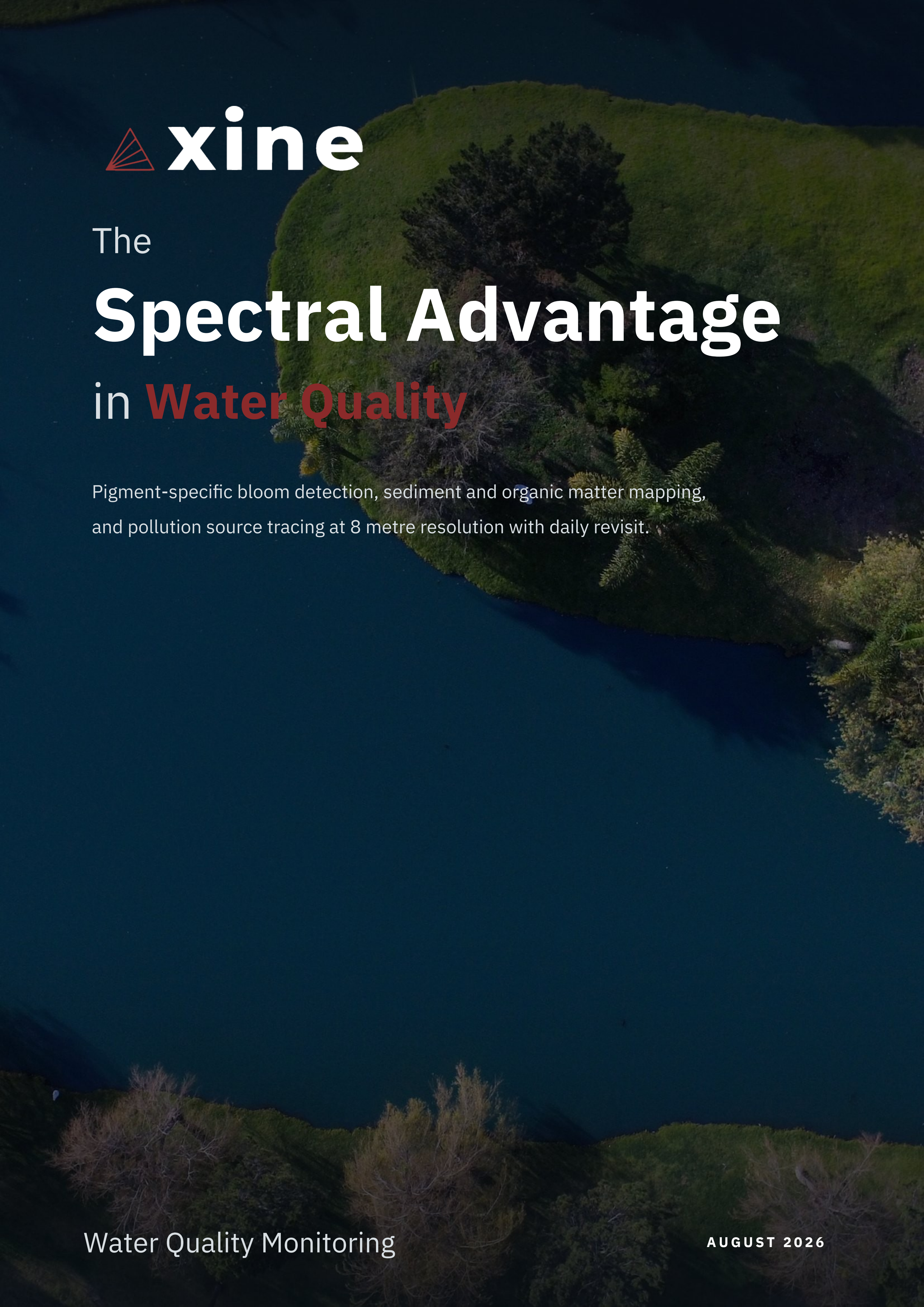

xine

The Spectral Advantage in Water Quality

Pigment-specific bloom detection, sediment and organic matter mapping, and pollution source tracing at 8 metre resolution with daily revisit.

Water Quality Monitoring

AUGUST 2026

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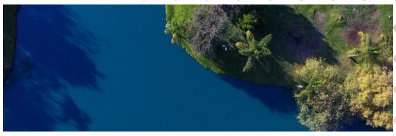
Introduction



This paper sets out how hyperspectral imaging supports water quality monitoring, and how Axine Laboratories applies satellite spectroscopy to bloom detection and speciation, sediment and organic matter mapping, and pollution source tracing across inland and coastal waters. It is written for environmental regulators, water utilities, catchment managers and industrial operators with discharge or impoundment obligations.

A small forest pond with growth across one arm of it. At this size a bloom is obvious from the air. The problem is the reservoir nobody flies over, and the fortnight before it looks like this.

Motivation: an obligation to measure, and not enough measurement

Water quality monitoring is expanding and still falling behind what is being asked of it. Reporting against the United Nations ambient water quality indicator grew from 89 countries in 2022 to 120 in the 2023 data drive, yet the proportion of monitored water bodies classified as good slipped from 57 per cent in 2017 to 56 per cent in 2023, and the United Nations Environment Programme warns that the health and livelihoods of 4.8 billion people could be at risk by 2030 if monitoring is not improved[1]. The distribution of that measurement effort is as significant as its volume: just three per cent of in situ data submitted came from the lower income half of the world[2].

The reason is structural rather than a lack of will. In situ monitoring is precise at a point and silent everywhere else. A sampling programme with a monthly cadence and thirty stations produces 360 measurements a year across a catchment that contains millions of hectares of water surface. Buoys, autonomous vehicles and research vessels extend that reach at costs that scale linearly with the ground covered, which is why the parts of the world with the greatest water quality pressure tend to have the least water quality data.

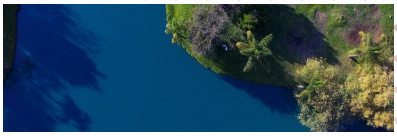
The cost of finding out late

Harmful algal blooms are the clearest illustration. The National Oceanic and Atmospheric Administration estimates that blooms cost the United States economy at least 82 million dollars a year, with a single major event capable of reaching tens of millions[3]. In 2014 roughly half a million residents of Toledo, Ohio were advised not to drink or use their tap water for three days after cyanotoxins were detected at the treatment plant intake, and the 2011 Lake Erie bloom covered more than 2,000 square miles[3]. Lakes and reservoirs serving as drinking water sources for an estimated 30 to 48 million Americans may be periodically contaminated by algal toxins[4].

One analysis of public records identified more than 1.1 billion dollars spent by United States communities since 2010 on preventing or treating algae outbreaks across 85 locations in 22 states[5]. Almost all of that expenditure is response. The value of early warning lies in converting response into management: a reservoir operator who knows a bloom is developing, where it sits and what species dominates it can move an intake, adjust treatment or issue an advisory while those remain inexpensive options.

Satellite hyperspectral imaging addresses the coverage problem and the early warning problem with the same instrument. It measures the optical properties of a water body directly, across its full extent, on a cadence set by orbital revisit, and it resolves the pigments that distinguish one kind of bloom from another.

What is hyperspectral imaging?



Water is not a single optical material. What a sensor measures over a water body is the combined effect of everything suspended or dissolved in it: phytoplankton pigments, suspended sediment, dissolved organic matter, and the water itself. Each of these constituents absorbs and scatters light at characteristic wavelengths, and the measured spectrum is their sum.

Separating that sum into its parts is a spectral resolution problem. Chlorophyll-a absorbs near 665 to 675 nm and produces a reflectance peak near 700 to 710 nm. Phycocyanin, the accessory pigment specific to cyanobacteria, absorbs near 620 nm. Phycoerythrin absorbs near 565 nm. Those features sit within tens of nanometres of each other, inside the same broad green-to-red region that a multispectral sensor records in two or three wide bands.

A comparison of RGB, multispectral and hyperspectral imagery.

Type	Number of bands	Bandwidth (FWHM)	Wavelength range
RGB	3	~50-70 nm	450-700 nm
Multispectral	4-20	~15-35 nm	400-2350 nm, discontinuous
Hyperspectral	100-500+	Under 10 nm	400-2500 nm, contiguous

The operational consequence is direct. A multispectral sensor can report that a water body is green and that its chlorophyll concentration is elevated. It cannot report whether the organism responsible is a diatom bloom that will feed the food web or a cyanobacterial bloom that may produce microcystin. That distinction is the one a water utility actually needs, and it is carried by a pigment absorption feature roughly 20 nm wide.

The tasked acquisition tier

For operational monitoring, Axine acquires imagery from a commercial hyperspectral constellation of six identical microsatellites offering:

+ 472 contiguous spectral bands across the full visible to short-wave infrared range, 400 to 2500 nm, spanning every pigment and constituent absorption feature of interest.
+ 8 metre ground sample distance in the hyperspectral channels, the finest commercially available hyperspectral resolution currently in orbit.
+ 3 metre panchromatic imagery co-acquired for spatial context and shoreline definition.
+ Revisit of up to daily for most locations worldwide, with directed tasking over a specified water body.

Resolution determines which water bodies are addressable at all. At 30 or 60 metre ground sampling, small reservoirs, river reaches, farm dams, tailings ponds and near-shore zones are dominated by mixed land and water pixels, and the shoreline consumes much of the useful surface. At 8 metres a river a hundred metres wide is more than a dozen clean pixels across, which brings an entire class of inland water into scope.

Revisit determines whether the product is a survey or an early warning system. Blooms develop, drift and dissipate over days. A sensor with a sixteen day repeat cycle documents that a bloom occurred. A constellation offering daily tasking can track it while it is still developing.

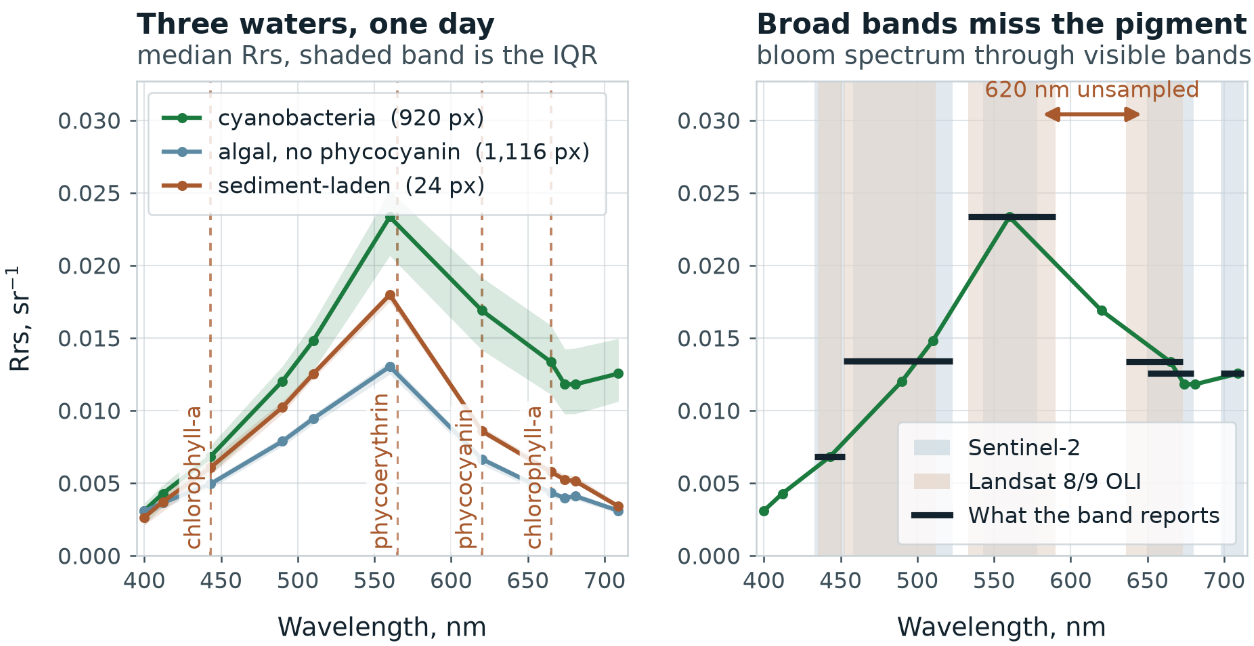
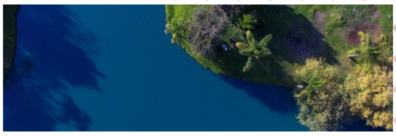


Figure 1 — *Median remote-sensing reflectance for cyanobacteria, green algae without phycocyanin, and sediment-laden water — one scene, one day. The pigment that separates the first from the second absorbs at 620 nm. On the right the same bloom spectrum read through broadband sensors: 620 nm is unsampled and the distinction disappears.*

Challenges in monitoring water quality



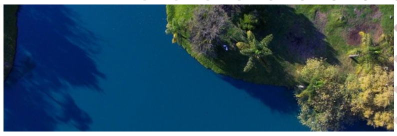
Agencies, utilities and operators are being asked to characterise more water bodies, more often, against more parameters, with budgets set when monitoring meant a boat and a bottle. The constraints below are the ones satellite spectroscopy is well positioned to relieve.

A river reach from directly above. Turbidity, coloured dissolved organic matter and chlorophyll separate within one acquisition, along the whole reach rather than at the single point where the gauge happens to sit.

+ **Point measurement against a spatial problem:** In situ sampling is precise at a point and provides no information about the rest of the water body. Blooms, plumes and stratification are spatially heterogeneous by nature, and a station network samples a small and often unrepresentative fraction of that heterogeneity.
+ **Sampling cadence against event timescales:** Monthly or quarterly sampling cadence is common, while blooms develop over days and discharge events over hours. Much of what monitoring is meant to detect occurs between visits.
+ **Access to the water that matters:** Marine protected areas, remote reservoirs, transboundary rivers and industrial impoundments are precisely the water bodies where measurement matters most and where deploying crews and instruments is hardest.
+ **Distinguishing harmful from harmless blooms:** Knowing that chlorophyll is elevated does not establish whether a bloom poses a health risk. Cyanobacteria carry the toxin risk, and distinguishing them from harmless phytoplankton is the operational question behind most freshwater bloom monitoring.
+ **Attributing pollution to a source:** Establishing which of several outfalls, tributaries or land uses is responsible for a plume requires observation of the plume as a connected spatial object, which point sampling cannot provide.

+ **Compliance evidence:** Regulatory frameworks increasingly require documented, repeatable, spatially explicit evidence of water body condition rather than assertions supported by sparse sampling.
+ **Emerging contaminants:** Substances such as microplastics, pharmaceuticals and personal care products occur at low concentrations and lack standardised detection methodologies, leaving agencies aware of a risk they cannot yet routinely quantify.

Hyperspectral imagery in action



Across inland and coastal waters, hyperspectral imagery supports three fundamental capabilities.

- **Detection:** Identifying whether a constituent or condition is present in a water body: a bloom, a sediment plume, an oil slick, an anomalous discharge.
- **Classification:** Determining what is present, in particular which pigment group dominates a bloom, and whether a plume is sediment, organic matter or contaminant in origin.
- **Quantification:** Measuring how much: concentration surfaces for the optically active constituents, plume extent, and change between acquisitions.

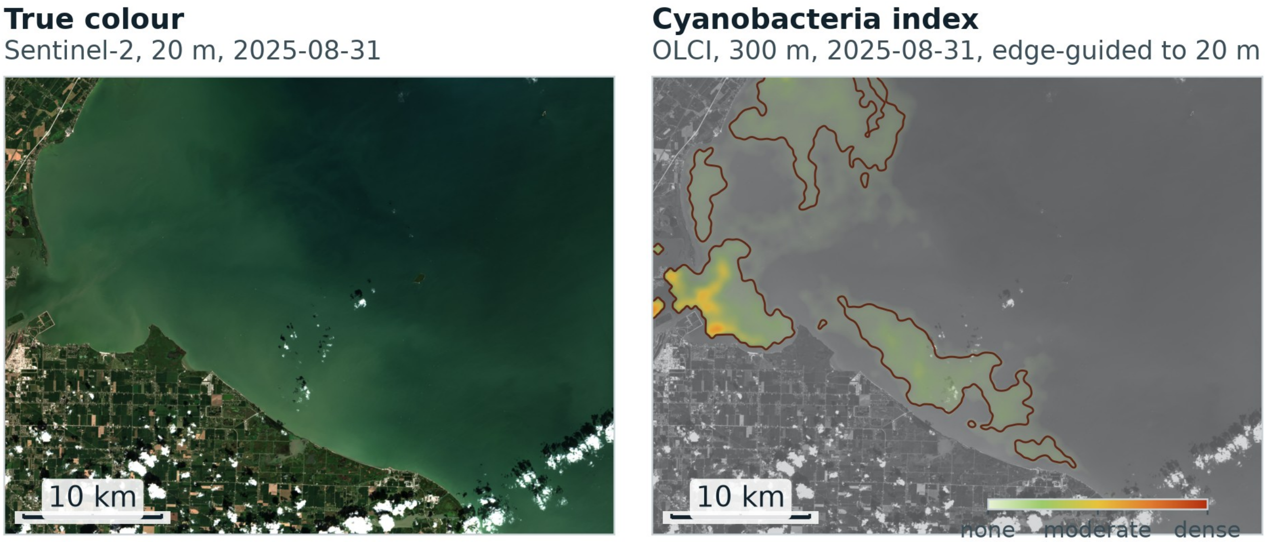
The table below sets out the spectral features that carry water quality information and their significance.

Water quality parameters, diagnostic wavelengths, and significance.

Parameter	Wavelength (nm)	Significance
Chlorophyll-a	665-675 absorption, 700-710 peak	Phytoplankton biomass and trophic state; the primary indicator of eutrophication
Phycocyanin	~620	Specific to cyanobacteria; separates a potentially toxic bloom from a harmless one
Phycoerythrin	~565	Accessory pigment supporting further algal group discrimination
Total suspended solids	600-900	Sediment load, water clarity, light availability and habitat condition
Turbidity	650-750	Cloudiness from suspended particles; widely used regulatory parameter
Coloured dissolved organic matter	400-500 absorption slope	Proxy for dissolved organic carbon; traces water masses and pollutant pathways
Total phosphorus (optical proxy)	467-675, 690-710	Inferred through its optical consequences; indicator of nutrient loading pressure
Submerged vegetation and benthic cover	550-700	Habitat extent and condition in shallow water
Hydrocarbons on water	1200, 1730, 2300	Slick presence, extent and product discrimination

Parameter	Wavelength (nm)	Significance
Floating debris and plastics	1215, 1732 absorption	Aggregation and accumulation zones; an emerging detection capability

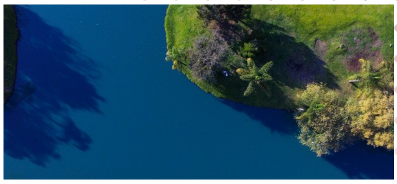
Parameters marked as optical proxies are inferred from their effect on water colour rather than measured directly, and are reported as such. Axine layers are released progressively and each carries an explicit validation posture, described in section 8.



Counted on the 300 m measurement, before any smoothing: 1,959 of 17,760 usable water pixels carry a positive cyanobacteria index, 176 km2, 11.0% of the basin's clear water that day. The same water is uniformly green on the left. The index is a spectral shape across 665, 681 and 709 nm; a phycocyanin depth at 620 nm was built and rejected because water's own absorption fakes it across the whole lake. The 20 m detail is an edge guide from the optical image, not spectral resolution.

Figure 2 — *A lake basin in true colour, beside a cyanobacteria index for the same day. The water is uniformly green on the left; on the right 176 km², 11 per cent of the basin's clear water, carries a positive index. The index is a shape across 665, 681 and 709 nm rather than a single band.*

Hyperspectral versus multispectral imaging in water quality

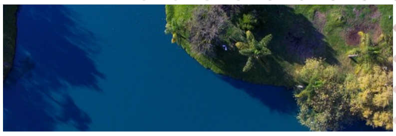


Multispectral imagery has real utility for water quality and remains the basis of most operational satellite monitoring. Hyperspectral imagery extends that basis into constituent-level discrimination, because separating pigments requires bands narrower than the pigment features themselves.

Parameter	Multispectral imaging	Hyperspectral imaging
Chlorophyll-a	Concentration estimation with established algorithms	Concentration estimation with reduced interference from sediment and organic matter
Algal group discrimination	Not resolvable	Pigment-specific separation of cyanobacteria from other phytoplankton
Cyanobacteria	Inferred from chlorophyll and context	Phycocyanin absorption measured directly at 620 nm
Suspended solids and turbidity	Robust and widely validated	Equivalent retrieval with particle type discrimination
Dissolved organic matter	Limited separation from sediment	Absorption slope resolved and separated from other constituents
Simultaneous parameters	A small number, with cross-interference	Multiple constituents retrieved from the same acquisition
Hydrocarbons on water	Visible slicks	Carbon-hydrogen absorption measured directly
Spatial detail	10-60 m typical	8 m, bringing rivers, small reservoirs and near-shore zones into scope
Revisit	Fixed orbital schedule	Directed tasking, up to daily for most locations

The distinction is a matter of physics rather than vendor preference: pigment discrimination requires narrow contiguous bands, and narrow contiguous bands are what defines a hyperspectral sensor.

The Axine analytical method



A still, forested lake. Water is a dark target: most of the signal arriving at the sensor came from the atmosphere, which is why the aquatic correction step is the technical differentiator rather than a formality.

Atmospheric correction over water

Water is dark across the near and short-wave infrared, so the signal leaving a water surface is a small fraction of what the sensor records, and the atmospheric contribution dominates. Correction schemes developed for land surfaces are not valid over water, and applying published band ratios to land-corrected reflectance produces numbers that look entirely credible and are not. Axine therefore applies aquatic atmospheric correction before any water product is generated. It is the first step in the chain rather than an option, and it is the single largest determinant of whether a satellite water quality product is trustworthy.

Water masking and validity

Water extent is delineated per acquisition rather than from a static mask, so that changing water levels, exposed sediment and shoreline vegetation are handled correctly. Cloud, sun glint, shadow, adjacency-affected shoreline pixels and optically shallow bottom returns are screened and reported explicitly as not evaluated. Every retrieval carries a validity floor, so that nodata and near-nodata cells cannot resolve into apparent detections.

Constituent retrieval

Optically active constituents are retrieved through established band ratio, band difference and baseline algorithms operating on the corrected reflectance, selected per constituent and per optical water type. Retrievals are computed per pixel, producing concentration surfaces rather than single-value summaries for a whole water body.

Pigment separation

Cyanobacteria discrimination rests on the phycocyanin absorption near 620 nm, measured as a baseline-corrected feature depth so that it is separated from the chlorophyll-a signal that surrounds it. This is the retrieval that multispectral sensors cannot perform, and it is the one that turns a bloom map into a risk assessment tool.

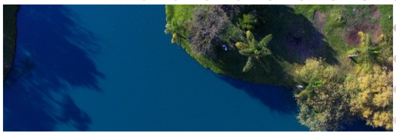
Change detection and time series

Repeat acquisitions are differenced against a baseline, producing trajectories per water body and per zone within it. Bloom development, plume migration and seasonal turbidity cycles are reported as time series rather than as isolated observations, which is what makes the output useful for early warning rather than for record keeping.

Reporting

Results are compiled into reports aligned to the parameter definitions and thresholds a client is regulated against, generated from the same evidence base the analysis was performed on, with the acquisition dates, processing version and validation posture recorded on the face of the document.

Use cases in water quality monitoring



Bloom detection and early warning

+ **Chlorophyll-a and trophic state:** Concentration surfaces across the full water body, supporting trophic state classification and long-term productivity trends rather than a single station value.
+ **Cyanobacteria discrimination:** Direct measurement of the pigment specific to cyanobacteria, separating blooms that carry a toxin risk from those that do not. Toxin concentration itself is established by laboratory assay, and the pigment map is used to direct that sampling to the right part of the water body on the right day.
+ **Bloom extent and trajectory:** Extent, intensity and movement tracked across successive acquisitions, giving operators the development trajectory rather than a snapshot.
+ **Drinking water intake protection:** Monitoring focused on the water immediately around abstraction points, where the operational decisions about intake depth, intake location and treatment adjustment are actually made.
+ **Recreational water advisories:** Bloom presence and extent at designated bathing and recreation sites, supporting advisory decisions with spatial evidence.

Sediment, clarity and organic matter

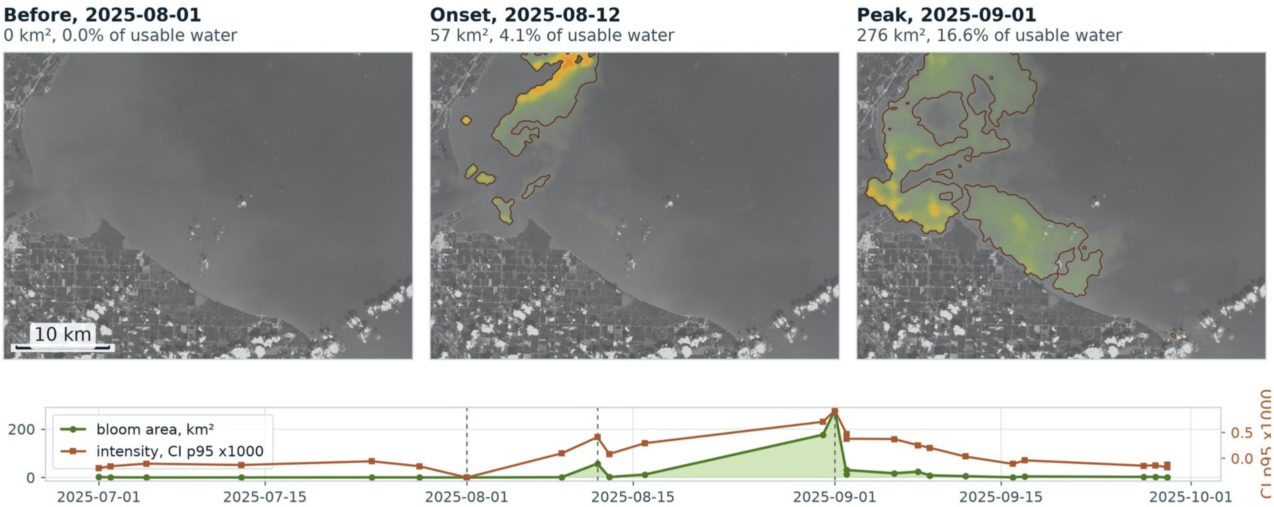
+ **Suspended solids and turbidity:** Sediment load and water clarity mapped across whole systems, supporting erosion assessment, dredging oversight and habitat condition reporting.
+ **Coloured dissolved organic matter:** Organic matter distribution as a proxy for dissolved organic carbon, used to trace water masses and to identify catchment sources.
+ **Plume mapping and attribution:** Sediment and organic plumes from river mouths, outfalls, dredging operations and construction sites mapped as connected spatial objects, which is what allows a plume to be attributed to its source.

Pollution and industrial monitoring

+ **Hydrocarbons on water:** Slick extent and product discrimination on inland and coastal water, supporting response prioritisation and post-event documentation.
+ **Impoundment and tailings water:** Surface condition of tailings ponds, produced water impoundments and process water storages, tracked over time without site access.
+ **Discharge and receiving water:** Condition of receiving waters upstream and downstream of a discharge point, providing the spatial context that a compliance point sample cannot.
+ **Floating debris:** Aggregation zones for floating material identified through near and short-wave infrared absorption features, an emerging capability reported as such.

Regulatory and programme monitoring

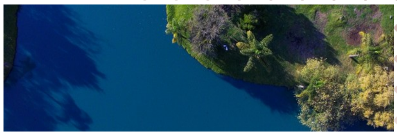
- **Ambient water quality reporting:** Wall-to-wall coverage of water bodies within a jurisdiction, including those without station networks, supporting national and international reporting obligations.
- **Catchment and basin assessment:** Consistent parameter surfaces across an entire catchment or basin, including transboundary reaches where coordinated in situ programmes are difficult to sustain.
- **Baseline and outcome monitoring:** Water body condition documented before, during and after an intervention, providing objective evidence of the effect of nutrient management, restoration or infrastructure works.



Every usable acquisition is on the chart, 25 of them, not only the three drawn above; the dashed lines mark those. The index is zero across July, first turns positive on 12 August, reaches 276 km² on 2025-09-01, and has collapsed to nothing by 16 September. The three panels share one frame and one colour scale, which is the only way three dates can be compared by eye. Area is counted on the 300 m pixels before smoothing; the 20 m detail is an edge guide from a single optical mosaic reused on every panel as a backdrop, not a measurement.

Figure 3 — *The same basin before, at onset and at peak: nothing on 1 August, 57 km² on 12 August, 276 km² on 1 September, and collapsed again by mid-September. All twenty-five usable acquisitions are on the chart, not only the three panels drawn above it.*

Validation and confidence



Axine treats validation as a product feature. Every analytical layer carries a stated validation posture, and every performance figure we publish is traceable to a documented test against an independent reference.

Validation posture on every layer

Each layer renders with an explicit posture: calibrated region, validated region, or screening. Deterministic band mathematics quotes no accuracy figure because none is claimed for it. Retrievals and learned products quote accuracy where they have been tested against in situ measurement for that water body or optical water type, and ship as screening elsewhere with the reason stated. A client always knows which of the three they are looking at, which is what makes an Axine layer safe to place in front of a regulator.

Reference data

For water products the reference is in situ measurement: matched-up samples collected close in time to the overpass, covering the concentration range of interest across the optical water types present. Axine secures matchup data alongside development rather than after it, and characterises retrieval performance per water type rather than quoting a single global figure, because optical conditions in a sediment-laden river and a clear oligotrophic reservoir are not the same problem.

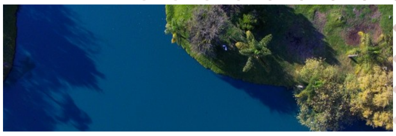
Protocol

+ **Pre-registration:** Test design, thresholds and success criteria are fixed and recorded before evaluation data is examined.
+ **Frozen parameters:** Retrieval parameters are fixed prior to evaluation and are not adjusted after results are seen.
+ **Hash-sealed inputs:** Input imagery and reference data are hashed, so any published result can be reproduced against the exact data that produced it.
+ **Stability testing:** Leave-one-region-out and single-site-removal runs confirm that reported performance is not carried by any single water body.
+ **Leakage controls:** Label permutation runs confirm that measured performance collapses when labels are destroyed, the standard test for information leakage.
+ **Append-only logging:** Every comparison run is written to an append-only log, providing a complete audit trail behind any figure we quote.

Reporting practice

Performance is reported with the validation regime named, as intervals rather than point estimates, and per water type rather than pooled. On the mineral products where this discipline is longest established, Axine publishes comparisons against independent United States Geological Survey reference products and quotes ranking performance as an area under the ROC curve of 0.7465 with a 95 per cent credible interval of 0.663 to 0.819 under spatially blocked validation. The same reporting standard governs every vertical.

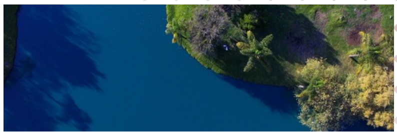
Operational benefits

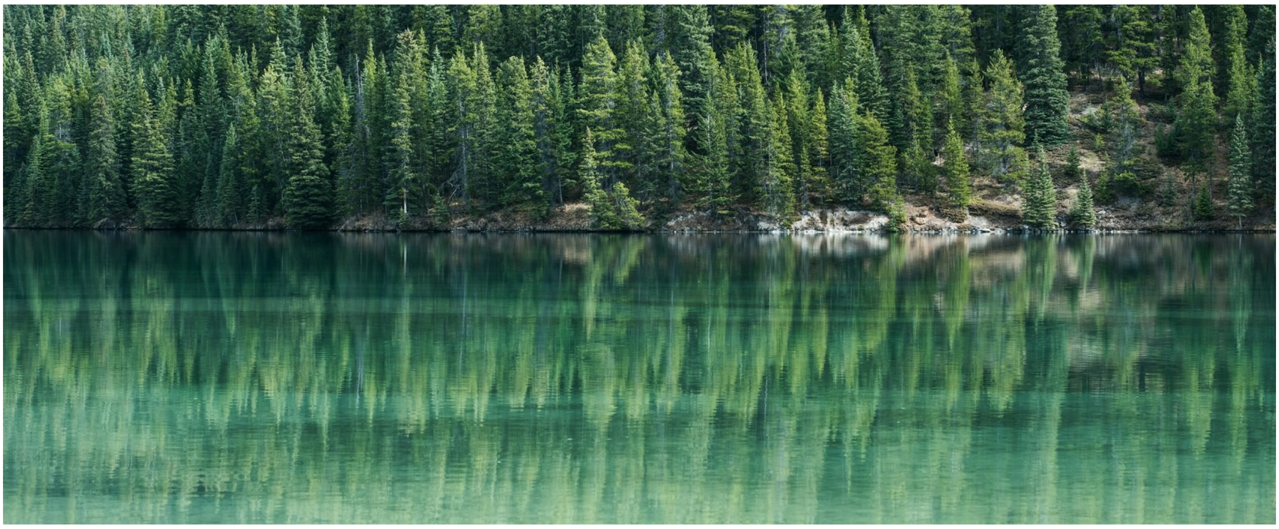


+ **Whole-water-body coverage:** A single acquisition characterises an entire water body rather than a set of stations, converting a sampling problem into a census and revealing the spatial structure that point measurement averages away.
+ **Early warning rather than record keeping:** Daily tasking availability means a developing bloom is observed while intake, treatment and advisory decisions are still inexpensive.
+ **Risk-relevant discrimination:** Pigment-specific measurement distinguishes cyanobacteria from harmless phytoplankton, directing laboratory sampling to the water and the day that warrant it.
+ **Reach without deployment:** Marine protected areas, remote reservoirs, transboundary rivers and industrial impoundments are monitored without deploying crews, vessels or moored instruments.
+ **Evidence-grade output:** Every retrieval is traceable to a corrected spectrum and a documented algorithm, reproducible on demand, which is what a regulator or an auditor requires.
+ **Predictable economics:** Everything derived from public satellite data is free, permanently. Tasked acquisition is priced per square kilometre against a defined area of interest, so programme cost is known before commitment.
+ **Complements existing programmes:** Satellite monitoring extends and directs an in situ network rather than replacing it, concentrating sampling effort where the imagery indicates it will be informative.

Surf on a bathing beach. Coastal recreational waters carry season-long monitoring obligations and are typically sampled at a handful of points on a handful of days.

Inherent product properties





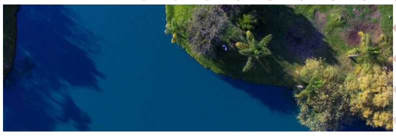
Clear, low-productivity water. Optical water type governs which retrieval is valid over a given scene, so it is reported alongside the result rather than quietly assumed.

- **Water-specific processing:** Aquatic atmospheric correction applied before any retrieval, which is the precondition for a satellite water product that can be defended.
- **Pigment-level discrimination:** Contiguous narrow-band coverage resolves pigment features tens of nanometres apart, including the phycocyanin absorption that identifies cyanobacteria.
- **Resolution matched to inland water:** 8 metre hyperspectral ground sampling with 3 metre panchromatic context brings rivers, small reservoirs, farm dams, impoundments and near-shore zones into scope.
- **Monitoring cadence:** Revisit of up to daily for most locations, turning a survey into a monitored time series with alerting between epochs.
- **Multiple constituents, one acquisition:** Chlorophyll, phycocyanin, suspended solids, organic matter and hydrocarbons retrieved from a single acquisition rather than from separate programmes.
- **Analysis-ready delivery:** Cloud-optimised GeoTIFF outputs, API access and generated reports designed to enter an existing GIS or environmental reporting workflow.
- **Explicit data integrity:** Screened ground reported as not evaluated and validity floors applied on every retrieval, so that unmeasurable water is never rendered as a measurement.

Optimal operating conditions

Optical water quality retrieval measures the light leaving the water surface, so the method performs best in daylight, cloud-free conditions, away from strong sun glint, over water deep enough that the bottom does not contribute to the signal. Optically shallow water, heavy glint and cloud are screened and reported as not evaluated. Parameters retrieved as optical proxies, including phosphorus and dissolved oxygen conditions, are inferred from their effect on water colour and are labelled as inferences throughout, so that no figure is presented as a direct measurement it is not.

Platform, access and data handling



The platform

Work is ordered and delivered through a web application. Users define a water body or upload a boundary, search available imagery or request a tasked acquisition, and follow the order through a staged job queue. Results are served as cloud-optimised GeoTIFFs with map tiling, and any pixel can be opened to inspect its full corrected spectrum and the features the retrieval was based on. Monitoring subscriptions run the same analysis on a schedule and raise alerts against a baseline. Results are catalogued, reports are generated as PDF, and workspaces support teams, roles and notifications. An API is available for clients working in their own GIS or environmental data environment.

Lisa

Lisa is a client-facing assistant that runs entirely on Axine infrastructure rather than on a third-party model service. She searches imagery, estimates pricing, retrieves results, saves and lists areas of interest, geocodes, and reports the current model version with its validation metrics. Order submission is confirmation-gated by design, and any request requiring judgement is escalated to a human analyst.

Self-hosting is a procurement decision rather than an engineering preference. Monitoring locations and results remain within Axine infrastructure and are never transmitted to an external model provider.

Access tiers

Tier	Coverage
Free	Everything derived from public satellite data, including screening layers, visualisation, Lisa and API access. Axine does not charge for information obtained freely.
Tasked	Directed 8 metre hyperspectral acquisition over a specified water body, with full analysis, priced per square kilometre against a stated minimum area.
Monitoring	Scheduled repeat acquisition with change detection, alerting and reporting between epochs, on volume terms.

About Axine Laboratories

Axine Laboratories builds commercial hyperspectral analytics for water monitoring, energy, mining and agriculture. The company is registered in the United States and run by a technical team of geologists and engineers.

Our approach rests on three commitments. Detection is physics-based and reproducible, derived from corrected measurements and documented algorithms rather than inferred by an untraceable model. Every published figure is backed by a pre-registered test against an independent reference, with the validation regime stated alongside it. And analysis derived from public satellite data is free and will remain so, because we do not charge for information obtained freely.

Revenue comes from tasked high-resolution acquisition and the analysis performed on it, which aligns our interest with delivering observations a client could not otherwise obtain rather than with metering access to imagery that is already public.

Axine Laboratories

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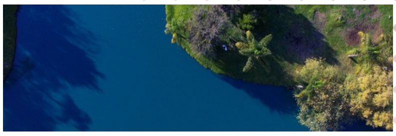
References



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