Data down under: Creating a risk-based approach to dam monitoring and maintenance

Facing on-going influences such as climate change, dam owners are under increasing pressure to ensure the safety of their assets. The consequences of failure are becoming more significant too, in light of factors like downstream urbanisation. With asset owners integrating new solutions to help them rise to the challenge, Australia's Hunter Water has turned its eyes skyward in a bid to advance its asset monitoring performance to the next level.

As dam assets age, accurate monitoring becomes increasingly important to ensure safety. With the impact of broad trends such as increasing urbanisation and global warming, the challenges facing dam owners and the potential consequences of failure are mounting.

Urbanisation, for example, is seeing more people living downstream of a dam than ever before. This represents a significant increase in the consequences of failure and associated catastrophic risk. Meanwhile, global warming is introducing far more volatility to weather events, making them much harder to predict and manage.

"The biggest problem with climate change, particularly with dams, is the unpredictability of precipitation, causing too much or too little water," says Professor Mark Maslin FRGS, FRSA of the Department of Geography at University College London.

"Leakage through or under a dam can cause blowout. But if you have a sudden massive rainstorm, this can cause overtopping, and the water spills over the top and cuts down through the dam, causing catastrophic failure. Climate change is already causing more intense rainfall bursts, which are shorter and more unpredictable and are a major worry for dam owners."

Maslin continues: "Hot, dry summers are also creating problems. Dams don't like pressure to be released and lowering the level of water is also problematic because it starts to put a strain on the dam structure."

In Australia, for example, which as the driest inhabited continent also has the highest per capita surface water storage capacity, the large number and size of water storage assets is a particular challenge. Earlier this year a leak at a privately-owned irrigation dam in Queensland prompted evacuations and flood warnings at the town of Talgai after a 3.5 metre-wide hole appeared in the structure, which was at maximum capacity.

Under the influence of climate change, Australia's already highly variable rainfall is likely to become far less predictable, with one in 20-year maximum rainfall events predicted to become one in 15 or even one in five-year events by the end of the century.

At the same time, while dams are extremely long-lived, huge numbers are already many decades old. By 2025, nearly 75 per cent of the 91,000 dams in the US could reach half a century in age. Nonetheless, even dams which have been constructed relatively recently can present problems. The spillway at another Queensland dam, Paradise Dam near Bundaberg, was damaged during 2013. This dam was only built in 2005.

Ensuring dam safety

For dam safety engineers tasked with developing and maintaining systems to ensure, so far as is reasonably practicable, that people downstream are not put at risk from the dam owners' business activities, the growing consequences and changing risks have prompted a reappraisal.

Supported by field staff, dam safety engineers undertake asset monitoring and inspections which include assessing if dams meet modern standards, and making sure that any risks are effectively managed. Inspection and monitoring need to determine if there are any trends that might indicate an emerging problem.

However, the need for comprehensive monitoring presents a number of challenges. "Dams are very large assets, and very high or extreme consequences result if they are to fail," explains Daniel Turnbull, Dam Safety Engineer at the New South Wales (NSW)-based Hunter Water.

Among other assets, Turnbull is responsible for the Grahamstown Dam in NSW. Constructed between 1955 and 1965, Grahamstown is Hunter's largest drinking water supply dam, providing 40 per cent of water to the region and meeting up to 75 per cent of the company's daily supply requirements. It holds a reservoir of some 182,305 million litres behind a five km-long embankment.

"You're doing your best to monitor all the key points, and in terms of inspecting that is fine. Yet, considering actual reading of measurements it is very hard to have absolute coverage of a dam," says Turnbull.

"It's not physically practical to monitor every aspect of the dam, especially with a dam like Grahamstown where we've got over 5 km of the embankment. That's one of the big challenges we face, making sure that our monitoring is targeted and effective."

As Turnbull says: "The first thing is making sure that you don't become complacent about the risks that dams pose. We really need to make sure we have a good understanding of what the potential failure modes are for our particular dams and target our monitoring towards those failure modes."

However, Grahamstown presents a number of additional challenges when executing effective monitoring, not least because the top of the dam is home to a major road with an 80 kph speed limit.

"Grahamstown is a bit unique in that the shoulders of the dam are actually constructed of sand, which we know move quite a bit during normal operations. The stable portion of the dam is the solid clay core which is directly underneath a road," says the dam safety engineer.

Monitoring under these circumstances is costly and inconvenient for people trying to use the road and for local government.

"If we were to install permanent marks on the road, then every time we read them, we would have to shut one lane at least of that road. We would be putting people in harm's way by monitoring permanent marks on the road. As a result, we were only really monitoring the embankments by visual inspection, where there's nothing that's measurable," adds Turnbull.

Assessing alternatives, including drone surveillance

Faced with these challenges to effective monitoring and keen to ensure their assets are safe, Hunter began exploring alternative approaches to the traditional measurement survey and visual inspection.

"We were looking at other options that we may be able to implement where we can actually get some measurements and start plotting trends rather than relying on photos or people's opinions of what has changed over the years," says Turnbull.

One avenue they explored was the use of drones in surveying the site.

"We had tried some drone surveys, which are becoming cost effective. We could do them multiple times a year, and they provided us with the required coverage of the embankment," says Turnbull.

However, he adds: "The issue was the accuracies were just not as good as a traditional survey. As opposed to the 1 to 2 millimetres of movement that can be derived from satellite data, they were only picking up 20 to 30 millimetres."

Grahamstown Dam is also located very close to the end of the Newcastle airport runway, which had to be taken into consideration.

"Whenever we've got a drone in the air over that side of the dam, we've got to be in communication with air traffic control, and take the drone down every time there's an aircraft movement. It wasn't overly good for the purpose of performing the work efficiently."

Having explored aerial surveying, in September Hunter Water signed a three-year contract with UK-firm, Rezatec to provide satellite-based data and geospatial analytics to monitor structural and environmental changes at Grahamstown Dam.

Offered in partnership with Detection Services, Rezatec will use analysis of satellite-derived imagery and geospatial data, in addition to a wealth of historic archive satellite data, to look retrospectively at changes and trends over time.

Exploring the past with future technology

In order to determine any anomalous behaviour in the dam structure, it's important to use historical data to establish a baseline. Synthetic-aperture radar (SAR) is a common form of radar that is used to create two-dimensional images and present a significant amount of archived data for analysis.

"The retrospective data analysis is key to providing the client with a better understanding of their dam," adds Camilla Braithwaite, Product Manager at Rezatec.

“We use SAR to monitor ground motion and multispectral data to monitor vegetation, both of which are good indicator for potential failure modes. The traditional survey doesn’t provide enough data points, on which to provide peace of mind. Rezatec’s Dam Monitoring product uses three years of SAR data and two years of multispectral data in the retrospective analysis, collected at 6-12 day intervals. It identifies anomalies, or observations outside the acceptable baseline trend from this large tranche of data to notify dam operators, where they should direct their skills and resources."

Data from Hunter Water, such as water level information affecting movement, is overlayed with satellite data to help pinpoint exactly where issues are down to a few millimetres of displacement. In addition to precise movement, satellite data can also pick up other indicators of problems with dam infrastructure, such as vegetation moisture and vigour, using a two-year retrospective.

This is a point picked up by Turnbull who says: "We started off with a two-year retrospective analysis and over that period of time we had a couple of areas on the dam where we had completed some work. We installed a couple of pipelines through the crest of the dam, so we had an open excavation for a short period of time.

"On another occasion, we did some topsoiling of the embankment to try to generate some vegetation growth. During its retrospective analysis, Rezatec was able to pick out exactly where that work had been undertaken at that period of time. That gave me confidence that they were picking up movement as well as the vegetation vigour that they are looking at."

As Braithwaite says: "Water level and seasonality can affect vegetation. Adding these into the analysis means we can take these into account, and only identify observations that are truly anomalous. Vegetation is a really nice indicator for seepage, which is obviously a real worry for dam owners. It's not something they can spot straight away very easily. We can provide dam operators with an understanding of what's normal, benchmarking and then identifying anomalies that can help direct their ground crew."

Switching to satellite but keeping people

Despite some concerns, adopting high tech observations from space is not suggestive of reducing the number of inspections and staff. Instead, it enables resources to be more efficiently focused on potential problems before they become significant issues, as well as reducing the number of unnecessary inspections.

The Hunter Water team still carries out routine daily inspections, with team members visually inspecting to note changes.

"We wanted something to complement that," adds Turnbull. "Previously, if they noticed an issue, we would either increase our monitoring frequency to a couple of times a day to try and ascertain if it is changing, or if we're still not sure then we would undertake further detailed investigations where we might be excavating within the embankment to try and get some additional information. Now, if visual monitoring picks up that there's a potential issue, we're able to refer to satellite monitoring and reveal if there is something measurable to support that theory."

Professor Maslin expands on this idea: "Geospatial analysis doesn't replace people; it makes them more efficient. Instead of excellent engineers running around to make sure that they can cover however many dams, they can have a monthly check on each of their dams and use their skills to identify which structures are causing concern and where.

"We know that most times, dams are fine. It means that you can focus your resources and use them as efficiently as possible and use the expertise you have. With new technology, you have to be absolutely sure that this is going to improve efficiency and improve safety."

This is a point echoed by Turnbull, who says: "I liked the thought of being able to use whatever system we came up with to provide an early warning system, so the satellite monitoring was perfect given that data are being collected every 11 or 12 days; we can start to see changes over that much shorter frequency. Another aspect was again something unique to Grahamstown with its 5km of embankment.

"Trying to cover that embankment length with a traditional technique, there's nothing to say that if the issue was to arise, it wouldn't be directly between two monitoring points. You may not pick up any movement at all at our formal monitoring points, but the dam could fail directly in between them. Satellite monitoring, just because of the coverage it provides, gives us a more holistic view of what's happening with the dam."

Consistency and safety

Dams are assets that have long lives, with dam safety engineers inevitably inheriting these structures that other people have been monitoring and maintaining over a long period of time.

Satellite-based geospatial data analysis provides a high degree of consistency even as the employment market becomes more fluid and roles change every few years. The use of frequent millimetric surveys also allows asset owners to go beyond regulatory requirements to establish a key measure to assess asset risk. "Regulations for an extreme consequence category dam require a movement survey once a year, for a high consequence category dam, then it's every two years. We wanted to have a bit more scrutiny than the bare minimum that we're required to have," adds Turnbull.

Satellite observations also address the challenge to increase the frequency of monitoring remote dam assets.

"In Australia, we've got some dams in rural areas which take several hours drive or flights to get there. In terms of being able to monitor those sites without having to send a team of surveyors out there to do it is very attractive," adds the dam engineer.

More importantly, though, satellite observations are repeatable, testable and achievable at a much higher frequency and more accurately than physically sending a survey team out to a site. These key abilities are becoming far more significant, considering climate change and other megatrends like urbanisation.

"With carefully thought through monitoring, you should be able to understand exactly how your dam or dams are performing, so you know what is normal and more importantly what is not," says Ian Garside, Director at project partner, ProjectMax.

"Robust monitoring can go further and allow you to manage the risks across your reservoir portfolio, helping to drive your business and regulation in a targeted way. Possibly most importantly, though, good monitoring takes you from managing your dams reactively to proactively, with all the benefits that that will bring."