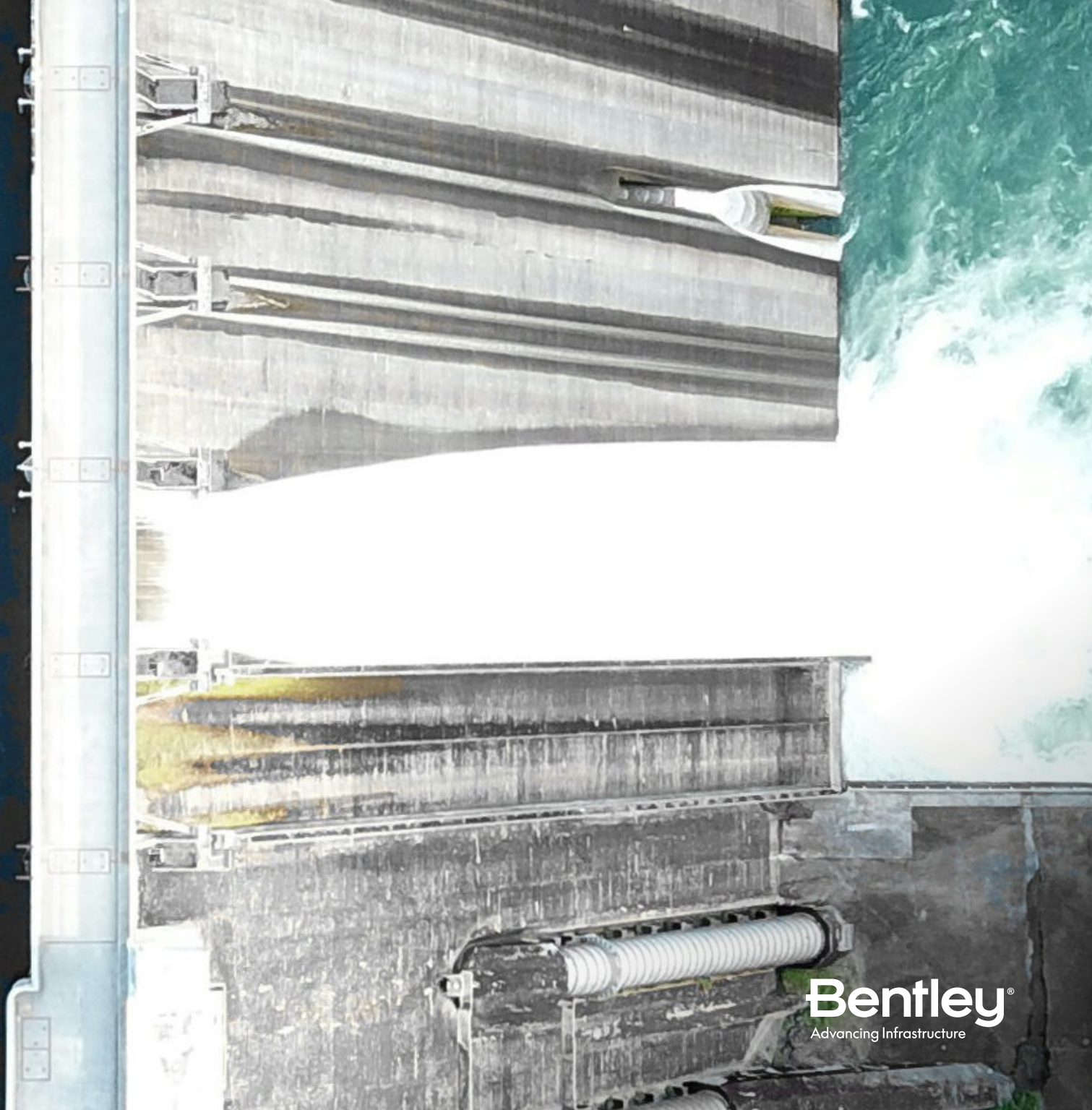


Condition monitoring in dams

2024 Report



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See how automation has improved condition monitoring for dams and get insights for making the transition from those who already have.

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Introduction

A large, curved dam structure is the central focus, spanning across a deep valley. The dam is dark and appears to be made of concrete or steel. To the left, a steep, forested hillside rises. To the right, a rocky, sparsely vegetated slope descends towards the water. The reservoir behind the dam is a deep blue color, reflecting the sky. In the background, more forested mountains are visible under a cloudy sky. A metal walkway or staircase runs along the base of the dam on the right side.

Dams are critical infrastructure components that play a vital role in water storage, flood control, and power generation around the world. According to the American Society for Civil Engineers (ASCE), there are over 91,000 dams in the United States, and 15,600 of them are considered high-hazard potential dams. Any failure or deterioration in their structural integrity can have catastrophic consequences, leading to loss of life and extensive environmental and economic damage. By continuously monitoring the condition of a dam through sensors and other technologies, dam owners can gain deep insights into the health and performance of their asset, enabling them to detect potential issues early, conduct predictive maintenance, and enhance overall resilience.

To understand current and future condition monitoring trends and practices, Bentley Systems commissioned ThoughtLab to conduct a global survey of 400 industry experts from the U.S., Canada, Europe, and Australia. Experts included C-suite executives, technical managers, and technical staff working for companies ranging in size from under 100 employees to over 1,000. This report is based on responses from the 49 dam owners and service providers who focus specifically on dams. Among that distinguished group, the data is clear: automation of condition monitoring in dams is growing faster than ever. A continuous data stream gives owners and service providers more comprehensive data to make faster, more analytical decisions and heightens their ability to be responsive in key moments when an action plan is required.

This report shows the progress that dam owners and service providers are making in automation and other condition monitoring practices, which will help them increase dam safety and heighten efficiencies over the longer term.

An aerial photograph of a large concrete dam. The dam is a curved structure with a grid-like pattern of reinforcement. To the left of the dam is a reservoir of dark blue water. To the right is a steep, rocky hillside covered with dense green trees. The text 'Current landscape' is overlaid on the left side of the image.

Current landscape

Condition monitoring is largely automated

Collecting data for monitoring dam conditions is now mostly automated. However, service providers are ahead of dam owners in automation, particularly automated remote monitoring for transmission via telemetry, the most advanced data collection method. Nearly half of service providers no longer manually collect any data, compared with a quarter of dam owners.

Service providers are leading the move to automation

One reason for the difference is that dam owners tend to rely on their on-site staff to do routine visual inspections and manual monitoring tasks. When needed, they can opt to outsource more advanced automated monitoring, data analysis, and specialized assessments to service providers with the required capabilities, technology, tools, and experience. However, dam owners have an opportunity to do more to drive their efficiency and their ability to head off problems by shifting to automated approaches.

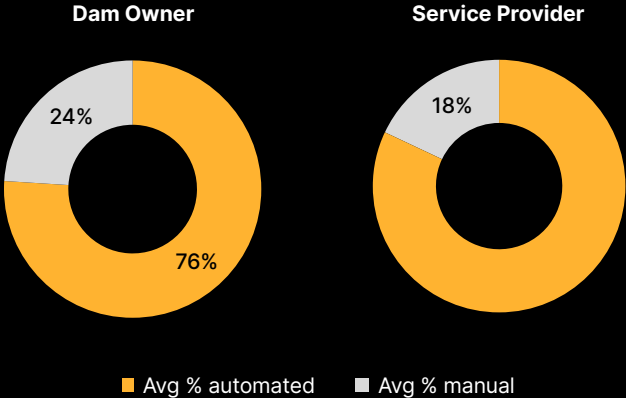


The shift to automation is not just about replacing manual tasks, but also about leveraging technology to enhance productivity, efficiency, and performance.

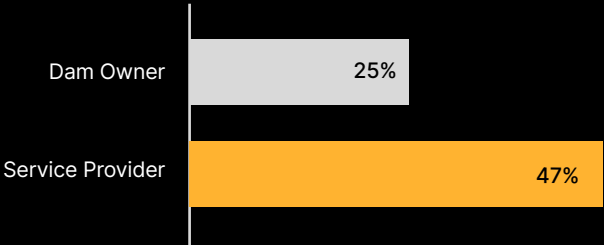
– COO, Canadian dam owner

Q. How does your organization collect data for its monitoring programs?
 Q. What percentage of your organization’s monitoring utilizes manual data collection?

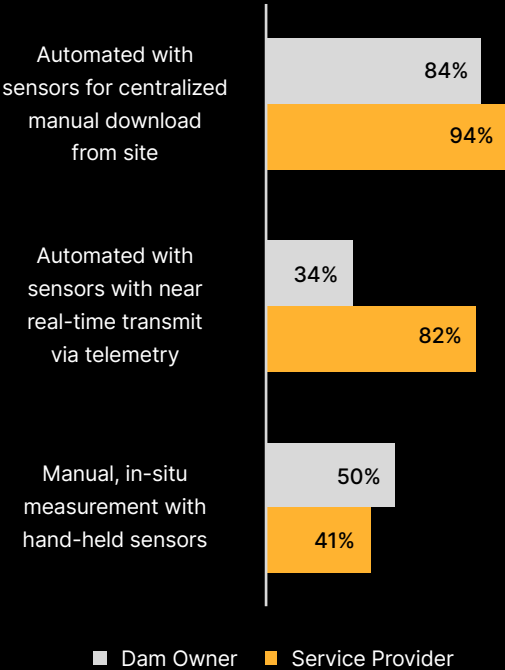
Average % automated vs. manual data collection



% of Companies That Fully Automate Their Data Collection



Monitoring data collection methods



Integrating data to improve results

Both dam owners and service providers leverage a variety of software for analyzing condition monitoring data; on average 3.8 applications. More organizations use general-purpose programs—such as Excel, Tableau, and Power BI—than specialized software designed to analyze sensor data.

As dam owners and service providers automate their condition monitoring, they have an opportunity to streamline their activities by drawing on specialized monitoring software, which can enable real-time monitoring of data and advanced visualization and customized reporting.

Integration with other data sources is key

Dam owners and service providers can unlock greater value from condition monitoring data if they integrate it with additional information sources. Service providers, which tend to be more automated, do this more often than dam owners.

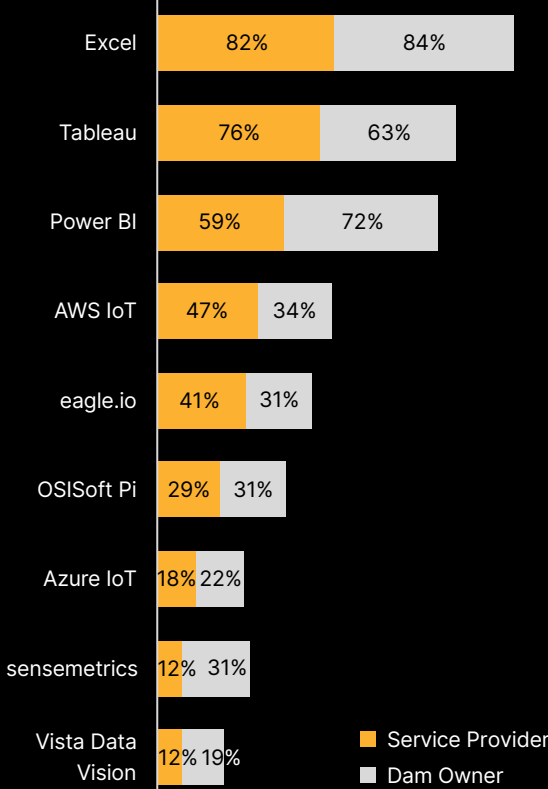
One example is the use of asset management systems, which provide a more holistic view of dam performance and maintenance history. Service providers also integrate sensor data more often with public and government data. It gives them a fuller context on environmental conditions, regulatory information, infrastructure projects, and demographic trends.

Almost four out of 10 organizations overall integrate sensor data with predictive models and 28% with digital twins, which give them the ability to predict the need for maintenance, identify and mitigate risks, and make more informed and timely decisions.

Q. What software do you leverage for sensor monitoring activities?

Q. Is your organization currently integrating sensor data with additional information sources to increase insights? If so, which of the following apply?

Software used for analysis



Integrating sensor data with other sources

	Dam Owner (%)	Service Provider (%)
Asset management systems	41%	88%
Public data	41%	47%
Predictive models	38%	41%
GIS layers	38%	41%
Digital twins	28%	29%
Remote sensing data	22%	35%
Drone-based photogrammetry	28%	12%
We do not currently integrate sensor data	19%	0%

Automation reduces monitoring challenges

As part of our research, we compared the performance of organizations with fully automated monitoring against those with any degree of manual monitoring. We labeled the first group as “fully automated” and the second group as “any manual.”

Digitized processes deliver higher data integrity

On average, fully automated organizations experience fewer challenges (1.6) than those that do manual monitoring (2.9). Manual organizations are almost four times as likely to face sampling errors than automated ones, which benefit from the data consistency and integrity inherent in digitized processes. They are also more than three times as likely to see data ingestion and compatibility as a hurdle.

Meanwhile, more than four in 10 manual dam owners and service providers report problems maintaining visualizations and charts. Because of the efficiency and speed of digitized data management, that is not a challenge for any automated organization in our survey. Manual organizations also report more difficulties with sample collection and sharing of data with stakeholders.

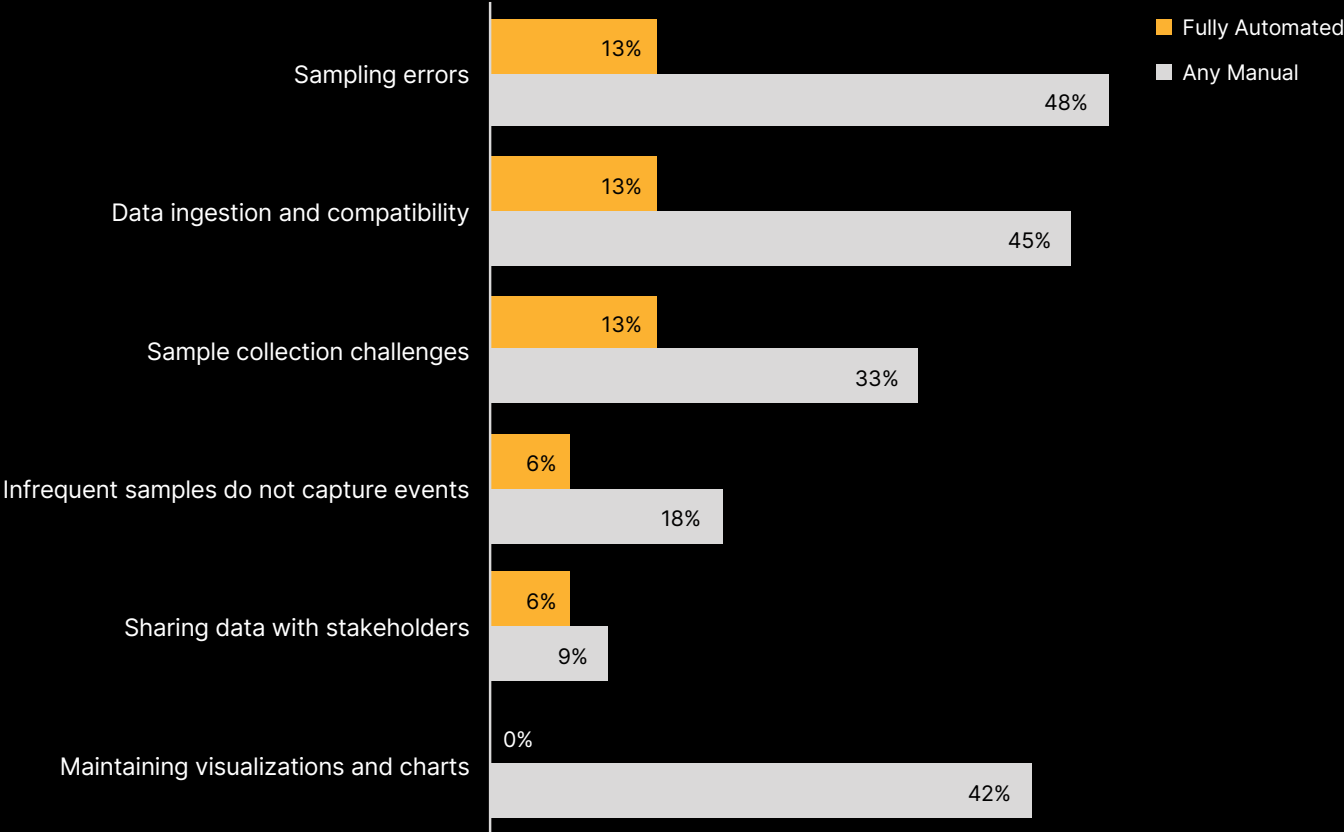


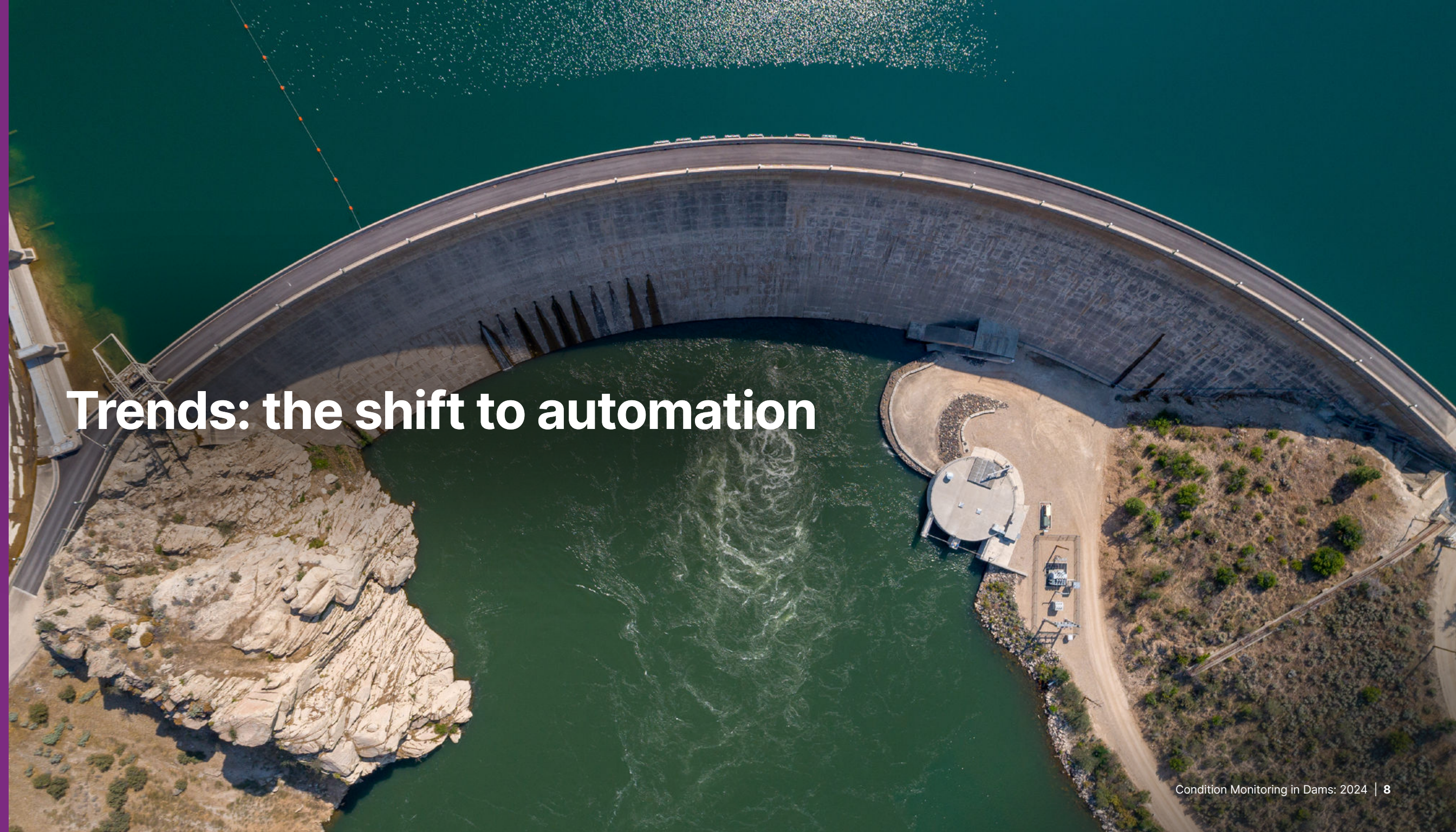
Automation enhances the precision and dependability of data.

– COO, Canadian dam owner

Q. What are the largest challenges that your organization experiences with its current monitoring programs?

Condition monitoring challenges





Trends: the shift to automation

Dams take monitoring to the next level

In the last two years, there has been a decisive shift toward automated data collection among both dam owners and service providers. Over half of dam owners and almost two-thirds of service providers ramped up their use of automated real-time data collection during that period.

Monitoring capabilities widen significantly with automation

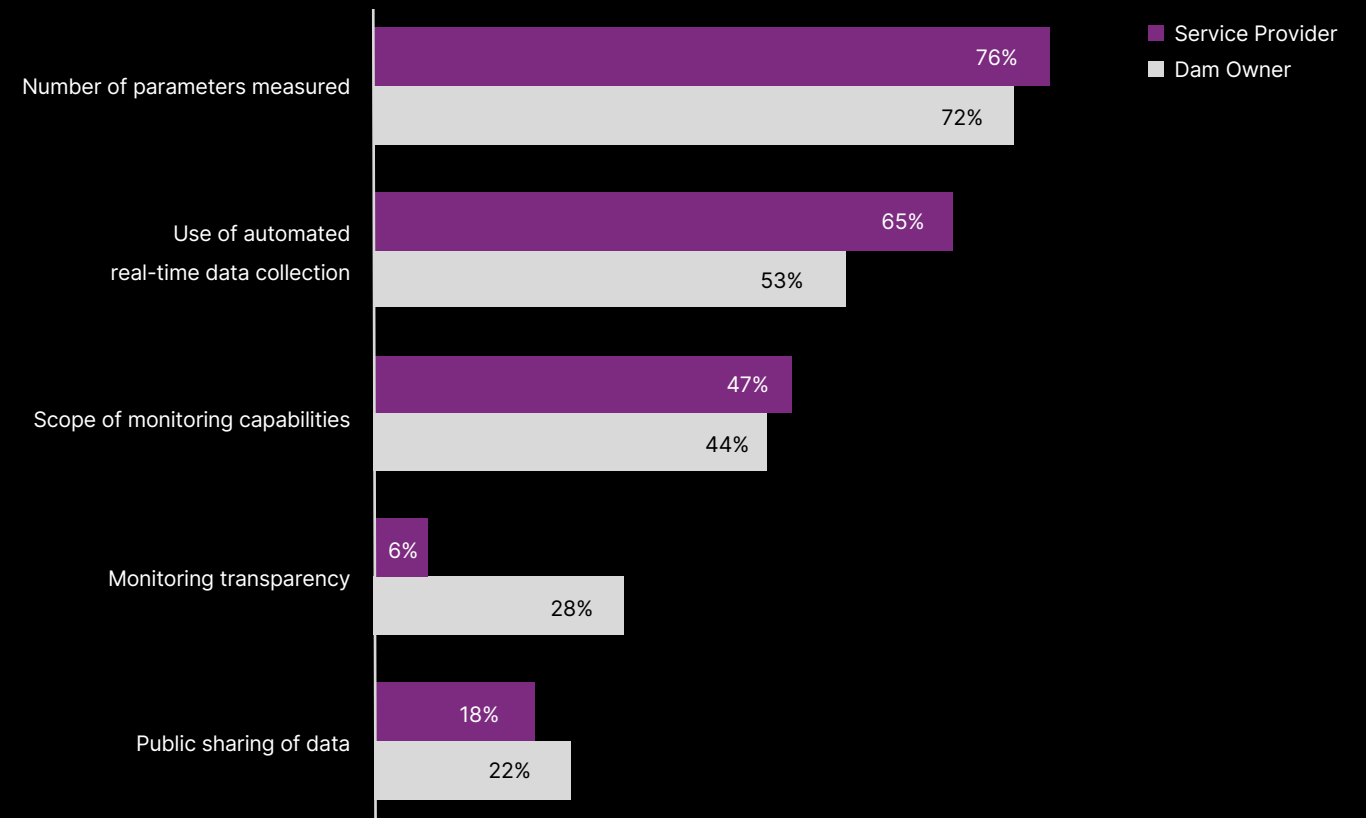
This move to automation has facilitated other major trends. Because of the greater accuracy, efficiency, timeliness, and scalability of automated solutions, nearly three-quarters of organizations have increased the number of parameters they measure. Similarly, automation has enabled over four out of 10 organizations to widen the scope of their monitoring capabilities.

To build trust with customers, meet regulatory demands, and show a commitment to environmental responsibility, about 20% of organizations, particularly dam owners, have increased public data sharing over the past two years. Dam owners have also increased monitoring transparency—clarifying data sources and improving reporting to internal and external stakeholders.

Three times more automated organizations increased their public disclosure of condition monitoring data compared to organizations using manual processes, possibly because they are more able to produce high-quality data.

Q. How have the following monitoring practices at your organization changed over the last two years?

Organizations reporting increases in monitoring practices



Market forces drive automation

Social license—the need to communicate strong condition performance to stakeholders—is the biggest reason for organizations to automate condition monitoring. Some 63% of dam owners, subject to rising environmental and safety demands, and 76% of service providers that support them, see it as very influential.

Dam owners also say they are heavily influenced to automate by operational demands—the need to measure and respond to issues in real time to ensure safety and minimize environmental impact.

Growing impact of technology and regulations

While the advent of more accurate, lower-cost sensors and other digital advances has a clear impact on dam owners, technology is a larger factor for service providers. The reason: they need to keep on top of the latest technological developments to maintain a competitive edge and serve a wider set of clients.

With growing recommendations for automated monitoring systems coming from regulatory bodies, such as the U.S. Federal Energy Regulatory Commission, as well as professional groups, such as the Australian National Committee on Large Dams, organizations are feeling the pressure to up their game. However, service providers that support clients across different countries are more likely to face regulatory pressure than dam owners, which often operate in fewer countries and have smaller businesses.

Q. How influential are the following external market forces in driving adoption of automated monitoring?

Forces driving adoption of automated monitoring

		Dam Owner	Service Provider
Social license - Need to communicate strong condition performance to stakeholders	Very influential	63%	76%
	Moderately influential	19%	12%
Operational demands - Requirement to measure and respond to conditions that might impact my business in real time	Very influential	44%	47%
	Moderately influential	47%	47%
Technology - The advent of more accurate, lower cost sensors, gateways, telemetry, and cloud processing	Very influential	34%	59%
	Moderately influential	63%	35%
Regulatory - Increasing governmental requirements to implement real-time monitoring to detect or avoid harm	Very influential	31%	47%
	Moderately influential	59%	53%
Economic - e.g., the cost of labor and manual monitoring is increasing over time, automated data collection is becoming more economically feasible	Very influential	16%	47%
	Moderately influential	48%	53%

Benefits of automation to service providers

Service providers, which are more automated, report more benefits than dam owners overall. On average, service providers surveyed report 3.1 benefits vs. 2.6 reported by dam owners.

More than three-quarters of dam service providers say they can execute more projects in a year due to automation, compared with 38% of owners. Also, nearly six in 10 of the providers cite the ability to operate with leaner teams, about three times as many as dam owners.

Automated monitoring boosts productivity and a competitive advantage

Because of the larger size of service provider organizations (2,500 employees on average vs. 1,400 for owners), automation is particularly effective at boosting their productivity, enabling them to handle more projects with fewer people.

Six out of 10 service providers believe that automated monitoring has improved their ability to move into new markets. And a similar percentage say that they have unlocked recurring revenue by adding new clients and upselling value-added services to existing ones.



Automation often requires re-evaluating and redesigning existing processes for optimal efficiency.

– Instrumentation specialist,
Australian service provider



Adapting to evolving requirements or technological advancements can improve the overall durability of automated workflows.

– Instrumentation specialist,
Spanish service provider

Benefits of shifting to automated monitoring

	Dam Owner	Service Provider
We can execute more projects in a year	38%	76%
We can execute projects more cost effectively	75%	59%
We have more capability to move into new markets	69%	59%
We can unlock recurring revenue	63%	59%
We can operate with leaner teams/staff	19%	59%

Q. How has the shift to automated monitoring affected your business?



A look to the future

The shift to automation will continue

Dam owners and service providers will continue to move rapidly toward automation over the next two years. Owners will increase their share of automated monitoring from 76% now to 82% in two years, while providers will increase it from 82% to 87%.

The dam industry is moving faster than others: the combined average automated percentage for dam owners and providers will be 84% in two years vs. 80% on average across all industries in our study (which includes transportation, mines, utilities, and water distribution/wastewater infrastructure owners and service providers).

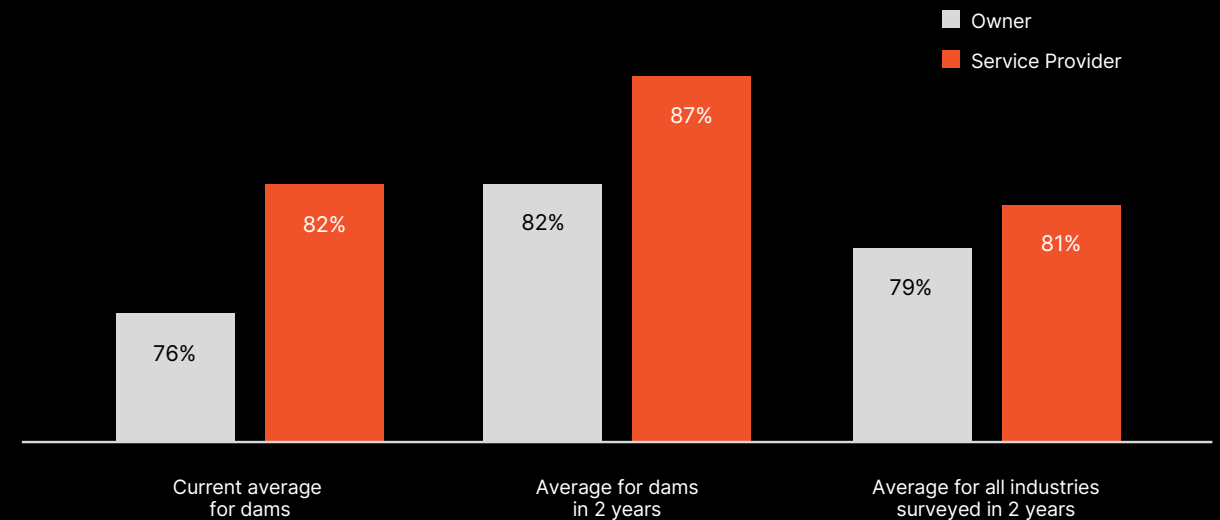
The misconceptions of full automation

Some organizations move more slowly than others on automation because of concerns about giving up manual monitoring. But such worries are often unfounded. For example, some organizations, particularly those that are still mostly manual, think that manual processes are cheaper. Yet 78% of automated dam owners and service providers said that the shift to automation enabled them to execute projects more cost effectively.

Another common misconception is that automating data collection removes human thinking from the process. In fact, it frees up people from the mundane task of collecting data, so they can use their judgment to make better decisions or their creativity to find innovative approaches.

Q. What percentage of your organization's monitoring utilizes manual data collection? What percentage of your organization's monitoring data do you expect to still be manually collected in two years?

Average percentage of automated monitoring



Automation is needed for long-term viability

The writing is on the wall for both dam owners and service providers: automated data collection is essential for the long-term economic viability of an organization's condition monitoring approach.

Automated condition monitoring practices provide value and efficiency

For dam owners, stakeholder demands for accurate, real-time data, along with the need to drive cost efficiencies while extracting more value from data, will make automation a necessity. That is why 100% of automated dam owners believe that their condition monitoring practices will meet the demand of stakeholders in 10 years, while 17% of those doing any manual monitoring say that their practices will not meet stakeholder demands.

Service providers also recognize the importance of automation to their future. Every automated service provider believes that their condition monitoring practices will remain economically viable in 10 years, while 22% of manual providers think otherwise.

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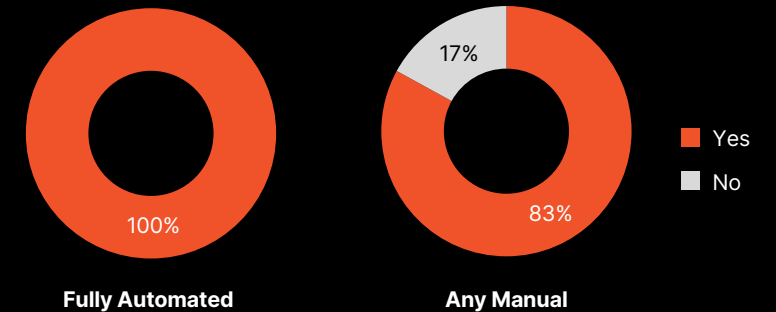
It is essential to be ready to refine and adapt your automation processes as necessary in order to achieve the best possible outcomes.

– Project manager, Australian service provider

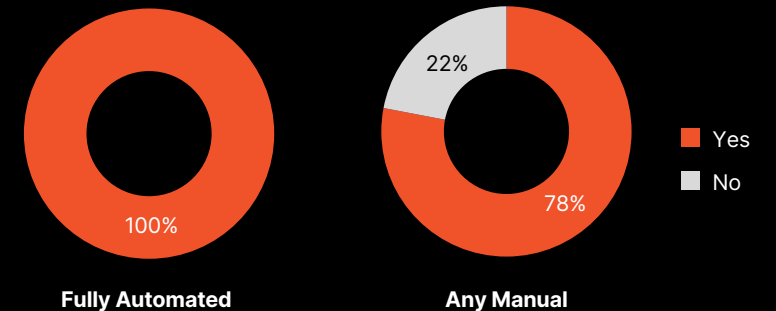
Q. Dam Owners: Do you think your organization can continue to meet the demands of various stakeholders in 10 years if it continues with its current data collection approach?

Q. Service Providers: Do you think your organization's condition monitoring practices will be economically viable in 10 years if you continue with your current data collection approach?

Meeting stakeholder demands through data collection practices



Economic viability of condition monitoring practices



Key takeaways



How automation is improving condition monitoring for dams

The survey found that condition monitoring for dams is now largely automated, with dam owners currently doing 76% automated monitoring, while service providers do even more at 82%. Over the next two years, these organizations will continue to increase automation to 82% and 87%, respectively. Our analysis reveals that the move to automation generates five key benefits to dam owners and service providers.

- 1. Easy Integration of sensor data with other information sources.** Automating condition monitoring makes it easier for organizations to integrate data with other information sources, such as asset management systems, public sources, GIS layers, and digital twins. It enables them to maximize the value from their condition monitoring programs.
- 2. Fewer challenges and better data visualization.** Automated organizations encounter fewer hurdles in condition monitoring than manual ones: an average of 1.6 vs. 2.9, respectively. Data ingestion and compatibility, as well as maintaining visualizations and charts, are some of the main challenges that organizations overcome through automation.
- 3. Ability to monitor more parameters and areas.** Over the last two years, 67% of automated dam owners and service providers have boosted the number of parameters they measure, such as turbidity and pore pressure. Another 63% have broadened the scope of their monitoring capabilities, and 35% have increased monitoring transparency.
- 4. Greater cost savings and staff productivity.** Dam owners and service providers realize significant cost efficiencies and productivity gains by embracing automation. Over three-quarters of automated organizations (78%) say they can execute projects more cost effectively, while 32% can operate with leaner teams.
- 5. Increased market penetration and growth.** Some 71% of dam owners and service providers report that the shift to automation has enabled them to move into new markets. At the same time, automation has allowed 63% to execute more projects throughout the year and 53% to unlock recurring revenue.



Lessons learned on the road to automation

Key insights for transitioning to automated condition monitoring

We asked dam owners and service providers for their advice on shifting to automation in condition monitoring. Here are four lessons learned.

- 1. Establish clear plans, roles, and processes.** Organizations that establish implementation plans and organizational structures up front achieve better results when automating condition monitoring, according to executives surveyed. For example, the CAD designer at an Australian dam owner told us that “enforcing predefined rules and processes plays a crucial role.”
- 2. Ensure ongoing communication and collaboration.** Top-down guidance, along with open communication and collaboration among teams, is crucial, executives say, to ensure a smooth transition to automation and avoid organizational resistance. “Transparent decision-making and effective communication are essential,” said an IT manager at a U.K. dam.
- 3. Install proper quality controls over data and processes.** Organizations should routinely assess the performance of automated processes and install rigorous data quality assurance procedures. “Enhance adherence to regulations and audit trails, guaranteeing data precision and governance,” advises the chief data officer at a U.S. civil construction firm working with dams.
- 4. Educate and engage employees.** Organizations should ensure their technical staff know they are not being replaced by automation. Rather, it removes the mundane, time-consuming work of data collection so they can focus on the high-level analysis and problem-solving that they are uniquely qualified to perform. “Automation allows for the reallocation of human resources to more valuable activities,” said a project engineer at a Canadian dam organization.

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iTwin IoT is a cloud-based software designed to integrate real-time data from sensors and other connected devices with digital twins—virtual models of physical assets. This platform enables the collection, visualization, and analysis of data, providing comprehensive insights into the performance and health of infrastructure assets such as dams, bridges, and buildings. By leveraging iTwin IoT, users can monitor conditions, predict maintenance needs, and enhance decision-making processes, ultimately improving the efficiency, safety, and resilience of their infrastructure.

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