ADVANCES IN LEAK PREVENTION TO MINIMISE UNACCOUNTED WATER

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ABSTRACT
Sydney Water in collaboration with the University of Technology Sydney (UTS), have deployed 229 permanent acoustic sensors and 150 lift and shift sensors across Greater Sydney to enhance their existing leak monitoring system to reduce customer disruption and unaccounted water loss. Locations have been prioritised for sensor deployment with the use of the Sydney Water-UTS pipe failure prediction model. With the development of a machine learning algorithm to reduce false positive leak alerts and a common web portal, this proactive approach to fixing leaks and breaks will be integrated into Sydney Water's business-as-usual. This will create planned and scheduled maintenance works for Sydney Water employees.

INTRODUCTION

Leaks and breaks are a challenge for all water utilities, and while by world standards, Sydney Water rates in the top 10% of water utilities for leakage levels, each year Sydney Water experiences 6,500 leaks and breaks across its large and complex water network of approximately 23,000 kilometres of pipework. This causes disruptions to its network and customers, resulting in costly pipe maintenance and an unaccounted water loss of 8%. With ever-advancing smart technology and the rise of the Internet of Things (IoT), acoustic sensors, as a method of leak detection, can effectively identify potential leaks for proactive and targeted repairs.

To improve leak detection, Sydney Water in collaboration with the University of Technology Sydney (UTS), has deployed 229 permanent acoustic sensors across five Central Business District (CBD) areas since December 2019. The Sydney CBD, Bankstown, Penrith, Chatswood, and Liverpool have been prioritised for sensor deployment using a pipe failure prediction tool model. Using this model, 150 lift and shift sensors have also been deployed across three small pressure zones (<2500 properties) in Bantry Bay, Wahroonga, and Holroyd.

Since their deployment, acoustic data from all sensors has been analysed, with signal processing algorithms developed to automate the analysis and increase the reliability of leak alarms. A web portal has been developed, which hosts the data from the range of acoustic sensor models in one location for ease and efficiency within Sydney Water's wider IT systems.

METHODOLOGY/ PROCESS

Pipe failure prediction tool

For the deployment of acoustic sensors, a water pipe failure prediction tool is used to identify high risk pipes, and the acoustic sensors are installed around the prioritised high-risk pipes in the selected areas.

Sydney Water and UTS have developed a data-driven solution for pipe failure prediction. The solution consolidated domain knowledge and advanced machine-learning techniques [1] to obtain a cost-effective approach to water pipe failure prediction in the water network.

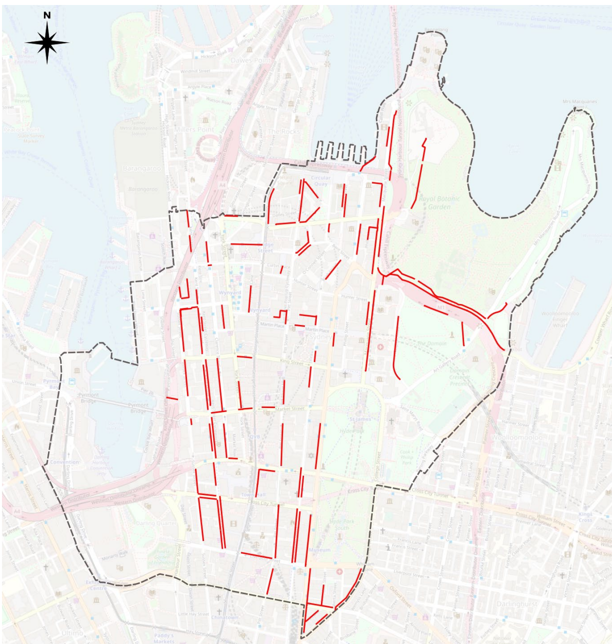

Figure 1: Priority map of Sydney CBD based on pipe failure prediction

Pipe failure behaviours are closely associated with pipe attributes such as sizes, materials, pressures, and environmental factors such as topography, soil types, etc. A high volume of historical pipe failure data, pipe attributes, operational data, topographic and soil information from public sources has been collected to conduct feature engineering and failure prediction, which is crucial to applying machine-learning techniques [1]. The developed failure prediction tool is used to prioritise the high-risk pipes for sensor deployment

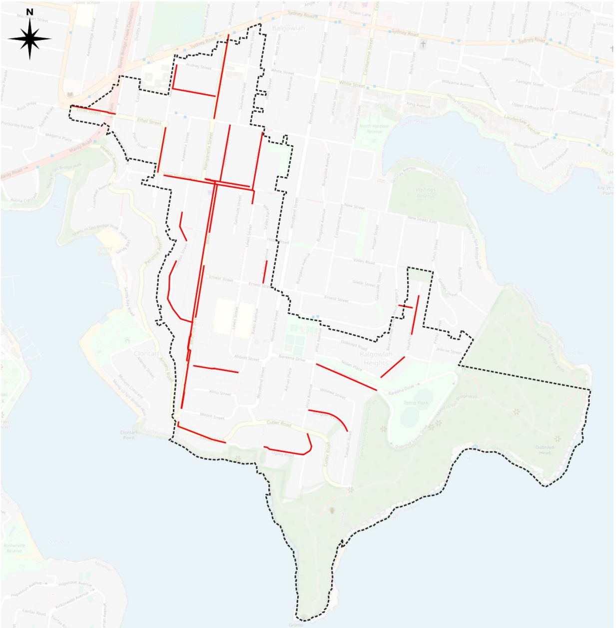

Figure 2: Priority map of Bantry Bay based on pipe failure prediction

Acoustic sensors

Acoustic sensors are fixed onto a pipeline structure and are used to sense real information about pipeline resources. Sound recordings are typically made between 2 and 4am, at a time when environmental noise from water usage and traffic are reduced (but not eliminated). Through the analysis of the recorded data, the water network can be effectively monitored for changes. As shown in Figure 3, Sydney Water has deployed a variety of permanent and lift and shift acoustic sensors across wider Sydney since December 2019.

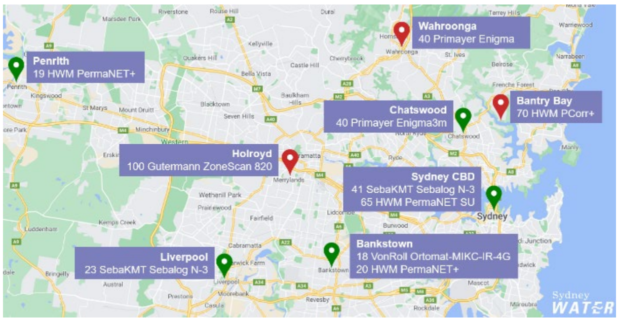

Figure 1: Deployment locations - permanent acoustic loggers (green), lift and shift loggers (red).

Individual manufacturer hosted sensor portals have leak alarms that are typically raised based on simple noise level thresholding algorithms, or correlations between loggers. As illustrated in Figure 4, this generally results in many false positive leak alarms being raised by the various systems.

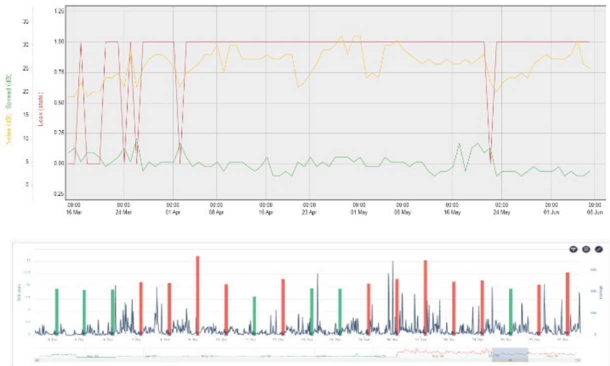

Figure 2: Portal false positive leak alarm examples - noisy locations (non-leak noise); HWM (top), Von Roll (bottom).

Instead of relying on these portals for accurate leak alarms, UTS performs weekly screening of the data to determine the likelihood of a potential leak, prior to Sydney Water crews attending site for further investigations. This screening involves signal processing and analysis of the audio files in the frequency domain to determine the persistence of noise for a given day (spectrogram - Figure 5 left) and across multiple days (power spectrum density - Figure 5 right).

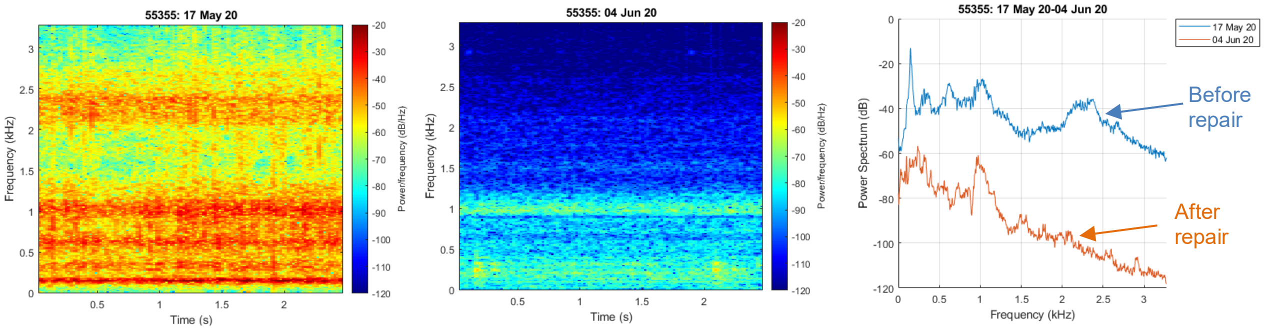

Figure 3: Sebalog N-3 signal processing example - before and after repair of leak found in Liverpool, caused by a hole on a 50mm service; spectrograms (left), power spectrum density plot (right)

Common web portal

UTS has developed a web portal that consolidates all six sensor providers' sensor data. It can also incorporate the pipe failure prediction tool to produce regular reports on leaks and high-risk pipes, which support operational teams in Sydney Water for better asset management.

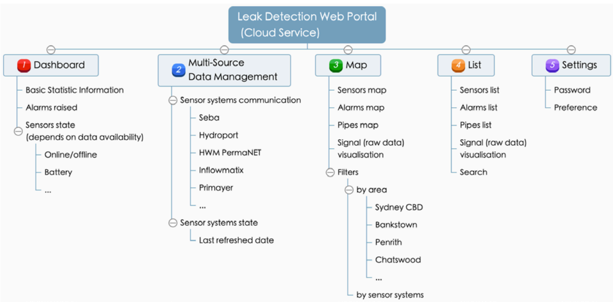

Figure 4: The architecture of the common web portal

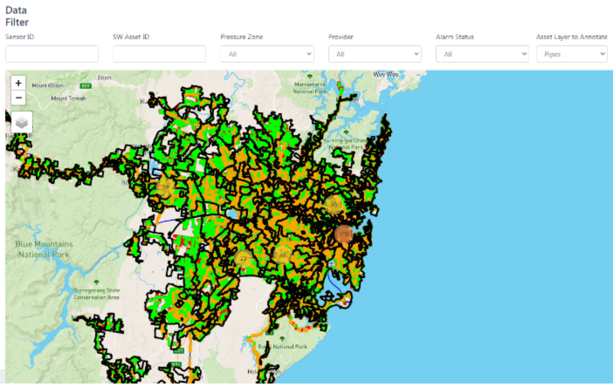

Figure 5: The dashboard view of the web portal

As shown in Figure 6, the common web portal is comprised of the following components:

- *Dashboard* (Figure 7): provides the basic attributes on sensors, e.g., sensor IDs, asset IDs, alarm status, pressure zones, etc. A data filter function can be used to allow the end-user to filter sensors by their attributes.
- *Multi-source data management*: shows the connection status of all individual sensor portals, i.e., whether the data from the portal is active, and the date of the last data update.
- *Map view* (Figure 8): visualises the sensor data on a map viewport. End-users can zoom out the map to check more details. The retrieved sensing data, e.g., sound recording files from all sensors can be accessed from the map panel.
- *List view* (Figure 9): shows the sensor data in list format. Filter functions are also provided.

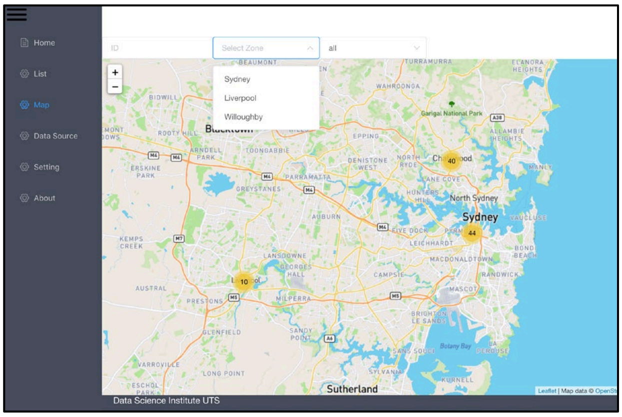

Figure 6: Map view of sensors provided by the common web portal

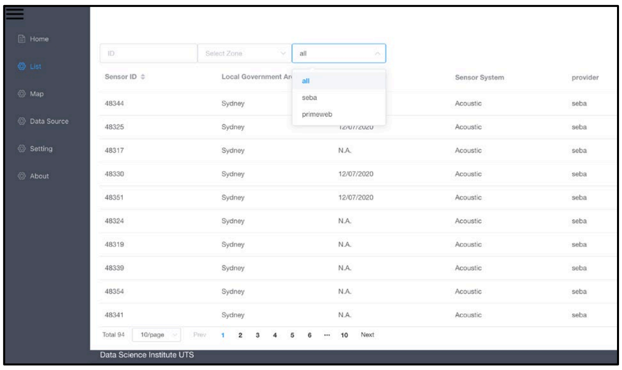

Figure 7: List view of sensors provided by the common web portal

Figure 8: Leak in Liverpool discharging into the stormwater pit, caused by a hole on a 50mm copper service

RESULTS

Permanent acoustic sensors

Since the first deployment of sensors in December 2019 in the Sydney CBD, 72 possible leaks have been detected across the five CBD areas. Sydney Water field crews have confirmed 52 of these as leaks and 2 as main breaks. Approximately 60% of these leak locations have matched with the pipe failure prediction tool model.

Faults detected by the sensors have included leaking hydrants, main taps, service lines, stop valves, dividing valves, main breaks, meter taps and meter couplings of varying leak rates. Most of these leaks and breaks had water running into the ground and not surfacing or appearing as runoff in drains. One leak detected by sensors in Liverpool (audio signals shown in Figure 5, leak shown in Figure 10) was previously undetected and not reported to Sydney Water, despite water discharging into a nearby stormwater pit at an estimated rate of 3 L/s.

The process of manual signal analysis, along with listening to the audio file has proven successful in identifying leaks and ruling out locations with other environmental (non-leak) noises that are raised by the manufacturer sensor portals as leaks. All confirmed leaks and false positives are documented, to assist with the development of an automated leak detection algorithm using a staged process of signal processing and machine learning to further reduce the number of false positive leak alarms.

As a result of thorough signal analysis, several sensor locations which did not appear in the manufacturer sensor web portals as having entered a leak state have also been raised for investigation, with all resulting in leaks being confirmed and located by Sydney Water. One recent example is a HWM PermaNET+ logger in suburban Penrith which is located between two large apartment buildings, with high levels of usage being detected even in the early hours of the morning, resulting in varied daily correlation locations.

Signal analysis revealed that a faint leak noise was present when the logger was first installed in the area in late November 2020. However, the HWM portal (Figure 12) did not indicate a potential leak until mid-December, when the leak noise appeared to increase in volume and shift to multiple peaks across several higher frequency bands as shown in Figure 13. In mid-February 2021, the logger was dislodged from the asset for approximately 6 days, which is visible in both the HWM portal and power spectrum density plots, where the leak noise seemingly disappears, then re-appears.

This leak has been confirmed by Sydney Water and marked up for leak repair. It is believed to be a disused main tap in the driveway of one of the large apartment buildings, approximately 30 metres away from the logger.

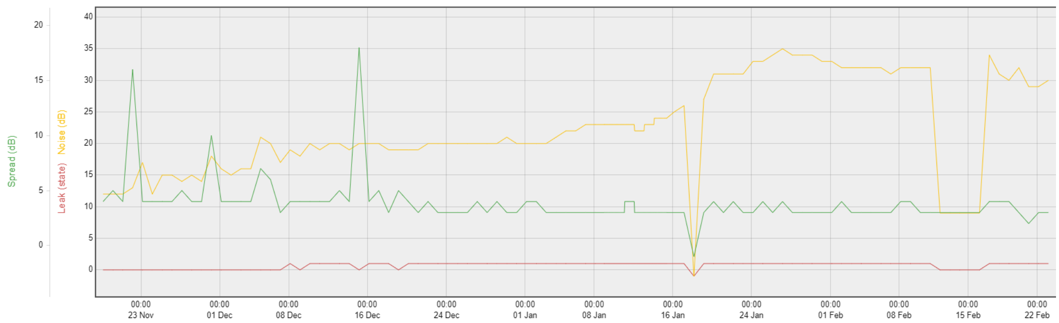

Figure 9: HWM logger noise level (yellow) and spread (green) from November '20 - February '21

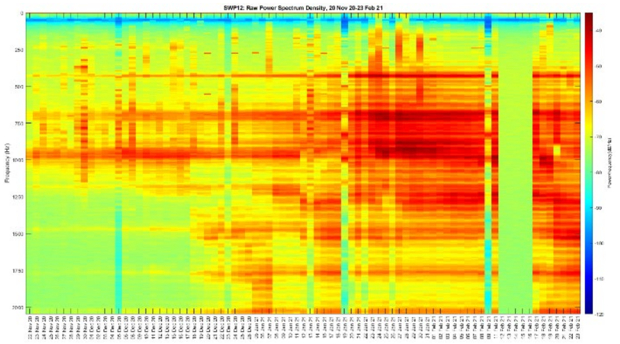

Figure 10: Power spectrum density plot for HWM logger in Penrith (November '20 – February '21) initially detecting a faint leak.

Lift and shift sensors

Three lift and shift logger deployments have been conducted since June 2020, in small pressure zones with fewer than 2500 service connections (Bantry Bay, Wahroonga and Holroyd) which have been calculated to have higher than expected MNF, which could be attributed to leakage in the zone. In total, sensors detected 16 leaks and 2 main breaks across the three targeted zones (all confirmed leaks).

100 Gutermann ZoneScan 820 loggers were deployed in Holroyd for a one-week period, with daily drive-by data collection required to obtain the daily recorded audio files. The data was then uploaded to the Gutermann Cloud portal, where autocorrelations and logger noise levels were displayed for the user to interpret. Engagement and analysis by the sensor provider were limited, with many automatically system generated correlations being raised with Sydney Water for further investigation on-site. Offline signal processing and analysis was hindered by the inability to bulk download audio files and the compressed nature of the available audio files, some of which also had harmonic distortion.

Since each targeted zone was a pressure reduced zone, elevated noise levels were expected to be recorded around the PRV locations in each of the deployment zones. Most of the consistent auto-correlation locations reported by the Gutermann cloud portal were clustered around the PRV location, as shown in Figure 13.

Table 1 shows the details of locations raised by Gutermann with Sydney Water for further on-site investigations. All three of the confirmed leaks were small and visible, with few or no confident autocorrelations calculated by the Gutermann Cloud system. Several locations raised with Sydney Water also led to no leak findings.

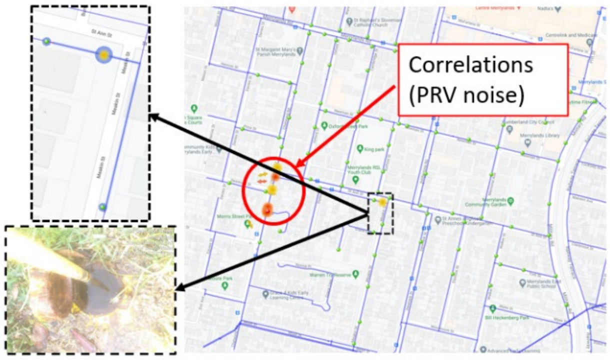

Figure 11: Example of correlations in Gutermann Cloud Portal on 18th June.

Table 1: Holroyd logger auto correlation results for locations raised with Sydney Water for investigation

Number of logger auto correlations (/6 days)	Leak Details
0	Visible leak – Broken hydrant leaking and water surfacing on road.
3: all 70% confidence and at the location of leaking SV.	Visible leak - Broken SV leaking and water surfacing.
2: 80% and 90% confidence.	No leak
1: 100% confidence.	No leak
0	Visible leak - constant running water in male toilets block.
0	No leak
Multiple, every day of the deployment (all around the PRV).	No leak

After confirming that the DVs in the zone were not breached, a second sweep of the zone was conducted with HWM PCorr+ loggers. This sweep, along with further investigation including logging the meters of high users in the zone (RSL club, bowling club, etc.) revealed no detectable leakage in the zone. It was concluded that the higher-than-expected MNF could be attributed to customers such as industrial and commercial units that consume water during the night-time. Customers are divided mainly into residential and non-residential types, whose water consumption can influence the actual MNF values. Though the residential consumption is assumed minimal at night, this may not be the case for non-residential consumption, which could have a different pattern due to their nature. For example, RSL clubs tend to consume more water at night than in daytime. Therefore, the observed MNF values need to be adjusted based on the types and numbers of non-residential units inside the area.

70 HWM PCorr+ loggers were deployed across two deployment stages to completely cover the Bantry Bay zone over a two-week period (Figure 14). These loggers were left in-situ for multiple days to collect data, with a daily drive-by data collection performed using a Patroller unit. The data was then uploaded to the HWM web portal for further analysis, with points of interest automatically flagged by the system as those loggers which had entered a system calculated "leak" state, as shown in Figure 14. Prior to sweeping the zone with loggers, a DV audit was conducted, with one breached DV located.

The MNF prior to the sensor sweep was ~7 L/s, with a target MNF of ~2 L/s expected to be achieved following leak location and repairs in the zone. In total, six leaks and two main breaks were confirmed as a result of the logger deployment. Of these leaks, only three were visible leaks, with water flowing onto the road or footpath, the remainder of the leaks were hidden. After the repair of these leaks and breaks, the MNF reduced to approximately 2.6 L/s.

Offline signal processing and analysis was limited in this deployment, due to loggers only recording audio files when they entered a system calculated "leak" state. Thorough on-site follow-ups were conducted by the contractors to further pinpoint and confirm all leak locations prior to passing information onto Sydney Water for further confirmation and leak repair action. This process was found to be most effective in reducing the number of false positive leak alarms raised by the HWM loggers and portal.

5 boxes of 8 Primayer Enigma correlating loggers were deployed across multiple deployment stages to completely cover the Wahroonga zone over a two-week period. These loggers are a traditional lift-and-shift logger, which are deployed overnight and collected the following day for data download (no drive-by data collection method available). Each logger recorded three one-minute-long audio files which were analysed offline following the retrieval of loggers.

Correlations were performed by Primayer and signal processing and analysis by UTS to raise points of interest for field investigation by Sydney Water technicians. From this joint analysis, ten points of interest were raised with Sydney Water. The field findings were as follows: 5 confirmed small leaks (meter couplings, meter taps and stop valves), 1 confirmed faulty DV, 1 suspected private issue that was repaired before the technician could attend to site, 1 suspected PRV noise, 1 high usage premises (large school with large sporting grounds and aquatic centre) and/or private leak (currently under investigation) and 1 possible false positive.

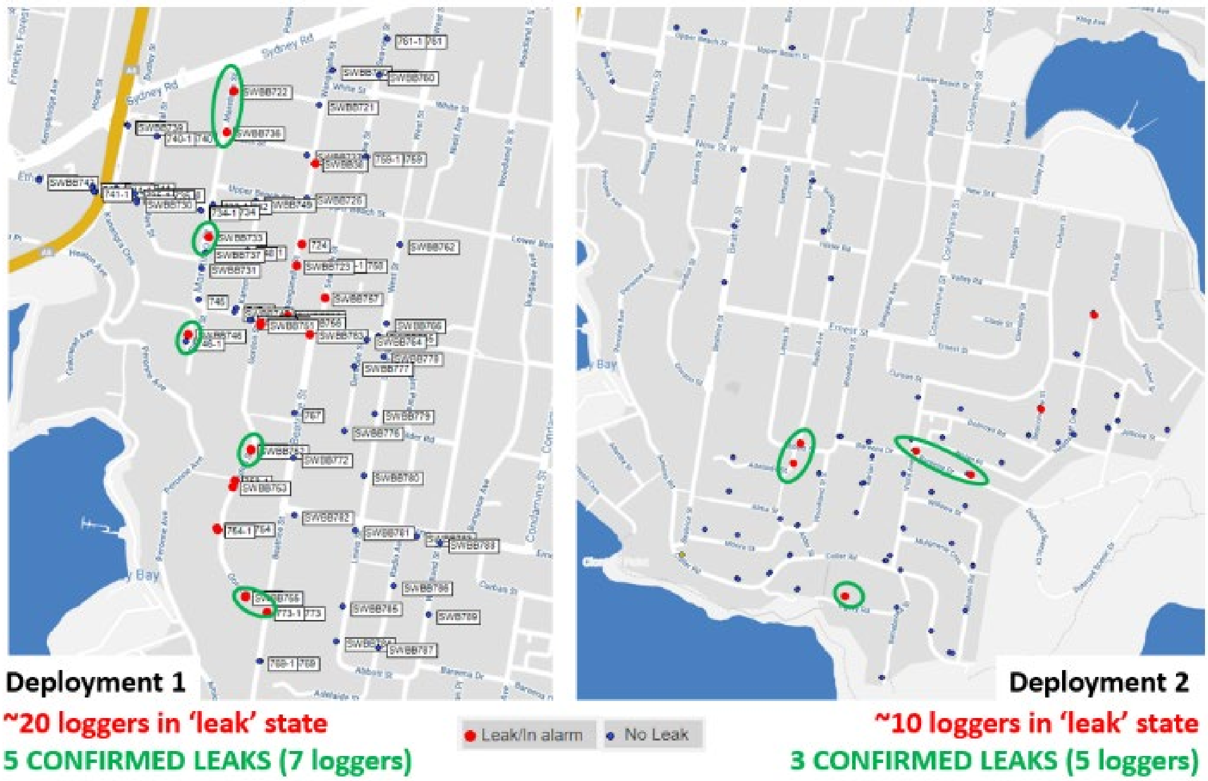

Figure 12: Bantry Bay HWM PCorr+ logger deployment locations and results

Pipe failure prediction tool

The prediction results are evaluated by comparing them with the ground truth data. This comparison looks at the percentage of detected failures with respect to the percentage of prioritised pipes (all pipes are ranked by their failure likelihood as output by the prediction tool). The prediction tools have been applied to forecast failures for critial and small pipes based on data from financial years 2018-19, and 2019-20.

As shown in Figure 15, more than 80% of failures can be detected if the top 20% of the pipes are inspected. Results demonstrate that the model is capable of providing valuable assistance to forecast and plan water main renewals with more confidence by using predictive analytics.

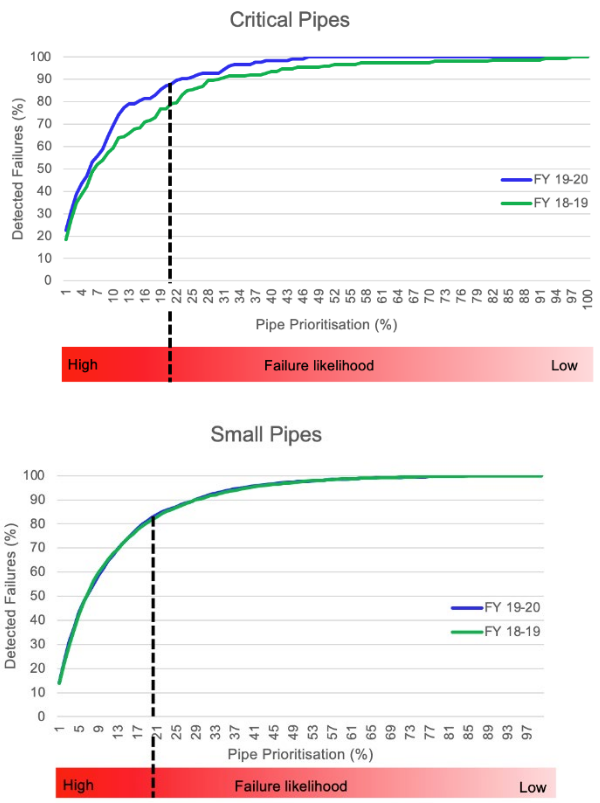

Figure 13: Failure detection and validation results

We have also compared the predicted failure locations with the locations with actual pipe failures, by checking the distribution of distances between the actual and predicted failures. As shown in Figure 16, about 80% of the predicted locations are within 200 meters of the actual failure locations. This can help water utilities to accurately identify potential failures.

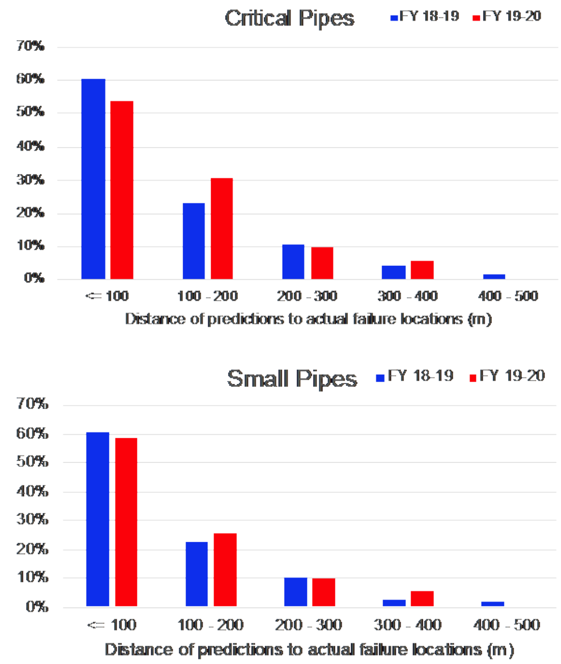

Figure 16: Failure location prediction and validation results

Common web portal

As shown in Figure 8 and Figure 9, the common web portal provides quick and easy access to leak alarms, in list and map views.

VALUE

The current deployment of sensors has saved 700ML/year and more than $3 million in water production costs in the Sydney CBD alone**.** The savings will increase with the growth of sensor deployments in other CBD areas, which target the prevention and reduction of unaccounted water. Sydney Water has a plan to install sensors in 118 small zones and in a few larger zones to deliver more impact.

CONCLUSION

Acoustic sensors are a proactive solution to detecting hidden leaks before they turn into main breaks and help to enhance Sydney Water's vision to create a better life with world class services.

By using acoustic monitoring capabilities, Sydney Water will reduce customer disruption, reduce unaccounted water loss, and allow Sydney Water resources to focus on repairing pipes proactively and efficiently. This will become business as usual for Sydney Water once a UTS machine learning model has the ability to accurately reduce acoustic sensor false alarms and provide reliable leak alerts in the common web portal.

Based on the UTS pipe failure prediction tool acoustic sensors were successfully deployed in the right place and at the right time, further validating its effective predictive capabilities. This will assist in future acoustic sensor deployments resulting in precise coverage across Sydney Water's 22,000km network.

The outcomes of this research ensure that Sydney Water is providing reliable and resilient services to its 5 million customers across Greater Sydney.

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