Australia's National
Science Agency

# AquaWatch Australia

## Science, Technology and Implementation Roadmap

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Indigenous acknowledgement

CSIRO acknowledges the Traditional Owners of the lands, seas and waters, of the area that we live and work across Australia. We acknowledge their continuing connection to their culture and pay our respects to their Elders past and present.

Cover image credit

Satellite image from Sentinel Hub showing where our AquaWatch Mission is monitoring sediment flow from the Fitzroy River out towards the Great Barrier Reef. Credit: European Union, contains modified 2023 Copernicus Sentinel data processed with EO Browser.

# Contents

# Acknowledgements

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# Executive Summary

AquaWatch Australia (AquaWatch) is one of the world's most ambitious water quality monitoring and forecasting programs, establishing a 'weather service for water quality' to provide free and public access to actionable information on inland and coastal water quality.

This Roadmap builds on the AquaWatch Australia Mission Plan and identifies the key technology implementation and research program activities required to achieve the objectives of AquaWatch. The Roadmap is intended to be used as a guide for the AquaWatch team and its implementation partners to identify important technology and R&D priorities and gaps, and highlight focal areas where additional capacity may be required. It is also intended to enable new prospective partners to identify areas where they may be able to engage and contribute.

For the first time, AquaWatch will combine data from networked in-situ water quality sensors, a 'virtual constellation' of conventional and customised Earth observation satellites, and water quality & hydrodynamic models. It will also include state-of-the-art advanced data management, cloud-computing analytics, machine-learning and water quality forecasting. While the baseline water quality information from AquaWatch is expected to be provided freely, AquaWatch will be a driver and catalyst for further innovation and commercialisation activities across the in-situ sensor, bespoke data services & analytics, and space sensor industry sectors.

Key activities in each of the AquaWatch major research areas are presented in terms of i) contributions to the implementation of the AquaWatch system of technologies, or ii) a concurrent research program to improve the accuracy and availability of water quality information and forecasting skill to support a growing range of stakeholders and end users nationally and internationally. These activities are categorised into three time frames: 'By 2026', which is the first major milestone demonstrating a fully operational network of technologies operating over a small number of sites for a small number of use cases; 'By 2030', as an operational system over a larger network of sites and use cases; and 'Beyond 2030' in support of continued science excellence and operational effectiveness of a system operated by third party organisations.

In addition to the underpinning science and technology activities, partnerships, business development and communication activities will be vital to achieve impact. Activities in these areas are presented in the same timeframes as the technology elements, but the focal areas of the activities are described in terms more specific to each of those activity areas.

This Roadmap concludes by drawing together information from the individual activity areas to present a detailed overview of the expected configuration of AquaWatch 2026, which is the first major milestone for the AquaWatch Mission.

# Abbreviations and Acronyms

| | |
|---|---|
| AI | Artificial intelligence |
| ADB | Asian Development Bank |
| app | Software application |
| ARD | Analysis Ready Data |
| BD | Business Development |
| CDOM | Coloured dissolved organic matter |
| Chl | Chlorophyll |
| CoP | Community of Practice |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| DO | Dissolved Oxygen |
| DOC | Dissolved organic Carbon |
| EASI | Earth Analytics Science and Innovation (EASI) platform – Centre for Earth Observation (csiro.au) |
| EO | Earth observation |
| FTP | File Transfer Protocol |
| GBR | Great Barrier Reef |
| GEF | Global Environment Facility |
| HAB | Harmful algal bloom |
| HAPS | High-altitude pseudo satellite |
| IoT | Internet of Things |
| ML | Machine learning |
| NASA | National Aeronautics & Space Administration |
| NCI | National Computation Infrastructure |
| ODC | Open Data Cube |
| OGC | Open Geospatial consortium |
| SAG | Science Advisory Group |
| SATM | Science Applications Traceability Matrix |
| SDG | Sustainable Development Goals |
| TSM | Total Suspended Matter |
| UN | United Nations |
| USGS | United States Geological Survey |
| UX | User experience |

# 1 Introduction

## 1.1 Background

CSIRO Missions are large-scale scientific and multi-partner collaborative research initiatives aimed at making significant breakthroughs. Through Missions, CSIRO aims to accelerate the pace and scale at which Australia can solve the world's greatest challenges and unlock a better future. Each Mission aims to deliver positive impacts for the community, environment and economy, and increase scientific excellence in a particular domain.

The AquaWatch Mission aims to connect in-situ and Earth Observation (EO) data sources in an advanced data analytics system to deliver a 'weather service for water quality' across Australia and the globe. The objective is to improve the accuracy and availability of water quality information to service civilian, commercial, environmental and research community needs by 2030.

In the context of the AquaWatch Mission, water quality is defined here as:

> *The physical, chemical and biological characteristics of water that affect its suitability for a given use such as drinking, irrigation, recreation or ecosystem health*

Implementing AquaWatch technologies across a limited number of national and international pilot sites by 2026, and expanding to wall-to-wall continental coverage of Australia by 2030 are major milestones captured in the AquaWatch Mission Plan approved by the CSIRO Board in December 2022. Partnerships will be essential to achieve these objectives, to grow awareness of AquaWatch and increase the user base, and ensure continuity of the system and services beyond the life of the CSIRO AquaWatch Mission.

This Roadmap outlines the key development needs for the technologies and partnerships that are required to achieve the objectives of AquaWatch. The Roadmap is intended to be used as a guide for the AquaWatch leadership team and its implementation partners to identify important technology and Research and Development (R&D) priorities and gaps, and focal areas throughout the Mission's phases. The Roadmap will also enable new prospective partners to identify where they may be able to engage with, contribute to, or leverage off the AquaWatch technologies, data services and activities.

## 1.2 Overview of the AquaWatch Mission Plan

The AquaWatch Mission Plan is the primary document submitted to the CSIRO Board for approval to launch a Mission. While not a public document, the Mission Plan formalises the high-level context and objectives described in this Roadmap.

The AquaWatch Mission Plan highlights the importance of improving the availability of water quality information nationally and internationally. AquaWatch aims to improve the timeliness and delivery of water quality information to inform management actions to reduce impacts from poor water quality. Water quality information is currently not collected routinely across many areas of

Australia, and there are also opportunities to improve and harmonise the collection of water quality information amongst relevant national agencies.

Globally, the United Nations (UN) estimates that more than 3 billion people are at risk from unsafe water, and that more than 2.2 billion people lack access to safely managed water for drinking, sanitation and hygiene. These risks result in the deaths of more people each year than from all forms of violence combined, including wars[1]. Most of these people are in low-income countries[2], however many remote Indigenous communities in Australia also do not have access to safe drinking water[3].

AquaWatch is making a significant national contribution to the UN Sustainable Development Goals (SDG), particularly SDG 6 (Clean Water & Sanitation for All), SDG 14 (Life Below Water) and SDG 17 (Partnerships for the Goals). AquaWatch was listed as an Australian contribution to achieving the SDGs during UN Water Week in March 2023[4].

The importance of engaging with Indigenous communities is also highlighted in the AquaWatch Mission Plan. AquaWatch will be a major catalyst for partnering with Indigenous peoples and integrating their knowledge with a modern technology system. There may be valuable education, business and development opportunities for Indigenous communities through engagement with AquaWatch.

In addition, the Mission Plan highlights the importance of engaging with industry partners who may have specific needs in terms of the timeliness, format and focus of their information needs. Servicing these industries, and supporting the development of existing and new third-party, potentially commercial services is also a goal of AquaWatch. Ensuring that AquaWatch harnesses the necessary capacity to support these needs and growth of the AquaWatch network into the future is a key challenge.

The two major milestones for AquaWatch are: a limited implementation of the technology systems across a network of 10-20 pilot sites by 2026, and a more complete rollout across a larger number of sites, potentially including a handover to an operational organisation, by 2030. The Mission Plan provides high-level details on the impact and engagement, and technology development activities for each of these phases, plus some pointers to the potential outlook for AquaWatch over the longer term. This Roadmap provides more details to guide implementation of each of these elements.

[1] https://www.unwater.org/

[2] https://www.unwater.org/water-facts/wash-water-sanitation-and-hygiene

[3] https://public-health.uq.edu.au/article/2018/11/clean-water-remote-Indigenous-communities

[4] https://sdgs.un.org/partnerships/aquawatch-australia-0

## 1.3 Themes and timeframes

To achieve its objectives, AquaWatch will conduct activities along two themes:

1. A ‘technology system’, to deliver the network of integrated technologies across the pilot sites, and
2. A ‘research program’, to fund continuous improvement of the technology system and support aligned R&D activities to advance the AquaWatch technologies and support growth in the user base.

The activities are presented in the context of three timeframes, consistent with the major milestones of the Mission:

1. ‘By 2026’, when a fully functional integrated monitoring system including forecasting will be operational over 10-20 well monitored sites in Australia and overseas. This will enable the benefits of AquaWatch to be demonstrated, results validated and performance improved in collaboration with local partners and stakeholders
2. ‘By 2030’, when the system will be providing continental coverage across Australia for selected parameters, and system performance will be further validated over a larger network of sites and countries. It is also expected that by this time, key partnerships will be built to help operate the system on a routine and sustainable basis into the future
3. ‘Beyond 2030’, with the aim that AquaWatch data will be routinely available from third party providers and aligned activities will be supporting a range of additional public-good and commercial operational services

AquaWatch is driving innovation across a wide range of domains including sensor technologies, data connectivity and transfer systems, the design and manufacture of Earth observation (EO) sensors and systems, data analytics and forecasting, and improved global research and water quality management domains. For some of these domains AquaWatch has identified ‘stretch goals’ that point to future needs and development directions for key technologies and activities to ensure that AquaWatch remains relevant into the future.

## 1.4 Pilot sites

Testing and development of AquaWatch through to 2026 will primarily occur in collaboration with our academic, research and industry partners at the pilot sites in Australia and other countries (Figure 1). The objectives of the pilot sites are:

- Engage with local research, government, community, and industry partners to co-design, build and improve the robustness and accuracy of the AquaWatch system,
- Build a user network and Community of Practice (CoP) amongst prospective users and stakeholders in agriculture, aquaculture, irrigation, drinking water supply, desalination, blue carbon, extreme event management and other use cases,
- Become a mechanism to connect with local Indigenous and First Nations people in both Australian and international pilot sites, to draw from their knowledge of their lands and

waters, and build capacity in their communities to use and maintain the AquaWatch technologies,

- Develop capacity to enable partners to be the key custodians of each site, and
- Attract co-investment with the project partners to increase the activity at each site and demonstrate locally-applicable outcomes.

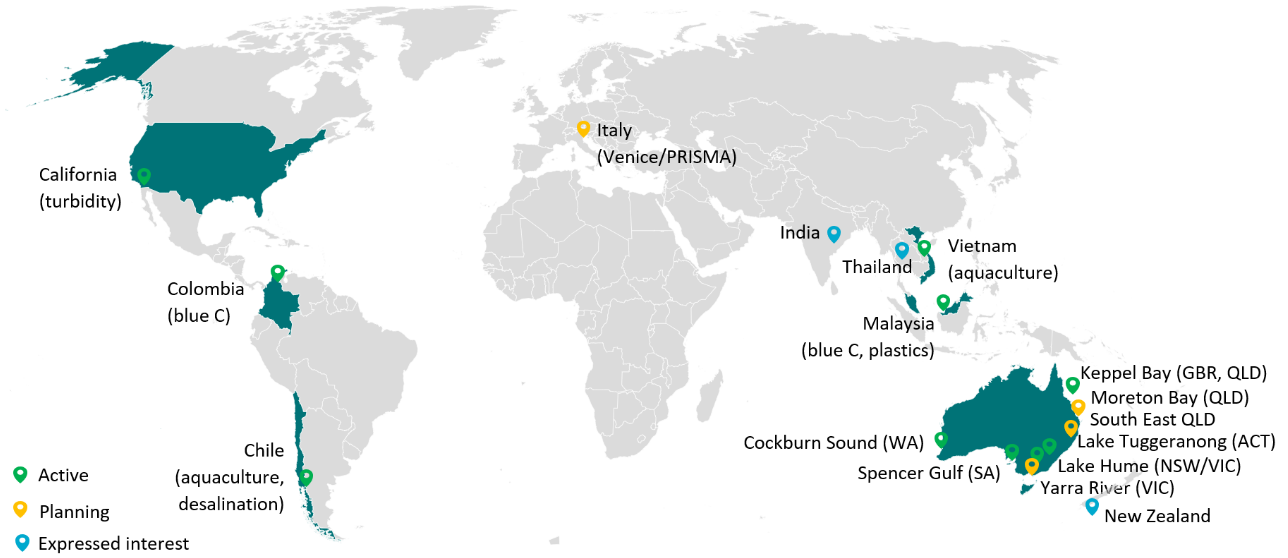


Figure 1. Location and key monitoring objectives for AquaWatch pilot sites (July 2023)

## 1.5 System architecture

The five key technology elements in the proposed AquaWatch system (Figure 2) are:

1. In-situ sensor network
2. Data integration and analytics system and services
3. In-situ sensor data relay system
4. EO 'virtual constellation' and satellite payload sensor design, optimised for aquatic observations
5. Water quality forecasting (inland surface freshwater and coastal)

These technologies will work synergistically, where for instance the HydraSpectra in-situ sensor collects measurements of the reflectance and colour of the water in the same way as the satellite sensors. Linking in-situ and EO measurements collected in the same way simplifies the process of calibrating the EO data and validating derived water quality products, and also reduces errors in extrapolating the in-situ measurements across the EO images. AquaWatch can also incorporate a range of other sensors that can provide data on parameters that we cannot measure optically, such as dissolved oxygen (DO), salinity or nitrates.

The AquaWatch technologies are intended to be modular, with the option to use individual elements as stand-alone facilities, or connected as a ground-to-space network. For instance, the HydraSpectra in-situ sensors capture spectral data which can be processed to indicate a range of water quality parameters, including chlorophyll concentrations and light attenuation which may indicate sediment loads. In areas with persistent cloud cover, for example, the in-situ sensors may be the only source of usable data. Alternatively, EO may be the only source of water quality data in locations without in-situ sensors.

The AquaWatch data system (powered by CSIRO's EASI technology) will facilitate access to EO data archives on the cloud. It will capture and process data from across the in-situ sensor network, and enable processing and modelling of water quality for AquaWatch. This system presents an opportunity to 'modularise' and harmonise the processing and analysis of water quality data collected using different technologies or by different agencies or organisations.

Conceptually, the AquaWatch technology system operates as shown in Figure 2 which shows the main data sources on the left being ingested into the data system where it is integrated and prepared for distribution and further analysis, with the main data services and information distribution modalities on the right. AquaWatch data services will include Web services and other data sharing facilities such as Jupyter notebooks, which may support forecasting, and site-specific decision making for water managers, and industrial and recreation users at the pilot sites.

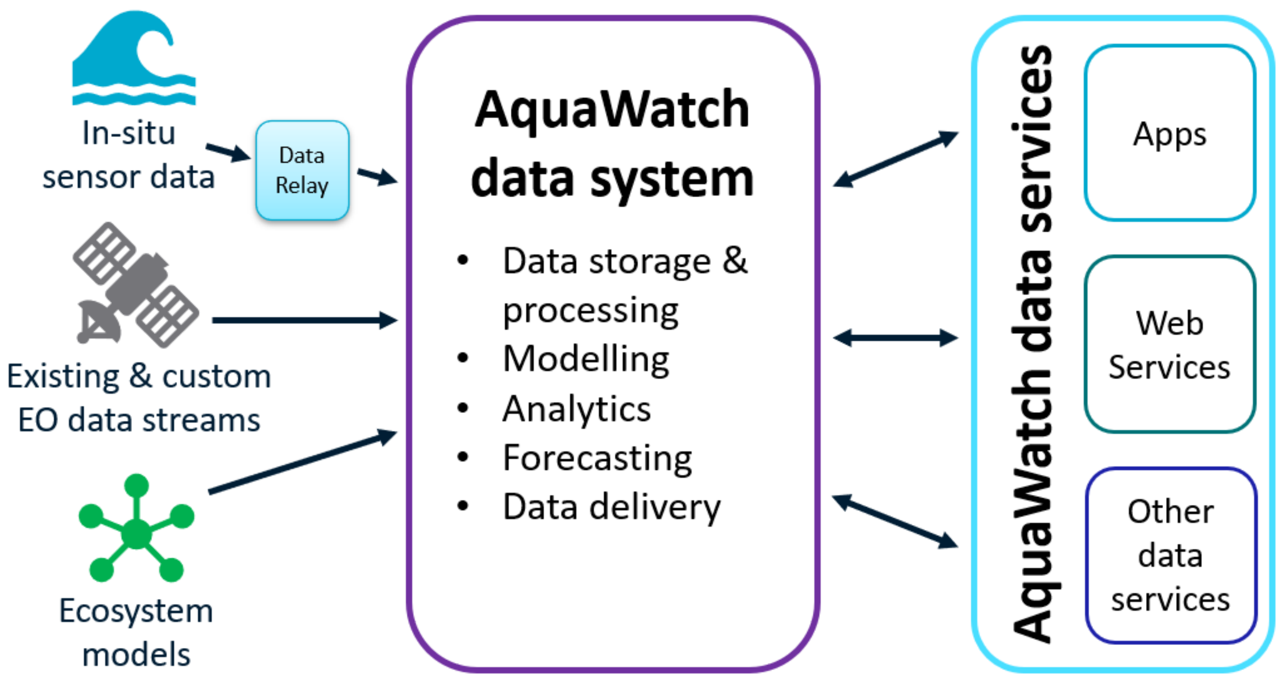


**Figure 2. Data and information flows through the AquaWatch technology system**

The following sections describe the key development needs for each of the input and analytics elements of the AquaWatch technology system to build the network of sites and connected systems to deliver AquaWatch.

# 2 Science and Technology Components

## 2.1 In-situ sensors

In-situ sensors include one or more instruments located at a site of interest providing potentially high-frequency measurements of one or more water quality variables as stand-alone data sources, or to validate products derived from the less frequent satellite observations. Operating continuously, these sensors can provide complimentary data on some elements of water quality that cannot be measured by EO systems. In-situ sensors span a wide range of parameters including temperature, salinity, turbidity, phytoplankton pigments, pH and chemical concentration amongst many others. Sensors for some parameters of interest to AquaWatch may not yet exist, however, and their development will be a necessary part of the ongoing research required to realise the AquaWatch Mission (Table 1).

Commercially-produced sensors are often compact, reliable and simple to operate, and can provide accurate information for a given location. Their cost effectiveness for a continental scale sensor network needs to be further evaluated, however. Sensor data will most often be transmitted via the mobile phone network, or via the Internet of Things (IoT), but in some circumstances the data may need to be retrieved from loggers manually.

In situ sensors within AquaWatch have a range of functions including:

1. Vicarious calibration of satellite derived water-leaving radiance estimates
2. Validation of the information products from pathfinders/AquaWatch satellite sensors
3. Detection, measurement and monitoring of water quality covariables that cannot be measured by EO (e.g. depth profiling of variables, nutrients, heavy metals, pesticides, toxicity of algae)

AquaWatch will most often integrate data from in situ sensors with EO data. However, to provide information in smaller water bodies (e.g. narrow river channels) or persistently occluded locations, the in-situ sensor data will be of high value on its own. Its high frequency of acquisition will also be important for parameterising and validating models.

Currently, one novel in-situ sensor instrument being developed for use in AquaWatch is the HydraSpectra[1]. This CSIRO-developed hyperspectral radiometer is designed to sit above the water surface and capture a time series of reflectance spectra and images from the water surface throughout daylight hours. Through a single spectrometer, the HydraSpectra sensor simultaneously measures the amount of incoming radiance, scattering from the sky and water surface radiance to obtain a high-resolution hyperspectral water-leaving reflectance measurement between 400 nm and 900 nm. These data are collected at a programmable time interval, which is typically every 15 minutes at most sites. The data can then be used to infer concentrations of optically-active water quality parameters such as chlorophyll, turbidity and coloured dissolved

[1] https://www.csiro.au/en/research/technology-space/data/HydraSpectra

organic matter (CDOM), which may be complimented by other sensors measuring other non-optically active parameters (salinity, pH, heavy-metals, etc.) in a 'sensor pack' configuration.

HydraSpectra sensors are being provided for use at most AquaWatch pilot sites either as the sole source of data, or paired with other sensors deployed by local partners. Several HydraSpectra have been deployed in Australia and internationally. Being above-water typically reduces sensor fouling compared to submerged sensors. Many of these have operated reliably over several years with minimal maintenance including approximately monthly lens cleaning and seal checking. This has proven their usefulness, durability and ease-of-use for AquaWatch and is one of the key objectives of the AquaWatch pilot site program.

**Table 1. Key milestones for in-situ sensor development activities**

| | TECHNOLOGY SYSTEM | RESEARCH PROGRAM |
|---|---|---|
| By 2026 | • Develop AquaWatch integrated in-situ sensor package concept, using currently available low-cost sensors plus HydraSpectra<br>• Demonstrate HydraSpectra capability for pilot site use cases (Chl, turbidity, CDOM, DOC) including uncertainty assessment<br>• Prove HydraSpectra durability<br>• Deploy HydraSpectra in fluvial riverine and high tidal variation coastal settings<br>• Explore options for technology licensing large industrial production of HydraSpectra | • Identify and develop onboard/edge processing requirements<br>• Evaluate methodologies to determine the number of sensors required for national monitoring across Australia and their likely locations<br>• Identify pathway for further miniaturisation of HydraSpectra<br>• Investigate low cost in-situ sensors<br>• Assess ability to detect nutrients, heavy metals, plastics, pathogens, eDNA and antibiotic residues, other |
| By 2030 | • Facilitate access to additional existing sensor network data across Australia<br>• Large-scale distribution of HydraSpectra<br>• Deploy low-cost sensors | • Investigate alternative sensor technologies and networks for suitability for AquaWatch<br>• Determine HydraSpectra suitability for additional use cases (pathogens, plastics)<br>• Implement onboard/edge processing systems |
| Beyond 2030 | • Deploy updated/alternative sensors into AquaWatch<br>• Explore licensing and industrial partnerships for export opportunities of HydraSpectra | • Reduce cost and size, improve performance |

Reducing the size and cost of the AquaWatch sensor packs, increasing their robustness and reducing maintenance needs is a critical element of the development work required under AquaWatch. This factor limits the opportunity to build very dense national networks of sensors for the Mission.

## 2.2 Data integration and analytics

Integrating data from the in-situ and EO sensors, implementing generic and bespoke algorithms to convert these datasets into water quality information, and providing a customisable interface to summarise, present and interact with the data is critical to the success of AquaWatch (Table 2). This activity supports internal and external users by:

- Supporting other AquaWatch activities by providing data, analytics and visualisation infrastructure for research and operational services
- Supporting the development and implementation of training programmes and materials
- Delivering AquaWatch products and services
- Developing and maintaining the operational services required for data acquisition, integration, analysis and archives for production and research

**Table 2. Key milestones for data analytics development activities**

| | TECHNOLOGY SYSTEM | RESEARCH PROGRAM |
|---|---|---|
| By 2026 | • Implement ingestion pipelines for required in-situ and EO data sets<br>• Ingest relevant EO data from suitable, public satellites<br>• Implement data dashboard and analytics interface<br>• Implement analytical and/or machine learning water quality retrieval models from in-situ and EO data<br>• Present validated water quality information spatially<br>• Generate baseline historic water quality maps at continental scale | • Continuous improvement of cloud optimisation<br>• Develop training materials<br>• Develop mechanisms to ingest high resolution and/or hyperspectral data<br>• Feasibility study for production of gap-free data products<br>• Review opportunities for integration of Quantum computing into AquaWatch<br>• Review opportunities for integration of generative AI into AquaWatch |
| By 2030 | • Supervise scaling of network<br>• Ingest aquatically optimised EO data<br>• Support customisation for end user applications | • Develop citizen science/mobile platform apps |
| Beyond 2030 | • Support CoP<br>• Update the AquaWatch data system | • Continual improvement and CoP support |

For most end users, the AquaWatch data services will be the main point of interaction with AquaWatch. To date, development of the AquaWatch data system and services has focussed on implementing back-end computational elements related to performance on the cloud in terms of scalability, cost minimisation and data access and transfer efficiency. Intuitive, adaptable and easy-to-use front-end data services will also be essential to encourage widespread use and uptake of the AquaWatch system. Other key elements for ensuring uptake, including the development of appropriate information products and training materials, conducting end-user workshops and consultation roadshows, may occur through the CoP.

## 2.3 Sensor network data relay

Data collected by the network of in-situ sensors will need to be quality controlled and transferred from all in-situ locations into the AquaWatch data system via existing data relay systems (ground-based or satellite; Table 3). In the case of the HydraSpectra, data is currently transferred by mobile phone network, typically to a FTP facility where the data are collected by Senaps[5], processed to reflectance and made available for integration into the AquaWatch data system.

**Table 3. Key milestones for sensor network data relay activities**

| | TECHNOLOGY SYSTEM | RESEARCH PROGRAM |
|---|---|---|
| By 2026 | • Evaluate sensor network relay service provider options in Australia and globally<br>• Ensure data connectivity with HydraSpectra and other in-situ sensors at all pilot sites | • Evaluate edge processing data reduction techniques |
| By 2030 | • Deploy satellite connectivity for HydraSpectra globally | • Evaluate optimum data relay mechanisms globally |
| Beyond 2030 | | • Evaluate emerging data relay technologies |

There is an additional need to support the ingestion of shared data from in-situ sensors other than HydraSpectra in order to link AquaWatch to existing water quality monitoring programs in collaboration with local partners. At present, data from these sensors are typically transferred by mobile internet to the cloud-based eagle.io[6] platform which is then integrated into the data system.

The 'best' data transfer network varies between locations, including the country in which the system is deployed, which necessitates multiple options and often a bespoke solution for each

[5] https://products.csiro.au/senaps/

[6] https://eagle.io/

location being implemented into each sensor. Differences in the coverage and reliability of the mobile phone network may also impact data transmission from certain regions in Australia and globally. The emergence of IoT connectivity systems may provide an option to harmonise the data relay mechanisms across the globe, and also facilitate some advanced remote device control opportunities. Satellite IoT systems may have limited data transfer rates and present security concerns in some implementations, however.

AquaWatch is unlikely to develop or implement a single data-relay solution or an IoT network specifically for its needs. The system that is used will need to be fit-for-purpose in terms of cost, frequency of coverage, security and interoperability, and ideally operate seamlessly across the globe.

## 2.4 AquaWatch 'Virtual Constellation' of Earth Observation Satellites

The concept of a 'virtual constellation' is used here to describe a collection of EO datasets and image data products from freely available sources that are collated and processed specifically for the needs of AquaWatch (Table 4). The virtual constellation facilitates use of existing and emerging EO technologies, and provides the necessary redundancy, frequency of observations and continuity of data inputs required by a 24/7 integrated data system. Initially, AquaWatch will draw on freely available EO datasets from international agencies including Landsat, MODIS and Sentinel which have significant archives of historical data in the optical and thermal domains, and assured continuity into the future in most cases. These datasets can be processed routinely into relevant water quality parameters, based on well documented case studies developed over the last 10-15 years by CSIRO and our partners. Other sources of EO data for AquaWatch may include data from experimental hyperspectral satellites or commercial providers, on a case-by-case basis.

In order to monitor conditions over very short time frames or at high spatial resolutions, including tracking the development of toxic algae blooms or off-shore red-tides, or supporting emergency response needs, AquaWatch may need to incorporate high resolution, high quality and low latency EO data from commercial providers. The AquaWatch End-to-End simulator is being developed as a tool to assess the utility of a variety of commercial EO datasets to meet AquaWatch needs.

To accurately forecast changes in water quality, it is also essential to incorporate information on weather patterns and land condition, much of which can be provided by EO. Some of the main influences on water quality are climate variations and catchment conditions, including factors such as droughts, floods, land cover, land use and vegetation condition amongst others. For instance, information on the location of the source of potential sediment plumes may support prediction of non-optically active correlates such as pathogens, toxins and heavy metals.

Significant data processing will also be required to ensure consistent results across the large volumes and wide range of EO datasets that may be used in AquaWatch. Given the high volumes of data required to accurately forecast changes in water quality, and the central role of EO data sources in the AquaWatch system in the forecasting process, Artificial Intelligence (AI) and Machine Learning (ML) technologies will also be evaluated as ways to more rapidly process the imagery, especially for areas where ground and ancillary data are scarce or not available.

Table 4. Key milestones for in-earth observation image data activities

| | TECHNOLOGY SYSTEM | RESEARCH PROGRAM |
|---|---|---|
| By 2026 | • Identify existing EO sensors to be integrated into the AquaWatch Virtual Constellation<br>• Implement atmospheric correction algorithm(s) appropriate for aquatic applications<br>• Implement data processing pipelines for the initial set of satellites and priority water quality measurements (eg Chl, Turbidity, TSM, DOM, Cyanobacteria pigments)<br>• Implement an EO-based algorithm nationally to map selected water quality parameters | • Define accuracy requirements for atmospheric correction<br>• Test and compare atmospheric correction models for use across inland and coastal waterbodies<br>• Investigate application of hyperspectral satellite data over pilot sites<br>• Initiate demonstration project with high resolution/low latency data provider for emergency response monitoring<br>• Contribute to hyperspectral water quality spectral libraries<br>• Operationalise end-to-end simulator<br>• Develop ML models for nutrient forecasting in coastal and estuarine ecosystems<br>• Investigate integration of drone systems and images<br>• Develop ML models to integrate in-situ sensor network data into satellite remote sensing models |
| By 2030 | • Implement EO-based ML models for nutrient predictions across pilot site network<br>• Implement drone imagery and systems into monitoring (where appropriate and cost-effective)<br>• Implement ML models that integrate AquaWatch sensor network data into remote sensing inversion models to achieve dynamic representation of changing aquatic ecosystem conditions | • Support CoP training needs<br>• Develop data processing and integration methods for aquatically optimised EO datasets |
| Beyond 2030 | • Implement new models and operational image processing streams on AquaWatch infrastructure | • Develop models and processing methods to extend the supported range of water quality parameters |

Critical elements of the processing chain include automated ingestion of the range of EO datasets, and identifying an atmospheric correction model that performs well in both terrestrial and aquatic applications. Processing of these images to Analysis Ready Data (ARD) formats may require additional processing steps including geometric registration and terrain correction. Producing 'Decision Ready' information products by implementing AquaWatch-derived data, models and forecasts will require the development of appropriate processing pipelines, potentially including AI/ML analytics.

## 2.5 AquaWatch Custom Earth Observation Sensing Systems

AquaWatch aims to be a national catalyst to develop capacity across the Australian space industry by supporting the development of satellites carrying EO sensors optimised to meet AquaWatch needs. While existing EO datasets may provide useful data, current EO operational satellites do not meet all aquatic remote sensing objectives, and cannot discriminate among different types of algae or phytoplankton types, some of which may be toxic to humans and animals.

For this reason, aquatic remote sensing experts in the AquaWatch team are developing the necessary future sensor and satellite operational requirements to satisfy many more key objectives and improve the accuracy of EO-based water quality globally. Discussions are underway with Australian and international partners around the development of potential new 'pathfinder satellites' that would complement existing EO data streams and be more precisely customised for aquatic applications.

A range of activities will be undertaken to identify the opportunities, needs and gaps in existing EO systems for use in AquaWatch (Table 5). These will include:

- Developing baseline system requirements and satellite design specifications to identify the key technology gaps for AquaWatch needs
- Design, manufacture, and operation of AquaWatch pathfinder and demonstration satellite payloads
- Evaluation of design trade-offs through feasibility studies.

Demonstrator payloads will improve the development of EO sensors optimised for the needs of AquaWatch through customised programs of design, manufacture, and system operation and control. Demonstrator payloads include CyanoSat, a prototype hyperspectral imaging payload designed to detect cyanobacteria, which was successfully launched in June 2023.

Table 5. Key milestones for Earth observation sensing activities

| | TECHNOLOGY SYSTEM | RESEARCH PROGRAM |
|---|---|---|
| By 2026 | • Develop and test CyanoSat, and deliver it for launch (mid 2023)<br>• Define SATM for EO sensors optimised for water quality monitoring of inland and near-coastal waters<br>• Baseline an AquaWatch satellite design and identify technology gaps in Australian capability<br>• Explore the use of the new Kanyini Satellite data in support of AquaWatch | • Evaluate design trade-offs through feasibility studies with international partners<br>• Operate an AquaWatch pathfinder satellite and validate water quality retrieval<br>• Increase TRL to level 7 of satellite systems identified as gaps in local capability through collaborative industry engagement<br>• Demonstrate complementary EO sensor platforms (I.e. HAPS, drone, etc.)<br>• Design and manufacture an engineering model payload based upon system requirements and validate through airborne trials<br>• Evaluate opportunities for bespoke AquaWatch sensors in terrestrial applications |
| By 2030 | • Support commercial partners to deliver AquaWatch constellation. | • Investigate complementary EO sensor technologies, potentially including thermal, short-wave infra-red and synthetic aperture radar amongst others |
| Beyond 2030 | • Ongoing support and maintenance of AquaWatch constellation | |

## 2.6 Water Quality Forecasting

Forecasting potential changes in water quality is a key differentiator between AquaWatch and other existing water quality monitoring systems (Table 6). The objective of AquaWatch is to provide estimates of uncertainty over the short term, approximately 3 to 7 days in advance, for processes such as blackwater events and bushfire-generated sediment loads. Forecasting over the longer term will be implemented for processes such as changes in sediment loads from rivers into coastal waters, or changes in the likelihood of Harmful Algal Blooms (HABs).

Modelling and forecasting will initially focus on temperature and mixing dynamics, with other parameters, potentially including DO, DOC, sediment load, and the concentrations of HABs or nutrient levels being added over time.

Table 6. Key milestones for inland water quality forecasting activities

| | TECHNOLOGY SYSTEM | RESEARCH PROGRAM |
|---|---|---|
| By 2026 | • Implement forecasting system for all pilot site use cases<br>• Validate against in-situ measurements at each pilot site<br>• Assimilate HydraSpectra data for improved forecasting capability<br>• Implement basic modelling toolset on AquaWatch data system | • Explore mechanisms for forecasting water quality in riverine and coastal systems<br>• Define forecasting accuracy requirements for inland waters<br>• Design the roll-out of the eReefs methodology originally developed for GBR, for application across full Australia coasts<br>• Develop framework for seamless integration of hydrodynamic and biogeochemical models<br>• Evaluate hybrid (ML/process) methods for transfer to data scarce sites<br>• Assess the use of high-frequency nutrient data<br>• Develop data-driven water quality forecasting models (both at point and spatial scale)<br>• Assess social and economic benefits of water quality forecasting |
| By 2030 | • Implement hybrid models for water quality parameters (Chl-a, nutrients, DOC) in lentic and lotic systems on a continental scale<br>• Basic relocatable coastal model system with EO assimilation capability<br>• Use spectral libraries for species classification to improve toxic HAB forecasts | • Integrate catchment information on nutrient and organic matter loads in river systems<br>• Evaluate the integration of terrestrial remote sensing data in water forecasting system<br>• Develop roadmap for use of AquaWatch in other areas of research: e.g., water borne diseases, water quality and human health |
| Beyond 2030 | • Integrate alternative data streams and novel in-situ sensors into forecasting system | • Evaluate future compatibility with similar international products |

Forecasts will be provided for rivers, lakes and coastal water bodies, each of which have unique fluvial, transport and mixing characteristics, and will require a specific hydrodynamic modelling approach over unique scales of space and time. While individual models for specific case studies exist (e.g. the eReefs model suite for the GBR[7]), there is a need to generalize models to be deployed at other locations, including at un-monitored sites, to generate regional to continental scale water quality forecasting.

Water quality forecasting will integrate process-based simulation models with data-driven machine learning models. In combination with expert knowledge, these hybrid models enable optimal use of the large volumes of in-situ and remote sensing data that will be gathered by AquaWatch.

Continuously updated in-situ modelling of water quality parameters will provide simulations of water quality conditions at times when the view of the waterbody may be occluded by clouds or smoke, for instance, and will also simulate processes relevant to aquatic ecosystem dynamics from the substratum to the surface. This will improve the consistency of time-series water quality datasets, and enable estimation of vertical changes in the water column, including beyond the depth visible by the EO sensors. Furthermore, it will enable simulations of water quality parameters that are either not sufficiently covered by in-situ monitoring or are not optically active and thus not directly observable by EO sensors, such as DO or nutrient concentrations.

Process-based forecasting models will initially be co-designed, developed and tested with partners for specific case studies at the pilot sites. As noted above, water quality forecasting relies on a wide range of ancillary data sources, and the availability of those datasets will determine the ability and accuracy of forecasts at each location. ML methods will then be used to transfer model approaches to other locations and successively enable continental coverage of water quality forecasts.

[7] https://www.ereefs.org.au/

# 3 Partnerships, Business Development and Communications

## 3.1 Partnerships

AquaWatch will co-develop monitoring, data and information delivery systems with partners to support new research and commercial activities, and to add value to existing activities and organisations. Key stakeholders with whom AquaWatch is seeking to partner include, but are not limited to:

- Industries involved in water quality management, or that engage with clients or industry sectors relying on water quality information
- Regional State Governments and relevant State-based water quality management agencies
- Australian Commonwealth agencies with national and international outreach in areas of water quality policy development and program implementation
- International aid agencies involved in improving water quality outcomes globally, particularly in the Pacific region
- Companies and agencies involved in the design, development and construction of sensor and satellite systems and programs that have an interest in implementing EO systems to improve water quality monitoring
- Custodians of sites seeking improved water quality information, which may be considered as AquaWatch pilot sites
- Researchers interested in becoming involved in the AquaWatch program, including in the CoP

Our partnering activities are ongoing and we welcome additional opportunities for co-investment and partnership to implement the Australian and global elements of the AquaWatch program.

### 3.1.1 Indigenous partnerships

AquaWatch will contribute to the CSIRO Reconciliation Action Plan (RAP) goals around relationships, respect and opportunities. The AquaWatch team is committed to achieving this in line with the values of being Respectful, Reciprocal and Responsible in all of our engagements and activities, including aiming to:

- Provide opportunities to partner with Indigenous capability to use advanced technologies for water quality monitoring to support understanding of conditions on Country
- Establish research agreements with Indigenous communities and organisations in which we will include Indigenous leadership, ICIP (Indigenous cultural and intellectual property) protection, FPIC (free prior informed consent), data access and sharing, and ethics clearance
- Provide business and employment opportunities for Indigenous service providers, researchers, advisors and research managers

- Engage Indigenous CRA (Community Research Assistance) to support connections to local Indigenous stakeholders
- Partner with Indigenous stakeholders to co-design and co-develop proposals to plan, establish and fund Indigenous-led pilot sites in Australia and globally

Success in relation to Indigenous engagement and capacity building against the CSIRO RAP will be monitored and measured in line with the metrics used by CSIRO Indigenous Engagement, and through community and Indigenous partner feedback.

AquaWatch is also driving international Indigenous connections on water quality. Project agreements for many of the international pilot sites include milestones for the pilot site leaders to host a workshop demonstrating AquaWatch to their local Indigenous and First Nations people. AquaWatch is also connecting Australian Indigenous water knowledge to other Indigenous and First Nations water knowledge globally. A joint proposal from AquaWatch Australia and GEO AquaWatch[8], entitled 'Melding AquaWatch & Global Indigenous Knowledge (MAGIK)' was recently selected as one of five finalists from 62 proposals to the UN Global Challenge on Water Quality Monitoring and Assessment[9].

## 3.2 Community of Practice

Building a community of users with an interest in supporting the continuation of the AquaWatch facilities is expected to be crucial for the continual improvement of the system, and for ensuring the continuation of AquaWatch services beyond the life of the Mission.

One of the main mechanisms for establishing the CoP is through connecting the AquaWatch Work Package and Program Leaders, the national and international pilot site network and the Science Advisory Group (SAG) through regular virtual and potentially in-person meetings. However, the AquaWatch CoP will also connect AquaWatch stakeholders including researchers, developers, industry partners, water managers, government agency and Indigenous partners.

The CoP will align closely with the activities of the communications and partnership managers and potentially business development roles, however the CoP will more strongly focus on fostering activity on the technical elements of the system (Table 7).

The CoP aims to:

- Ensure connections across AquaWatch to support end-user involvement in system development, information sharing, access to data, activities in science and system validation, and new opportunities, with the key objective to support the use of AquaWatch data products at all levels
- Develop connections and maintain ongoing communications with end-user communities, and harness end user feedback to guide AquaWatch development

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[8] https://www.geoaquawatch.org/

[9] https://www.unwater.org/news/open-call-innovation-challenges-water-quality-monitoring-and-assessment

- Facilitate discussion and information exchange on scientific opportunities and challenges through the SAG, advising on the Mission's development based on community knowledge, resources, and research opportunities in the sector
- Stimulate knowledge sharing between end-user communities, external scientific experts, and the AquaWatch science leadership team through customised workshops

**Table 7. Key milestones for the Community of Practice activities**

| | TECHNOLOGY SYSTEM | RESEARCH PROGRAM |
|---|---|---|
| By 2026 | • Support coordination of Science Advisory Group meetings<br>• Coordinate Mission-wide partner meetings and events<br>• Implement engagement strategy | • Support development of training programmes and materials<br>• Support development of partner engagement strategy |
| By 2030 | • Coordinate partner meetings and events | • Support development of AquaWatch 2030+ CoP continuity strategy |
| Beyond 2030 | • Implement AquaWatch 2030+ CoP continuity strategy<br>• Lead introduction of CSIRO technologies through CoP | • Support translation of CSIRO technologies into AquaWatch system |

## 3.3 Business Development

AquaWatch is likely to have a diverse range of end users including water managers, researchers, industrial users and citizens. Consistent with the vision of AquaWatch as a weather service for water quality, a key objective is to provide access to water quality information at no cost to most end users. The ambitions of AquaWatch are significant, however, and partnerships will be necessary to realise them all.

The scale and nature of commercial collaborations is likely to be diverse. Partners in the development phase may include large international technology companies or space 'primes' for example, with whom AquaWatch may collaborate under the umbrella of an enterprise level agreement. Philanthropic funders may be interested in supporting the extension of AquaWatch services into rural and remote areas.

There are also likely to be a range of potential opportunities for smaller commercial partners to engage with AquaWatch following its implementation. This may include the development of tools or information services that leverage off the freely available AquaWatch data to meet to the needs of a specific industry segment. While the specifics of all the commercial activities cannot be foreseen at this time, it is necessary to implement a commercial engagement strategy to ensure appropriate returns to CSIRO from this investment, and to ensure that AquaWatch operates consistently with all its partners (Table 8).

Table 8. Key milestones for Business Development activities

| | COMMERCIAL (OPERATIONAL) | PUBLIC GOOD (DEVELOPMENT) |
|---|---|---|
| By 2026 | • Develop AquaWatch prospectus for commercial, philanthropic and service provision partners, including service Tiers<br>• Establish reseller partnership with at least one private sector organisation<br>• Establish partnership to scale up sensor production<br>• Identify potential partners for app/UX development<br>• Develop commercial pathway for CyanoSat<br>• Identify spinoff business model to support third part commercial usage of AquaWatch data | • Define no-cost model for adding pilot sites<br>• Cost-benefit assessment for outsourcing opportunities (app development, sensor manufacture, analytics implementation, others)<br>• Identify strategic areas to implement pilot projects with key global funding agencies (such as World Bank, ADB, UN, GEF etc)<br>• Develop 'franchise' model for implementing AquaWatch at national-scale in other countries |
| By 2030 | • Facilitate at least one spinoff collaboration using AquaWatch data | • Facilitate at least one franchise implementation of AquaWatch internationally |
| Beyond 2030 | • Establish portfolio of paying AquaWatch users | • Review CSIRO technology developments for implementation in operational AquaWatch system |

## 3.4 Communications & stakeholder engagement

Timely and consistent communications with internal and external stakeholders are vital for establishing and maintaining engagement with AquaWatch, ensuring a focus on achieving Mission-level objectives, including amongst the Mission team, and raising the profile of AquaWatch across the globe to all relevant stakeholders (Table 9).

Communication activities in AquaWatch will work closely with the CoP and focus on:

- Positioning AquaWatch to the global audience as the world's leading water quality monitoring system in social and news media
- Positioning CSIRO teams and technologies as essential partners in the future development of the Australian space industry's water resources monitoring capability
- Supporting implementation of the community of practice with expertise and content
- Maintaining connection to current and prospective partners, internal and external to CSIRO

- Connecting AquaWatch to Indigenous communities via respectful and culturally appropriate communications
-

**Table 9. Key milestones for Communication activities**

| | COMMUNICATION | STAKEHOLDER ENGAGEMENT |
|---|---|---|
| By 2026 | • Develop suite of external communication assets with strong AquaWatch and CSIRO branding<br>• Develop storylines for major activities and media coverage<br>• Establish and maintain internal communication channels | • Work with BD team to develop engagement plan for target stakeholders<br>• Establish processes for prioritising engagement activities and events<br>• Support partner communications around AquaWatch<br>• Establish and support communication channels for CoP |
| By 2030 | • Support rollout of AquaWatch portal to broader audience<br>• Raise AquaWatch profile with government, industry and general public | • Support growth of pilot site network via partner communications<br>• Support engagement of long-term service delivery partners for AquaWatch in Australia and globally |
| Beyond 2030 | • Support AquaWatch visibility as opportunity for CSIRO science implementation | • Support communication needs of service delivery partners<br>• Support CoP continuity |

# 4 AquaWatch 2026

AquaWatch 2026 will be the initial demonstration of a fully integrated ground-to-space network of technologies across a limited number of sites, with analytics and forecasting for a small number of monitoring targets. The planned configuration of AquaWatch 2026 is as follows:

## 4.1 Pilot sites

- 10-20 pilot sites established under project agreement, providing regular data contributions into AquaWatch.
- About half of the pilot sites should be located in Australia and about half in other countries.
- About half of the pilot sites should be coastal and about half should be inland.
- At least two pilot sites should be in each of river, lake and coastal settings.
- Additional pilot sites will be selected based on:
    - Ability to demonstrate AquaWatch impact
    - Coverage across states & territories
    - Coverage across water body types
    - Coverage across applications/user segments
    - Operational considerations
    - Calibration & validation considerations
    - Partnership potential
    - Budget and resource constraints

## 4.2 Water quality monitoring objectives

- AquaWatch 2026 monitoring objectives will be determined by the monitoring objectives of the pilot sites, plus a cyanobacteria monitoring objective. The minimum set of monitoring objectives and approximate sensitivity levels for coastal waters are shown in Table 10.
- Additional monitoring objectives and parameters including Nitrates and DO, may be added as the network of pilot sites increases.
- Each pilot site may monitor only a subset of these parameters.

**Table 10. AquaWatch 2026 monitoring objectives and approximate sensitivity levels. All sensitivity limits are for coastal waters except Recreational Water Safety which is inland. EO limits and sensitivity values are estimated at approximately 30 m spatial resolution.**

| Goal | Objective | Parameter | Units | EO Lower limit | EO Sensitivity | In Situ Lower Limit | In Situ Sensitivity |
|---|---|---|---|---|---|---|---|
| **Water clarity** | Monitoring suspended matter | Turbidity | NTU | 1 | 30% | 0.1 | 10% |
| **Suspended sediment** | Suspended sediment concentration | Total Suspended Sediment | mg/L | 1 | 30% | 0.1 | 10% |
| **Algal blooms** | Phytoplankton abundance | Chlorophyll-*a* | ug/L | 3 | 30% | 1 | 1 ug/L or 10% |
| **Potentially harmful algal blooms** | Cyanobacterial abundance | Cyanobacteria biovolume | $mm^3/L$ | 4 | 30% | <4 | <30% |
| **Blue Carbon /Black Water** | DOC concentration | CDOM as a proxy for DOC | mg/L | 0.3 | 20% | 0.1 | 10% |

## 4.3 In-situ sensors and data relay

- Most, but potentially not all pilot sites will include the installation and maintenance of one or more HydraSpectra sensors.
- HydraSpectra sensors will be configured to collect spectra and images every 15 minutes.
- Third party sensor systems may be integrated into the AquaWatch sensor network at each site as required.
- Sensor data will be relayed via the mobile phone network to a CSIRO-managed FTP site. The frequency of data transfer to the FTP site may be lower than the frequency of data capture by the sensors.

## 4.4 Data integration and analytics

- AquaWatch 2026 will include an early production release of the AquaWatch data system and services for data ingestion, storage, processing and analysis.
- The AquaWatch data system and services will be the main online point of access to in-situ and EO data, analytics, modelling and forecasting capabilities.
- By default, all data contributed by AquaWatch users, including from the pilot sites, will be made accessible to all AquaWatch users through the AquaWatch data system and services. Access controls can be negotiated as required.

## 4.5 EO image data and processing

- AquaWatch will create a virtual constellation of freely available EO datasets and image products and make them available for analysis through the AquaWatch data system. The minimum set of EO datasets that will be included in the virtual constellation in is shown in Table 11.

**Table 11. Minimum set of EO datasets that will be included in the AquaWatch virtual constellation**

| Name | Type | Coverage | Spectral Range (nm) | Ground resolution (m) | Revisit time (days) |
|---|---|---|---|---|---|
| **Sentinel 2** | Multispectral | Global | 442-2204 | 10, 20, 60 | 5 |
| **Landsat 8 & 9** | Multispectral | Global | 430-2350 + thermal | 30 | 16 |
| **Sentinel 3** | Multispectral | Global | 400-1020 | 300 | 2 |
| **MODIS** | Inherent Optical Properties | Global | | 1000 | |
| **MODIS** | Ocean Colour | Global | | 1000 | |
| **MODIS** | Sea Surface Temperature | Global | | 4000 | |
| **Digital Earth Australia** | Sentinel 2 Level 2 Surface Reflectance | Australia | 442-2204 | 10, 20, 60 | |
| **Digital Earth Australia** | Landsat 5, 7 & 8 Level 2 Surface Reflectance | Australia | 430-2350 + thermal | 30 | |

- Existing hyperspectral EO datasets may potentially also be integrated.
- Additional ancillary datasets that may be ingested to support water quality forecasting may include:
  - Digital elevation data
  - Synthetic Aperture Radar imagery
  - Land cover/Land use products
  - LIDAR data
  - Weather data
  - Climate forecasts
  - Water extent layers
  - Hydrology and river flow data and/or forecasts
  - Other geospatial or tabular data available to support forecasting at specific pilot sites

## 4.6 EO sensor systems

- It is not expected that AquaWatch will deliver additional operational aquatically optimised data streams above those included in Section 4.5 by 2026.

## 4.7 Forecasting

- Water quality forecasts will be available for the monitoring targets identified in Section 4.2, and at selected sites that meet the forecasting data requirements.
- DO may additionally be forecast.
- Forecasting lead times may vary between parameters.
- Forecasting may be provided as data tables or spatial data layers.

## 4.8 Data products

AquaWatch 2026 data product types may include:

- Qualitative (traffic lights, flags or similar) nation-wide information for inland and coastal waters via an app and/or web portal.
- Quantitative (biophysical unit) information products for water quality decision makers at the inland and coastal AquaWatch pilot sites via an OGC-compliant web service or Jupyter notebook.

These data services may be updated daily, with information at a particular location updated as determined by satellite overpass frequency and cloud cover.

## 4.9 Community of Practice

- The CoP will be the focal contact point for stakeholders and end users to AquaWatch personnel.
- Two public webinars and/or in person meetings will be hosted each year.
- Coordinate Regular Steering Committee and Science Advisory Group meetings.

## 4.10 Business development

- Prospectus, and established engagement models for research, industrial, commercial and public-sector partners and end users in the water management and space industry sectors.
- Identified partners for scale-up of sensor production.
- Established partnerships with industry sector organisations to support commercial leveraging off AquaWatch data streams.

## 4.11 Communications

- Regular internal (CSIRO), external, national and international communication showcasing AquaWatch activities and successes.
- Co-lead regular showcase activities and events.
- Support partner communications on AquaWatch and the activities of the CoP.

# 5 Conclusion

This Roadmap is one of a series of documents supporting the establishment and implementation of AquaWatch. The Mission Plan describes the value and importance of this work to Australian and global stakeholders, and provides a top-down description of the activities and objectives of the Mission. This Roadmap provides a bottom-up perspective on the key activities required to implement the AquaWatch technologies, and build the science and engagement base to achieve the Mission objectives.

The Roadmap provides guidance to the structure and composition of the system of technologies, including estimates of the accuracy and sensitivity of assessment that is likely to be achieved in the first phases of the AquaWatch Mission. A more detailed set of specifications is required to determine the ultimate capabilities of the AquaWatch technology systems, and this assessment is currently underway through development of a Science and Applications Traceability Matrix (SATM) for each element of the technology system, and the system as a whole.

Production of Version 1 of the AquaWatch Roadmap included an extensive process of review with many key Mission stakeholders and partners. The very wide range of potential application areas for AquaWatch means that it has not been possible to engage with every potential stakeholder during this process. It is intended that the Roadmap will be reviewed approximately annually to ensure its relevance in light of changes in technology and the emergence of new priority areas of research. Readers are encouraged to submit any enquiries or comments on Version 1.0 of the Roadmap to AquaWatch@csiro.au.

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