EYES WIDE OPEN - MANAGING THE RESOLUTION OF FIELD ANOMALIES DURING CALIBRATION OF WATER SUPPLY MODELS

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ABSTRACT

In 2009 Metrowater accelerated its programme of Model Update and Master Planning for its water supply network. Previous master plans were up to 12 years old and considerable changes had occurred that required the development of new tools, strategies and solutions. Metrowater had completed a number of studies in prior years, but has recently updated five models (out of a possible 11 models) that will be used to assess network performance & develop solutions for meeting growth and level of service standards.

This paper examines the issues involved in achieving a robust calibration of the hydraulic models to be used for master planning. Despite a comprehensive field test plan being executed prior to calibration of three zone models, significant anomalies were identified, that required further investigation to meet the model calibration criteria set by Metrowater.

This demonstrates Metrowater's and the consultants approach and commitment to calibration, an eyes wide open approach that actively seeks to uncover and resolve anomalies. With a full complement of pressure and flow loggers in the initial calibration, it was possible to be confident of the model calibration parameters (pipe connectivity, diameter, minor losses and friction etc). The model parameters can be altered to match the calibration data, however this may require parameters outside the range of industry standards. In these cases the calibration data is indicating areas where the system is not behaving as it should, i.e. as an open water reticulation. The calibration effort then switched from tuning the model to further system investigations, as it was clear there were anomalies in the system.

These anomalies are typically part or fully closed valves or system restrictions (poor condition pipe). This paper will detail the system investigation process and show the findings of this investigation. Narrowing down the cause of the anomaly required in some cases system reconfiguration to isolate parts of the network and a systematic approach to obtain useable results. In some cases the anomaly was not resolved, but in most situations it was. This "eyes wide open" approach required a considerable investment of time and money to ensure that the final model was fit for the purpose of providing operational and planning outputs.

Ultimately the master plan projects have benefitted from the extra scrutiny with 14% lower cost solutions being developed. A register of outstanding issues has been created to ensure the field anomalies are flagged & prioritised for removal once they impact on

customer service. The resulting solution set will ensure that Metrowater and its successor will continue to provide quality water services into the future.

KEYWORDS

Hydraulic Modelling, Anomaly, Master Plan, Calibration, Water Supply

1 INTRODUCTION

In 2009 Metrowater accelerated its programme of Model Update and Master Planning for its water supply network. Previous master plans were up to 12 years old and considerable changes had occurred that required the development of new tools, strategies and solutions. Metrowater had completed a number of studies in prior years, but has recently updated five models (out of a possible 11 models) that will be used to assess network performance & develop solutions for meeting growth and level of service standards.

Metrowater identified that an integrated approach to network planning was required to avoid conflicts that arise when undertaking single driver projects. Such studies may compromise other service standards, such as pressure management schemes that create water quality or fire flow issues. Master planning provides a number of benefits, including:

- A clear understanding of the network performance and issues arising
- Solutions to meet growth and levels of service resulting in a forward Capex programme and an optimised operational strategy
- The opportunity to re-baseline the network configuration (especially where development and operational tinkering have lead to “drift” from the ideal state)

Metrowater has developed a robust template for undertaking master planning studies for its water supply network, which covers a range of service standards that must be met. These service standards are expressed in both customer terms (i.e. number & duration of service outages) and modelling terms (calibration criteria) so that there is a clear linkage between the hydraulic performance and the service delivered to the customer.

Whilst the primary tool used in this process is a hydraulic model, other data sources are used to ensure that the model outputs are validated. These data sources include a comprehensive field test regime, compliance monitoring data, SCADA and operator knowledge. Furthermore major events occurring during the field monitoring are noted to explain demand spikes and other anomalies that may affect the field data. Billing data from the customer meters is used to allocate demand at a property level and this is scaled up for the future model scenarios. The flow balance is checked against the SCADA records from bulk (zone) meters operated by Watercare.

Model calibration and validation using the data sources listed above will reveal areas where the system is not functioning as designed, these are anomalies. Identifying and resolving anomalies requires a systematic approach, imagination, persistence and a degree of luck. This process is described below, along with a discussion of the benefits and value of anomaly resolution.

2 WHAT IS ANOMALY RESOLUTION?

2.1 ANOMALIES – WHAT ARE THEY?

Anomalies occur in both the water network and in the model representation of the network. Water network anomalies are where the system does not function as it has been designed. This can be due to;

- Improper system operation e.g. part/fully closed valves, pipe breaks/caps
- Incorrect pipe connectivity or pipe diameter-due to a lack of system knowledge
- The set up of valves, pumps and control devices in the field is not as intended by the designer
- System deterioration (corrosion/tuberculation of pipes)
- Incremental operational tweaks that allow the system to drift from its ideal state
- Ad hoc development that does not follow a strategy (in Auckland's case this is predominantly in fill housing and intensification)
- Incomplete project work

Anomalies in a model are where the model does not faithfully represent the system, within the limits of the calibration criteria. These limits are a key part of defining whether a model has anomalies or not. It is through the calibration process that anomalies in both the model and system are identified. By iterating the calibration process the understanding of the system increases, the model representation improves and anomalies are eliminated. Through this process the model is configured to represent the system, and the anomalies that remain point to parts of the network where it is not functioning as designed. The remaining anomalies then require further data gathering, field investigation and analysis to resolve. Some never get resolved, and remain as a part of the model/network where the system is not behaving as expected (as an open network). However, having knowledge of this allows more informed, prudent operation and planning of the network.

2.2 WHY ARE ANOMALIES IMPORTANT?

The anomalies identified may ultimately have an effect on the service provided to customers. In the case of the Metrowater Zone Master Plans, the first step was to identify whether the anomalies were significant. Using the model the system performance with and without the anomaly was compared. If they had an impact on service it was important to understand how severely and whether the service level was one that Metrowater could tolerate or posed an unacceptable risk. As an example if the anomaly related to fire flows this was deemed very important and required a solution; however if the anomaly presented a security of supply issue, Metrowater determined a threshold of 100 customers affected as a measure of whether an intervention was justified.

As engineers, we like to feel like we understand a system, and can predict its behaviour. Anomalies are where we cannot do this and it is tempting to spend a lot of time trying to resolve them or to ignore them altogether. There is a balance between these two approaches that must be struck and with the need to better manage our assets there is an increasing need to resolve anomalies so we can better design and operate the network.

A "properly" calibrated model will predict real world behaviour to an accuracy appropriate for model use. Calibration levels do depend on the intended model use but it is generally impractical to have a different model for each intended use. Today's computational power means we generally now build one all-mains model with the expectation it will be suitable for multiple purposes (planning, operational predictions, water quality, fireflow, security of supply etc). This model must be calibrated to perform the most exacting task required. Therefore in general practical terms calibration standards are more stringent and so anomaly resolution has become more important.

2.3 WHAT SHOULD WE DO ABOUT THEM?

In the Metrowater master plan analysis it was decided that it was not enough to assume that the anomalies would be resolved in time. Metrowater wanted to know when they would impact on service levels and would use this as the threshold for intervention. Metrowater requires the current and future (50 year) scenarios to be modelled. Interim scenarios at 5, 10 & 20 year horizons were developed and system performance with, and without the anomalies was established. This defined when an anomaly would cause an issue and provided Metrowater with a staged approach to resolving the anomalies. The future capital programme could then be justified by its impact on customer service.

3 WHEN SHOULD ANOMALY RESOLUTION BE UNDERTAKEN?

There are no hard and fast rules to say when anomaly resolution should be undertaken- just the need to balance the available time and resources with efficient operation and a clear understanding of the system. Engineering judgment must be used, considering the following factors:

- The impact of the anomaly – both in current operation and future predicted performance – with problems arising in the future being of diminishing importance .

- The history of the anomaly – has this problem been known about from past work, or is it new. Is it common through the system or an isolated case?

- The likely cost of finding/resolving it

- How well the anomaly is understood – the confidence in the likely type and location of the anomaly

Often anomalies can exist in a system that under normal demands performs perfectly well, but under high demands (from say fireflows) or during maintenance the performance is inadequate. This shows the insidious nature of anomalies. The looped and redundant nature of water networks allows them to remain undetected until an emergency and then it is too late to try and resolve them. On this basis it is believed that every opportunity should be taken to at least identify anomalous areas, and best practice would have them resolved as they become apparent to realize the full capacity of the network.

4 HOW WERE THE ANOMALIES IDENTIFIED?

Anomaly identification is a process of building up knowledge and familiarity with the network and using this to identify areas where it is not behaving as expected. The process of anomaly identification starts even before a model is built. Discussions with the system operators can often reveal anomalies. These can be places where there is a gap in operator knowledge or where things do not work as they should.

Model building can reveal anomalies with the system, such as inconsistent pipe diameters along a length of pipe or discontinuities in the network. This may be due to incorrect base data used for the model build. These topologic anomalies may be identified using the automated checking routines available in the current modelling packages or through careful examination of network plans. Considered colour coding of the plans can make anomalies easier to spot.

Model calibration is commonly the main means of anomaly identification. Through the model build and field test design process a number of more obvious anomalies may be identified. (Field test design can involve looking at available system pressures and flows from SCADA or other sources. This can reveal anomalies). The deployment of flow and pressure loggers and recording of manual system operation associated with a field test is a unique opportunity to examine the system. It is generally the only time that such a complete and detailed picture of the system operation may be obtained.

Gathering enough data during calibration is vital for anomaly resolution. This data includes:

- All key locations (Source flows and pressures, reservoir depths, control valve and pump up and downstream pressures and flows if possible)
- A sufficient density of general loggers in the reticulation (a common recommended density is one logger per 250-350 properties)
- All manual operator actions (pump starts, valve operations etc) and any unusual operations during the test (a pipe burst or fire etc)
- Large consumer flows (a laundry, rest home or other large institutions, other wet industry such as meat works etc)

After this data has been checked for consistency and correctness it is combined with the best spatial demand distribution available for the model build and calibration process. Billing data generally gives the best spatial demand distribution (especially in Auckland where all properties are metered and regularly read), however population data or number of lots, or even area can be used to represent the varying demand across the network. The calibration process is generally improved by concentrating on inputting the most detailed and correct connectivity, diameters and flows and not relying on model “fixes” (e.g. non industry standard friction or minor losses, imposed valve controls etc), as these may mask anomalies.

After undertaking the normal calibration process (e.g. dividing the area into sub-networks if possible at known flow or pressure locations, imposing these boundary conditions, calibrating the sub network downstream and then removing these boundary conditions and calibrating the whole open network) a number of areas that cannot be calibrated will generally remain. These point to areas where the system is not flowing as an open network and indicates the presence of anomalies. Examples of this are described in the following sections.

4.1 METROWATER ZONE MASTER PLAN ANOMALY RESOLUTION

Three Metrowater zones in Auckland city were subject to the model build/calibration process outlined above, as part of the Master Planning for these areas. They cover about one third of the Metrowater supply area and serve a current population of about 100,000 people. As the Master Planning for all three zones was undertaken concurrently using a combined model, the anomaly resolution for all three zones was able to be done simultaneously, which lead to economies of scale.

A total of 35 anomalies were identified in the three zones. Some anomalies covered a relatively small area (say one street), representing a small localized area of uncertainty. Others covered a wider area covering several streets or more. These were due to multiple restrictions/issues and presented more of a challenge in the resolution process.

The list of 35 anomalies was first prioritised to concentrate the resolution effort, in conjunction with the external peer reviewer of the project. Prioritisation was based on the impact of the anomaly on the system flows and pressures, considering the difference between field data and model predictions. Criticality increased the priority, for example if the anomaly was near a bulk meter (source for the reticulation) or a large pipeline feeding a discreet area. The calibrated model (with anomalies still present) allowed a quick performance assessment to be carried out to identify areas that would not meet the required level of service. Anomalies in these areas received greater priority. The 35 anomalies were reduced to 11 areas for further investigation, as shown for one of the zones in Figure 1.

4.2 VALVE STATUS CHECKS

The first and simplest step in anomaly resolution is to check valve status and location. This was carried out using detailed documentation. The field crews were sent out with clear plans of the area and a listing of all valves believed to be in the area. The plans showed pipe layout and size, property boundaries and all valves, hydrants and fittings. The status of each valve as found was recorded, along with the date and time of the visit and the signature of the investigator. Any valves that were not found, or found but not on the plans were noted on the plans for further investigation. This method engendered a thorough and conscientious approach by the field crew, which is vital to understand the system.

The results of the valve checking were fed into the model. In some cases this resolved the anomaly. After checking with Metrowater Operations staff the closed valves were opened, and left in this state for the anomaly field test if further investigation was required.

4.3 USE OF SCADA DATA TO CONFIRM CONNECTIVITY

Interrogation of available SCADA data was repeated to resolve one anomaly immediately downstream of a bulk meter. A bulk meter is where water is transferred from the bulk network into the Metrowater system, and forms a source for the zone. It is shown as Area 4 in Figure 1. The calibration effort indicated that there was a closed cross connection between the twin 200mm diameter mains downstream of the bulk meter, and that the supply was only going into one pipeline. Valve checks did not reveal any closed valves. An additional field test was undertaken in which pressures were recorded in both pipelines and hydrants flowed from each pipeline. Results showed that when the hydrants were flowed the pressure drop was evident in both pipelines, indicating that they were connected.

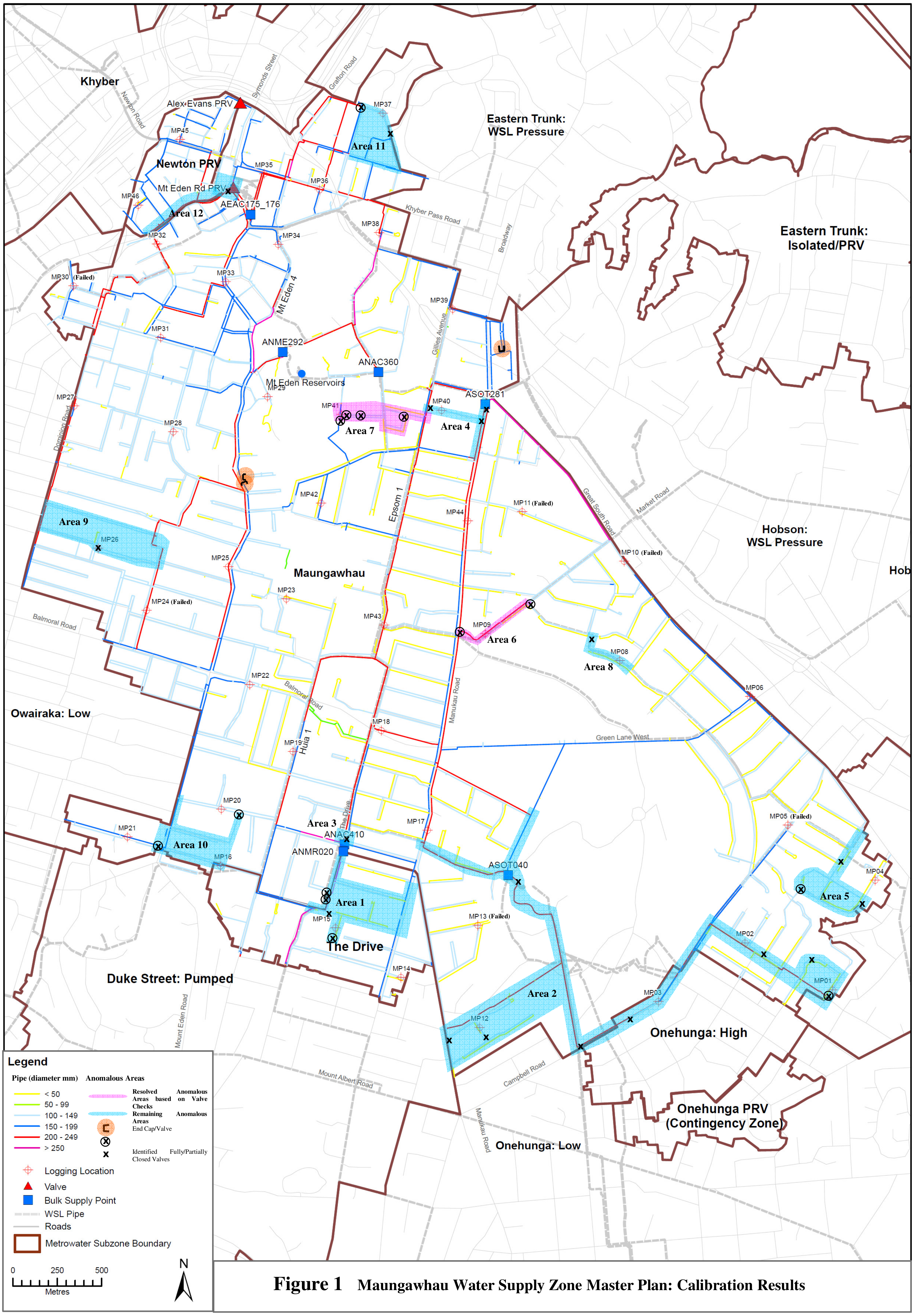

Figure 1 Maungawhau Water Supply Zone Master Plan: Calibration Results

To resolve whether the pipes were connected or not, SCADA bulk meter flow data for a one year period was obtained, as plotted in Figure 2. This shows a flow jump in July 2009, around the period that valve checking was being undertaken. This confirmed that the two pipelines were connected (i.e. that the cross connection was opened), as the increased flow corresponded to model predictions of flow with the valve open.

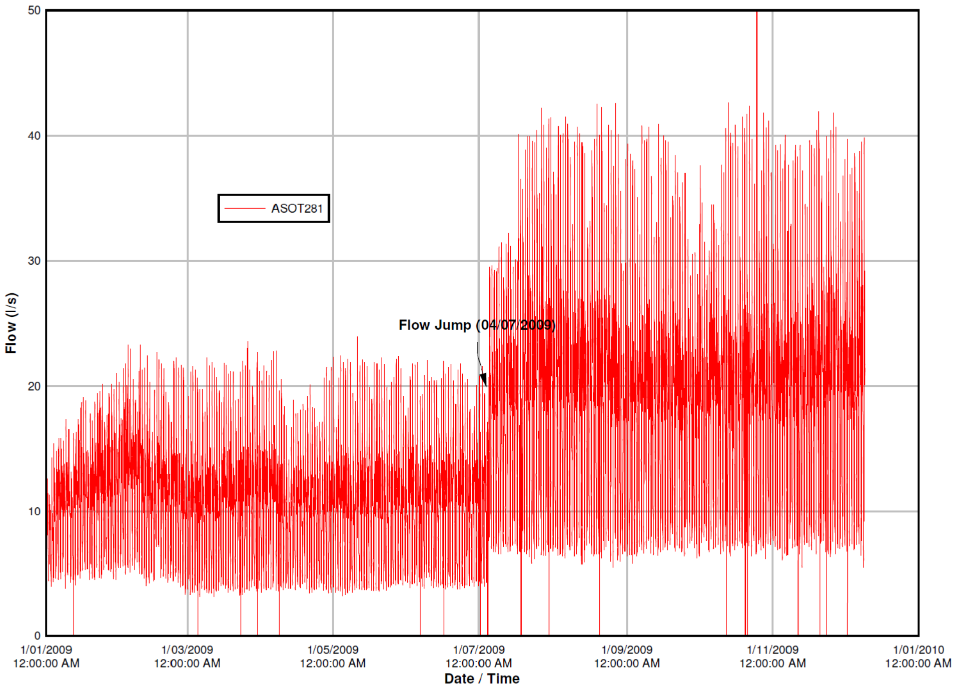

FIGURE 2 – SCADA flow data

4.4 INCREASING LOGGER DENSITY AND USE OF NOISE CORRELATION

One of the areas thought to have an anomaly was subject to intense logging to refine the anomaly location. Immediately downstream of a bulk meter the reticulation splits to supply five pipelines. Each pipeline was logged and the hydraulic grade lines compared. One was significantly lower than the other four (Site MA10 shown in Figure 3), indicating a restriction in this line.

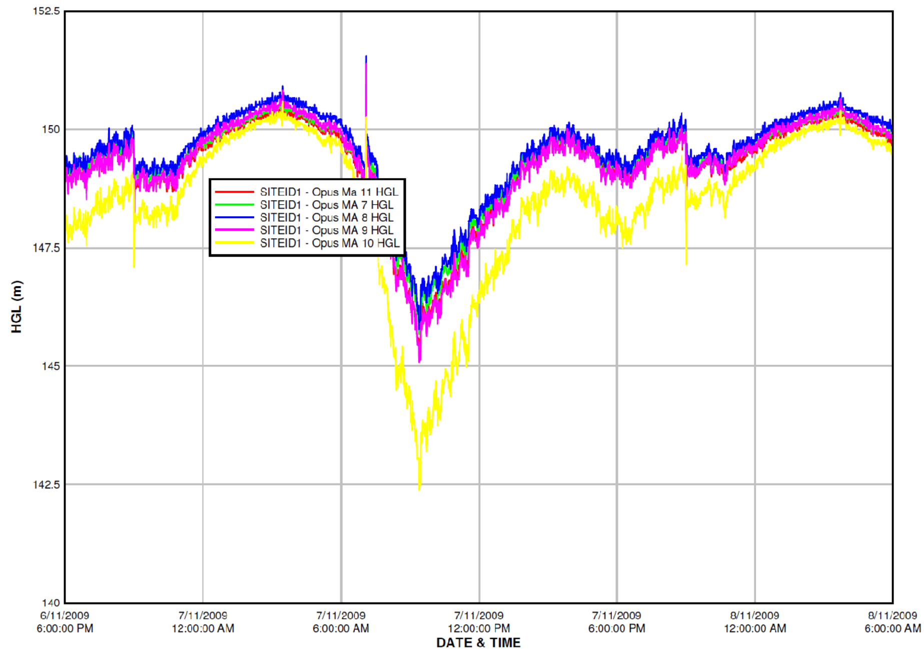

FIGURE 3 – Multiple pressure logger hydraulic grade lines

It was not possible to refine the location of the restriction with the available logging data, however, novel use of leak detection equipment in subsequent testing has done so. This involved flowing a hydrant along this line and using noise correlators to listen for a leak sound. The flow through the restriction caused this sound and the correlators indicated the location. A part closed valve was found at this location, which was partially buried and not on plans.

4.5 INCREASING LOGGER DENSITY AND HYDRANT FLOW TESTS

Hydrant flow testing with a high logger density was the main means of anomaly resolution. Flow and pressure loggers were deployed at strategic locations and fire hydrant flow tests undertaken within the anomaly area to narrow down the anomalous areas. In some cases valves were closed and a hydrant flowed to force water down specific pipe lines.

During the hydrant flow tests, records were made of the flow and time of the test to simulate them in the hydraulic model. Hydrants were flowed adjacent to each logger to increase the flow and headloss in the local area and highlight any restrictions. The logged pressures were converted to hydraulic grade line and plotted on a common graph to check for consistency, an example of which is shown in Figure 4. The plots were examined to see that the pressure drops in loggers adjacent to the flowing hydrant were as expected. If the drop expected was not present at a logger, then a restriction was suspected between that logger and flowing hydrant. Multiple hydrant flows allowed this process to be repeated for an area, building up a picture of likely restriction locations.

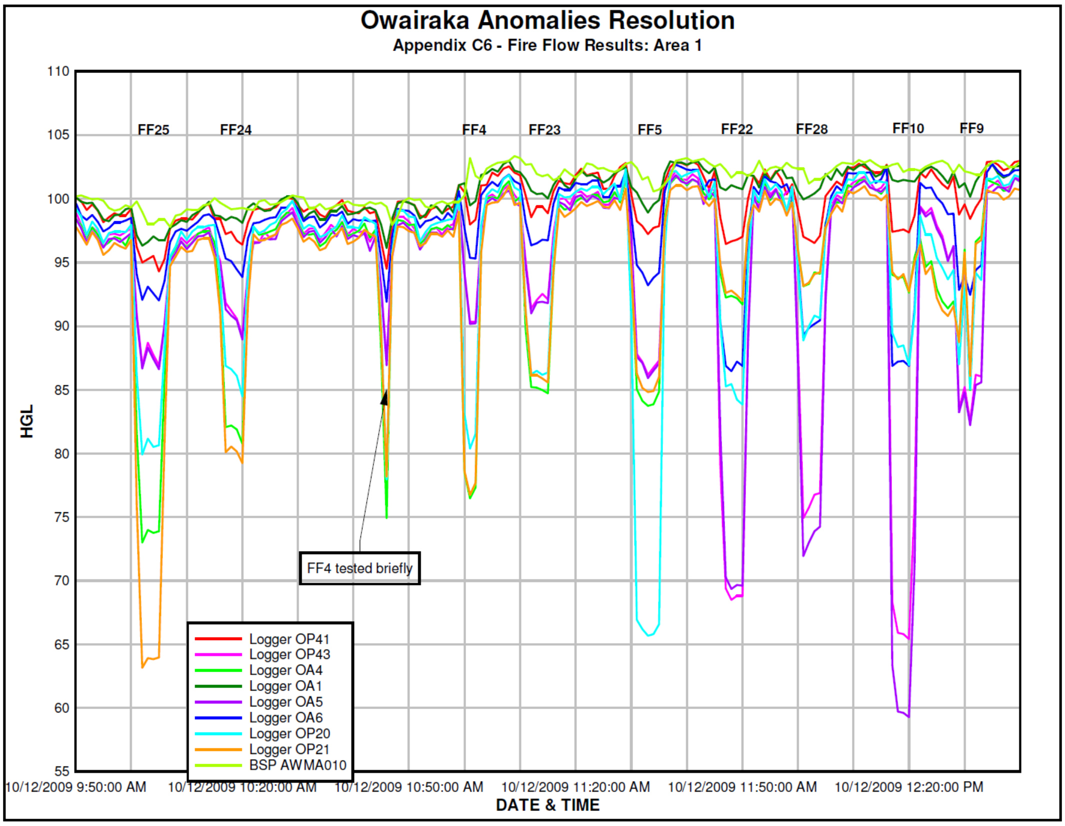

FIGURE 4 Multiple hydrant flow test results

This method was used in areas where multiple restrictions were suspected over a wide area. In many cases it was necessary to model the entire set of hydrant flow tests carried out in an area, as it was not possible to narrow down the restriction location through examination of logger plots alone. In these cases numerous combinations of restrictions would allow the model to match field data, and no obvious set of restrictions was apparent. Figure 5 shows an area suspected to have restrictions from the initial calibration. Following the intense hydrant testing and logging described above the anomaly locations were reduced to the four shaded areas shown in Figure 6.

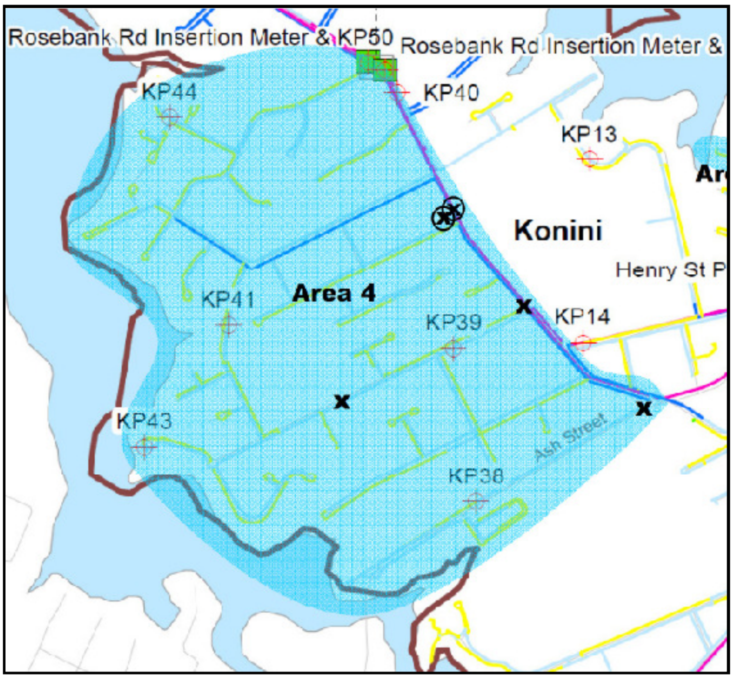

Figure 5 Anomalous area before anomaly resolution

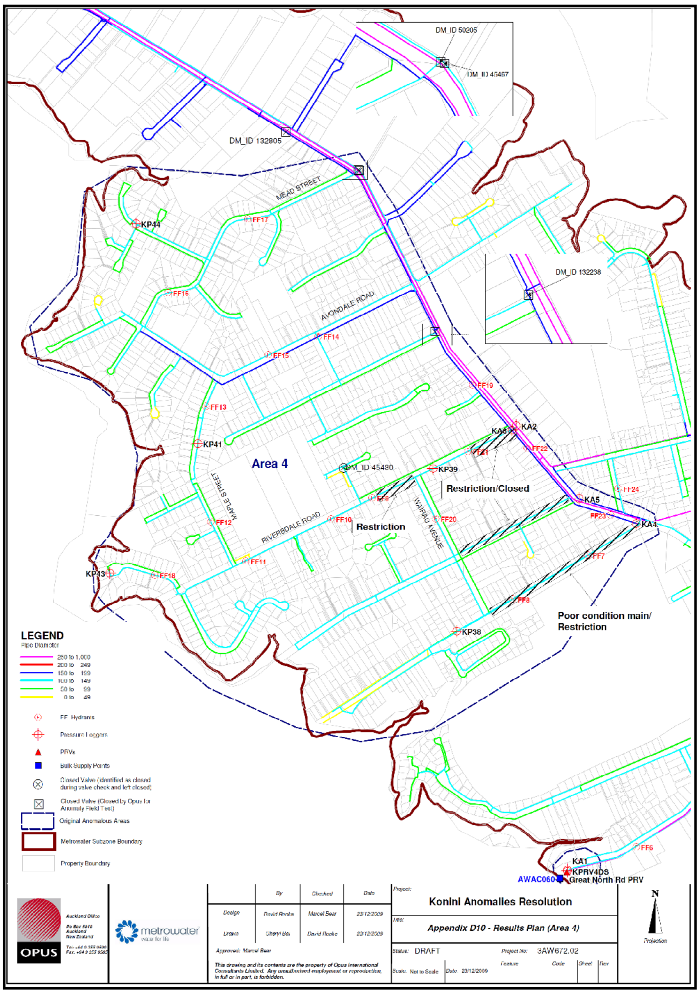

Figure 6 Anomalous areas after anomaly resolution

4.6 SYSTEM RECONFIGURATION AND HYDRANT FLOWING

Persistence is often required to resolve anomalies. During the implementation of a pressure management scheme, fireflows to a school at the extremity of the proposed pressure management area were not being achieved. The field test flows were not sufficient and less than the model predicted flows indicating an anomaly in the network.

The reticulation consisted of two main pipelines supplying the school along parallel separate streets, with a distance of 1.7 km separating the source (a bulk meter) and the school. Over this distance were 7 connecting streets running between the parallel pipelines, like rungs on a ladder. This typical looped reticulation presents a challenge for anomaly identification, as any restriction in the main pipelines can be bypassed through one of the loops. The approach taken was to shut all of the connecting streets and force flow along the two main pipelines by flowing hydrants. This was combined with the deployment of 16 loggers to measure the pressure drops.

The resulting pressure drop logger plots were interpreted as described in the above Section, however no clear anomaly location emerged. A second set of field testing was carried out with increased system reconfiguration (by closing valves) to eliminate an additional loop at the top of the system (the top rung of the ladder). At the end of the day of testing, it was clear that both main lines were completely isolated and an alternative approach was tried that quickly yielded results. Working from the end of the system back to the source, hydrants were flowed and the change in flowrate noted, i.e. the flow available from the main pipeline was checked, from the extremity to the source. A significant jump in flow was found when comparing the flow from one hydrant to the next adjacent hydrant, about two thirds the way down the main pipeline. Excavations showed a cap (break in the line) between these hydrants, which when repaired restored the system to full capacity.

This method therefore consisted of system reconfiguration to eliminate loops from the network and force flow through the main pipelines in the network. Two attempts were made to log pressure drops associated with hydrant flows throughout the area, however a clear indication of where the anomaly was present did not emerge. Once a sufficient number of side loops were eliminated it was possible to simply flow hydrants and note the flow change to find the anomaly, in this case a end cap on the pipe.

5 INTEGRATING ANOMALIES INTO THE PLANNING PROCESS

One issue addressed in the Master Planning process was whether to include the anomalies in the model used for planning, or remove them. Including them may mean overly conservative solutions would be adopted, whereas excluding them may mean the solutions would be inadequate. The approach adopted was to use the model to establish a timetable for anomaly resolution, based on whether an anomaly would cause a level of service failure. Having models for the current, 5, 10, 20 and 50 year horizon allowed a staged examination of the effect of the anomalies. The process was as follows:

- Start with the best available estimate of where the anomalies are. Input this into all model horizons.
- Establish whether an anomaly would cause a level of service failure (i.e. pressure or fireflow inadequacy) by modeling the system with and without the anomaly.

- Start at the future most (50 year) horizon. If the anomaly would not cause an issue then, it would not cause an issue earlier as the demands would be less.
- Work through each anomaly considering progressively earlier horizons and establish a timetable to remove them.

This approach also identified anomalies that would not cause a level of service failure at any time in the planning period. These were classed as low priority in the anomaly resolution process. The advantage of this approach is that it focuses the anomaly resolution process and establishes the relative impact of each anomaly. It also optimizes any solutions developed to be driven by the performance of the system in its ideal state, i.e. not encumbered by the effects of anomalies.

The solutions will be reliant on the anomalies being removed to the timetable established, so anomaly removal has become part of the set of solutions proposed in the Master Plan. This effectively brings the anomalies into the planning process.

6 WHAT BENEFITS DID ANOMALY RESOLUTION BRING?

The benefits of the improved system knowledge that anomaly resolution brings touch the operational, planning and management functions of water supply.

The identification and resolution of discontinuities, restrictions and other anomalies immediately improves the operation of the network. Flows are increased, fireflows improved, circulation improves, water quality improves and the system functions as intended. Operations staff find it easier to do their job in the field as there is less chance of shutting off supply. Customers experience improved service.

Greater certainty in planning proposals is achieved. The solutions proposed are based on actual system performance and include interventions to remove anomalies and shift the network to its ideal state. These interventions are based on customer levels of service indicators, and there is better understanding of the need for these interventions.

The level of expenditure planned is optimized. An estimate was made of the additional expenditure that would be required had the planning taken place with the identified anomalies left in place, for the three zones included in the Metrowater Master Plans. The total capital and operational expenditure proposed in these zones for the next 50 years is some $7M. Had the study been undertaken with the anomalies present the expenditure would increase by about $1M, an increase of 14%.

The rigorous auditing and investigation of the system has improved the knowledge of the network. This improves the data held in the corporate GIS system and in the models. It also improves the operational strategies that can be put in place, such as improving the ability to reduce system pressures and leakage, and optimizing pump and pressure reducing valve settings.

The anomaly resolution process has involved people from planning and operations within Metrowater, engineering consultants and maintenance contractors. The chance to all work together on a common project has improved communications between these groups and the understanding of each other’s roles in providing water supply.

7 HOW MUCH DID IT COST?

The anomaly investigation process including planning, management and field work cost approximately $100k. A total of 35 anomalies were considered and 11 taken forward for field investigations. This gives a range of per anomaly cost of $3k to $9k. A further $100k is budgeted to remove these and other known anomalies in the Metrowater network.

These costs can be balanced against the estimated capital and operational savings from anomaly resolution, $500k. The value in doing this work is apparent.

8 WHERE TO FROM HERE?

The anomaly resolution work has left Metrowater in a strong position to manage its water network with confidence, from a position of knowledge and awareness of what is going in its network. Field investigations and resolution of anomalies are continuing based on a prioritised list, using the same field crew for continuity.

The models have been updated with the results of the field investigations to maintain currency and relevance for further work. They will be handed over to Watercare when the Territorial Local Authorities are merged into the Auckland Council later this year. The Master Planning process has been comprehensively documented and the projects identified have been used to populate the Watercare Regional AMP.

A number of lessons have emerged in the process, including;

- Interventions to resolve anomalies may be required now or in the future or not at all. The process developed has enabled the necessity to be established.
- The impact of not intervening is understood
- The value of data auditing and preparation in model building and robust network data recording systems has been reinforced. This includes ensuring all as-builts are entered into GIS.
- Valve status auditing prior to calibration data gathering simplifies the calibration process and reduces the number of anomalies. This includes checking that line valves are open and zone valves are closed. The redundancy inherent in looped networks means the presence of closed/part closed valves can build up unnoticed. This can slowly choke a network and leave it in a state unable to perform in the case of an emergency (e.g. fire or mains break).
- Valve checking is a simple and quick way of finding and resolving anomalies.
- Reconfiguration of the network to eliminate loops and force flow along pipelines aids anomaly identification.
- Flowing hydrants to locally stress the network makes the presence of anomalies more apparent. They can then be detected by pressure logging, noise correlation or simply noting the hydrant flow.
- Persistence is required for anomaly resolution, and several methods of investigation may be required.

9 CONCLUSIONS

An “eyes wide open” approach to water network anomalies has been adopted by Metrowater in preparation of Zone Master Plans. The anomalies have been actively pursued using both the model calibration process and field investigations.

A wide range of data sources has been used, including; GIS data, network plans, billing and SCADA data, system flow, pressure and hydrant flow data, operator and planning staff knowledge, maintenance contractor knowledge and consultant knowledge. Bringing together this wide range of data improved the chances of finding and resolving anomalies. Some novel approaches were used, including use of leak detection noise correlators to find restrictions and system reconfiguration to highlight the effects of restrictions.

Knowledge of the anomalies has been integrated into the Master Planning process. The model has been used in the planning process to establish when the anomalies need to be removed to maintain customer service levels. This has lead to anomaly resolution being included as part of the solution set for the Master Plan.

Anomaly resolution improves system operation immediately, allows more certainty in network planning, reduces the expected expenditure on the system, increases the knowledge of the system, increases the opportunity for optimising system operation including reducing pressures and leakage and engenders a cooperative approach between the many parties involved in the water network. The extra effort and cost involved has been repaid by the improved network operation and enhanced planning and operational solutions in the Master Plan.

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