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Calibration of Redcliffe Water Supply Network

K Goraya, J Xu

ABSTRACT

Unitywater has conducted water network calibration for various Demand Management Areas (DMAs) in the Redcliffe Peninsula using Genetic Algorithm (GA) with Extended Period Simulation. The calibration was carried out to understand the fire flow performance of the water network after formation of DMAs. The tuberculation of unlined fittings in the network was considered as a significant issue affecting the fire flow performance.

In order to have confidence in the calibrated friction factors for water mains, hydrant flow tests were conducted. These tests induced flows in the network about 7 times above background flows. This technique ensured that useful information about pressure drop was not obscured by other sources of error. Pressure loggers were installed in the network at strategic locations to record pressure drops associated with the high flows. Calibration was carried out in the InfoWater software using GA to optimise friction factors with engineering judgement used to identify local constrictions or closed valves. This was reiterated until the desired tolerance between the simulated and logged pressures was achieved.

The calibration process identified some limitations in the methodology that may hinder its widespread adoption in the larger water supply networks. Nevertheless, Unitywater intends to use the calibrated model as a tool to develop the future capital program within Redcliffe to ensure service standards are met in a cost-effective manner.

This paper describes the importance of detailed calibration of hydraulic models and their limitations, and demonstrates the risks of simply adopting standard parameters in uncalibrated models. The paper also details the authors' experiences in troubleshooting poor fits between data and the model, the limitations in the use of the generic algorithm as a calibrating tool and some techniques used to overcome these difficulties. This information may be valuable to other modellers attempting to calibrate pipe networks.

INTRODUCTION

Unitywater provides water and sewerage services to the Moreton Bay Regional Council, Sunshine Coast Council and Noosa Council areas. Unitywater was formed in 2010 through the amalgamation of six former councils' water functions.

During the Millennium Drought, the various councils at the time, including the Redcliffe City Council, divided their water distribution area into Demand Management Areas (DMAs) to better manage leakage. This was achieved by closing boundary valves as indicated (circles with red crosses) in Figure 1.

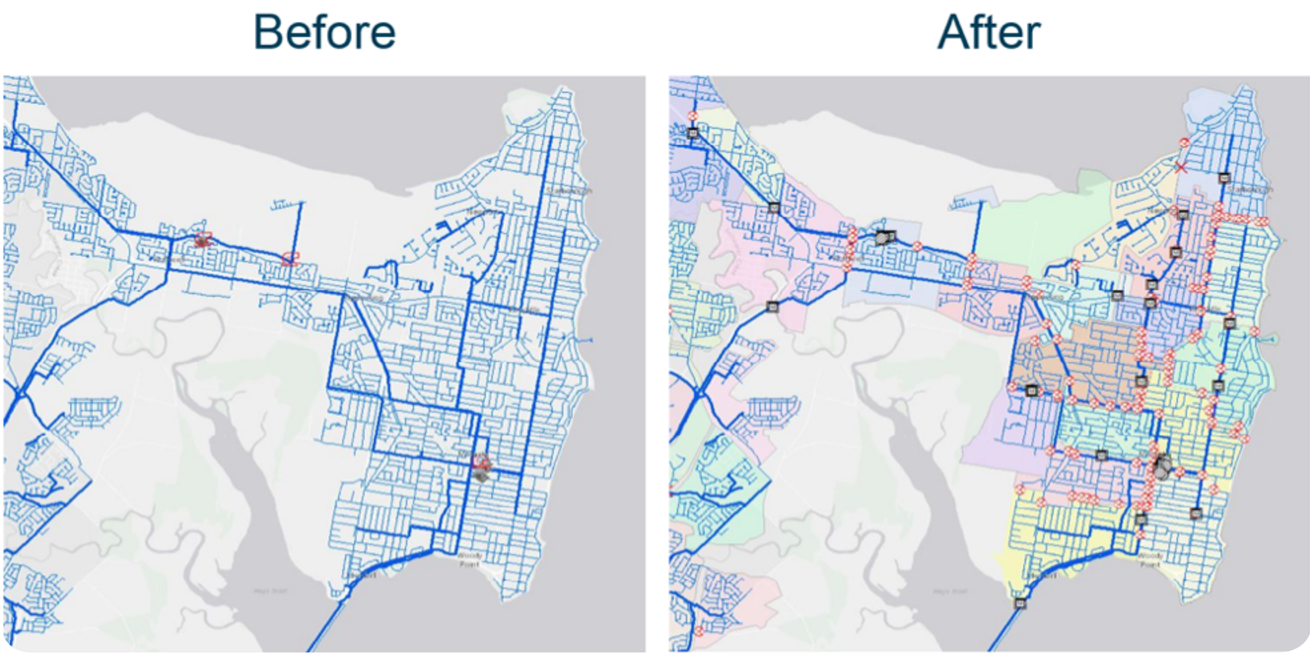


Figure 1: Redcliffe water network before and after DMA formation

In the years after the establishment of the DMAs, commercial customers and the Queensland Fire and Rescue Service (QFRS) occasionally advised that the required fire flows and residual pressures were not being achieved. However, in many circumstances, Unitywater's uncalibrated water network model predicted adequate performance at these sites. The hydraulic model was, however, only validated for reservoir levels, pump operations and pressure at the critical points in the network during a high demand day. The discrepancy was more obvious in the older parts of Unitywater's network, such as Redcliffe, where 58% of the infrastructure was installed prior to 1975, when unlined cast iron fittings were frequently used. These unlined fittings are prone to tuberculation (due to iron/manganese deposits) and contribute significantly to local head losses. These losses often only become apparent when high flows are drawn through the network. Examples of severe tuberculation in fittings from the Redcliffe water supply network are shown in Figure 2.

Unitywater has a program in place to test hydrants at critical facilities such as hospitals, schools, etc. A fitting replacement program has also been conducted throughout the scheme area over the last few years. However, there is still a risk of unknown fire flow standard failures at hydrants where tests have not yet been conducted.

The Moreton Bay Regional Council's planning scheme allows for the densification of the Redcliffe area including the potential construction of large numbers of high-rise buildings. Using uncalibrated models for planning may result in incorrect augmentation recommendations to deliver the standard of service for future growth. This has implications for capital work forecasting and workload for the detailed planning team.

Consequently, Unitywater undertook the calibration of the Redcliffe water model using induced high flows in order to improve confidence in the model's ability to faithfully predict network performance. Genetic Algorithm was used with Extended Period Simulation (EPS) in the Infowater Calibrator module to calibrate DMAs. The Genetic Algorithm (GA) optimisation calibration technique was selected as the method for calibration based on literature review (Kapelan, Savic and Walters, 2005). GA is an optimisation technique inspired by natural selection. Initially, a cohort of friction factors is randomly selected from the range of friction factors provided for each pipe group. During simulation, pressures at logging points were evaluated against observed pressures for fitness (how close the match is).

The candidates exhibiting closer fitness are retained and recombined, and in some cases mutated in order to produce the next generation of candidate solutions. This is repeated until the calibration tolerance is achieved, or a predetermined number of iterations is completed.

METHOD

Any significant sized hydraulic model has some assumed information incorporated due to limitations in asset data availability. The known initial assumptions made in the model are based on the "known-unknowns" as shown in Table 1. These include unknown pipe material and pipe class that influence the internal diameters and the use of conservative planning friction factors based on standard design codes.

Figure 2. Tuberculation of unlined cast iron fittings

There may be other assumptions built into the model that the modellers are unaware of. These are referred to as the "unknown-unknowns" and are largely the result of incorrect asset information or status captured by as-constructed drawings or GIS. They could also include incorrect pipe nominal diameters, elevations and connectivity due to incorrect valve positions or missing pipes.

It is common for water hydraulic models in Queensland to be validated for seasonal max hour demand conditions for long term planning. This is achieved by altering model pipe friction factors or local losses to closely match the pressures recorded on a hot summer day. A previous Unitywater study revealed that the maximum daily draw for hot summer days for this area was 2.5 times that of average day demands (Figure 3). Even under these conditions, the observed head loss is still small in comparison with other potential errors, such as incorrect elevations, instrumentation errors and pressure losses caused by demand spikes. This may perhaps give a false impression that the model is adequately calibrated for all conditions (Walski, 2000).

Tabezh, et.al. (2011) considered four scenarios of minimum, normal, maximum and fire consumption for the calibration of a water network and concluded that the best results are obtained with fire flow consumption. According to Koppel and Vassiljey (2012), there are inaccuracies in the pressure logger readings. However, the sensitivity of results to random errors in pressure measurements is smaller under high flows.

Table 1. The assumptions in models

	Known	Unknown
Knowns	- Assets with good quality information	
Unknowns	- Incomplete asset information - Pipes with unknown pipe class - Pipe condition - Friction factors	- Incorrect pipe nominal diameters - Incorrect materials and pipe class - Incorrect elevations - Valve position

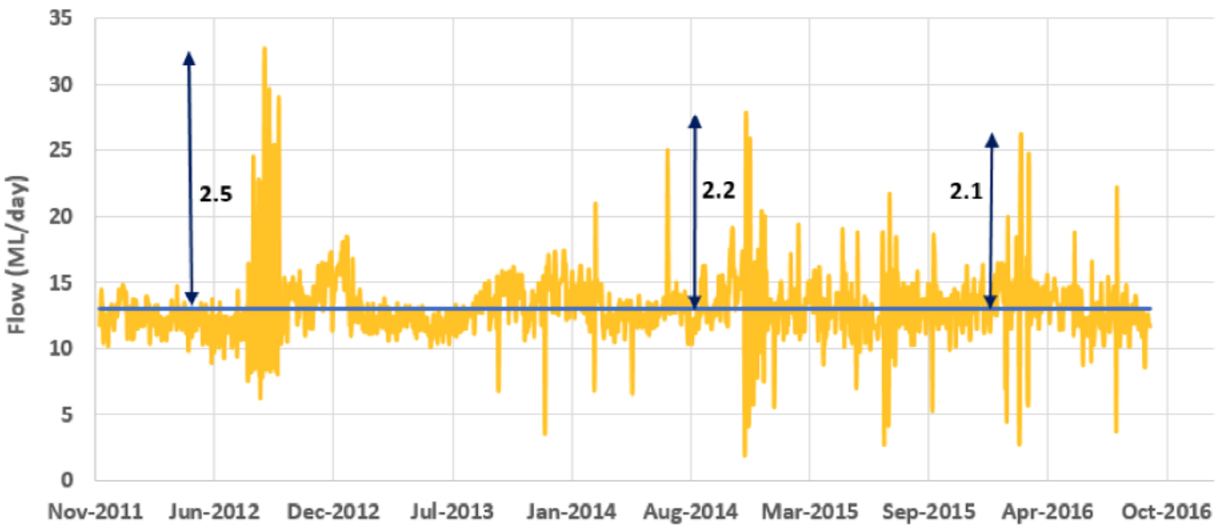


Figure 3. Daily demand in the Redcliffe area

Therefore, to achieve a higher level of confidence in friction factors and constrictions within the network, Unitywater calibrated the network model by drawing high flows (and thus velocities) through individual DMAs. This was done via a series of hydrant flow tests. The induced flows ranged from four to fourteen times that of the background demand, with an average of about seven times. These flows were reflective of firefighting conditions within the DMA. This ensured that the induced friction head losses were significantly higher than other potential sources of error. The recorded data was then used to calibrate DMA networks.

Field Data Collection

Hydrants at the extremities of the DMAs and adjacent to critical customers (schools, hospitals, etc.) were selected for hydrant flow tests. Pressure loggers were installed close to the test hydrants and on the mains en route to the flow test locations. A typical DMA with the chosen hydrant and pressure logging points is shown in Figure 4.

The DMA Pressure Reducing Valves (PRV) were set to a constant downstream pressure to remove the dynamic impacts caused by the upstream pumps and the behaviour of the PRVs under the flow modulation mode. The fire flow tests were then conducted with the pressure drop from every hydrant test recorded at each logging point.

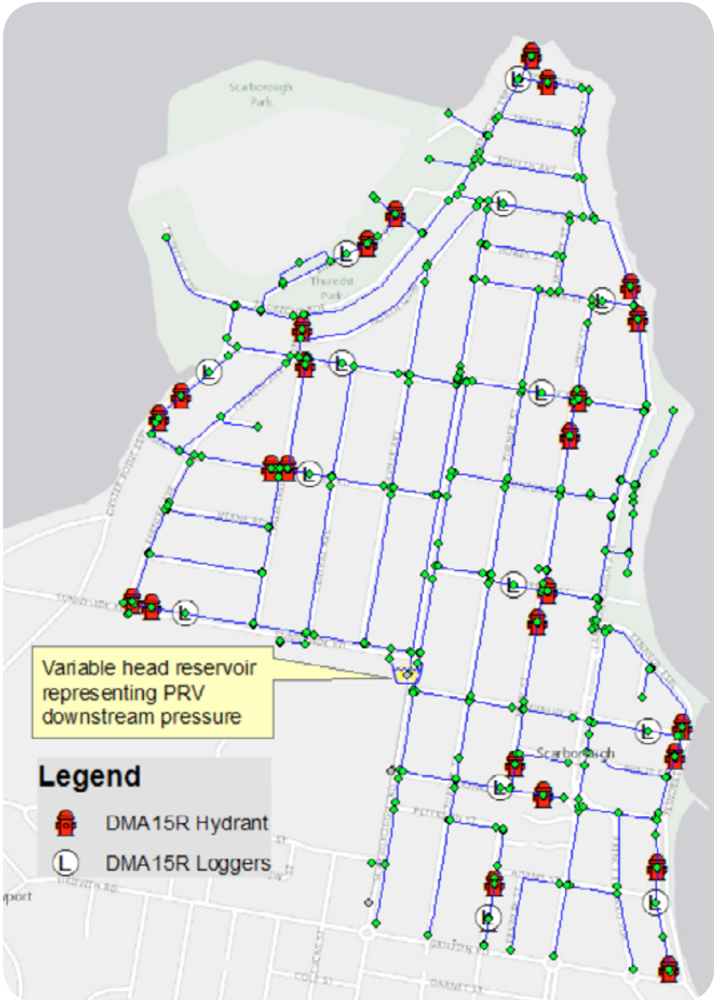


Figure 4. Flow test hydrants and pressure logging points in a DMA

Model Preparation

The DMA was prepared in InfoWater for calibration by creating scenarios with only the DMA activated. The upstream trunk and the DMA PRV was replaced with a variable head reservoir simulating the pressures observed downstream of the DMA PRV.

Calibration using the GA algorithm requires grouping pipes within the network based on their specific characteristics. The pipes were grouped according to the year installed, materials and internal diameters. Altogether, 43 pipe groups were created for the entire Redcliffe peninsular, though no more than 12 were actually used in each DMA based on the characteristics of the pipes in the network.

The previous quarter retail billing data was geocoded to distribute the actual demand to each node in L/s.

Preparation of Input Data

The flow and logging data was time aligned, cleansed and trimmed before being transferred into the model (Figure 5). The model node elevations were added to the logged pressures to derive the hydraulic head for the each logging point. The difference in recorded head at low flows was used to adjust the node elevation in the model. The flows from the hydrant tests were deducted from the DMA flow meter readings to produce a background demand pattern. This background flow was then divided proportionally to all nodes by the billing data demand in the DMA.

Input Data Into the Model

The observed hydrant flows were input into the model as flow-time patterns. These patterns were allocated to nodes representing tested hydrants. An initial simulation was then run. The observed DMA flow meter readings were compared with the simulated flow meter readings to validate hydrant and background demand allocations.

The logged pressures were added into the InfoWater calibration module. It was observed to be beneficial to only input pressure logged data during the flow tests to ensure the calibration result (which is an average score of fitness between the simulated and observed pressures) was not influenced by pressures logged under background flow conditions.

Pipe friction factor ranges were specified in the model for each pipe group. Each pipe group was given a minimum and maximum roughness value and a number of levels to divide the range between the minimum and maximum. For example, if the range between the minimum and maximum was 50, and 5 levels were used, the model adjusted the pipe roughness in increments of 10.

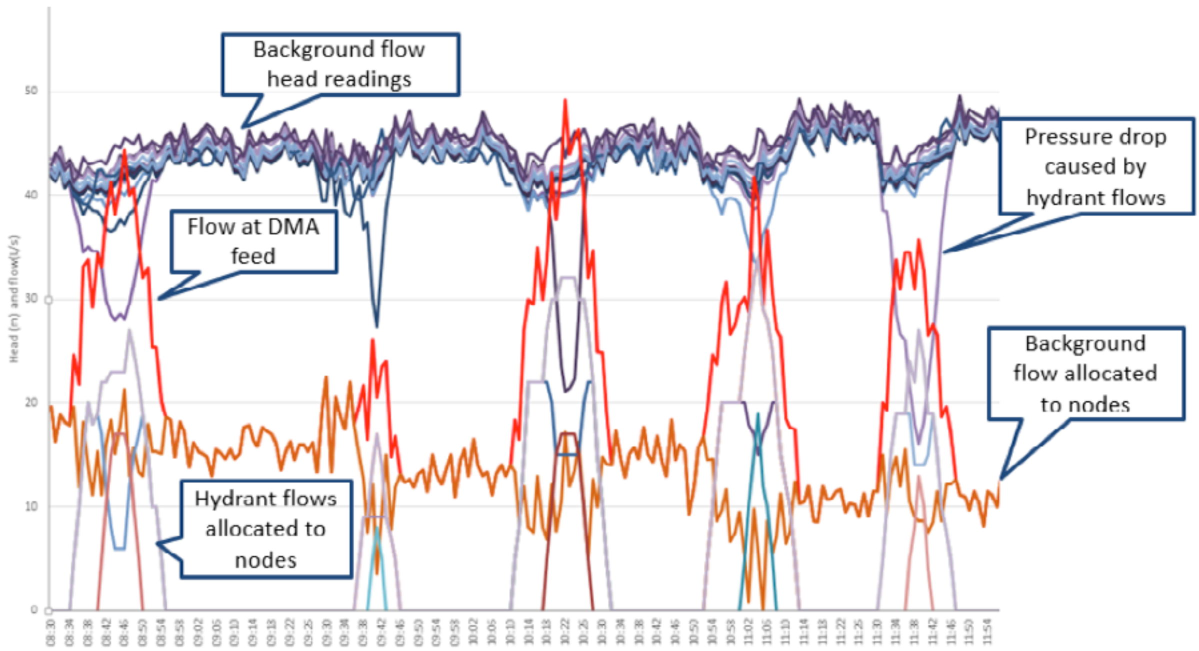


Figure 5. Flow and HGL Plot for a single DMA

Evaluation of Calibration Results

The calibration results were presented in the form of

- overall fitness statistics
- a table of friction factors for each pipe group, and
- graphs with the actual and simulated pressures at each logging location.

The overall fitness statistics were reviewed, however, their averaging nature masked the quality of the calibration at each logging point. The graphs for each pressure logging point were found to be more useful for evaluating the calibration quality.

It was found that the simulated and actual pressure drops observed in loggers further away from the test hydrants generally matched, but was not particularly informative in determining the quality of calibration, as the pipe leading to those logging points did not experience high flows and high friction losses.

The closer the logging points were to the flowing hydrants, the greater the influence hydrant flow had on the logged pressure (Figure 6). These observed pressure drops were more useful in determining the quality of calibration.

Troubleshooting and Fine Tuning the Calibration

Poor fitness observed at pressure loggers close to the test hydrants could have been caused by incorrect model connectivity (such as closed valves), incorrect pipe diameters, and friction factors.

Pipes with possible closed valves or severe constrictions were identified when two pressure loggers on alternate flow paths close to the flowing hydrants experienced very different levels of head loss during hydrant operation. This indicated that the hydraulic connectivity between a pressure logging point and the flowing hydrant was compromised.

When a closed valve or severe constriction was suspected, the pipe was deactivated in the model, the calibration was re-run, and the logging point comparison graphs were checked to identify if a better match between observed and simulated pressures was achieved.

When major obstructions were suspected in pipes, due to rust or tuberculation of unlined cast iron fittings, these pipes were allocated a separate pipe group with low Hazen-Williams friction factor ranges (high friction losses) before re-attempting calibration.

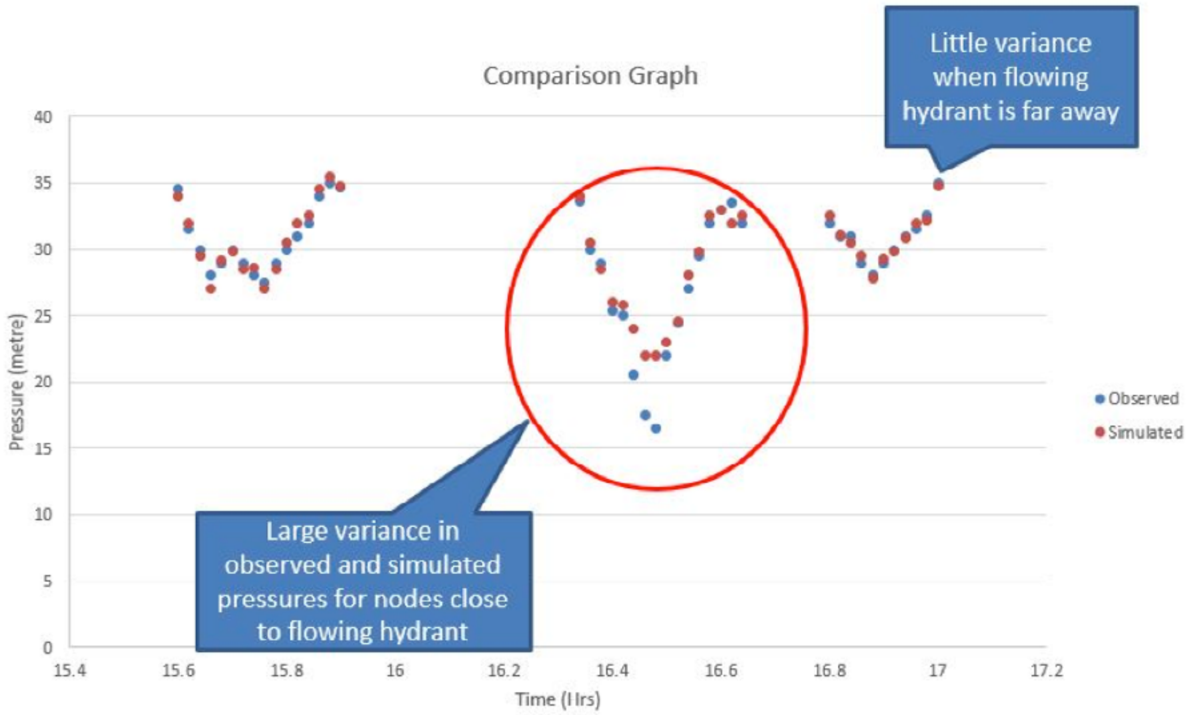


Figure 6. Comparison of simulated pressures using the calibration friction results with observed pressures

This was done to prevent the performance of highly constricted pipes or fittings from affecting all pipes in the pipe group.

For some older mains, the pressure class of the pipe is assumed in the asset record system. In circumstances where the Hazen-Williams friction result for these pipes was inexplicably high (low friction losses), it was decided to adjust the assumed pipe class. This was significant for some pipe materials, particularly smaller AC pipes where the difference in cross sectional areas between AC pipes with a nominal diameter of 100 mm of different classes is up to 27 per cent.

On occasions, changing the pipe class was still insufficient to explain superior field performance, and in a few instances, potholing revealed that a DN150 pipe was actually installed instead of a DN100 pipe shown on the as-constructed drawings. This allowed adequate firefighting performance to be achieved even though the model predicted otherwise. Modifying the model accordingly allowed the field and simulated performance to match.

Nevertheless, potholing to verify diameters or pipe classes was not widely commissioned as part of this project as the aim of the calibration exercise was to get the model to more accurately replicate the behaviour of the physical network rather than achieve an accurate record of assets.

The calibration was re-iterated with modified input parameters until simulated pressure losses of all logging points were within 1 or 2 m of observed pressures.

Outputs

The outputs from this calibration exercise included:

- Maps indicating locations of potentially closed valves, severely constricted pipes, fittings, etc. These maps were issued to the Unitywater renewals team for field verification and, if necessary, prioritisation of renewals works.
- A hydraulic model incorporating modified pipe friction parameters arising from the calibration exercise. This model will be used in future master planning exercises to identify fire flow augmentations and fine-tune DMA PRV settings to reduce water loss.

DISCUSSIONS

How Calibration Benefited Unitywater

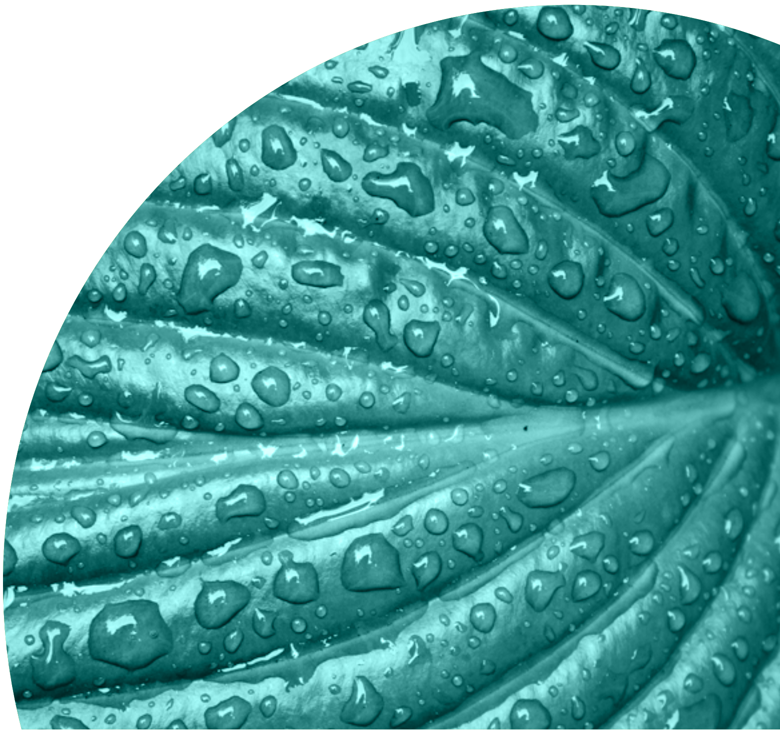
This calibration of the Redcliffe Water Supply Model is expected to result in the following benefits:

- Identification of areas with performance deficiencies without having to test every hydrant
- Greater certainty in terms of asset performance
- Improved assessment and planning of fire flow augmentations
- Identifying valves that have accidentally been left shut, allowing them to be opened to improve network performance.

Limitations of GA and EPS Calibration

However, this exercise did highlight some limitations in the use of Genetic Algorithm and EPS. In particular:

- Determining fire flow performance throughout the network based solely on a calibrated model is risky as individual hydrant or fitting condition can severely affect performance. A trade-off between the number of fire flow tests and logging points for higher levels of certainty and the overall exercise cost has to be made.
- Conducting fire flow test and calibration is resource intensive. It takes 3 to 5 working days to calibrate each DMA. This does not include the time and resources for field data collection. Consequently, this methodology is perhaps best suited to older sections of the network where performance deficiencies, and their resolution, are a significant problem.

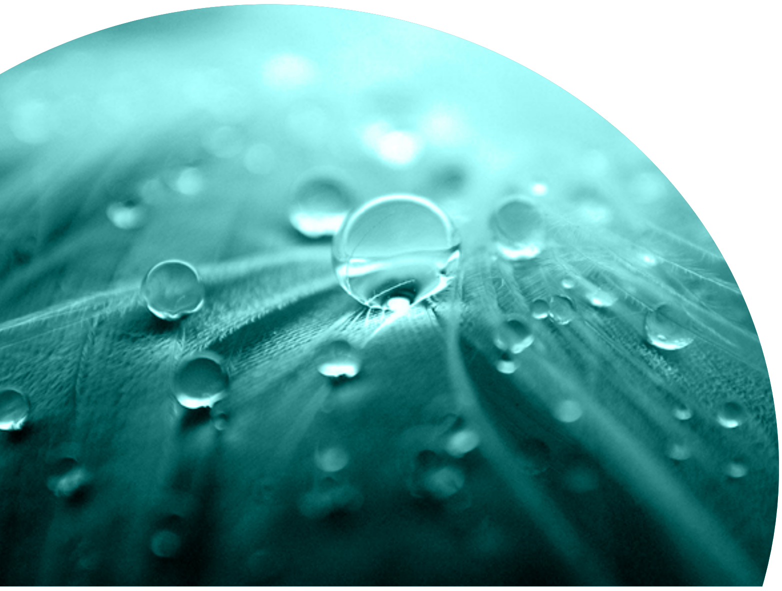


- GA provides a quick optimisation alternative to manual adjustment. However, the quality of the calibration outcome is ultimately dependent on engineering judgement employed in the analysis especially for older networks with possible constrictions. The GA friction results are a "blind" assessment, and whilst they might ultimately provide a correlation, they are not necessarily the whole truth. More localised testing needs to be conducted in the field prior to commencing any detailed augmentation planning or construction.
- The calibrator module in InfoWater calculates the friction factors for pipe groups which does not differentiate between pipe friction losses and local losses. Consequently, the performance of pipe types are not transferrable to other areas, especially where the number and condition of fittings may have a large impact on the network performance.

Number of Pipe Groups

Koppel and Vassiljev (2009) found that the calibration of pipe roughness is difficult if the water supply distribution network contains pipes of different ages. Clustering of pipes under such circumstances is difficult because higher age differences of pipes leads to a large number of pipe groups, and consequently, to a large number of parameters to be calibrated.

Transky (2008) found that dividing the pipes into many groups based on physical characteristics and materials did not improve calibration outcomes over using just a few general groups. This is because as the sample size of each pipe group becomes smaller, larger margins of error occur in the calibrated friction factors.



A large number of pipe groups were used in this Redcliffe model calibration to account for the different pipe ages, diameters and roughness. It was observed that a small change in input parameters, such as the upper or lower bound of pipe group friction ranges, resulted in different friction results even though the friction factor results were within both ranges. This supports Transky's (2008) findings about a larger margin of error when the sample size for each pipe group is small.

This calibration revealed substantially different friction factors for pipes with seemingly similar internal roughness characteristics. Moreover, the same pipe type behaved very differently in different DMAs. This is likely to be due to the significant contribution of local fitting losses relative to friction losses generated by the pipes under high flow conditions. Using fewer pipe groups will lead to more pipes in each pipe group. This would cause the performance of the entire pipe group to be influenced by multiple local restrictions, which could make the identification of local restrictions more difficult.

Therefore, the number of pipe groups chosen should depend on the characteristics of the network. It may be suitable to use fewer pipe groups to gain a smaller margin of error in networks that are of roughly the same age. However, the physical realities of older mixed-age networks would require a larger number of pipe groups to be employed with an acceptance of a larger margin of error in the results.

Elevation of Pressure Loggers

Transky (2008) also found that correct elevations were more important than the number of pipe groups to achieve a good calibration result. During this calibration exercise, incorrect elevations caused the calibration module to run a larger number of iterations to achieve the required convergence. It also led to poorer average levels of fitness in the calibration statistics.

Incorrect elevations were easily identified when the simulated pressure trends were identical to logged pressures with the exception of a consistent offset (during low demand periods). After correcting the elevation, the calibration statistics improved but the friction factors for each pipe group largely remained the same.

From the service provision or firefighting perspective, the achievable pressures and flows at the customer meter point or hydrant (typically at ground level) would be more important than the actual pressures in the middle of the buried pipe where the pressure probe was installed.

These are more influenced by the accuracy of the friction factors and the surface elevations. As such, surveying each logging point to derive accurate elevations was not deemed to be necessary though accurate elevations will contribute to better calibration statistics.

Friction Factor Ranges in GA

The performance of GA was highly dependent on the input parameters including the range of friction factors provided for each pipe group. Initially, the provided friction factor ranges were set as wide as possible on the basis that GA was able to optimise the solution. However, the optimised friction factor outcomes arising from this approach were sometimes unrealistic. This was the consequence of GA providing an answer out of many possibilities that fulfilled the tolerance requirements. When the provided friction ranges were too wide, unrealistic solutions emerged, and GA stopped iterating upon meeting the tolerance requirement. Therefore, it is important that the provided pipe group friction factor ranges are realistic.

CONCLUSIONS

The calibration of water networks is required to get a true understanding of network performance. It is through calibration that the assumptions in the model about the network are tested and adjusted so that the model reflects the behaviour of the network. Stress testing the network, coupled with engineering judgement, is required to achieve good calibration results. GA should only be regarded as a time-efficient alternative to manually adjusting friction factors. However, in aging mixed pipe networks, with confounding influences such as corroded and degraded fittings, it should not be entirely relied upon to generate good calibration outcomes.

The number of pipe groups chosen for each calibration exercise should be selected based on the condition of the network. Fewer pipe groups may yield satisfactory results if fitting losses are expected to be dwarfed by pipe friction losses. However, for aged networks with restrictive fittings, smaller calibration areas and a larger number of pipe groups are likely to produce a more useful outcome.

Ultimately, water network calibration using Genetic Algorithm (GA) and Extended Period Simulation (EPS) is time and resource intensive. In larger networks, this may limit its application to troubleshooting problematic areas of the network. However, if applied in the right manner, water network model calibration has the potential to improve the efficiency of capital spend and enhance the confidence of utilities in providing the required standard of service for the community.

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THE AUTHORS

Ken Goraya (kengoraya@unitywater.com)
Ken Goraya has more than fifteen year experience in water distribution utilities in the fields of infrastructure planning and asset management. In its present role at Unitywater, Ken is responsible for development of network master plans to guide capital works investments to provide for growth and to maintain levels of service for existing residents.

Joseph Xu (joseph.xu@unitywater.com)
Joseph Xu is a network modelling engineer with Unitywater. He has worked in operational, planning and project delivery areas of the water business. He builds/updates water and sewerage models, use them to conduct network investigations and develops network master plans to ensure the desired levels of service can be met for current and future customers.

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