that the monitors listed do actually exist and have not been removed or modified. The current status of each of these meters will be verified as part of the enabling works for the field test. This is an important step, as the model validation highlighted a number of sites which were not in operation in 2006. The list of existing monitoring points developed in this study will be compared with the SCADA system as there may be additional meters which have not been identified in this study that would be suitable for monitoring.

The water depth at each reservoir complex is currently monitored. The total number of depth monitors proposed is 56, which is based on monitoring all the reservoirs in the network. This number may reduce if a reservoir is confirmed to be out of service during the field test.

Unmetered off takes

There are a large number of Retailer off takes supplied by the Melbourne Water network that are not metered. The flows through these are derived by a flow balance using the surrounding meters. The total number of these off takes is estimated to be 537 from examination of the detailed network plans. These off takes range in size from approximately 150mm to 900mm diameter. The large number of off takes (and large diameter of some of the off takes) will have a significant impact on the flows in the network, the demand distribution and subsequent calibration results.

It is understood that a number of off takes may be metered by the Retailers or closed. The Retailers will be approached and the status of any meters on these off takes established. Ideally each of the open off takes would be metered during the field tests, and if this is not feasible than at least the larger diameter off takes (over 600mm say), and ones with significant flow should be metered. Having this information available during calibration will greatly enhance the demand distribution in the model which will improve the confidence and uses of the model. Any meter accuracies associated with these off takes will need to be taken into account.

Proposed Additional Monitoring Sites

Additional (new) flow monitors have been specified at locations on the bulk water system to provide information on the transfer of the flow around the network. A total of only 9 new flow monitor locations are proposed which indicates that the existing (270) flow monitoring sites provide good coverage of the network.

A total of 109 new pressure monitor locations are proposed within the bulk water system. These have generally been proposed to measure the pressure at least every 5km along a main, and where it is considered there may be significant changes in the pipe hydraulics (i.e. at (T) intersection points, changes in diameter along a trunk main and at the location of large diameter retailer off takes). For each of these proposed sites a description has been given for the location but the exact location of these monitors has not been determined. This will be confirmed during Stage 4 , the finalisation of the field test. The detailed network plans show a large number of air valves in the system which could be utilised for pressure monitoring. As these are also generally located at high points in the network they can be critical points to measure.

Pressure monitors have been specified (either existing or proposed) upstream of inlet valves into reservoirs. However, pressure loggers have not been specified on the downstream side of the inlet valve or at some reservoir inlets where there are no inlet valve complexes as it has been assumed that there is minimal restriction on the inlets and that the reservoir depth will represent the hydraulic grade line at this point. It is suggested this is verified onsite.

Similarly, new pressure monitors have not been specified upstream and downstream of each flow meter for the purposes of identifying head losses across the meter, as this would result in a significant number of additional pressure logging sites (potentially two per flow meter). Additional pressure loggers could be specified either side of older (i.e. orifice) meters or those meters which are suspected of having accuracy issues.

Proposed and existing monitoring sites are shown on the schematic shown in Figure 12.

Split of the network to reduce the data gathering risk

Once the identification of both existing and proposed monitoring sites was complete, it became apparent that due to the large number of monitoring sites and the size of the system that the best approach for field testing would be to split the system into manageable sized areas. This allows the enabling works to be staged (by area), limits the number of loggers and simplifies the calibration process. An additional benefit is that any issues that arise during the field monitoring are limited to one area and won't affect the entire model calibration, thus reducing the risk.

The field monitoring plan for the entire network has therefore been separated into five areas (A, B, C, D and E) which each can be field tested separately. The area boundaries have been chosen to ensure a similar area and number of monitoring sites within each area. A number of key logging points will be in place for the entire logging period. The will provide continuity and boundary conditions between the areas. The cost of renting these loggers would cover their purchase, which could be considered by Melbourne Water.

If these continuity loggers are purchased in advance of the field test they could be used for anomaly resolution then deployed into their locations for the field test. This would help gain a better understanding of the system operation and performance prior to the field test, improve the confidence in the model and inform the finalisation of the field test plan.

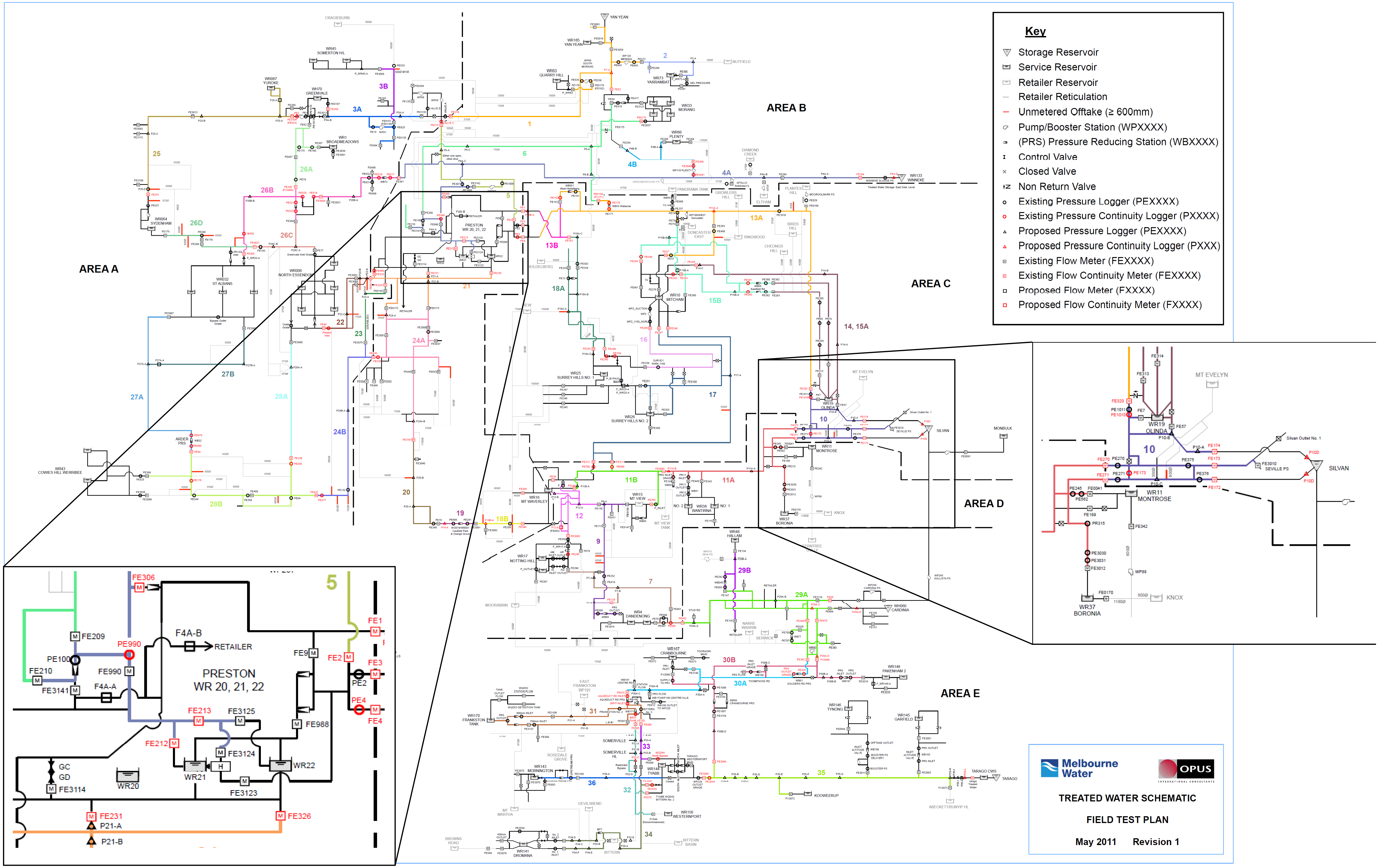


Figure 12 Field test plan with blow up of details

11.4 FIELD TEST IMPLEMENTATION

Participants

The field testing will involve the following participants:-

- Melbourne Water Planning – responsible for the planning, overall coordination and execution of the field test
- Melbourne Water Operations – to provide guidance in the planning, support and assistance for the field equipment deployment and network operation during the test
- Melbourne Water Mechanical and Electrical – to provide assistance with accessing the SCADA system and planning monitoring sites
- Consultants – to plan, coordinate and manage the field test and audit the gathered data
- Field Monitoring Contractor – responsible for the supply, installation and removal of the logging equipment and delivery of the monitoring data
- Retailer companies – to provide access to the unmetered off takes – for flow monitoring purposes.

A One Team approach will be adopted to involve all participants throughout the field test in the planning, execution and disestablishment phases. Regular, open and honest communication and a shared goal will ensure any issues are promptly identified and resolved to the satisfaction of all participants.

Enabling works

The enabling works required will depend on the investigation of the sites and the precise location selected. These will be defined during the finalisation of the FTP.

Pressure monitoring is relatively straightforward – requiring a tapping point into the network. This can often be an existing valved offtake, an air valve or other such fitting. It is not envisaged that significant enabling works will be required for the pressure sites.

Reservoir water level monitoring can be achieved by using a probe lowered into the tank or by monitoring the pressure at the outlet pipe with a suitably sensitive pressure monitor. Both methods require minimal enabling works.

Flow monitoring at existing flow meter sites is also relatively straightforward, however monitoring at new sites requires the installation of either a temporary or permanent flow meter. The installation duration (temporary or permanent), flow meter type (eg insertion electromagnetic probe, insertion ultrasonic probe, permanent electromagnetic meter, strap on ultrasonic etc), site access, pipe material and size, location hydraulics and cost must all be considered to finalise the flow meter location. At this stage, flow meter installation sites have been identified and a budget cost developed assuming permanent installation. These will be refined during the FTP finalisation stage (Stage 4 of Table 2).

Equipment accuracy, selection and procurement

The accuracy required for the monitoring and measurements for the field testing is shown in Table 3

Table 3 Monitoring accuracy

Parameter	Accuracy	Notes
Flow	5% to 10%	Expected overall site accuracy.
Pressure	0.1% of full scale reading	eg if the full scale reading is 160m then accuracy is 160 mm. SCADA accuracy expected to be 0.5%. Logging may be required at specific key SCADA sites.
Reservoir Depth	10mm	High accuracy required to capture volume changes in the reservoir
Level survey	+/- 25 mm	At pressure sites to convert pressure to hydraulic grade line

Flowmeter accuracy as quoted by manufacturers is typically 2% to 5%, however this is in a laboratory bench test. The accuracy in the field depends heavily on site conditions and hydraulics, and Table 3 shows a realistic accuracy to expect from field measurement of flows. Pressure accuracy depends on the full scale reading of the pressure transducer. Pressure loggers are generally selected to maximise the accuracy by choosing a logger with the smallest full scale reading that is capable of withstanding the maximum pressures expected at the site. Reservoir level loggers (which are essentially pressure loggers) need to have a very small full scale reading to provide the fine resolution needed to capture the change in reservoir water level, as 10 mm of water level change can represent a significant volume/flow. The level survey is a standard appropriate for calibration of water supply models.

The majority of the equipment for field testing will be provided and owned by the Monitoring Contractor. However an opportunity exists for Melbourne Water to purchase some pressure/flow loggers as the rental costs for the continuity loggers (which will be deployed for 16 weeks) may cover the purchase of these units. This would provide future logging capability within the organization. As these loggers will be GSM capable they would have enhanced usefulness as remote monitoring is very cost effective in the large area served by Melbourne Water. The loggers can be purchased in advance of the field test and deployed in the anomaly resolution stage and to capture long term data at key sites.

11.5 SUMMARY CONCLUSIONS

The model validation process involved a thorough investigation and audit of the bulk water system to develop an understanding of its components, layout and operation. This process has been captured in the documentation of the project, especially the schematic of the network, and transferred into the model.

The information has been checked for consistency, specifically in the trunk main and reservoir balances. Indeed, the whole validation process can be viewed as an audit. This has highlighted areas where there are gaps in the data - due to dubious or missing; flow meter data, reservoir water level or dimensional data, system operational data or demand data. These areas have been identified to enable their resolution or capture during the calibration.

The demand points in the system are generally metered. There are a number of mostly small off takes that are not measured. Some larger (over 450 mm diameter) unmetered off takes also exist. The demand through these connections was inferred from the surrounding flow meters, which is satisfactory for billing. However, this results in an assumed flow distribution in parts of the model, which can affect the model predictive ability.

The trunk main and reservoir balances indicated areas where leakage may be present, either from the reticulation (Melbourne Water or Retailer) or from a reservoir. Reservoir drop tests were recommended at sites where leakage is suspected, to confirm the reservoirs' performance.

A generally successful validation was achieved within the limits of the data available. This provided a good platform to understand the system operation and model representation of the network. From the data gaps and understanding gaps identified (ie anomalies), a targeted field test plan has been developed which will lead to the calibration of the model.

The preliminary field test plan. is the first stage in a seven stage programme to complete the field test, subsequent stages include addressing unmetered off takes, anomaly resolution, field test plan finalisation, enabling works, the actual field test and data checking.

The sites already monitored form the starting point for the field test plan. From this study 263 flow, 195 pressure and 56 reservoir depth monitor sites have been identified as currently being monitored in the entire Melbourne Water network. To improve the understanding of the network and subsequent calibration of the model an additional 9 flow monitors and 113 pressure monitors have been proposed. A suggested location has been given for these monitors, and the exact logging point will be determined following site investigation.

A significant number of Retailer off takes that are not monitored by Melbourne Water have been identified during this study (estimated at 537). Further investigation is required to confirm the number, location, status (open or closed) and size of each of the off takes, and whether they are metered/monitored by the Retailers. For the model calibration ideally all of these off takes would be monitored during the field test as this would provide the most complete picture of the network flows and provide important information on the demand distribution within the network. However, given the significant number of these off takes monitoring all of them may not be practical. It is important that at least the large diameter off takes are monitored.

The operation of the network needs to be considered in conjunction with the field monitoring locations. The operation of key assets, including sources, reservoirs and control sites (e.g. pressure reducing stations, valve complexes, pump stations) also needs to be confirmed to ensure that the monitors proposed are in the most appropriate locations. It is important that the operation of the network on the field test dates is as close to the typical operation as possible to ensure the calibrated model represents a typical day for the network.

The anomalies identified during the model validation should be taken into account when undertaking the enabling works for the field monitor plan. Further investigation at the locations of the anomalies prior to the field testing will deepen the understanding of the issues and data gaps. This would improve the model immediately and reduce the risk that the anomalies remain after the calibration. Flow meter calibration may be required at some locations to improve the accuracy of the results.

The field test plan has balanced the need to gather sufficient data to perform a reliable calibration of a complex and large trunk network system of this nature against the cost of data gathering. Some redundancy has been built in to allow for the inevitable logging failures. The data gathered will allow all pipes to be assessed for roughness and all sites (reservoir's, pumps and PRV's etc) to be calibrated for pressures, flow rates and depth changes.

12 FUTURE STEPS

The validation and field test plan are the first steps to implement the Model Improvement Strategy for Melbourne Water. The completion of these two tasks has materially increased the knowledge of the system, its representation in the model and knowledge of anomalies/areas of uncertainty. The project process (Figure 1) shows three tasks. The third task includes anomaly resolution, field testing and calibration. The work to date has provided a solid platform to complete these tasks, which will see the evolution of the model for planning and operational use for the entire Melbourne Water organization.

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REFERENCES

Melbourne Water Request For Proposal -*Water Network Improvement Project. Validation of the water hydraulic model and preparation of a field monitoring plan*. 1 September 2010.

Water Network Model Improvement Project. *Model Validation.* Report prepared for Melbourne Water by Opus International Consultants. Reference 3AW733.00. May 2011

Water Network Model Improvement Project. *Field Test Plan*. Report prepared for Melbourne Water by Opus International Consultants. Reference 3AW733.00. May 2011