NON-REVENUE WATER SAVINGS, ACHIEVED THROUGH VIBRATION SENSOR INTEGRATED DIGITAL METERS

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ABSTRACT

Water utilities globally are focused on reducing non-revenue water. Water loss leaks and supply interruptions increase operation and capital costs, reduced service performance, and customer dissatisfaction.

Most water utilities in Australia and New Zealand are trialling or considering the business case for Digital Metering (DM). DM provides significant efficiency gains, including automated billing and improved customer engagement to reduce demand and detect customer-side leaks. The deployment of DM for any water utility is considerable and does not assist in identifying physical losses in the network. One approach to locating physical leaks in the network is to include vibration sensors as part of the DM deployment.

South East Water (SEW), a large water corporation in Melbourne, Australia, developed the Sotto® network leak detection sensor (Sotto), an innovative technology designed to be integrated into static Digital Meters. Sotto can be included in the DM deployment at marginal cost, providing early detection of leaks and reduced water loss.

A Sotto-based approach provides permanent surveillance of a water network to identify and locate leaks. Water utilities have insights that enable better planning of their maintenance and renewals, ultimately reducing non-revenue water.

SEW tested Sotto in a trial deployment of 5,000 Sotto-enabled digital meters in concentrated in 5 suburbs (including suburbs in and surrounding Frankston and Port Melbourne). SEW found that the trial successfully showed early detection and reduced water loss.

Jacobs was engaged in 2022 to review SEW’s findings and extrapolate the results across the wider SEW customer footprint in advance of a submission to the regulator for their next regulatory period. SEW’s business case assumes at least a 1% reduction in water purchased from Melbourne Water is achievable with Sotto-enabled meters. Jacobs’ analysis determined that installing Sotto sensors will improve the early detection of leaks and meet this target in either a

density of one Sotto per property or one every two properties, with the former providing a better return on SEW's investment.

This paper details how Sotto can be useful in network leak identification and location, potential operational changes and the benefit analysis undertaken by Jacobs presented as a case study. The case study results do not infer or imply that equivalent results may or could be experienced by any other water utility.

KEYWORDS

Non-revenue, leakage, sensors, digital, IoT, savings, vibration, integrated sensors, digital meters

PRESENTER PROFILE

David Lo Jacono is a Global Principal for Data Science and leads the Advanced Data & Analytics team for Jacobs. He builds data expertise through a data-centric approach across multiple domains. He spent 20 years in academic research as an interdisciplinary scientist. David focuses on applied AI/ML, coupling sensors and engineering modelling.

1. INTRODUCTION

In Australia and around the world, we live with the harsh realities of climate change, including higher temperatures, less rainfall and heightened bushfire risk. The UN Secretary-General Antonio Guterres has declared climate change a 'code red for humanity'. The CSIRO estimates that river flows are likely to reduce by 10 to 25% in some regions of Australia by 2030, but further climate change could produce even more profound reductions of water resources in southern Australia (Prosser and Chiew, 2011).

Water resources are vulnerable to both climate variability and change. Climate change and its impact are expected to worsen, with droughts, floods, fires, and other extreme weather events threatening our water, food security and health. As our urban populations grow, given constraints on increasing supply capacity, water utilities are considering supplementing the water supply with recycled water and desalination. These alternative sources lead to increased financial and environmental costs.

The options for water utilities to increase water supply are limited and expensive. Water reuse/recycling and desalination can supplement supply but may not be environmentally friendly. Manufactured water, such as desalination, is an expensive, energy-intensive option with a high carbon footprint; however, it will augment water supplies during drought. Water utilities are seeking ways to delay such an augmentation as long as possible.

Australia's water utilities are taking measures to increase the efficiency of its water distribution network, focusing on reducing water losses and optimising operating costs. A consequential effect of managing leakage is a reduction in the energy/materials required to treat or transfer the water.

2. SHORT BACKGROUND IN LEAKS AND LEAK DETECTIONS

2.1 NON-REVENUE WATER

Non-revenue water is defined as water that is lost in the system before it is delivered and billed to the customer. The International Water Association (IWA) Task Forces (Lambert, 2003) produced an international best practice standard approach for water balance calculations, depicted in Table 1. A water balance is used to calculate the volume of water in and out of a system. Figure 1 is the standard water balance applied by water utilities in Australia and internationally.

Table 1: IWD Australian Standard water balance definition (International Water Association, 2003)

<table>
<tr><td rowspan="9">System input volume</td><td rowspan="4">Authorised consumption</td><td rowspan="2">Billed authorised consumption</td><td>Billed metered consumption (including water exported)</td><td rowspan="2">Revenue water</td></tr>
<tr><td>Billed unmetered consumption</td></tr>
<tr><td rowspan="2">Unbilled authorised consumption</td><td>Unbilled metered consumption</td><td rowspan="7">Non-revenue water</td></tr>
<tr><td>Unbilled unmetered consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorised consumption</td></tr>
<tr><td>Metering inaccuracies</td></tr>
<tr><td rowspan="3">Physical Losses</td><td>Leakage on transmission and/or distribution mains</td></tr>
<tr><td>Leakage and overflows at storage tanks</td></tr>
<tr><td>Leakage on service connections up to the measurement point</td></tr>
</table>

Water losses can be apparent losses or physical losses. For example, apparent losses can result from water theft and metering inaccuracies, while physical losses are from leaks in transmission mains, storage facilities, distribution mains or service connections.

In this document, including the case study (Section 4), Non-Revenue water losses are defined as leakage on transmission and/or distribution mains as well as leakage on service connections up to the measurement point, as depicted in blue, in Table 1.

2.2 PHYSICAL LOSSES

Water utilities have developed strategies to detect and manage water losses in the network. These include the construction of District Metering Areas (DMAs), acoustic leak detection, customer reporting of leaks and other sources of data.

Drinking water distribution systems typically consist of trunk or major distribution pipe, secondary distribution pipes and customer service line pipes. A water utility's pipework topologies have often been unstructured in Australia until recently. A structured DMA or zone approach usually supports water balances more accurately. Many water utilities are converting to DMAs and zones; however, these can be costly to establish and maintain.

Many water utilities will construct DMAs or zones as a leakage management tool allowing for other techniques in the field like step testing, targeting these activities and measuring performance against targets. Digital Metering (DM) supports a water balance or Minimum Nightly Flow (MNF) by recording and transmitting the water use at set, synchronised intervals. DMAs, however, are unable to ascertain how many leaks are present in the area, how large each of them they are and their location within the DMA.

The deployment of DM is widely acknowledged as a baseline strategy to detect and reduce apparent losses and revenue water loss. A characteristic of many Digital Meters is their accuracy at low flow rates; furthermore, this accuracy is also maintained over the life of the meter. However, DM does not assist in identifying physical losses, hence should also be used in conjunction with other strategies to enable the water authority to detect leaks in the network.

Acoustics in detecting leaks

Leaks in pipework emit audible sounds and water utilities have long used listening devices to listen for leaks. The relative intensity of the sound can be used to indicate the proximity of a leak. Originally by deploying teams of people with listening sticks, water utilities could approximate the location of leaks.

More recently, water utilities have deployed portable acoustic correlators, hydrophones, or other electronic listening devices fixed to pipework or fittings. They are however rarely permanent due to the capital and deployment costs required to undertake leakage management activities across a wider area. Advancements in Internet of Things (IoT) technologies with low power requirements have enabled lower-cost monitoring of leaks, including permanently deploying low-cost sensors integrated into DMs.

Improving accuracy by overlaying data sources

Locating leaks in a water distribution network is challenging, with water utility leak experts often relying on multiple technologies and techniques to detect and locate leaks. By combining the data from water balance within DMAs and other detection technology, the water utility can build a body of evidence that helps pinpoint any leak's severity and location. Traditionally this analysis has been performed manually however in the future, water utilities can use IoT sensors integrated into DM to provide daily data to platforms that allow for automated detection and location of leaks. Leading to optimised resolution and avoiding bursts.

2.3 OPERATIONAL LEAK DETECTION, ISOLATION AND REPAIR

There are many approaches to leak detection, leak isolation and repair. The approach employed by the water utility impacts the time required to isolate and locate a leak.

A. **DM & DMA approach:** DM facilitates regular, precise water use data and greatly assists the MNF analysis, identifying losses within a zone or DMA. However, by definition, DMAs can range in size, up to 2500 connections. The MNF analysis process identifies if there is a leak but does not provide further details on its location. To identify the location of leaks, utilities generally issue field work orders. Such works may include temporary acoustic leak detection devices, crews with acoustic correlators, visual inspections, or other methods. These techniques can be slow and costly, especially for leaks in service lines which can be numerous and hard to find.

B. **DM & DMA & integrated meter leak detection:** DM equipped with integrated leak detection provides leak detection and location information as well as the MNF data. Integrated meter leak detection (on the network) proactively provides information on a regular, daily basis which is used to predict the location and indicative magnitude of leaks in service pipes and main. Equipped with more accurate location information, field crews can locate the leaks more rapidly, reducing costs. Non-revenue water physical losses are reduced compared to the first approach (traditional DM & DMA).

C. **DM & integrated meter leak detection (No DMA):** Water utilities may not have DMAs across their service area. DMAs can be costly to establish and may not be the priority to reduce water losses. DM has many use cases, and a water utility may roll out a DM network for reasons other than Water Balance and MNF analysis support in a DMA. Other benefits may include customer engagement, billing and customer leak detection.

Table 2: Approaches for leak detection and the effect on water utilities operations

Approach	Leak or Burst Prediction Analysis Options	Location and Isolation
A. DM & DMA	Minimum Night Flow analysis Pressure monitoring	Field leak location detection required across the DMA.
B. DM & Integrated meter leak detection & DMA	Minimum Night Flow analysis Pressure monitoring Integrated meter leak detection	Field targeted leak detection within a property or immediate surrounding properties. Reduces operational field location time. Quantitative loss may be inferred, assisting in prioritisation.
C. DM & Integrated meter leak detection (no DMA)	Pressure monitoring Integrated meter leak detection	Field targeted leak detection within a property or immediate surrounding properties. Reduces operational field location time. Qualitative loss is inferred, with limited quantification.

Regardless of the distribution topology and utility approach, integrated meter leak detection provides a permanent, daily leak location and detection layer that allows water utilities to prioritise and reduce the time to locate leaks. When leaks are identified, the field crew can be dispatched to locate a leak more rapidly. SEW determined that initial service crews could more precisely locate and repair leaks (depending on leak size) using the data from in-meter leak detection.

The remainder of this paper presents the specifications of the Sotto sensor that can perform integrated meter leak detection. It also outlines further analysis by Jacobs and SEW to determine the effectiveness of leak detection over the SEW network in the scenario of **DM & integrated meter leak detection (with Sotto) / No DMA.**

3. SOTTO AND ANALYTICS - CONTINUOUS LEAK DETECTION

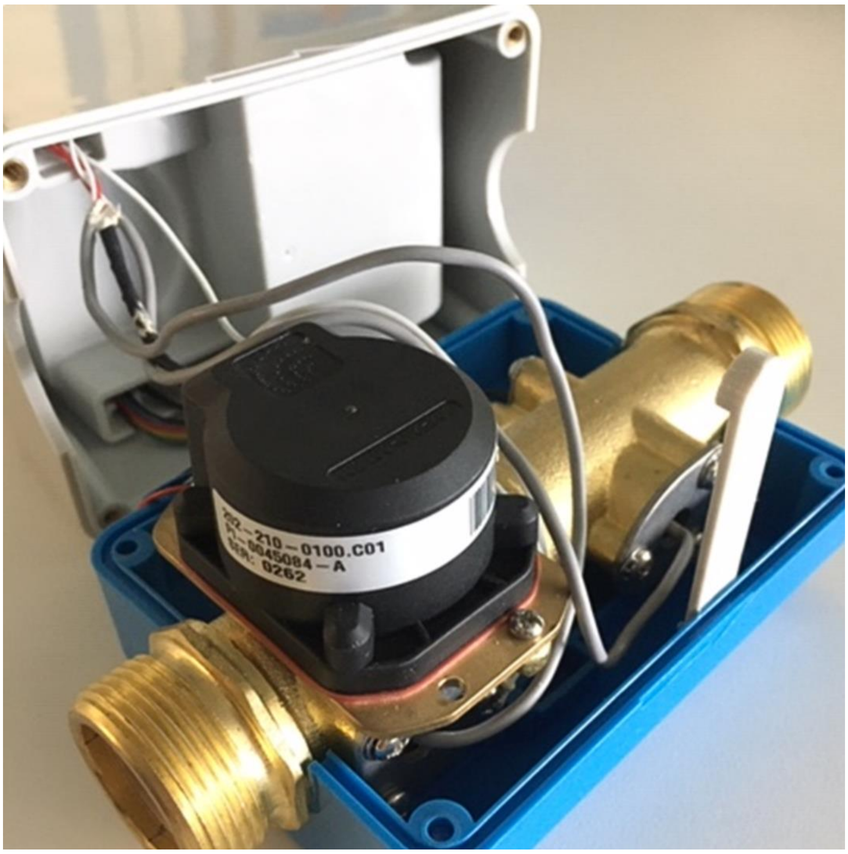
Integrating vibration sensors into DM in an advanced meter infrastructure deployment is an innovative approach to cost-effectively identifying network leaks. SEW has integrated the Sotto sensor into digital water meters with active deployments in their network. Sensors continuously monitor the network to record vibrations as a digital signal. A platform ingests and stores the vibration data collected, which is then used to triangulate and identify potential leak locations and intensity.

Water utilities considering a DM deployment program have an opportunity to include Sotto in the DM fleet at a marginal cost to deploy, manage and operate. It has the potential, as SEW found, that deploying integrated DMs with Sotto improves the net present value of the DM business case to make it more economically viable.

3.1 SOTTO SENSOR

The Sotto sensor is small enough to be packaged within a digital meter installed at customer properties. While digital meters can identify leaks on the customer property, the Sotto sensor is primarily tuned to detect leaks on the network infrastructure before they reach the surface.

Figure 1: Sotto sensor internals



Specifications provided by Iota:

- Fully integrated into the digital meter
- Utilises the integrated digital meter battery (reducing the total battery life by approximately 6 months (from 10-15 years)
- Uses the digital meter NB-IoT communication to minimise telecommunication costs
- Gathers nine data samples at 15-minute intervals, usually between 12am and 2am daily, refer to Figure 2.
- Small incremental cost when integrated into the DM
- Detects leaks up to 80 metres (Note this is indicative and based on preliminary studies conducted by SEW. The detection range will fluctuate based on leak size, the network configuration, pipe material and soil type)

Figure 2: Typical Sotto signal and associated flags

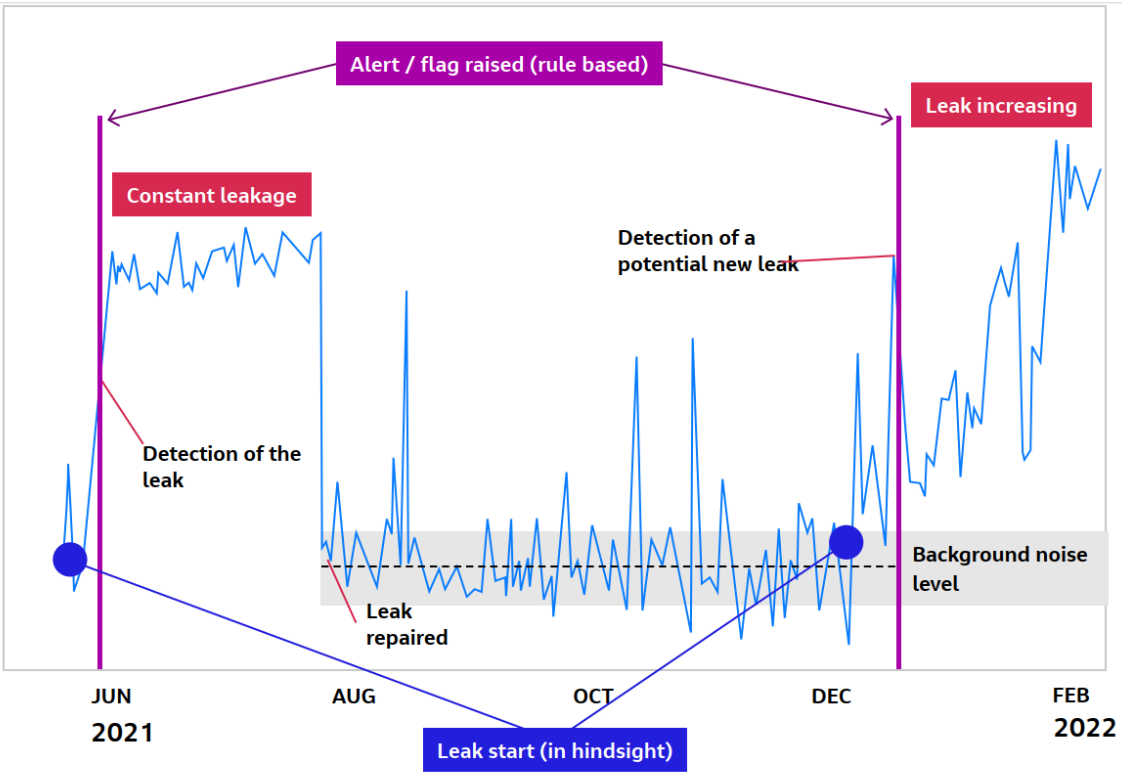


Figure 2 provides an example of the raw signal from Sotto (continuous blue line) and depicts how leaks are detected in the network. An algorithm determines potential leaks based on intensity behaviour. For example, the change in early June indicated a probable leak on the distribution side (several consecutive days at a higher-than-normal value). Subsequently, the leak was repaired at the end of July, immediately lowering the signal intensity. Note that in this example, in early December, detection indicated a new potential leak to be investigated (which continued to grow).

3.2 SOTTO DATA ANALYTICS

The Sotto sensors produce vibration data, which is analysed to determine the intensity and location of leaks in the service and local distribution pipes. Intrinsic to a DM and Sotto deployment is an Enterprise IoT platform to manage the devices as well as ingest and store the resultant data. SEW developed its own IoT Platform, Lentic, to provide this functionality for the digital meters and Sotto. It should be noted that any Enterprise IoT platform could be configured to provide this functionality. Once Sotto vibration data is ingested and structured in an Enterprise IoT platform, it can be made available to analytics, visualisation or reporting applications. Water utilities considering a Sotto deployment should determine their IoT platform requirements.

Data analytics are required to process the vibration data. Any potential leak will have a score related to its intensity recorded during the night when ambient noise is at its lowest. The intensities registered by some DM with Sotto at properties in the immediate neighbourhood or surrounding street can be used to approximate leak location through triangulation. Accuracy can be further improved for leakage flow rate when the data is combined with MNF analysis from the DMA. Processing the data includes determining and removing false positives (e.g. traffic noise, sprinklers) specific to the network.

Figure 3 depicts the vibration data from one sensor pre- and post-repair. Visualising every sensor on a map, including their magnitude (shown by coloured dots, red being closest to the leak), helps locate the approximate site of the leak. In this example, water surfaced very close to where the analytics indicated a leak existed, as depicted in the photos.

Figure 3: Left: Pictures associated with a particular leak. Right: Screenshots of the vibration sensors before and after the leak repair (note the colours flagging the leak). Chart: Vibration data from a given sensor showcasing the rise of the measured intensity (rising since June 2022) above a certain threshold (here in November 2022), triggering a flag and then an immediate drop in intensity post-repair (January 2023). An analysis based on each sensor's time history contributes to determining the leak's size and location.

The characteristics of the vibrations that reach the Sotto-enabled meter are affected by many factors, including the pipe material, soil type, pipe topology, and size and type.

Note, the financial modelling presented in Section 4 does not include the cost of the Enterprise IoT Platform, nor the Data Science analytics costs to interpret and locate the leak.

4. SEW CASE STUDY – LEAK DETECTION USING SOTTO

4.1 INTRODUCTION

In June 2022, an analysis of the SEW Sotto trials within several neighbourhoods was undertaken to determine the effectiveness and financial viability of including the Sotto sensor in a DM deployment to determine leaks in the network. Jacobs Smart Water SMEs, Digital Advisory and Data Science teams designed and implemented this analysis in conjunction with SEW. The information presented is intended to provide a case study for reference and insight when considering trialling and scaling leak detection sensing with these technologies.

The analysis results informed a pricing submission and broader investment decision to include Sotto in the advanced metering deployment for SEW. SEW sought to prove the hypothesis that a 1% reduction in non-revenue water purchased from Melbourne Water is achievable with a Sotto-enabled network.

The analysis was structured based on the following **Problem Statements** unique to SEW:

1. *What is the success rate of leaks being detected in an existing neighbourhood network using vibration data from Sotto?*

2. *What is the financial viability of including the Sotto sensors in an integrated digital meter deployment at every property?*

3. *What is the financial viability of Sotto sensors in an integrated digital meter deployment at every second property?*

SEW's current methodology of leak detection, location and subsequent repair is referred to as Business as Usual (BAU).

4.2 DETAILED PROJECT METHODOLOGY AND FINDINGS ON SEW CASE STUDY

The project was divided into two Phases to answer the problem statements.

Phase 1 – Estimation of the volumetric water impact of Sotto deployment – evaluation of the saved volume of water if the Sotto sensors were deployed at the network level.

Phase 2 – Financial calculations – estimation of total financial costs and uncertainty quantifications. For this phase, three scenarios were considered:

Scenario A: 1:1 Sotto sensor deployment density (i.e. one sensor at every property)

Scenario B: 1:2 Sotto sensor deployment density (i.e. one sensor at every second property)

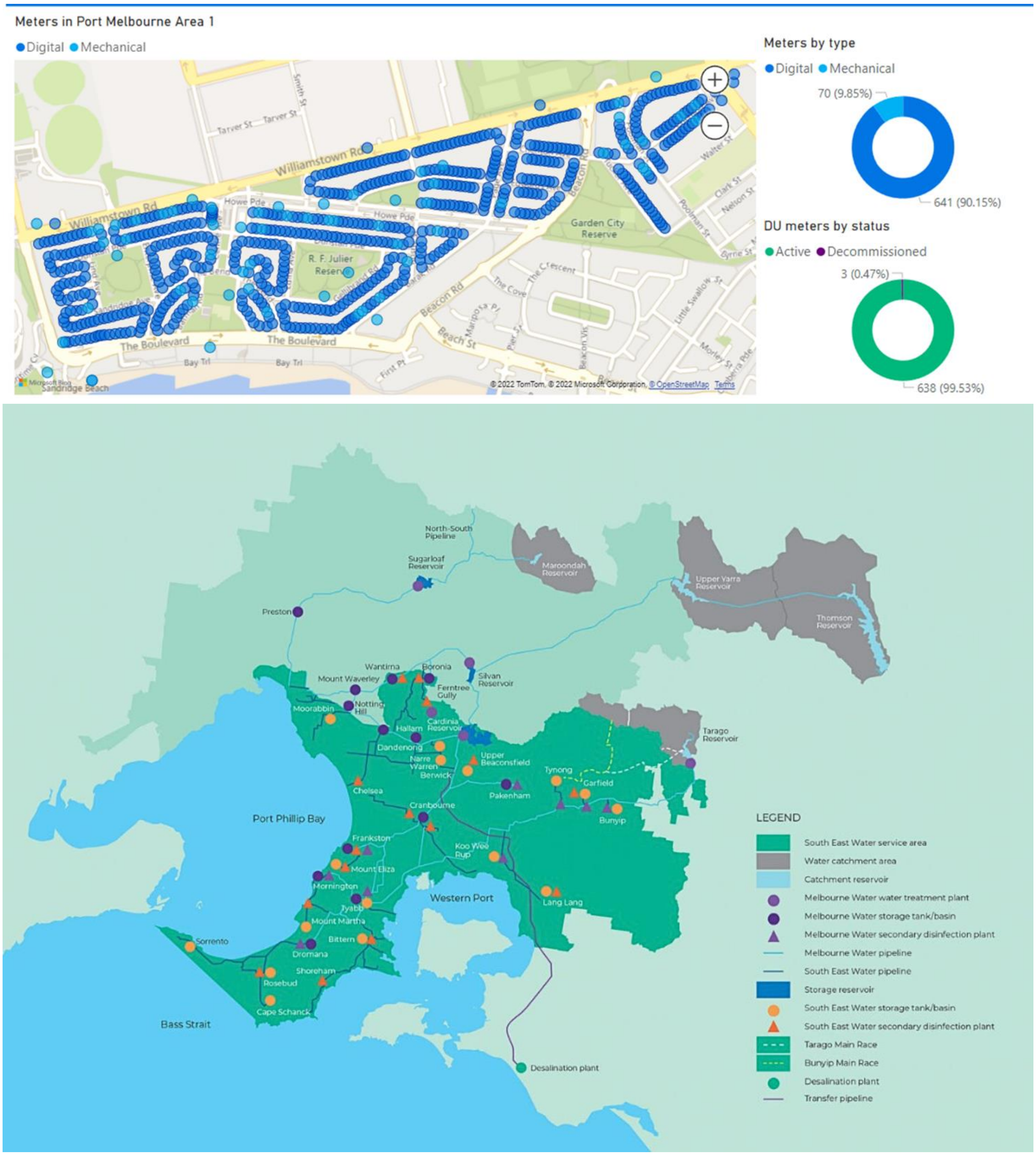
Scenario C: BAU - Do Nothing Baseline (No Sotto sensors deployed)

The existing management of leak detection activities would be maintained as part of BAU.

Jacobs leveraged data science methods and statistical analysis augmented with external insights to provide an estimate of potential benefits. Jacobs Smart Water, Digital Advisory and Data Science team worked in close collaboration with SEW's Data Scientist and other key stakeholders. The primary data utilised in the analysis included (and not limited to):

- The results of the leak detection trial from the 5100 sensors already deployed in SEW's network concentrated in 5 suburbs (including suburbs in and surrounding Frankston and Port Melbourne). This included comparing data from the Port Melbourne DMA trial (700 properties) undertaken in conjunction with deploying Sotto sensors in the network, see Figure 4.
- SEW's annual non-revenue water calculations, including FY20/21
- SEW's historical data on non-revenue water and active leak detection costs, numbers and types of leaks identified (along with, as available, leak size estimations) and cost to repair
- Draft Sustainable Economic Level of Leakage Report, September 2020 and ongoing Leakage Benchmarking Project report and findings
- National Performance Report published by Bureau of Meteorology

Figure 4: Top: Port Melbourne DMA trial area (approx. 700 sensors deployed), Bottom: SEW coverage area



Detailed Findings

Phase 1 Findings: Estimation of the volumetric water impact of Sotto deployment

- A portion of water can be saved through early detection of leaks. These leaks include leaks already detected by BAU and leaks that are not detected in BAU.
- The volume of water saved from Sotto's **early detection** of leaks that BAU would have detected:

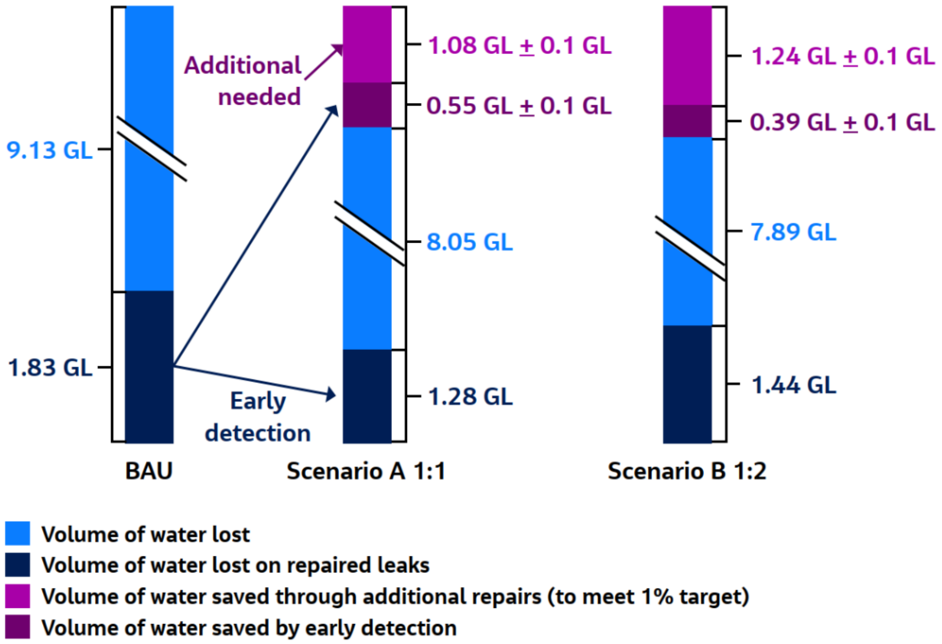
- 550 ML of water saved for Scenario A
- 390 ML of water saved for Scenario B

These values are represented as red-hatched areas in Figure 5 below.

- Modelling was undertaken to determine the number of leaks detected and subsequent water saved if additional repairs (leaks undetected by SEW-BAU) were undertaken.

In both Scenarios, SEW can achieve at least a 1% reduction in water purchased from Melbourne Water with a Sotto-enabled network. Figure 5 summarises the findings expressed in the volume of water lost at the network level. It includes the remaining volume of water to be saved (blue hatched), targeting a 1.63 GL volumetric reduction in leakage. The bar on the left labelled as BAU represents all Non-Revenue Water. Installing Sotto sensors will result in water savings. Due to early detection, water savings are possible without changing the number of repairs (pink hatch). Water savings are also possible by increasing the number of repairs (blue hatch).

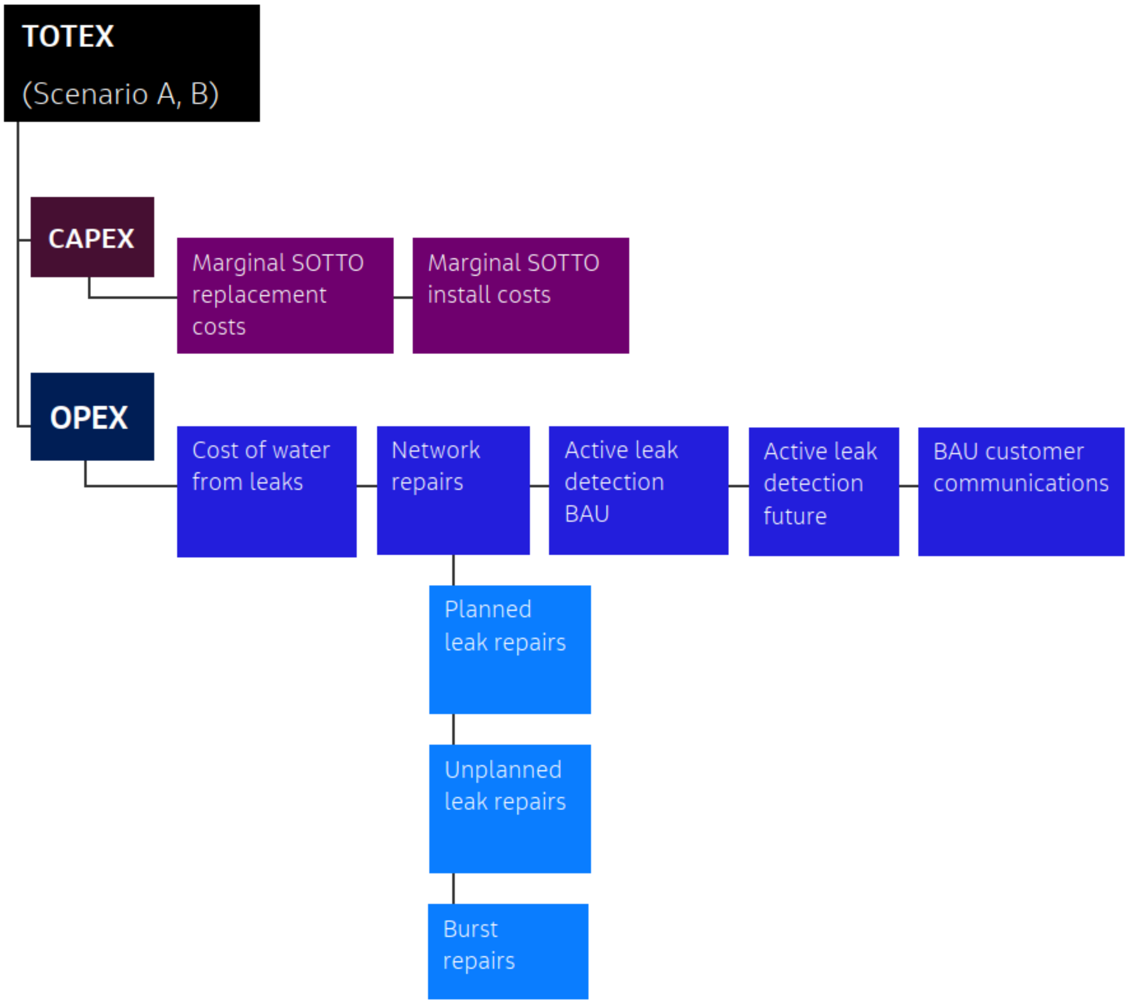
Figure 5: Potential leak savings from the Sotto deployment scenario throughout the SEW network



Phase 2: Estimation of total financial costs and uncertainty quantifications

A TOTEX financial model was used to estimate a 25-year time horizon to understand the benefits to the SEW NRW operational cost profile. The TOTEX model comprises many variables, as depicted in Figure 6. As instructed by SEW, the model solely focuses on the additional marginal cost of the Sotto sensor and does not include the cost of the digital meter which it is embedded into. This cost does not include the Lentic platform nor the analytics required. Scenario C only features an OPEX component. Scenario A and Scenario B have both a CAPEX and OPEX component.

Figure 6: Marginal TOTEX Model economic calculation CAPEX and OPEX components



The TOTEX model produced the results described in Table 3. The marginal TOTEX Calculations represent the future state cost profile attributable to leak detection operations at SEW.

Scenario A represents a 4.5% saving in TOTEX, and this includes a 10.9% saving in OPEX. The additional repairs are also included in the model, and they represent the repairs that aren't undertaken currently (1330 repairs out of 7600 additional leaks detected) but are required to save 1.63 GL water (water saving target). The estimated cost of these repairs is included in the OPEX costs.

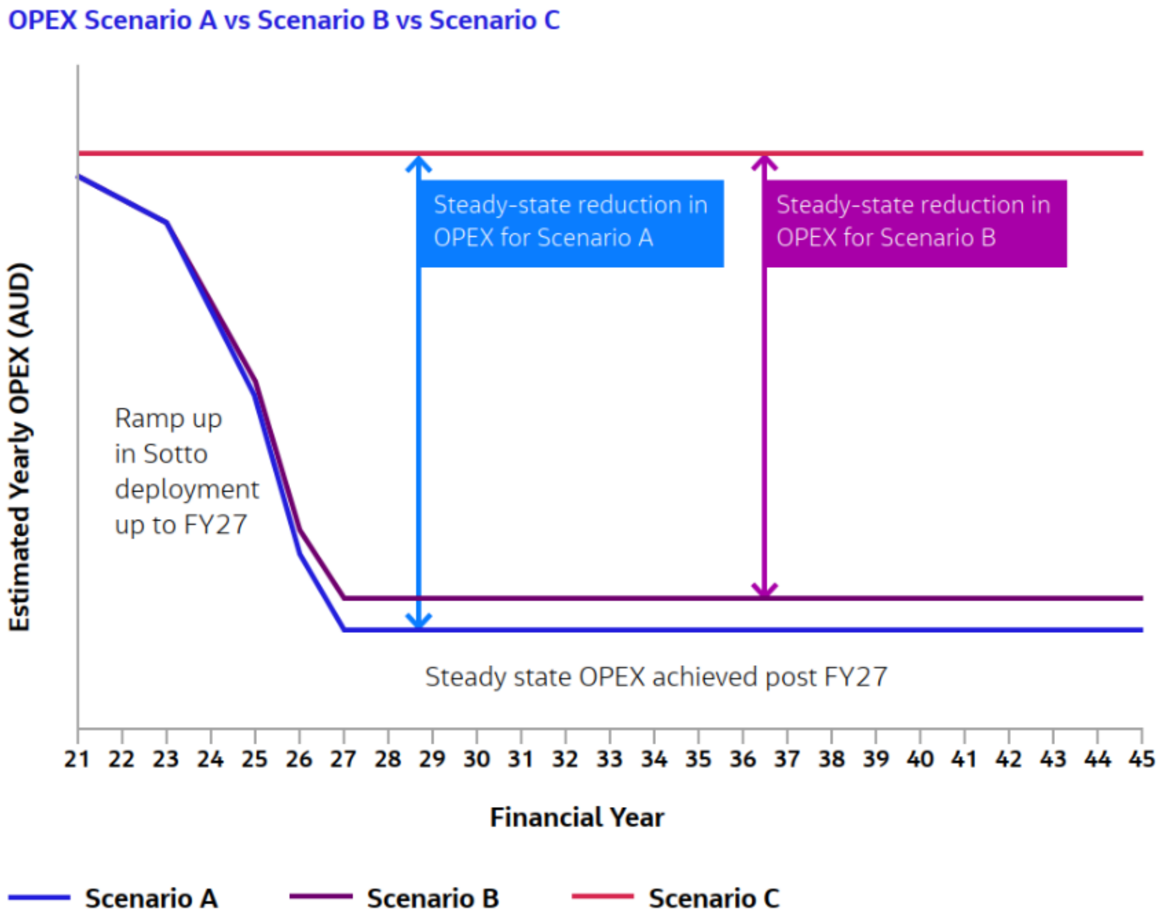
Scenario B represents a 5.6% saving in TOTEX, and this includes a 10.2% saving in OPEX. The additional repairs are also included in the model, and they represent the repairs that aren't undertaken now (2180 repairs out of 5400 additional leaks detected) but are required to save 1.63 GL water (water saving target). The estimated cost of these repairs is included in the OPEX costs.

Table 3: Comparison of TOTEX, OPEX, and additional repairs for each scenario. As one can observe, both scenarios A and B are economically viable to address 1% targeted water savings. Scenario B having a larger number of leaks to address

	Scenario C	Scenario A	Scenario B
TOTEX	BAU TOTEX	4.5% saving on BAU TOTEX	5.6% saving on BAU TOTEX
Steady State OPEX Cost	BAU OPEX	10.9% saving on BAU OPEX	10.2% saving on BAU OPEX
Total number of additional repairs (detected by Sotto) to meet 1% water savings target. Additional to repairs included in BAU.		1330	2180

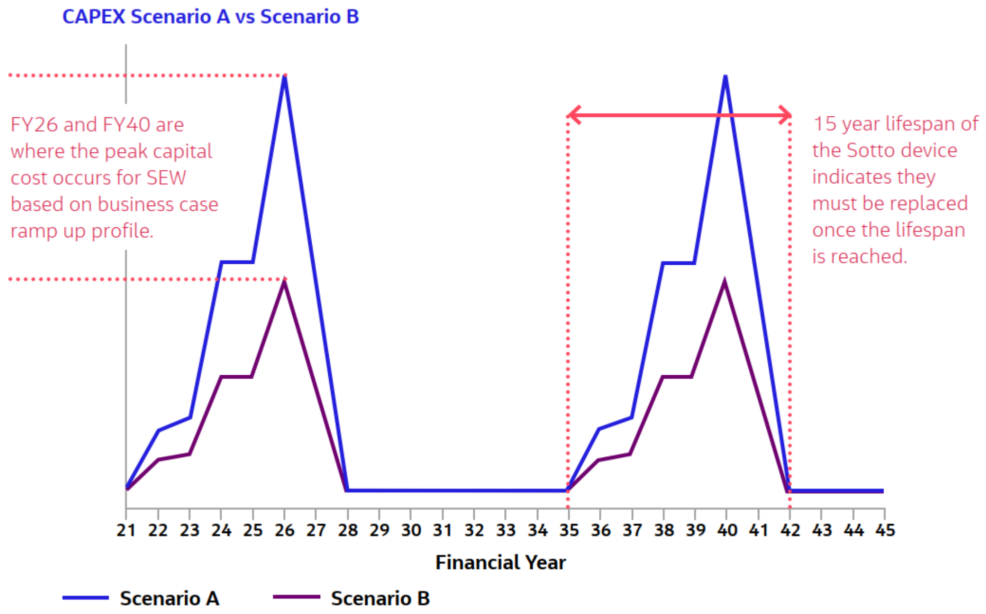
Figure 7 further details the steady state OPEX and what is achieved in FY27 once staged Sotto deployment is completed for the SEW network.

Figure 7: OPEX modelled for each scenario for 25 years



There is only an OPEX component for Scenario C. This OPEX component is assumed to be a constant value each year based on an assumed constant background real loss value and repair costs aligned to 2021. CAPEX for Scenario A and Scenario B is modelled in Figure 8. The second hump on the CAPEX profile with both scenarios indicates the digital meter replacements.

Figure 8: CAPEX Scenario A vs Scenario B with a scale up in FY36



The TOTEX model comprises many variables, a percentage increase or decrease in any of these variables has a different effect on the final resulting TOTEX cost calculation over the 25–year horizon. This is called a sensitivity analysis and was undertaken in the study to understand some of these factors. The analysis ranked variables based on their susceptibility to impact the bottom line.

The sensitivity analysis of the financial modelling shows that the Long-run marginal cost of water has an approximate 7.5% impact on the bottom line. The other variables did not significantly impact the model outcome (<1% impact on the bottom line).

Analysis assumptions and limitations

This analysis was undertaken on a subset of SEW network and then extrapolated to the entire network, thus creating known limitations. These limitations include the trial neighbourhood is not representative of the entire SEW network, which includes changing soil type, pipe type, and different property densities. The business analysis took into account these limitations.

Financial Analysis model assumptions include.

- A zero marginal capital depreciation expense considered.
- A zero defective rate of Sotto Sensors is considered, the sensor lifetime is 15 years, and the replacement cost is equivalent to the original installation.
- The volumetric reduction will be proportional to the number of Sotto Sensors deployed aligned to the installation ramp-up profile from the digital meters business case.

CONCLUSIONS

The following summary stems from a thorough set of hypotheses and business considerations unique to SEW. To summarise, the analysis determined the following:

1. *Previously undetectable leaks can be detected using Sotto sensors, and early detection of existing leak repairs could minimise water losses.*

   Extending the trial area to the wider SEW network found that an estimated volume of ~550 ML or ~390 ML of water can be saved through early detection. The range indicates the deployment scenario – sensor in every property or sensor in every second property. Furthermore, adding the early detection volume with the estimated volume of water saved through leaks determined uniquely by Sotto is greater than the required amount to achieve SEW 1% water reduction target (equivalent to a reduction of NRW of 1.63GL).

2. *It is financially beneficial for SEW to include Sotto sensors in their Digital Metering deployment at every property.*

   For the wider SEW network it is financially viable to include Sotto sensors on a 1:1 basis for relevant properties (excluding high-rise buildings and new builds), this configuration provides a modelled TOTEX saving of 4.5% over 25 years and an OPEX saving of 10.9% from BAU yearly once the DMs are completely deployed.

3. *It is financially beneficial for SEW to include Sotto sensors in their Digital Metering deployment at every second property.*

   For the wider SEW network it is financially viable to include Sotto sensors at every second property, this configuration provides a modelled TOTEX saving of 5.6% over 25 years and an OPEX saving of 10.2% from BAU yearly once the DMs are completely deployed.

In addition, the analysis determined the following key Sotto benefits after deployment:

1. A proportion of leaks are detected before customer detection or BAU. Leading to the volume of water saved through planned repair activities.

2. Some leaks not found by BAU are detected, and the associated volume of water can be saved when repaired. However, additional repair activities are expected.

ACKNOWLEDGEMENTS

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