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# Case Study: A Smart Water Grid in Singapore

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## Abstract

As aging water distribution infrastructures encounter failures with increasing frequency, there is a real need for integrated, on-line decision-support systems based on continuous in-network monitoring of hydraulic and water quality parameters. Such systems will form the basis of a Smart Water Grid, allowing water utilities to improve optimization of system operation, manage leakage control more effectively, and reduce the duration and disruption of repairs and maintenance. WaterWiSe is an integrated, end-to-end platform for real-time monitoring of water distribution systems that addresses these needs. This paper describes how WaterWiSe's sensing and software platforms have helped improve the operational efficiency of the water supply system in downtown Singapore.

## Keywords

Smart Water Grid, Continuous Monitoring, On-line modelling, wireless Sensor Networks, Water Distribution Systems, Management Efficiency, Leak and burst detection and localization, water quality

## Introduction

In cities around the globe, the drinking water distribution infrastructure is aging rapidly and encountering failures with increasing frequency. The result has been significant water losses (imbalances between water entering and leaving the system), inefficiencies in system operation, and concerns about the quality of drinking water that is provided to the consumer.

When major failures within the system occur, the utility must identify and resolve the problem with minimal disruption. With current monitoring technology this is not necessarily possible: in 2009, Los Angeles, Calif., experienced a series of pipe breaks and leaks causing significant disruption, which after expert review was associated with the introduction of a regimen of water rationing (Bardet et al 2010). However, the lack of monitoring data made this finding largely speculative. In 2010, a huge main rupture in Boston, Mass., caused two million residents of the greater Boston area to lose clean drinking water, prompting a state of emergency (Finucane et al 2010). The backup water supply did not meet US Environmental Protection Agency standards, and the lack of a real-time monitoring regimen for water quality caused a delay: data had to be collected and analyzed before authorities could assure residents that the water was safe for consumption.

The examples above illustrate a common situation among water utilities: there is limited on-line monitoring and analyzing capabilities within water distribution systems (usually at inlets to the water system), but an increasing need to reduce leakage, wastage and other operational inefficiencies (such as power consumption), while all the time maintaining a good public image. The idea of a Smart Water Grid is becoming increasingly favored as the natural next step to improve operational efficiency and improve understanding and prediction of demand and consumption in water systems.

From a water utility's perspective, a Smart Water Grid presents significant challenges in sensing, analytics and operational organization: measurements must be made and delivered more frequently, meaning more intelligent analytics must be available to transform the flood of raw data into useful information, and this information must be acted on in an appropriate and timely manner. There is also a non-trivial problem of integration: in-situ remote sensing systems are not typically well integrated with analytics and modeling software, leading to non-standard, hard-to-support solutions and inefficiencies in system operation, including management of overwhelming amounts of data.

This paper presents a case study about the operation of the WaterWiSe platform in Singapore with the Public Utilities Board (PUB). The WaterWiSe experience has given PUB considerable insight into the benefits of increased measurement frequency and density as well as the possibilities that are enabled with intelligent, hydraulics-based analytics.

## The WaterWiSe platform

WaterWiSe is a platform for real-time monitoring of water distribution systems that can be used by utilities to improve system management and operation by providing integrated measurement and analytics (Allen et al 2011). WaterWiSe can operate as a self-contained system with its own analysis and management interfaces, or can be integrated into a water utility's existing infrastructure and geographical information platforms. The core WaterWiSe platform has two key components: i) the Integrated Data and Electronic Alerts System (IDEAS), and ii) the Decision Support Tools Module (DSTM).

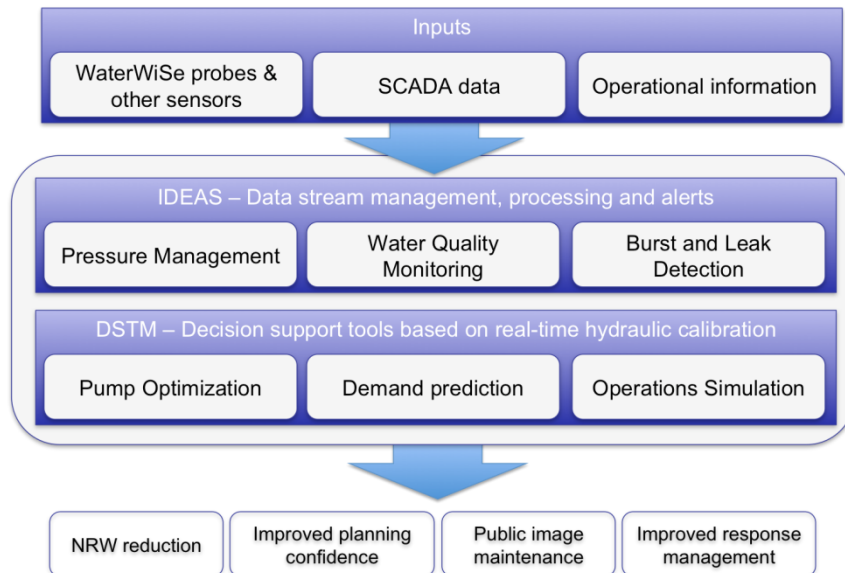


Figure 1: Overview of the WaterWiSe platform's functionality with a selection of applications enabled by both IDEAS and DSTM as well as a selection of benefits seen by the utility.

Figure 1 shows the WaterWiSe platform comprising IDEAS and DSTM in context. Inputs to the platform are shown (both data and information), as well as a selection of beneficial outputs seen by the utility. The IDEAS and DSTM boxes both show a selection of applications that are enabled by each component. These components, discussed in more detail below, provide key services to help both water supply network planning and operations teams in the office *and* in the field.

### Integrated Data and Electronic Alerts System (IDEAS)

IDEAS is responsible for data stream management, analytics and alerts. Real-time inputs presented to the WaterWiSe platform are aggregated and managed by IDEAS – examples of input sources are data from WaterWiSe multi-probes (or other in-situ sensors), SCADA data and operational information (for example, valve closures and pump schedules).

At this *data-stream* level, IDEAS performs analytics to detect and localize abnormal events, such as leaks and bursts, or longer-term trend changes. The case study presented in the following section shows examples where IDEAS has been used to detect bursts based on pressure transients and localize them to within tens of meters based on network structure and connectivity (Srirangarajan et al, 2010). If the data-stream analytics detect any abnormal events, IDEAS sends an alert email or SMS to each subscribed user. Alerts are configurable on a per-user basis.

### WaterWiSe multi-probes

WaterWiSe has an integrated multi-probe with associated wireless sensing node to sample and transmit data in real-time from within the network. This can be used as WaterWiSe's primary data source, although it is not required to operate IDEAS and DSTM if a utility has suitable existing data streams.

The sensor probe holds several commercial-off-the-shelf sensors for hydraulics (pressure, flow), acoustics (hydrophone) and water quality (pH, ORP and Conductivity). It is deployed within the network, directly inserted into the flow on pressured pipes. Data is typically sampled and transmitted at 5-15 minute intervals, although pressure and acoustic data is sampled at higher rates (hundreds of Hz) and thus can be processed locally to detect abnormalities using analytics that are similar to those used

by IDEAS. In this case, events and short data traces are sent to the WaterWiSe servers. Figure 2 shows an example multi-probe and sensor node deployment.

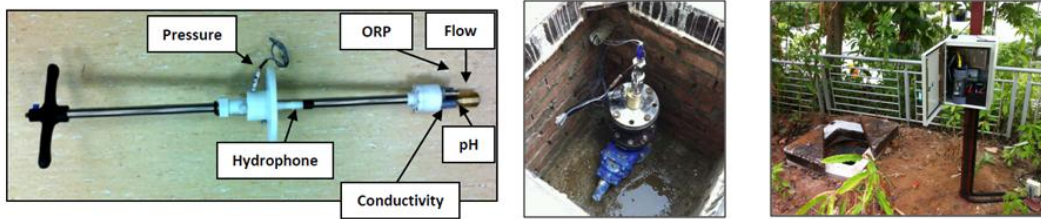


Figure 2: WaterWiSe sensor node and deployment

WaterWiSe sensor node placement is optimized according to an individual utility's requirements on IDEAS and DSTM applications – for example, IDEAS' leak and burst detection requires a higher density of measurements than DSTM's hydraulic calibration and modeling related tools. The node itself is easy to deploy with minimal space requirements, and is designed to have a low maintenance cycle.

### Decision Support Tools Module (DSTM)

DSTM uses the data aggregated by IDEAS to provide decision support tools on a demand-zone basis, rather than at a data-stream level. At the core of these tools is a real-time hydraulic model that calibrates the water network model every 15 minutes, using the most recently collected sensor data (Preis et al, 2010). To improve user confidence in the model, a user can compare model predictions with the actual data that was collected in a given time period. A selection of tools offered by DSTM is outlined in the rest of this section.

#### Demand prediction

Water consumption can be predicted in advance for a 24-hour rolling window. Predictions can be shown on a daily summary, with comparison to the actual consumption, as well as at 15-minute intervals, across the whole zone or in specific sub-zones.

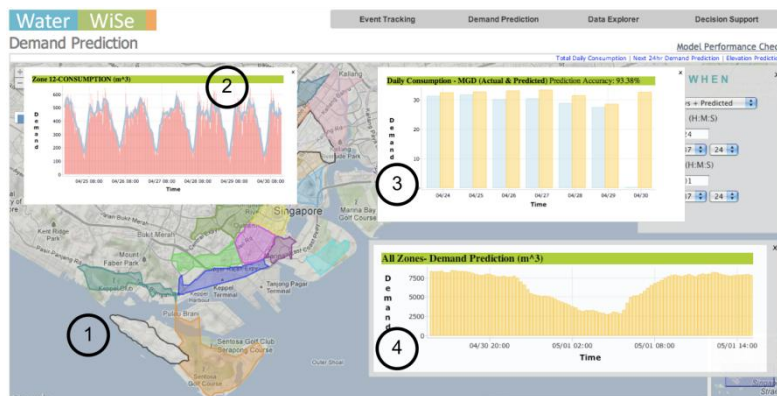


Figure 3: Screenshot of demand prediction interface with sub zone selection (1), sub zone consumption (2), per-day consumption prediction (3) and 24-hour rolling prediction in 15-minute intervals (4)

Figure 3 shows examples of the different modes of prediction. The prediction model assimilates historical trends as well as calendar and seasonal information (holidays, special events).

#### On-demand valve operation simulation

The operation simulation tool can be used by engineers to analyze the potential impact on the network of an operational event such as valve closures and pipe isolations. The simulation interface allows the engineer to select one or more valves to isolate and determine the times for which these valves will be closed. When it has completed, the simulation results are presented, identifying pipes that will have low or reversed flow, areas that will have abnormally low or high pressure, and customers that will be isolated by the operation.

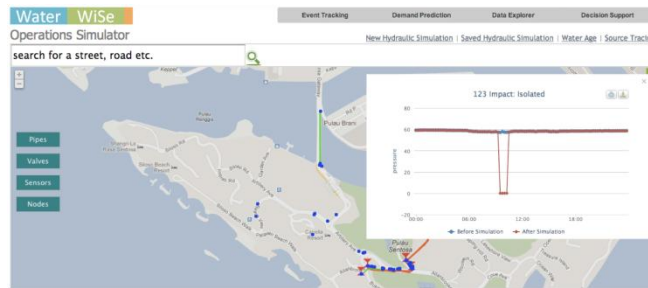


Figure 4: Example output from an operational simulation. Blue dots show isolated customers, red pipes show reversed flow and green pipes show increase velocity. The pop-up shows the predicted data trace with and without valve closure.

#### *Water age and water source analysis*

Using the hydraulic model, water age in the system can be predicted and compared against the real-time water quality measurements being taken in the system. This helps to identify areas of high water age that may be of concern. The mixing of water in the system from different reservoirs can also be predicted and visualized, showing relative percentages of water sources at any given location over user-defined time periods.

#### **Integration and Delivery**

WaterWiSe can operate as a stand-alone system and as well as a component in an integrated water management system. In stand-alone mode, a map-based web interface and dashboard is provided to both IDEAS and DSTM. This user interface is accessible through the web-browser on regular desktop PCs as well as tablet and smart phone, allowing for in-field analysis by the operations team.

#### **Case study: WaterWiSe in Singapore**

As a platform, WaterWiSe allows water utilities to better understand the behavior of their distribution network and thus improve its operation. This includes reduced response time to events, improved operational planning potential and associated efficiency savings. WaterWiSe also helps bridge the “experience gap” between senior and junior engineers, helping encapsulate expert knowledge into easy-to-run simulation/operational tools. To better illustrate the benefits of the WaterWiSe platform, this section gives a case study of WaterWiSe’s operation in Singapore.

At present, a 25-node wireless sensor network is deployed in the City area of Singapore (in collaboration with the Public Utilities Board of Singapore, PUB). The WaterWiSe platform is linked in to PUB’s SCADA system to exchange sensor data, and operates remotely with a stand-alone browser-based interface. WaterWiSe provides PUB’s water supply network operations and planning teams with decision support services including event detection (leaks, bursts), system modeling, demand prediction and operational simulation. At the same time as being an operational decision support system, WaterWiSe has been a test-bed to support research into leak and burst detection. Since 2009, WaterWiSe has been useful in several key areas:

#### *Pressure Anomaly Detection and Localization*

IDEAS has detected several pipe bursts through pressure transients, and numerous pressure abnormalities relating to both planned and unplanned system operations. Figure 5 shows an example, where several sensors within the vicinity detected a break that was traced back to a large main breakage

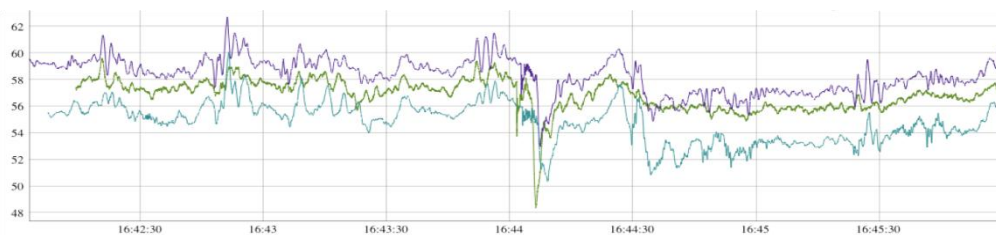


Figure 5: Detection of a burst event at several sensors that was traced back to a large main breakage (pressure is shown in PSIA)

In addition to detecting real burst events, IDEAS' leak and burst detection and localization has been validated with a series of controlled leak-off experiments, where leaks are created through fire hydrants. Early experimentation focused on detection of transients created by opening a solenoid valve into open air. This approach led to an average localization accuracy of 37.5m over 9 trials on a 1km<sup>2</sup> section of pipe network, using a wavelet-based detection approach and a graph-based localization method (Srirangarajan, 2010).

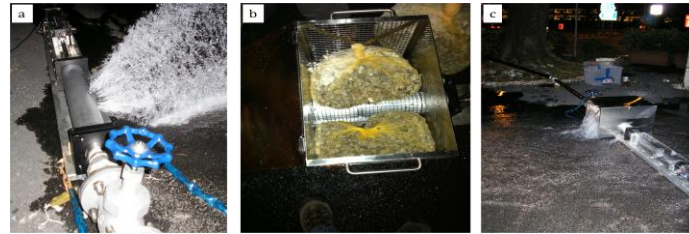


Figure 6. (a) Realistic burst mechanism connected during experiments showing open-air burst, (b) gravel pack covering the crack, (c) burst under gravel

Further validation of IDEAS' detection and localization capabilities has been enabled by the development of a mechanism to emulate water main leaks and bursts with improved realism. This device, shown in Figure 6, has three main components: (a) a replaceable pipe section with different types of cracks (longitudinal, latitudinal, pinhole and blowout), (b) a motor to control the speed of opening and (c) a gravel box to cover the pipe crack section. The mechanism improves control over leak size, opening speed and repeatability. In a recent test of 12 trials in the same 1km<sup>2</sup> section of pipe network, IDEAS detected all events successfully and was able to localize them to within an average of 20m of the actual location.

#### Post-event analysis

WaterWiSe has been used to trace back the sequence of events before a confirmed leak or burst event to understand which operations may have contributed to the leak.



Figure 7: An example of an event post-mortem, where (1) shows an unusual operation, (2) shows a suspected break event and (3) shows the first reports of leakage. Pressure is shown in meters.

Figure 7 shows a trace of events at several sensor sites where unusual system operation may have lead to leakage.

#### Understanding pressure characteristics

Working with the WaterWiSe platform, and having access to dense measurements, PUB has been able to see the characteristics of many normal and abnormal events.

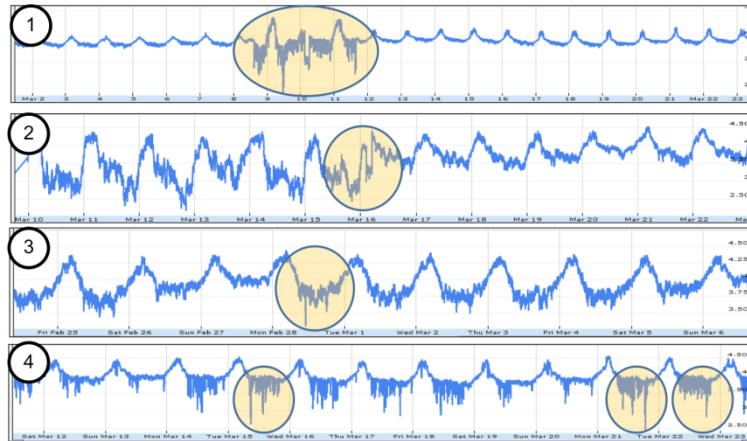


Figure 8: The characteristics of some normal and abnormal events: (1) a pipe isolation (from within the pipe), (2) removal of a non-approved consumer, (3) a fire hydrant operation, (4) near a construction site (pressure is shown in bar)

Figure 8 shows several examples. Figure 8.1 shows the pressure trace before, during and after a pipe isolation operation from a sensor deployed on the isolated pipe, which was kept pressurized during the operation. Figure 8.2 shows the response after removing an unauthorized water consumer from the network, and Figure 8.3 shows the response to a hydrant being opened. Figure 8.4 shows a pressure trace from an area of high consumption causing large transients at certain times of the day, but not usually at weekends; this was a construction area.

#### *Real-time feedback and validation*

Real-time email alerts and data visualization have helped PUB identify operation inefficiencies, perform remedial actions and immediately validate the results of these actions. In this example, a re-zoning operation was performed to reduce outflow and pump operation frequency. IDEAS' data, shown in Figure 9, confirmed this also reduced the magnitude of pressure transients seen within the zone.

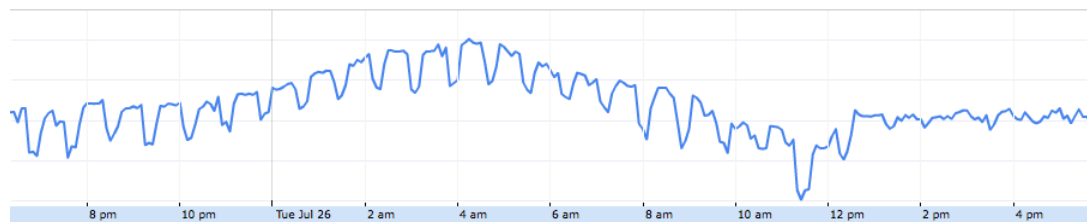


Figure 9: Validation of re-zoning operation to reduce outflow and pump operation frequency also removes pressure transients (pressure is shown in PSIa)

#### *Troubleshooting*

WaterWiSe's real-time data has given informative feedback to help quickly isolate complaints of low pressure in high consumption areas, saving time and frustration. In this example, a commercial customer was complaining of low pressure, prompting a field team to begin a search for leaks in the surrounding area. At the same time, the pressure traces collected by a nearby WaterWiSe node did not show any unusual activity, prompting the field team to return to the consumer, confident that there was no leak or burst in the vicinity. It was eventually determined by the customer that the commercial building's tank was too small to adequately supply the demand during peak consumption.

#### *Real-time modeling and sensor placement*

WaterWiSe's real-time hydraulic network model has provided PUB with an up-to-the minute view on demand and consumption in the network. This insight to system operation has helped longer-term planning of reservoir maintenance. The hydraulic model has also been used to determine optimal sensor placement for water quality sensors based on simulated contaminant injections within the system.

### *Real-time operations*

PUB engineers have used WaterWiSe's simulation interface to test-run numerous operational events and understand their impact. In particular, DSTM's simulator accurately predicted the impact of two complex events that resulted in pipe isolations. In each case, the impact of the isolation matched what was observed when appropriate valves were closed.

## **Conclusion**

To more efficiently operate and manage water distribution systems, it is important not just to intelligently increase the amount of measurements being made within the system, but also to use intelligent analytics to extract information from the data. A Smart Water Grid will allow water utilities to better manage their infrastructure from source to consumer through improved monitoring and data analysis. As an integrated, end-to-end, real-time decision support system, WaterWiSe provides key monitoring, decision support and feedback components that will form the building blocks of the Smart Water Grid.

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