USING EXISTING TECHNOLOGY TO BUILD A SMART WATER NETWORK

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ABSTRACT

For many years, hydraulic modelling has been a good predictor of system hydraulic behavior. Most water utilities build hydraulic models as part of their master planning processes. However, usually there have been two drawbacks to traditional use of hydraulic models for operations. First, utilities built heavily skeletonized models that didn't include all pipes in the ground. Second, a true operational model was difficult to use because many water utilities traditionally lacked a straightforward way to integrate a model to current supervisory control and data acquisition (SCADA) information.

With all-pipe models and SCADA connections in place, utility managers can think about a true real-time modelling system in which a server-based system with the model consistently runs without human intervention. Operators can incorporate SCADA information as boundary conditions or verification points in the output. Alarms and dashboards quickly identify discrepancies in the model predictions and the required level of service. A simplified modeling interface allows operators to quickly run what-if scenarios to examine solutions to forecasted problems.

The benefits of real-time modeling are enormous: improved model calibration; advanced system abnormality alerts; forensic analysis; and real-time evaluation and predictive optimization of water quantity, quality, and energy use.

KEYWORDS

Real Time Hydraulic Modelling, Smart Water Networks

1 INTRODUCTION

The technology we take for granted today was, at some stage in the past, someone's vision of the future.

It is now up to us to use what we have inherited in new and exciting ways to achieve all our goals, whether they are environmental sustainability, improved service, or reduced financial expenditure; to create our future. We need to ensure that we are collecting valuable data, using it wisely to provide meaningful predictions of the future to allow better decisions to be made,

Tools such as genetic algorithms (techniques that copy evolutionary ideals to help us determine the optimal solution to complex problems) and analysis of big data sets allow us to redesign our environment to provide clean water, and remove excess water, in increasingly clever, complex and cheaper ways.

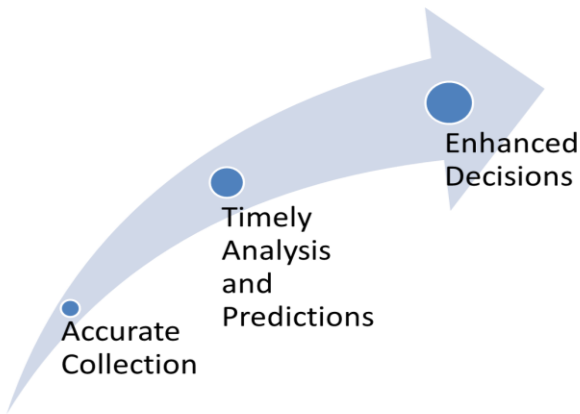

Figure 1: What we want from our systems

When we do this successfully the results are taken for granted by end-users who are unaware of the innovations that have made this possible.

2 SMART GRIDS

2.1 Why do we need smart grids?

Population changes, urban development and redevelopment have all put pressure on our water supply network. We don't have the funds to replace these pipes to meet peak demand periods, and if we did we would possibly create water quality problems in the non peak periods. Therefore we need to do things differently.

Many other networks, such as electricity and roading, also share this same problem. In the USA, growth in peak demand for electricity since 1982 has exceeded transmission growth by almost 25% every year. This has been driven by population growth, bigger houses, bigger TVs, more air conditioners and more appliances. Even as demand has skyrocketed, there has been chronic underinvestment in getting energy where it needs to go through transmission and distribution, further limiting grid efficiency and reliability. **In short, the electricity grid is struggling to keep up.**

Reliability is a major concern – in many instances the only way the energy supplier knows there is a problem is when the customer calls. Efficiency is another major driver – in the US, if the grid were just 5% more efficient, the energy savings would equate to permanently eliminating the fuel and greenhouse gas emissions from 53 million cars. Affordability, environment/climate change, security, global competitiveness and the effect on the national economy are also considered.

Many of us face the same issues in our water networks.

2.2 So what is the energy industry doing ?

The electric industry is poised to make the transformation from a centralised, producer-controlled network to one that is less centralised and more consumer-interactive.

Advanced Metering Infrastructure (AMI), visualisation technology, real time pricing changes (to reduce the peaks), inbuilt automatic health checks, and local generation (solar panel) are all being used to make a network that aims to be intelligent, efficient, accomodating of different sources, motivating change, creating new opportunities for innovation, capable, resilient and environmentally sensitive. Or in other words, they are creating a **smart** network.

3 SMART WATER NETWORKS

Data is collected from all over a water supply network – from the collection of water at the source, to the treatment and supply of water in the distribution network, to the use of the water by the end consumer.

Smart Water Networks aim to use this data to provide an increasingly automated way that sustainably provides water in the most efficient way possible.

SWAN, Smart Water Networks Forum (www.swan-forum.com) describes Smart Water Networks as the entire system of data techologies connected to or serving the water distribution network. They consider the network in five different layers, shown in Figure 2, allowing opportunities for each layer, or layers, to be developed to make the system as a whole more intelligent.

Figure 2: Components of a Water Network

3.1.1 PHYSICAL LAYER

This layer represents the physical elements that make up the water distribution system.

This includes the "wet" assets such as pipes, pumps, valves, reservoirs and taps.

These elements do not collect data but provide a function to deliver water.

A Pressure Reducing Valve (PRV) is an example of a "smart" device in this layer – the valve changes operation without needing a sensor or logic control. Alternate sources of supply – such as rainwater tanks – would also be included here.

3.1.2 SENSING AND CONTROL

The sensing and control layer includes all the equipment that measure the assets in the physical layer.

Elements of this layer typically have one "wet" end or aspect with direct contact or relation to water (such as a valve or the mechanical end of a flow sensor), and one "dry" data interface (such as a valve controller input, or a sensor's data output).

3.1.3 COLLECTION AND COMMUNICATION

This is a "dry" layer – none of the components in this layer interact with water, and are largely focussed on moving data between the layers. Collection, transmission, and storage of data points in a timely manner to a central location or the timely distribution of control signals from this central location to endpoints in the network occurs in this layer.

Data loggers, SCADA, AMI, and other technologies related to data transfer (without creating the data and without significant data processing) are all part of this layer.

3.1.4 DATA MANAGEMENT AND DISPLAY

This is the first "human" layer. It is here that the data from different sources comes together and is displayed as information for action.

Visualisation tools, such as dashboards (Figure 3) provide contextualisation of the data and create the information for decisions. Most authorities utilise these technologies for display of SCADA alerts or simple semi-automated system supply actions.

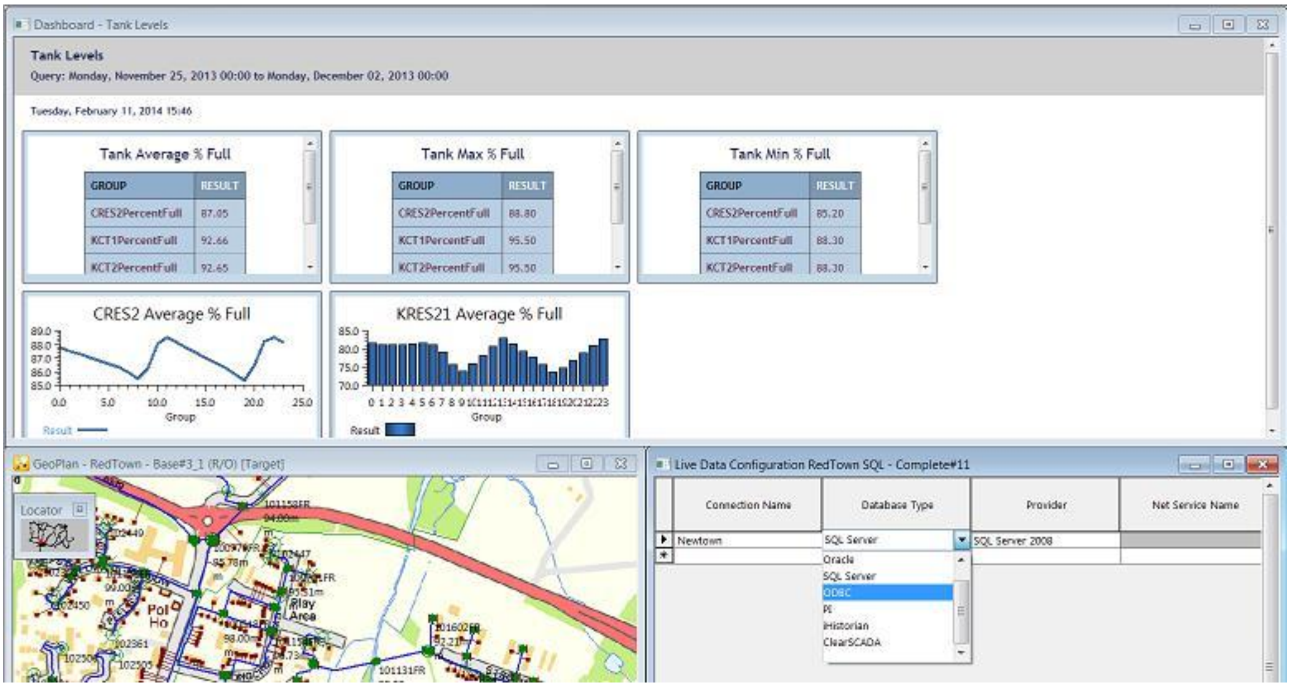

Figure 3: Example of a Dashboard

3.1.5 DATA FUSION AND ANALYSIS

This layer is most distant from the physical layer, and is where the processing of large quantities of data to derive insight into the system operation occurs. This is very different to the previous layer in that the data is actively used and mined. Hydraulic modelling systems, smart (not fixed feedback) pressure management , pumping or energy optimisation systems, Decision Support Systems, and near real time burst detection fall into this layer.

4 THE TECHNOLOGIES

Data from the water network requires - and enables - a broad range of solutions, often with a high level of IT complexity.

The foundation technologies and systems in Smart Water Networks include, among others:

- Flow and Pressure meters, Acoustic, water quality sensors, Data loggers
- SCADA and Alert systems, GIS and visualisation tools, Asset management systems

Leveraging on the data collected and stored in these systems are hydraulic models, and other advanced network analytics..

4.1 HYDRAULIC MODELS

Hydraulic models are widely used by authorities to undertake planning studies, however their uses can easily extend into the following areas:

- Water balance and leak detection,
- Pump optimisation,
- Demand Forecasting.

These areas are discussed further in following sections of this paper, but it is important beforehand to acknowledge that there are several percieved drawback or limitations of hydraulic models. Some of these are historical in nature (lack of computer processing power) and others are widely stated misconceptions.

4.1.1 PERCIEVED DRAWBACKS OF HYDRAULIC MODELS

There is still some skepticism about models in most organisations. The common reasons for this are discussed further below.

SKELETONISED MODELS

Historically models were skeletonised because of a lack of digital data of suitable quality for the creation of a model or simply because the computers couldn't solve the model quickly enough. Also as models tended to be reserved for higher-level master planning, rather than operations, it was often considered that including all pipes, valves and hydrants weren't necessary. However skeletonisation of models introduced another complication when the models were used for operational purposes – the models no longer represented the real system. For system operators this was confusing as **the model didn't show the network they knew**.

Now, in an era of faster computers, better software, and easily accessible electronic data, building and using an all-pipe hydraulic model is routine and to be encouraged as it reduces rework.

MODEL ACCURACY

Models are only as good as the data (and maths) used in them. Model accuracy is often questioned – and in many instances models are proven to be based on false assuptions – often made as there was a lack of adequate data. Models are data hungry.

To build a network the first item needed is a **complete** asset inventory, and in most organisations this is stored in a GIS. Connectivity between these assets is an advantage (pipes are connected to each other), but most models are able to generate connectivty based on spatial information if none exists. It is then necessary for the modeller to assume values such as pipe roughnesses (which can be based on an asset's age, and material but is ideally derived from field assessments).

Consumer demands need to be included, and in most instances this is a zone level assumption based on land use, and recorded zone meteres, not individual customer demands. This is changing as Advanced Metering Infrastructure (AMI), or Smart Meters, are becoming more widely installed.

The other key part to the model is the operational controls. In most instances the modeller refers to the Operating Manuals to determine how to replicate the system operation. The pump curves for variable speed pumps need to be entered, and often those provided are only for the pump when it was newly installed.

Calibration is the key step in ensuring model accuracy.

4.2 WATER BALANCE AND LEAK DETECTION (INCLUDING REAL TIME BURST ANALYSIS)

WHAT IS LEAKAGE?

The term leakage is used to describe the water lost from pipes, joints and fittings and overflowing service reservoirs, and is a part of the more generic term Unaccounted-For Water (UFW). UFW is difference between the total amount of water going into a distribution network compared to the amount that is consumed and billed for, and includes, as well as leakage other apparent losses such as theft or firefighting consumption.

TECHNIQUES FOR LOCATING LEAKAGE

During the 1990s, the UK's National Leakage Initiative (NLI) developed two main approaches to identifying and quantifying leakage. The first, known as the 'water balance', accounts for every aspect of the water supplied to the network. As such, it encompasses both sources of supply, such as reservoirs, and the mains distribution network.

Water Balance assessments (calculating the total of the flows into and out of a zone) are a key part of model building as this assists the modeller in understanding the zone setup, but also ensures that all zone boundaries have been identified correctly in the model. Analysis of the zone consumption at a per capita level, comparing this against metered billing data, as well as a review of SCADA and temporary pressure and flow meters are routine tasks undertaken during calibration, and will also identify anomolies.

Leakage generally falls into two categories – background leaks and bursts or breaks. Background leakage is the aggregation of losses from all the fittings on the network. Such leaks are typically too small to detect individually but can be identified at a network level. Hydraulic models will not necessarily identify background leaks – the analysis of consumption may identify areas where nighttime flows are unusually high which would indicate the likely presence of background leakage. Live hydraulic modelling will however identify areas where background leaks are slowly becoming worse – as the predicted night flows will start to vary from the observed values.

Burst leakage occurs from holes or fractures in the network, and typically happen suddenly. Live hydraulic models will identify these as the predicted values vary from those observed in the SCADA – and this comparison can be done in near real time and aid in early event detection. It is also possible to use triangulation, or simulate different possible flow locations, to determine the approximate location of the burst – however a suitable density of meters is required to make this worthwhile.

4.1 REGRESSION ANALYSIS OF DEMANDS

Water distribution network modeling is the most effective and viable way of predicting system behavior to solve a variety of design, operational and water quality problems. One critical component for ensuring reliable network model predictions is the **accurate estimation of short-term** (e.g., daily) **water demands**.

Techniques can be used that analyse patterns from historical demand data and combine this with Fourier transform and time-series autoregression modelling to accurately predict short-term (e.g., 24 or 48 hours) water demands. The patterns are used to identify seasonal and weekly periodicities in daily water demands as well as daily periodicities in hourly water demands. A sequential fitting of terms can be automatically generated to reveal patterns between days and hourly patterns within days.

Fourier transforms are used to find daily and hourly cyclical patterns. Autoregressive terms add a “short-term memory” in order to fine tune daily and hourly predictions, greatly increasing the accuracy of forecasted values. Typically water demand forecasts are generated at hourly intervals and can readily be input into hydraulic modelling of network operational performance over the next few hours or days. The results of these simulations can then be used for optimal operation and management of water distribution systems.

4.2 GENETIC ALGORITHM OPTIMISATION OF ENERGY COSTS

Network models can also be updated in real time to allow the determination of pump and treatment plant operation schedules that will yield the lowest operating cost while satisfying the system's hydraulic and water quality requirements.

Techniques such as Genetic Algorithms (GA) are useful in assessing a large possible solution space. Hydraulic models tend to take too long to run (when considering millions of possible solutions) so it is neceesary to reduce the hydraulics to a simpler mass balance model. The parameters of the mass balance model are accurate over a range of hydraulic conditions as the hydraulic model accounts for changes in demand, controls and other factors in each time step. Once a near-optimal solution for improved system operations is identified the values of the mass balance and hydraulic models are compared. If these are divergent then the mass balance model is re-parameterised and the optimisation is repeated.

The speed of this operation allows water utility operators to take advantage of sudden energy or operational changes and allows them to quickly and confidently develop improved system operations to deliver more reliable performance.

5 HOW SMART WATER NETWORKS CAN PROVIDE EFFICIENCIES FOR WATER COMPANIES.

Water scarcity, increased energy costs and increased regulatory focus on efficiencies are three compelling reasons why water companies need to invest in new, smart solutions that will enable them to make better decisions, faster, and with less effort. Discussions with several water authorities in Australia have identified four broad themes where they see benefits being realised by opeational modelling systems. These are discussed below.

5.1 KNOWLEDGE

The creation, dissemination and recording of operational knowledge is paramount for efficient, optimised system management.

5.1.1 UNDERSTANDING OF CURRENT SYSTEM OPERATION TO OPTIMISE LEVELS OF SERVICE

Historically networks were built with future growth in mind, and the philosophy was "build it to last". As household appliances become more water efficient the way we use water changes, as do the quantities needed. This means that many of networks are oversized, and can be causing problems such as water quality and experiencing leakage or bursts due to high pressures.

5.1.2 AUDIT CORPORATE "SOURCES OF TRUTH"

SCADA data is often considered a corporate truth, but it is rarely audited or checked for accuracy. Often operators are aware of errors in the data feeds, but when this data is analysed by other sections of the business (who don't know of the error), flawed decisions can be made. By using this data errors will become daylighted and (hopefully) corrected in a timely manner.

5.1.3 SHARING OF DATA LEADS TO BETTER UNDERSTANDING AND LESS ERROR

The creation of a hydraulic model requires input from many sections of the business including Network Operations, Asset Information and Planning. Data is often drawn from separate corporate systems like SCADA, GIS and AMS.

Erroneous data from the GIS or AMS systems found during the model build process or once the model is used can be fed back to Asset Information for update. Poorly calibrated monitoring devices providing bad readings will be more easily found when comparing the observed data against that predicted in the model.

Just even the act of predicting the system operation tests a modellers understanding of the assets, their configuration, and the loads they are subject to. Having all the data in one place means that inconsistencies can be found, and removed, making the data more reliable for everyone.

Technologies such as Dashboards provide better visualisation of data from multiple sources will allow errors to be quickly identified and corrected.

5.1.4 VISUALISATION OF SCADA AND NETWORK DATA

SCADA systems report the current state of the system, but do not allow operators to trial future scenarios, and often provide no system context. For instance a low tank alarm may be generated by failure of the supply pumps for the zone, a burst in the zone, or a failed sensor at the tank. In SCADA the operator would need to review pump operation (assuming they knew the primary sources of supply for the zone), assess system demands, and compare other telemetry feeds to identify the source of the alarm.

By providing a realistic forecast of tomorrow's system in an interface that allows the operators to simulate different operating or failure scenarios to quickly identify the system operation.

5.2 EFFICIENCY AND ACCURACY

Efficiency can be achieved in a number of areas – there are efficiencies in operating the network, reducing rework in analysis of zone meters and boundaries and keeping the operating manuals up to date while updating the model – the model could be considered the operations manual..

5.2.1 ENERGY COSTS ASSOCIATED WITH PUMPING CAN BE ANALYSED AND OPTIMISED.

Hydraulic models can be used to undertake real time genetic algorithm optimisation as discussed in earlier section of this paper.

5.2.2 INCREASED CONFIDENCE IN MODELS AND SCADA DATA ACCURACY

Planning staff will be able to verify and calibrate their models based on SCADA data increasing the confidence in both sources. Errors in SCADA will be identified (and hopefully fixed). The models will be more flexible as traditionally planning engineers tend to look to focus on the maximum day operation of the water system, whereas operations, and water quality, are dealing with the normal day.

5.2.3 MODELS, AND SUPPORTING DOCUMENTS/SYSTEMS, WILL BE KEPT CURRENT

Hydraulic models will not be put on the shelf to become out of date after calibration. Connecting the models to live data will keep the models current and calibrated as variances from SCADA can be clearly seen and investigated.

Operations manuals stay up to date as the model relies on the "theoretical" understanding of the system and will highlight real world differences, such as undocumented changes.

Simple links between the hydraulic model and other corporate systems such as SCADA, GIS and AMS will become an intrinsic part of ensuring those systems, as well as the model, contain the most up to date and correct information.

5.2.4 DESK TOP CONFIRMATION OF METER ACCURACY

Flow meters in the field can loose calibration and provide erroneous data. It can be almost impossible to verify this data quickly without going onto site. Automated daily review of the telemetered data should identify any meter drift and allow correction before the data is required for analysis.

5.3 CONTROL

Giving the operators the tools to better control the system is the primary aim of systems such as these.

5.3.1 FUTURE SYSTEM STATE PREDICTION AND OPTIMISATION

Once the real time hydraulic models are configured and running operational and planning staff will be able to simulate the network at the current time and hours or days into the future. This will provide operators with the opportunity to try alternate scenarios and assess the potential impacts – providing them with the tools and time to optimise the operation of the system for both planned events, and extraordinary situations.

5.3.2 REAL TIME UNDERSTANDING OF SYSTEM CHANGES

Operators will be better able to understand the effects on the network when they make proactive changes in the field or in the case of reactive changes during incidents. Incident scenarios can be tested in a training environment allowing improved responses when an incident occurs.

An example could be a major water incident that causes a shutdown of primary supply main to a zone. If the operators change the flow into the zone they could unknowingly reduce the supply pressure in the surrounding area and increase the flow through the supply pipe that could increase water quality issues. The likelihood of these outcomes can be simulated by the operators in a real time model prior to creating system changes.

5.3.3 MORE KNOWLEDGE OF THE SYSTEM ALLOWING TARGETED INVESTIGATIONS INTO LEAKAGE AND PRESSURE MANAGEMENT

Water supply systems become more complex. Pressure reducing measures are being implemented to reduce water loss from leakage or bursts. Dividing valves are installed to reduce the size of distribution zones into smaller zones so that the number customers affected by an isolation is reduced. AMI will also provide additional data points – as these are installed in the system they can be used to to detect leakages and other abnormal system issues.

By having access to live data and models of zones the operators will be better able to place the pressure reducing valves, install new meters or determine when alternate strategies such as closing a valve would suffice. Once these zones are set up in the live hydraulic model the operators can then monitor the efficacy of the solution.

5.3.4 ALLOWS UNDERSTANDING OF HOW MUCH CONSERVATISM IS IN THE SYSTEM, ALLOWING FOR OPTIMISATION

Comparison of average day water use compared to the more conservative planning peak day demands will allow a better quantitative understanding of where the network operations could be optimised.

6 CONCLUSIONS

Smart Water Networks are here. More data will be available as technologies such as AMI are installed. Consideration of the frequency and quantity of data collected by these devices will need to be given.

Other changes will also affect the industry. Imagine if water was charged at a different rate at peak periods, as is the case in the electricity industry – would that drive different consumer behaviors ? Customers currently have a choice in the source of some of their water supply – the use of rainwater tanks to replace some internal water uses, the installation of more water efficient appliances, and the option to connect to a third pipe system will all have significant impacts on the demands experienced in the system and the operations of the network.

Smarter Water Networks are needed. The use of hydraulic models can be extended by linking these to real time data and will be an integral part of a smarter water network.

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