ASSET MANAGEMENT OF BROWNFIELD RESERVOIRS - OPPORTUNITIES/LESSONS FROM A COMPREHENSIVE CONDITION ASSESSMENT AND REMEDIATION PROGRAMME

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ABSTRACT

The failure of several high-profile assets in 2019 triggered Wellington Water to commission asset condition inspections of its client council's most critical assets to determine the risks and interventions required to prevent critical asset failure. All 137 of the drinking water storage reservoirs operated by Wellington Water were identified as very highly critical. The reservoirs were of varying ages and construction types and included free standing, partially and fully buried reservoirs each presenting its own unique challenges to assessing and prioritizing remedial works.

This paper describes the process of reservoir failure mode identification, catalogued in various themes including being the ability to identify the subtle but very important difference between a reservoir's component condition grade and its functional performance which is tied back to Wellington Water's Customer Service goals.

It covers the digitised inspection, assessment, reporting and validation workflow, offering insights as to how other water utility providers around New Zealand may look to adapt a similar data-driven, assessment workflow that can be leveraged to inform rapid decisions through tailored automated outputs.

An output from this work programme included the development of a reservoir visual assessment guideline document – a document that was based off subject matter experts' interpretations of how the relevant Ministry of Health Guidelines documents for reservoirs should be best applied to the project, all through the lens of the field operative collecting the data.

An interactive digital dashboard tool was also created and is presently being used and remains relevant to both the internal technical teams as well as client-side personnel who have been using it to make rapid, informed judgements on the health of the reservoir network, and ultimately, derive work scopes and budgets from it. It provides examples of how the dashboard has been leveraged to inform answers to questions such as what works would be needed to be undertaken if a reservoir was taken offline, whether or not to undertake seismic strengthening, and should a particular component be replaced or not.

The importance of leakage testing is discussed with regard to informing visual assessment. Lessons learned and applicability of the information obtained is shared to inform decision making not only on the asset tested but also others of a similar construction.

The paper also describes opportunities and challenges of the current tranche of work which involves development of standardized upgrade details/arrangements for existing reservoirs as well as the opportunities to again leverage the dashboards to aid the development of budgets and physical works pricing and procurement models.

Lastly, the paper discusses the lessons learnt on the condition assessment and data capture programme and the risk management systems set up to manage the vulnerabilities uncovered during the assessment programme.

KEYWORDS

Reservoirs, Renewals, Contamination, Asset Management, Digitised Inspections, Failure Modes.

PRESENTER PROFILE

Stephen Molineux is a Chartered Professional Engineer at WSP New Zealand Ltd with 13 years' experience working in the New Zealand water infrastructure industry. Stephen's background is in the project management, design, and construction supervision of water infrastructure projects. During this time, he has specialised in the design and management of reservoir upgrades, undertaking numerous seismic, contamination and health and safety upgrades primarily within the Wellington Region.

BACKGROUND

Water Reservoirs are seemingly simple, yet complex multi-generational assets that can have obvious, significant and unacceptable impacts to its customers if they are removed from service for any given period of time.

They play a critical role in our drinking water systems, maintaining pressure and enabling changes in demand to be accommodated. They also contribute to network resiliency, making sure people's water needs are met should an incident occur that affects treatment plants or large pipes.

In New Zealand, there is an expectation that our water authority provides safe and healthy drinking water. While may of us have heard about how much it might cost to "make" safe drinking water, what perhaps is less clear is the cost it takes to "maintain" safe drinking water reservoirs.

In terms of contamination risk, reservoirs are inherently vulnerable as they are the few non-pressurized locations along the potable water network. While common entry points for vermin are typically at hatches, unguarded roof vents and overflow lines, other key risks include risk of water ingress through the roof or buried walls.

This paper discusses condition assessment and asset management of reservoirs drawing on lessons learnt from the condition assessment and remediation programme being undertaken by Wellington Water.

Wellington Water, manage 137 reservoirs for a population of 450,000. The reservoirs vary in ages and construction types and included free standing, partially and fully buried reservoirs each presenting its own unique challenges.

As Rob Blakemore from Wellington Water puts it "Each reservoir has a free surface that is potentially vulnerable to contamination and is inevitably a 'very high critical asset'. "

RESERVOIR FAILURE MODE IDENTIFICATION

Failure Modes and Effects Analysis (FMECA) principles were used to help identify, classify, and assess risks for each reservoir component.

Reservoirs were assigned criticality indices using Wellington Water's Criticality Framework. The framework links criticality to Wellington Water's service goals, on the basis that "Service goals underpin everything we do at WWL". Criticality is defined as "the significance of removal or damage of any individual component or asset on the ability of any part of the network or portfolio to deliver the intended services."

The resulting criticality index is an indicator of how critical an individual asset is for delivering Wellington Water Customer Service Goals and is relative to other assets in the network. Asset management decisions such as the priority for undertaking interventions are based on this index. The process promotes transparency and enables a consistent comparison of assets and risks across the many asset types that make up Wellington Water's networks.

The process for determining the criticality index is summarised in Figure 2. It involves:

1. Identification of all possible failure modes associated with the asset.
2. Assign relevant service goals to the failure mode. Key service goals that reservoirs affect are:
    a. The provision of safe and heathy drinking Water
    b. The operation of assets that are safe for our people and customers.
    c. The provision of regional wide firefighting supply
    d. The provision of reliable service to customers
3. Assess the severity of failure based upon the impact of the failure against customer service goals accounting for; the exposure of the failure, the duration to complete a repair and any asset redundancy or contingency.

Calculate the severity goal criticality from the performance assessment.

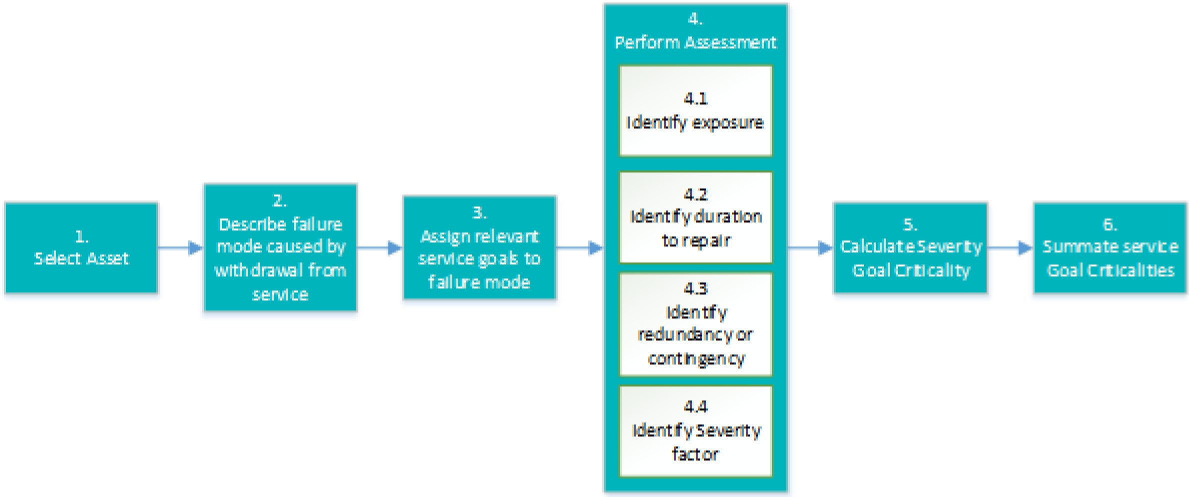

Figure 1 - *Wellington Water Flow Chart for assessment of asset criticality*

Through this process reservoirs were identified as being "Very High Critical Assets, i.e. assets whose failure has an unacceptable and extensive impact on the livelihoods of people and the environment and where time to restore service would be greater than 1 day.

The relevant Failure Modes being:

- Contamination entering a reservoir and impacting the 'Safe and Healthy Water' of customers.
- Failure of a reservoir access structure supporting the safety of an operator or person accessing the site and resulting in injury.
- Non-seismic collapse of a reservoir structure.

DEVELOPMENT OF CONDITION ASSESSMENT PROGRAMME

The next step was to determine which components to inspect and to develop a condition grading system. This was done by considering the various components of the reservoir and identifying the mechanisms that could result in failure. Failure of a height safety access structure due to loss of durability of a platform, stair or ladder is an example of failure at a component level that could lead to failure of the service goal, i.e., safety of an operator.

Condition assessment was then targeted at the assessment of those components and failure mechanisms. In many cases these could be adequately assessed through visual inspection.

This approach moved the focus away from the condition of the reservoir as a whole to assessment of key components and their ability to deliver the service goals. As an example of how this altered the condition assessment grading, the new reservoir shown in Figure 2 scored well from an overall condition rating perspective but scored poorly when subjected to a failure mode assessment due to roof leakage.

Figure 2 – *A new reservoir may score well from a condition rating perspective but may score poorly when subjected to a failure mode assessment due to the roof leakage shown in the photograph on the right.*

RESERVOIR VISUAL ASSESSMENT GUIDELINE

Whilst many defects could be identified through visual inspections, these assessments had varying degrees of judgement involved. A reservoir visual assessment guideline document was therefore developed. The guide enabled the knowledge of subject matter experts to be transferred to the more junior engineers undertaking the field assessments. It also enhanced data capture and ensured assessment consistency.

The guidelines examined critical Failure Mechanisms and provided clear scoring criteria with photographic examples to allow scoring (Very Good" (1) to "Very Poor" (5)) for each element. The guidelines were based off subject matter experts' interpretations of how the relevant Ministry of Health Guidelines documents for reservoirs should be best applied to the project, all through the lens of the field operative collecting the data. The guidelines also incorporated information gathered from similar studies within New Zealand and internationally.

The visual assessment guideline was utilised to guide inspections while undertaking external visual inspection of all above ground reservoirs and submersible drone inspection of all buried reservoirs.

A screenshot of the visual assessment guideline document is shown in Figure 3.

Figure 4 shows an example of the typical 'thought process' that the field assessors needed to follow, highlighting both the need, as well as the value of the Visual Assessment Guidelines for Failure Mode Assessment.

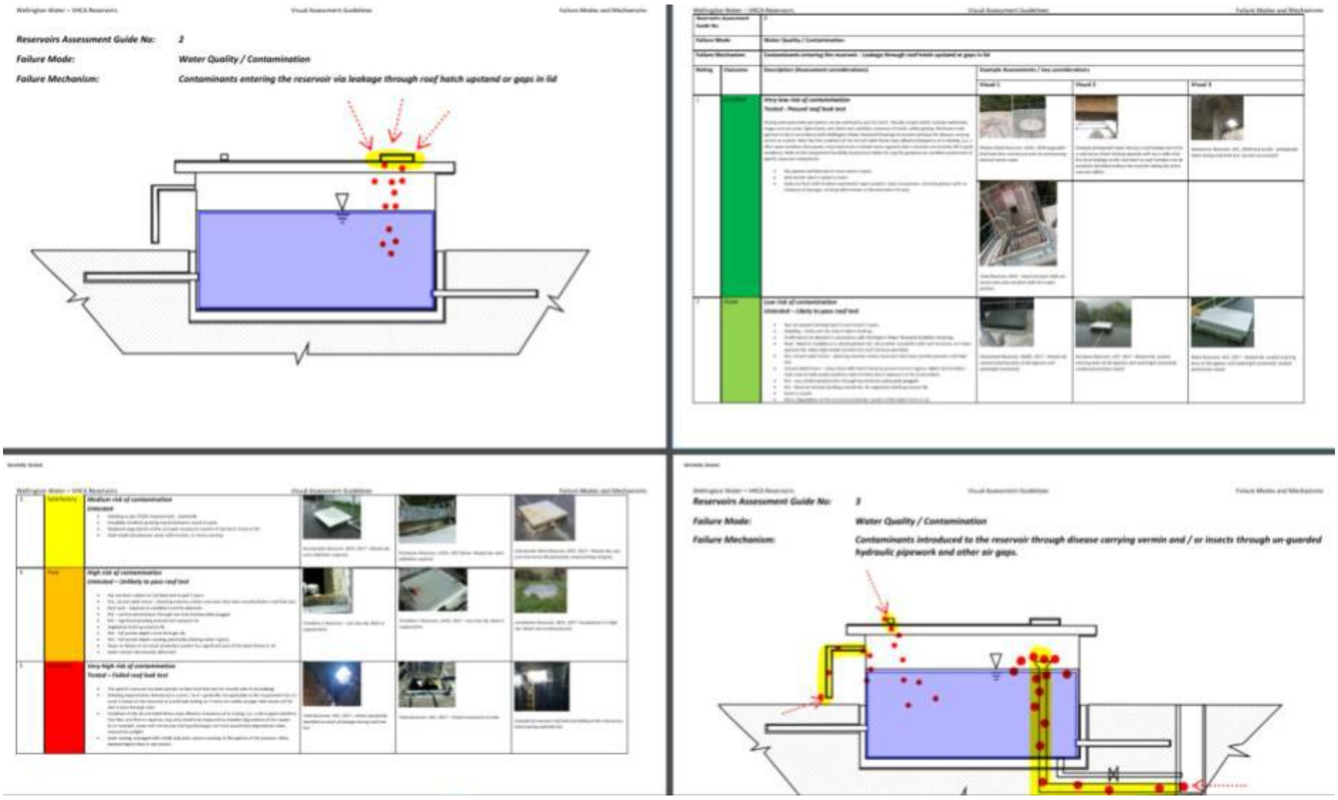

Figure 3 - *A snapshot of the visual assessment guideline document included a free body diagram representing the risk accompanied by numerous examples of "Very Good" (1) to "Very Poor" (5).*

Figure 4 - E*xample of the typical 'thought process' that the field assessors needed to follow,*

THE INTERACTIVE DIGITAL DASHBOARD TOOL

A mobile inspection tool and an interactive digital dashboard were also developed to support internal technical teams as well as client-side personnel to make rapid, informed judgements on the health of the reservoir network, and ultimately, derive work scopes and budgets from it.

The inspection tool asked leading questions and requested photographic input so that senior team members could provide any necessary support. Figure 5 shows a screenshot of the inspection tool which could be accessed via mobile app interface or desktop via web browser.

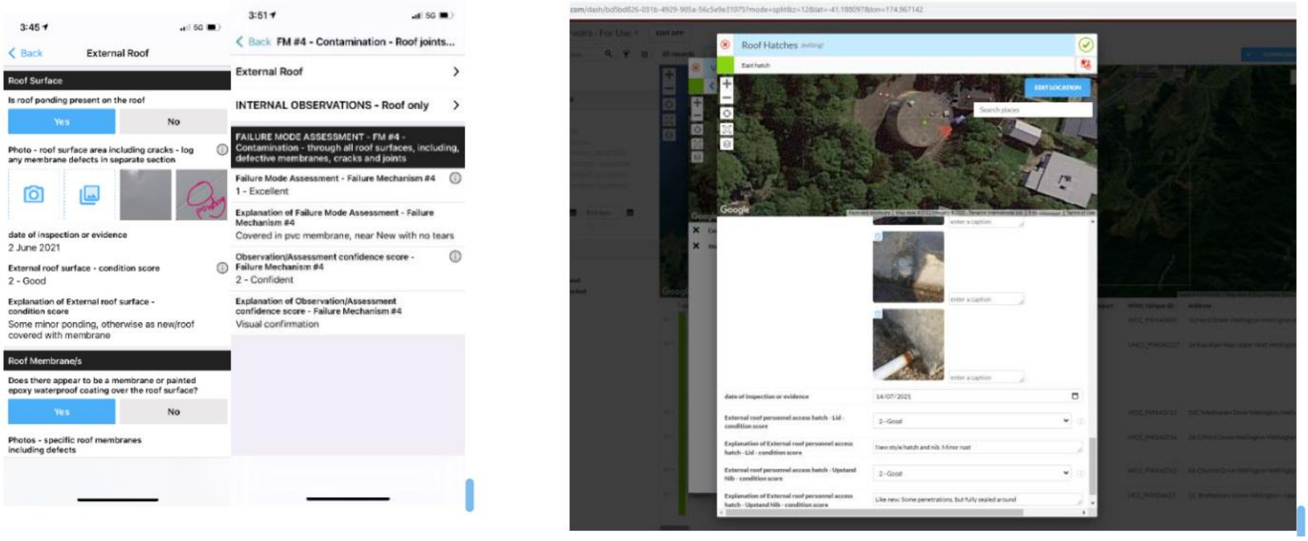

Figure 5 - *Inputs could be provided at any time via mobile app interface or desktop via web browser*

Building trust in the process was critical to realising the dream of a fully digitised inspection workflow. Once the data had been gathered, a technical reviewer edited the assessment within the digital tool, with outputs automatically displaying through the interactive dashboard.

The dashboard was designed to maximise aesthetics and usability, see Figure 6. The dashboard displays an interactive map showing colour-coded representations of reservoirs with issues, representing the scale of the problem. Reviewing and editing live source data was initially unfamiliar territory for the technical reviewers, who are typically accustomed to bleeding over pages and pages of A4 reports with their trusty red pens.

Using prepopulated construction rates and reservoir roof areas, the tool automatically calculated costs associated with each of the required remedial works. This allowed automatic manipulation of data to provide budget estimates for a range of client requirements and situations to ensure funding is available to deliver these works.

Whilst a mobile inspection tool was needed to efficiently log 200+ data inputs captured for each of Wellington Water’s 137 reservoirs, the real challenge and opportunity was to effectively leverage the data to influence asset life cycle interventions. Review of data within the dashboard could easily be used to help inform answers to frequently asked “scoping” questions such as what works could or would be needed to be undertaken if a reservoir was taken offline, help inform decisions that related to undertaking significant investments on seismic strengthening projects, and whether replacement of particular components was either a critical requirement or not.

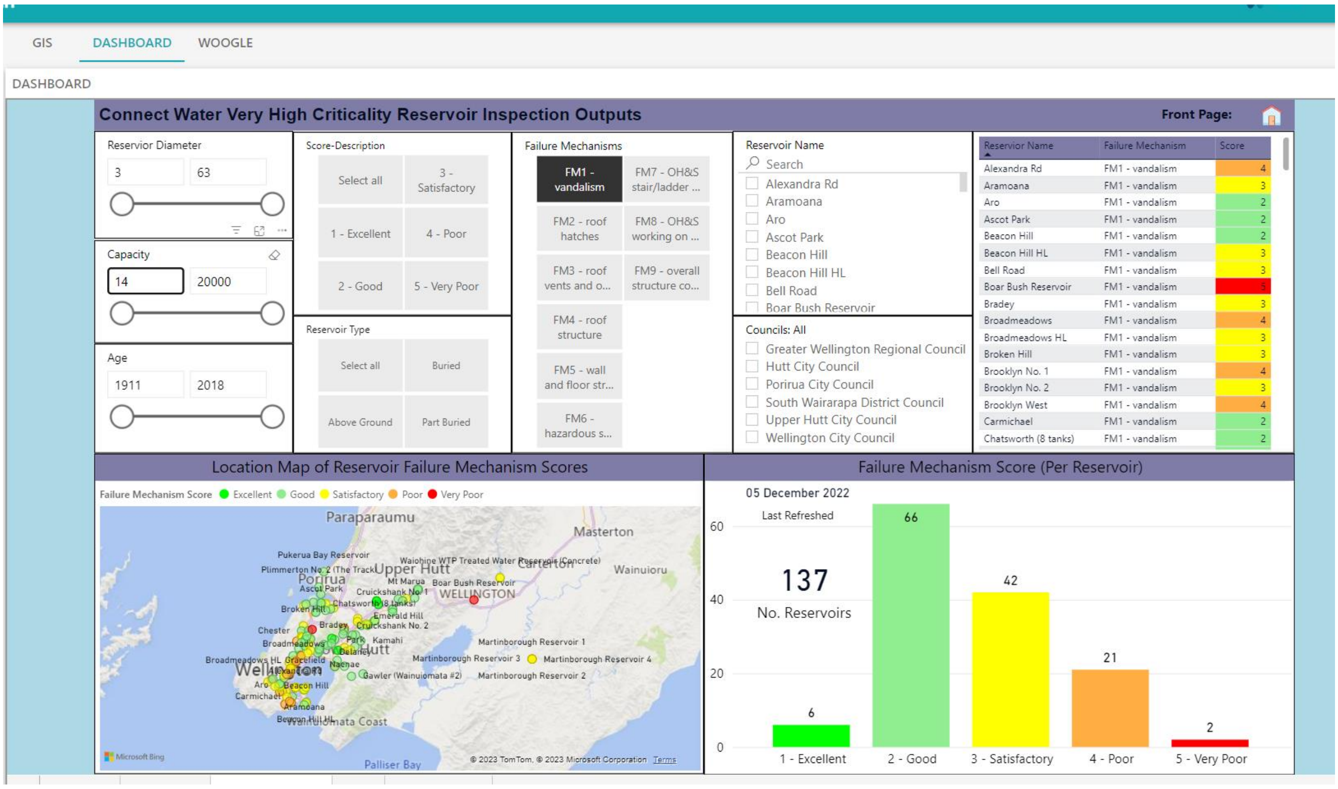

Figure 6 – Interactive Dashboard

IMPLEMENTATION OF REPAIRS

The visual inspections identified many shortcomings, the majority of which were relatively minor from a structural condition perspective but none the less could have resulted in failure to deliver a Wellington Water Customer Service Goal that are perhaps more commonly associated with pipeline failures. Repairs were required to improve operator safety and address watertightness issues to reduce the risk of contamination.

Repair works are currently underway with $14m being allocated over 3 years to complete the works on all above ground reservoirs. The budgets for these repair works have been sourced directly from the dashboard. Typical repairs include:

- Installation of external staircases, providing safer round the clock access.
- Handrail installations, reducing the reliance fall arrest systems and offering safer access to more of the tank roof.
- Repairs to hatch upstands to reduce the risk of surface water runoff entering the reservoir.
- Upgrades to hatch lids and roof mounted air vents to reduce the risk of damage and subsequent contamination risk due to unlawful vandalism.
- Installation of vermin proof mesh onto air vents and overflow pipes, to reduce the risk of vermin and insects reaching the free water surface.
- Installation of waterproof membranes and surface sealants to provide a barrier to prevent water leaking inwards through roofs.

The main consideration for undertaking repairs being will the repair avoid the relevant failure mechanism. Many of the repairs identified were simple and low-cost solutions, yet completely mitigated the risks associated with the relevant failure mechanic. For example, installation of mesh onto air vents is a very cheap yet effective way of eliminating the risk of vermin entering the reservoir and contaminating drinking water.

Repair methods were standardised wherever practical and all repairs on the above ground reservoirs were designed to be undertaken while the reservoir remained in service, to avoid significant costs and operational disruption associated with removing a reservoir from service.

A separate program of works is under development to address the risks associated with buried reservoirs. Typically, these sites are significantly more completed because repair and future maintenance may require the removal of covering soil. Instead alternative repairs from the reservoir interior need to be weighed up considering; the operational impact of taking a reservoir offline, the performance of an internal repair versus the cost a disruption of excavating the reservoir exterior.

The focus on failure modes and avoiding failure of deliver Wellington Water's Service Goals that was maintained throughout the project has ensured that efforts are concentrated on the issues that will have the greatest impact on reducing risk. It has also enabled budgets for repair works to be justified and prioritised against works proposed on other types of assets.

OPPORTUNITIES, CHALLENGES, LESSONS LEARNT

As part of the condition assessment program, there is considerable value in reviewing any historic investigations and assessments largely because of the challenges associated with undertaking the inspections themselves. Previous engineering reports highlight historic issues that may have been forgotten. Prior leakage testing information has proven to be extremely valuable. Historic information can be extrapolated and has applicability to inform decision making based on reservoirs that share similar designs or were built in the same period - different construction techniques. For this reason, the project team catergorised the roof construction types of every reservoir and integrated these into the digital dashboard. Where known defects or issues existed, this allowed instantaneous visibility of likely alternative locations vulnerable to the same problem.

Leakage testing is undertaken using either sprinklers, or a prolonged and heavy rainfall event to distribute water across the roof surface. For best results, leakage testing should be undertaken while the reservoir is offline, ensuring the inside of the reservoir is in a 'dry' state. This is so that any active leakage can easily and objectively be evidenced. Extractor fans can assist with drying the ceiling and floor slab prior to a test however, the atmospheric conditions can greatly influence their effectiveness. Taking a reservoir offline can cause significant operational disruption and is often uneconomical or impractical and therefore 'live' testing can be considered instead.

Roof leakage testing inside a 'live' tank environment can be completed using submersible drones or remote-controlled boats fitted with specialist lighting and recording equipment. Water 'droplets' can be recorded breaking the free water surface, to assist in identification of possible leakage locations. While testing a 'live' tank experience is key to differentiating between ceiling condensation and leakage. There are more sophisticated hi-tech options available involving mobile laser scanning units, however whether technology application meets a critical need is perhaps an opportunity that could be explored in the future.

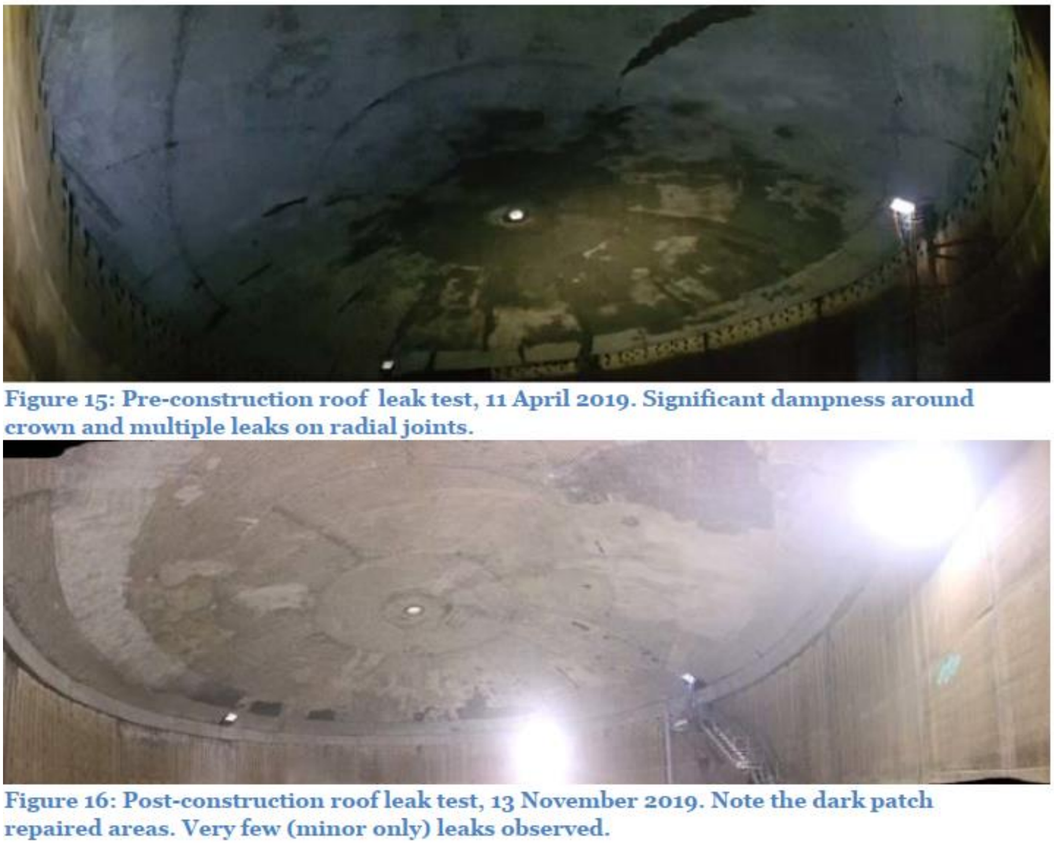

Figure 7 – Example of 'offline' roof leakage testing

Figure 8 – Example of 'online' roof leakage testing

Based on experience testing reservoir roofs both within the Wellington Region and other parts of New Zealand, the subject matter experts within the project team were able to offer invaluable insights that reflected their in-depth knowledge of concrete reservoir assets constructed in NZ over the last 100 years. Perhaps contrary to popular opinion, in some cases it was found that older assets performed better than newer assets.

Figure 9 – Commencement of a submersible drone inspection.

Rather than undertaking leakage testing at every location, the cost of testing should be weighed against the likelihood of failure (which can be informed by previous tests on similar roof construction types) and the cost of undertaking the repair. In many instances the cost to replace roof sealants and undertake the installation of a waterproof membrane may cost less than taking a reservoir out of service for testing.

Where a reservoir is found to have water tightness issues it is typically recommended that the nominated repair is applied to the entire structure and not just to the localised area of concern. This provides confidence that the entire structure will not fail prior to the next scheduled inspection and avoids asset management issues tracking which areas of the structure have been repaired. For example, identification of an aging or leaking roof sealant in most instances, should prompt the replacement of all sealants on the structure (and not just the area of concern). This ensures the performance of the structure through to the next scheduled inspection and simplifies the scheduling of future replacement of all these sealants at the end of its expected design life, minimising ongoing monitoring requirements.

Documenting the condition of all reservoir components along with their anticipated life expectancy within a 'whole of life' asset management plan is important to inform future decision making. Provision of such a plan provides visibility to amalgamate similar activities such as inspection, maintenance and upgrades, to ensure when the asset is required to be taken out of service the maximum benefit is derived from it. Proactive 'whole of life' asset management will minimise the risk of future asset failure, reduce the number of times the asset is required to be taken out of service and enable informed decision making of future upgrades.

This project has involved assessment and creation of a digitised record of numerous reservoir components, largely for the purpose of achieving a project outcome. The project digital dashboard has demonstrated to clients and consultants alike the benefits and efficiencies to budget development, work package scoping and project delivery, including dynamic physical works procurement models.

CONCLUSION

Water Reservoirs play a critical role in our drinking water systems but they can introduce risks. They are inherently vulnerable to the introduction of external contaminants into the potable water network which can potentially compromise public health. Personnel access are often required to work at heights and/or confined spaces to access reservoirs, meaning an in depth knowledge of the performance of the asset can be difficult to ascertain due to the potential cost and operational restrictions of traditional internal inspections.

Use of Failure Modes and Effects Analysis (FMECA) principles to identify, classify, and assess risks for reservoirs provides a direct line of sight between condition of the various components that make up reservoirs, their mode of failure and how and to what extent this failure can contribute to failure of the organisation’s overarching services goals. This ensures that efforts are concentrated on where they will have the greatest impact on reducing risk. It also ensures that budgets for repair works to be justified and prioritised against works proposed on other types of assets.

Significant understanding on the condition of reservoirs and the risk of components failing can be obtained through visual inspections. However, inspections can be subjective. It is therefore recommended that guidance documents be developed to enhance data capture and assessment consistency.

Leakage testing is an important tool to inform visual assessments but can be expensive and difficult to complete. Information obtained informs not only the performance of the asset tested but also aids decision making on other assets of a similar construction.

Development of a mobile inspection tool and an interactive digital dashboard supported both the internal technical teams as well as client-side personnel to make rapid, informed judgements on the health of the reservoir network, and ultimately, derive work scopes and budgets from it.

It enabled the data captured to be leveraged to influence asset life cycle interventions and streamline delivery of the capital works repair program.