SMARTSAT
COOPERATIVE RESEARCH CENTRE

TECHNICAL REPORT AQW-2

End-User Consultation Report

(PRELIMINARY REPORT)

TECHNICAL REPORT AQW-2

End-User Consultation Report

(PRELIMINARY REPORT)

AUGUST 2021

SMARTSAT COOPERATIVE RESEARCH CENTRE

CSIRO

This report should be cited as:
SmartSat 2021, End-user Consultation Report, SmartSat Technical Report AQW-2, SmartSat, Adelaide, Australia.

Acknowledgement:
SmartSat acknowledges the contribution made by CSIRO towards the AquaWatch Program. AquaWatch is a joint initiative between SmartSat and the CSIRO AquaWatch Australia Mission, supported by the CSIRO Missions Program and by CSIRO Business Units.

SmartSat acknowledges the contribution made by Water Research Australia in the facilitation of the study and towards the writing and compilation of this report.

Authors: Arnold Dekker[2] and Adam MacLeod[1]

Reviewers: Alex Held[1], Karen Rouse[3], Tapas Biswas[1], Rowena Smith[1], Klaus Joehnk[1], Tim Malthus[1], Tanya Griffiths[1]

[1]Commonwealth Scientific and Industrial Research Organisation
[2]SmartSat CRC
[3]Water Research Australia

Contents

Acknowledgments

Collaborators in AquaWatch Australia include:

- University of NSW
- Curtin University
- University of Queensland

In conducting this end-user consultation process, we had assistance from:

- Frontier SI
- Water Research Australia

Contributions of time & expertise were received from various organisations. We are very grateful for their assistance.

The CSIRO AquaWatch Australia Mission is supported by the SmartSAT CRC, CSIRO Missions Program and by CSIRO Business Units.

Executive Summary

Water is Australia's most precious natural resource and, in a country where drought, population pressure and lack of water is a significant feature of our climate and our landscape, the security of clean healthy freshwater resources and coastal waterways, including waters around the Great Barrier Reef, is critical to individuals, communities, industry and the environment.

The health and quality of our inland and coastal waterways are under profound threat due to increasing human activity and climate change as well as the environmental impact from bushfire sediment, storm events, pollution and contamination.

AquaWatch Australia's core objective is to develop a user-driven, nationally integrated ground-to-space water quality monitoring system that provides the necessary information for decision-making to safeguard the health, quality and safety of our waterways, reservoirs and coastal waters, using Earth observation data and spatial technology.

This system will require the development and integration of three key components: specially designed satellite sensors; the augmentation and interconnection of existing ground monitoring sensors to form a dense in-situ sensor network; and a dedicated data analytics platform to integrate the ground and space-based data with models and analytical tools.

By design, end-user consultation and co-design are included as essential aspects for the development of the AquaWatch system with the feedback and outcomes feeding into and supporting ground and satellite system design, data analysis and for building the overall mission operational plan.

This document provides a summary of detailed end-user consultation process, including the outcomes of discussions from several workshops conducted between July 2020 and June 2021, which provided very rich and useful guidance for design of the AquaWatch technical system requirements. Further end-user engagement is planned along all development and implementation phases of the mission.

During the initial consultation process, over 90 participants were approached, and grouped across the following end-user categories:

- Planning and Environment Users (including BoM, Geoscience Australia (GA), along with a range of State and Commonwealth agencies and peak bodies)
- Water Utilities (including water suppliers and the hydro-power industry)
- Primary Industries (broad range of users from agriculture and aquaculture)
- Water Sciences (specialists in water quality research from academia, non-governmental organisations (NGOs) and Commonwealth Scientific Industrial Research Organisation (CSIRO).

The AquaWatch end-user analysis team summarised the various contributions from the end users into measurable or quantifiable variables, that are required to gain insight into processes affecting the aquatic ecosystems as well as environmental reporting. Key variables identified included: the composition of the water column, water column depth and/or substratum; water body extent and volume; water temperature; biogeochemical variables; disease related variables and micropollutants.

The analysis resulted in very valuable insights into key variables, but also how the AquaWatch-derived information would be used. Multiple participants highlighted the necessity to include the characterisation of surrounding landscapes, climate and land-use activities to better attribute primary drivers of change in coastal and inland water quality.

Several end-users noted that there are situations where access to AquaWatch data in Near Real Time (NRT) would be invaluable for time-critical decision making and to provide early warning. NRT decision ready information needs to span large areas with high spatial resolution (resolve streams), with temporal frequencies mentioned of hours, to daily: the actual frequency being problem dependent. Predicting extreme events or managing the consequences of extreme events will impact the data processing infrastructure required. Essential criteria related to managing extreme events are near real-time delivery of data, including analysis, to the relevant authorities and organisations involved.

On the other hand, change and trend detection require valid, accurate long-term timeseries of information as subtle changes need to be recognised as early as possible, indicating an ecosystem is being affected by stressors or recovering due to e.g. management interventions.

There was considerable agreement that many end-users would also like to see the water quality forecasting and modelling extend as far as possible (e.g. 3 days or longer) into the future, in order to empower timely management decisions.

Many participants stressed the importance of open access, and ease of access to data and derived information from AquaWatch Australia. Government departments stressed the need for the data to be formatted in a consistent, agreed manner for easy ingestion into their own departmental systems, and that data should be made available via an automated querying system. Generally, it was felt that the large volumes of data require agreement of key standards to ensure consistency in data quality and analysis, as well as easy-to-use tools to manage/select/choose relevant temporal and spatial subsets of interest.

User-requirements covered a very broad range of requirements by potential end-users, that poses significant technical challenges and trade-offs in AquaWatch program design, in order to balance technical efficiency, breadth and depth, and quality of measurements, as well as short term versus long term impact and benefit.

Throughout this process, our aim has been to develop the strongest possible business case for AquaWatch alongside a feasible technical system design. This implies building an AquaWatch Australia system at a reasonable cost, but which satisfies the broadest possible range of end user requirements. As a system, AquaWatch Australia will be unparalleled world-wide in terms of performance and functionality, but it may not be all things to all people. Design trade-offs are inevitable. **Throughout the end-user consultation process one major trade-off was identified between "revisit time" (or how frequently a part of Australia is imaged by the Earth observation satellites) and the spatial ground resolution (pixel size) and data fidelity achievable by the EO satellites.**

One area where such trade-offs are unlikely to be necessary is in computing infrastructure. Initial assessment into computing infrastructure for the AquaWatch Australia Data Analytics system have shown that scalable cloud computing resources can adequately service the necessary processing capacity for various user-needs.

User-expectations for the operation of the AquaWatch in-situ water quality sensor network, were also significant. The sensor-network is expected to be dense and extensive, providing wide coverage of Australia's key inland and coastal waters, also providing unencumbered data access in remote areas of Australia where communications connectivity is limited. Some of the higher-performing water quality sensors are not necessarily cheap, easy to deploy, reliable or easy to maintain. There is therefore a strong imperative for AquaWatch to become a catalyst for industry, data communication providers and sensor-developers, to help improve the cost: performance issues that will provide the required service. The AquaWatch Australia technical team has developed an In-Situ Sensor Network 'green paper', addresses these requirements (See Malthus & Dekker, 2021).

Further, iterative end-user consultation will be done as the mission progresses, and through a dedicated End-Users Advisory Group (EUAG). This will be the primary interface for engaging the broad end-user community. The EUAG is intended to be a cross section of end user groups that provide an ongoing perspective issues and needs of their segment of the end-user community.

1 Introduction

Water is our most precious natural resource and, in a country where drought, population pressure and lack of water is a significant feature of our climate and our landscape, the security of clean healthy freshwater resources and coastal waterways, including the Great Barrier Reef, is critical to individuals, communities, industry and the environment.

The health and quality of our inland and coastal waterways are under profound threat due to increasing human activity and climate change as well as the environmental impact from bushfire sediment, storm events, pollution and contamination.

AquaWatch Australia's core objective is to develop a nationally integrated ground-to-space water quality monitoring system that provides the necessary information that supports decision-making to safeguard the health, quality and safety of our waterways, using Earth observation data and spatial technology.

The intent of the AquaWatch Australia system is to deliver timely information to government, water agencies, local communities, and industrial and commercial water users, that enables decision makers to best plan, manage and monitor resource and ecosystem health.

The broader AquaWatch Australia monitoring system will be delivered through the design and manufacture of advanced space-based and land-based remote sensing and sensor technology to provide real-time data on the health and quality of freshwater bodies and coastal waters.

This system will require the development and integration of three key components:

1. specially designed satellite sensors
2. the augmentation and interconnection of existing ground monitoring sensors to form a dense in-situ sensor network, and
3. a dedicated data analytics platform to integrate the ground and space-based data with models and analytical tools.

Airborne data from drones, aircraft equipped with sensors and very high-altitude flying platforms are also considered.

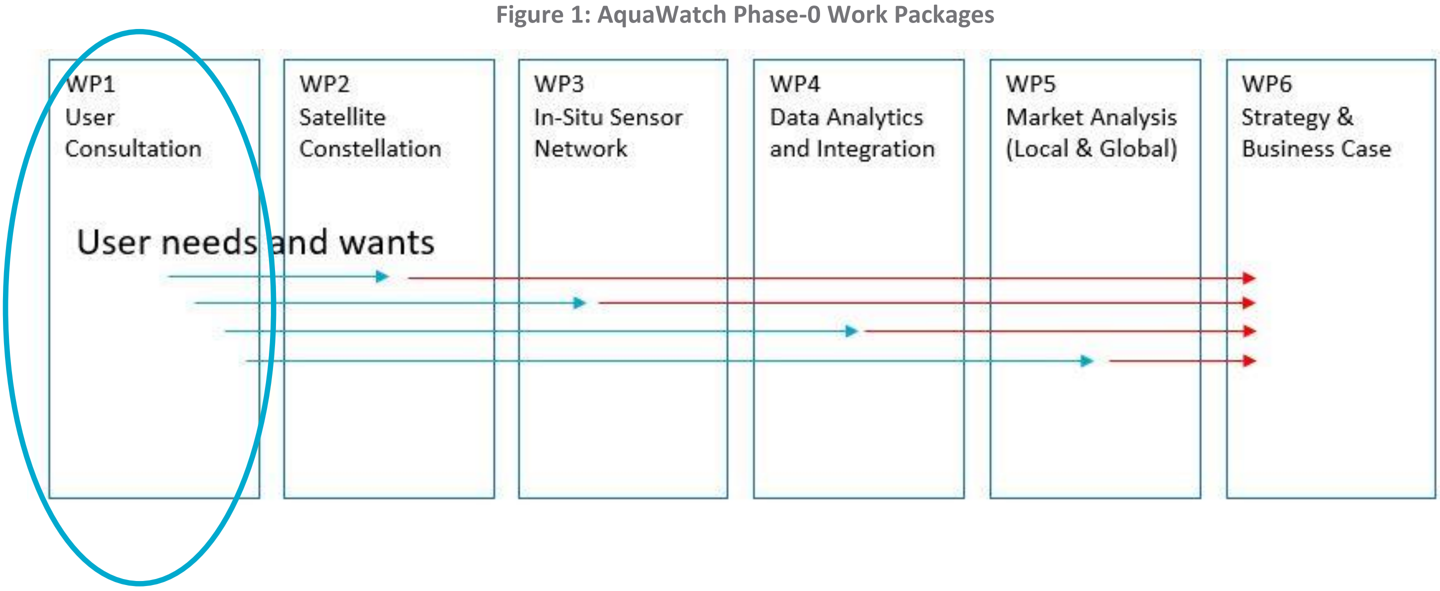
To support the development to the AquaWatch Australia program, an initial 12-month scoping study was conducted by the CSIRO and the SmartSatCRC. Known as Phase 0, the focus of this initial scoping phase was to undertake research and discovery activities related to the establishment of the AquaWatch concept development, its mission plan and feasibility.

The AquaWatch Australia program sponsors are the SmartSat CRC and CSIRO through the CSIRO Missions Program and several mission collaboration partners. Committed funds focus on project planning and preliminary design. Activities will include requirements analysis, research and development, and a pilot program for in-situ instrumentation and data analytics.

For comprehensive development, implementation and delivery of broad-scale impact for industry, communities and the environment, the AquaWatch Australia program is being co-designed with collaborators from across industry, research and government. It is expected co-development and co-investment will be from of a mix of Commonwealth, State and Local governments, along with industry, NGOs, and other entities.

At the AquaWatch Australia Introductory Webcast, we outlined various Work Packages being undertaken – See Figure 1 as part of the broader AquaWatch Australia program of work. End-user consultation was highlighted as our primary work package (WP1), with the feedback and outcomes of that activity feeding into and supporting our other work-packages in the areas of system design and building the mission plan.

Figure 1: AquaWatch Phase-0 Work Packages

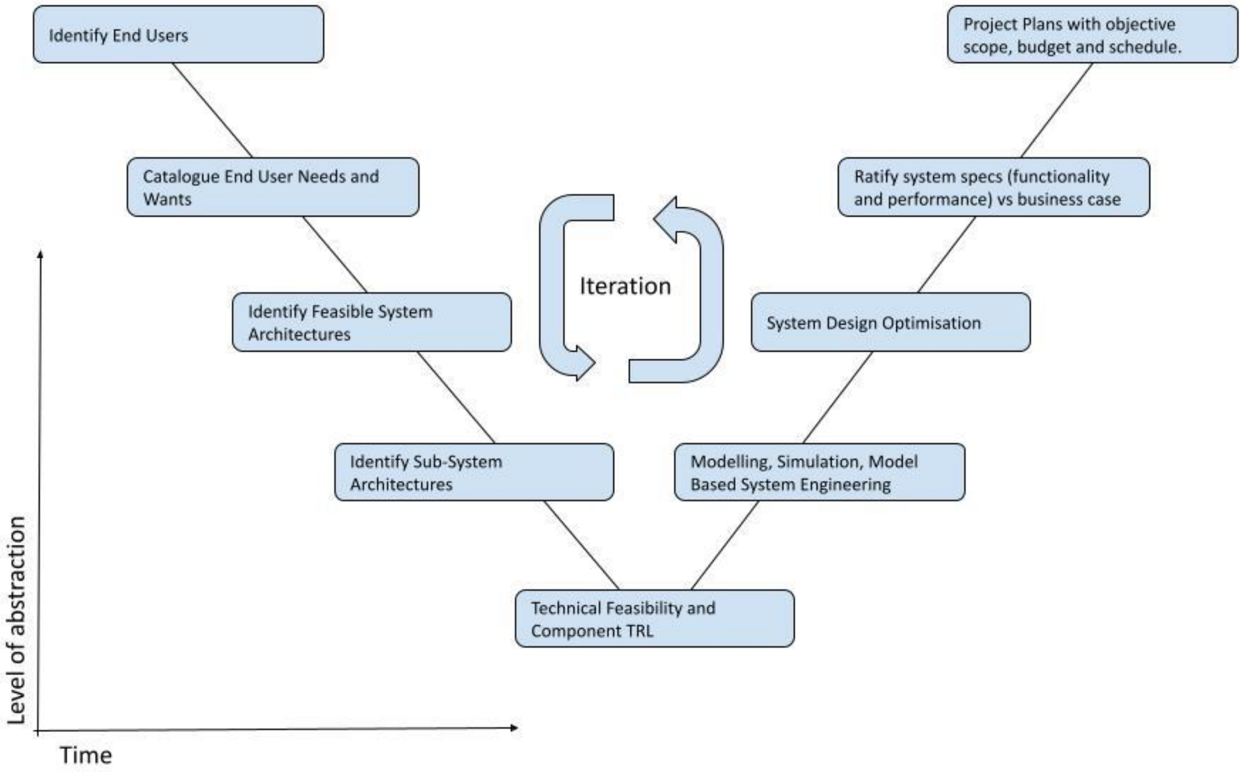


The process of End User Consultation (WP1) was focused on identifying the needs and wants of potential AquaWatch end users. The information gained is being used to:

- develop high level system specifications reflecting the performance and functionality desired of AquaWatch (WP2, WP3, WP4) and
- an understanding of the applications and impact that would provide the overall business case for the mission (WP5).

While the AquaWatch Phase-0 project does not involve the construction of the system, it does inform and influence the system engineering and design parameters. The activity to trace end-user requirements into a system design and a mission plan is an iterative process that involves zooming-in/out as we reconcile the performance and functionality of the system against what is desired and what is practical. The work being undertaken can be considered in terms of the System Engineering V-Model (see Figure 2). This illustrates how the end-user consultation process feeds into the work being done and why it is a priority for the AquaWatch Phase-0 project.

Figure 2: System Engineering V-Model Diagram Adapted to Concept Development Process



In addition, the end-user Consultation process undertaken in this initial scoping phase of the program has been supplemented by preliminary system design work; most notably through the Concurrent Design Facility (CDF) activities. These activities have **provided traceability from the end-user needs and wants to system and subsystem architectures that are feasible and practical to build**. Our understanding of end-user needs and wants, along with the corresponding system design, project plans and business case, will continue be refined through a process of iteration.

2 End-user consultation workshops

In late 2020 and early 2021, the project ran a series of workshops with potential AquaWatch Australia End - Users, across a range of industries. Attendees included primary industries, planning and environment water resource providers and water utilities, the Bureau of Meteorology (BoM), and the water science community.

The aim of these workshops was to:

a. Catalogue the greatest water quality challenges of our end-users.
b. Interpret their information requirements.
c. Identify issues and opportunities.
d. Understand the benefits to the end-user of having these addressed.

The output of these workshops is being used to identify shared requirements and high-impact applications for the system and provide an industry and market-based assessment on which to derive the overall AquaWatch Australia system requirements. The driver is to inform the system requirements that can be translated to an AquaWatch Australia system architecture that is practical and feasible to build and operate and meets end user requirements.

Through this consultation process and feasibility study we were able to identify a system that meets the majority of end-user requirements. Where there are trade-offs made in the system architecture, decisions are based on a coarse understanding of costs versus benefits.

This document provides a summary of the end-user consultation process, including

a. Outcomes of discussions from each workshop.
b. Simple strategic approaches to addressing the requirements of end users.
c. Draft system requirements.
d. Identifying a practical and feasible AquaWatch Australia system.
e. Next steps.

Workshops that were held between December 2020 and February 2021 were the **first of two rounds in an ongoing consultation process**. The second round, described further below, will invite further input from AquaWatch Australia end-users for considerations on system functionality, performance based on the evolving understanding of the potential applications and the system architecture and a preliminary estimate of costs.

(Please note, as part of the process of collating and analysing the qualitative feedback from the workshops, a level of assessment and reinterpretation of the outcomes has been applied. Several AquaWatch Australia programme related experts were involved in writing up and editing these results. As can be seen in Appendix A “notes by the facilitators”, the condensed verbatim recording was highly informative but in an unsuitable format to report directly. Thus, the AquaWatch Australia experts had to analyse and restructure the data. We realised that this could lead to too much reinterpretation by the AquaWatch Australia team. Some of the results given below are quite summary and often in dot point form. This was a deliberate choice to stay as close to the information provided by the workshop participants as possible. Any errors made in reinterpreting the data provided is entirely the responsibility of the AquaWatch Australia team involved).

3 Synthesizing the outcomes of workshops

The series of AquaWatch Australia end-user consultation workshops, held in late 2020 and early 2021, solicited input from a range of potential AquaWatch Australia end-users. This included experts from government regulators, primary industries, academics, water utilities, and catchment authorities, addressing the needs of public water supply, agriculture, aquaculture, indigenous cultural water, and environmental science groups. With 80+ participants attending across series of workshops, with each workshop attracting between 10 and 20 participants.

The workshops were grouped across the following end-users:

1. **Planning and Environment** (BoM, Geoscience Australia (GA), along with a range of State and Commonwealth agencies and peak bodies)
2. **Water Utilities** (including water suppliers and the hydro-power industry)
3. **Primary Industries** (broad range of users from agriculture and aquaculture)
4. **Water Sciences** (specialists in water quality research from academia, non-governmental organisations (NGOs) and Commonwealth Scientific Industrial Research Organisation (CSIRO)

Within each of these workshops we aimed to ensure representation from each state/territory and major industry (within the relevant category). The workshops included break out group discussions around a generalised list of questions. The discussion sheet is included in Appendix B. Detailed tables of discussion points raised during the end-user consultation workshops are contained in Appendix A

Overview

AquaWatch Australia intends to become an integrated ground-to-space national monitoring platform for water quality in Australia. This will be achieved by the integration of three components: i) specially designed satellite sensors, augmented by drones and aircraft or very high-altitude flying platforms equipped with advanced imaging sensors; ii) the augmentation and interconnection of ground monitoring networks to form a dense in-situ sensor network, and iii) a dedicated data analytics platform to blend the ground and space-based data with hind-casting, now-casting and predictive models and analytical tools. An overview of the international state-of-the-art is presented in IOCCG (2018).

Earth observation using passive optical sensing can measure a limited set of water quality determinants as the information measured from the water column is limited to the visible and nearby infrared wavelengths. Only optically active substances can be measured in the water column and the effects these have on under water light variables such as Secchi disk transparency, turbidity, and vertical attenuation of light. See CEOS (2018) for an overview of Earth observation for aquatic ecosystems. However, a range of other variables can be inferred from these variables using bio-optical, biogeochemical and hydrodynamic models.

Other Earth observation methods that were mentioned are:

- Light detection and ranging (LIDAR): uses visible (VIS) and nearby infrared (NIR) light beams from lasers to determine depth to substratum in cases of optically shallow waters and some discrimination of e.g. seagrasses, macro-algae and sand (if multiple wavelengths of laser light are available). LIDAR is mainly operated from aircraft and repeat measurements can become very expensive. In the thermal infrared (TIR) Earth observation can measure the surface skin temperature of water bodies. This surface temperature can be related to the water body temperature (down to just above a thermal stratification layer) under certain assumptions.
- Active imaging radar Synthetic Aperture Radar (SAR) signals do not penetrate the water column at all and only reflect surface roughness, radar can detect surface wave frequency and height and in case of interferometric synthetic aperture radar (InSAR)can estimate current velocity and direction.

In-situ monitoring through individual sophisticated sensor platforms or through networks of sensors will address different requirements for the AquaWatch Australia mission, each requiring potentially different sensor capabilities. The challenge will be in ensuring sufficient sensors are deployed to satisfy each role. For detailed information see Malthus et al., (2021).

These different roles of in-situ data are i) the satellite physics-based signal calibration of radiance and reflectance at the water surface; ii) satellite water quality product validation and iii) measuring water quality variables that cannot be directly measured by Earth observation such as pH, Salinity, organic micropollutants and heavy metals.

The dedicated data analytics platform intends to do model-data fusion and assimilation of the laboratory, in-situ, air-and space-based data with hind-casting, now-casting and predictive models coupled with the required analytical and visualisation tools to make all this information accessible.

The intent is to deliver timely information Commonwealth and state organisations, water agencies, local communities including indigenous users, and industrial and commercial water users, to enable decision makers to support industry, manage human or animal health impacts and better manage ecosystem health.

In the next section we summarise required introductory information regarding what can and cannot be measured from airborne or space borne sensors, and where in-situ and laboratory measurements would be required. Simultaneously the information from the workshop participants is summarised for their information needs.

3.1 Key water quality variables of interest

This section summarises what the workshop participants considered key water quality variables of aquatic ecosystems measurable in the laboratory, in-situ, above the water surface and from space using optical (VIS-NIR) and other sensors. The editors of this report put those variables that may be estimated from Earth observation, but that are still experimental in italics.

In the questionnaires there were three sets of questions or discussion points. These varied from generic questions to more specific question through to quantitative questions. The workshop leaders and break out group rapporteurs focused on letting the workshop participants determine what was discussed and at what level. As can be seen in Appendix B, (where the condensed verbatim recording is given) the workshop participants also discussed more topics and identified other ways of responding to this end user consultation. The AquaWatch team deliberately allowed a free form response to get as much information as possible from the participants. Thus, in the following synthesis we had to introduce a new structure to properly report the breadth and depth of provided end user requirements. Here we briefly recap the questions that were used as guide in the workshops.

1) See Appendix A: Generic questions:
    - Main interests, key challenges, and opportunities
    - Key water quality variables of interest
    - Scale of importance, or benefit
    - Related issues to consider

Subsequently the workshop participants were asked to answer or discuss any of these more detailed questions below. It depended on the expertise and interest of the workshop participants to choose which of these subjects they found relevant. Thus, the scope and range of answers varied significantly within each workshop and breakout group.

2) See Appendix B.1.
    - Water bodies and water quality: what are some of the key issues, challenges, and opportunities that you (or your industry) are facing?
    - Water bodies and water quality: what are some of the things you would like to detect?
    - What is the importance, or benefit, of being able to detect these things?

- What functionality or performance measures of AquaWatch Australia are most important, or useful to your industry?
- What are the ways that Earth Observation data be combined with in-situ sensor data most effectively for your application?
- Would you like to see existing in-situ sensor networks integrated into an AquaWatch system?
- What kinds of data products would you like AquaWatch Australia to provide (e.g. any considerations with respect to format & presentation of data; the usefulness of raw data, post-processed data, analysis ready data, interpretation ready data, decision-ready data; considerations around data access and data archiving).

Finally, a questionnaire table was provided to gather quantitative information required for developing the satellite sensor specifications. Few workshop participants provided relevant information here for several reasons: the workshops were time bound; the translation of water quality related end-user requirements to physical variables that an Earth observing sensor measures is an expert area etc. A separate report on the AquaWatch Australia Concurrent Design Facility Study is in preparation and will provide this type of detailed sensor specification information. Thus, we provided the following information but received little feedback.

3) See Appendix B.2. End-User Consultation Quantitative AquaWatch Variable/Requirement Table with the following assessment:
   - Still Useful
   - Preferred
   - Stretch Goal
   - Notes, Considerations and Trade-Offs

Using these outcomes of the 3 sets of questions/topics/discussion points, we developed the following structure to provide a synthesis. The new groupings are based on the answers, discussion points and issues as provided by the workshop participants. The topics identified are:

- Variables of the water column
- Variables of the water column depth or the substratum: measurable in-situ, from the air or from space using optical (VIS-NIR) sensors
- Water extent and volume
- Temperature
- Biogeochemical variables
- Disease related
- Micropollutants
- Catchment related

These outcomes are presented below.

3.1.1 Variables of the water column

Measurable in-situ, from the air or from space using optical (VIS-NIR) sensors (The editors of this report put those variables that may be estimated from Earth observation, but that are still experimental in *italics.*):

- Suspended sediments (resuspension and settling)
- *Separating organic sediments from inorganic sediments*
- *Particle size distribution*
- Light scattering and backscattering
- Coloured or chromophoric dissolved organic matter (including separating inland from coastal CDOM)
- Algal species and algal pigments (*some can be measures using earth observation*)
- *Phytoplankton functional types (PFT): note that function definition can vary between user groups*
- Potentially toxic phytoplankton (note that strains can only be detected by genetic

methods), shifts in composition. e.g. for oyster harvesting *(note that remote detection methods cannot determine toxicity)*

- Harmful algal blooms (HABs), detect low to high concentrations of (*potentially toxic*) algae detect surface scums
- Under water light climate variables such as turbidity, Secchi disk transparency and vertical attenuation of light (e.g. K_d PAR)
- Trophic status (by combining suspended sediments, algal type pigments and concentrations, CDOM, turbidity, transparency, and vertical attenuation of light)
- Macro*/micro plastics* (at surface or below surface)
- LIDAR DEM of floodplains: trees hanging over waterways is a potential challenge (*can LIDAR be incorporated into the satellite system to detect this*?)
- Water conditions in tailings ponds (size of ponds often approximately 1 * 1 km); but spatial resolution down to 10 m would be good

3.1.2 Variables of the water column depth or substratum

Measurable in-situ, from the air or from space using optical (VIS-NIR) sensors.

- Bathymetry (e.g. for port development, estimating light availability at substratum) *Note: only feasible down to approximately Secchi Disk transparency.*
- Seagrass and macro-algae mapping (patchiness, extent, density)
- Coral (habitat) mapping
- Freshwater macrophytes mapping (patchiness, extent, density)

3.1.3 Water extent and volume

Extent measurable using radar and optical satellite imagery, volume needs to be derived from extent and bathymetry.

- Water extent
- Water level *and water flow*
- Water quantity
- Water *volume*

3.1.4 Water temperature

Measurable in-situ, from air or from space using thermal sensors in the Thermal Infrared (TIR).

- Seawater temperature
- Freshwater temperature (effects on native species)
- Horizontal *and vertical* temperature stratification

3.1.5 Catchment related

- Catchment run-off (erosion, sediment, nutrients).

The workshop participants also mentioned fire spotting (observable form Earth observation using TIR imagery) and greenhouse gases (measurable by using mid infrared (MIR) wavelengths) e.g. related to methane production, being significant issues.

The following variables are **not** observable by Earth observation methods such as: VIS, NIR, TIR, LIDAR or radar. Thus, they will need to be measured by in-situ instrumentation and/or laboratory samples or estimated by water quality modelling supported by inference from in-situ and EO methods.

3.1.6 Biogeochemical variables

- Taste and odour components of concern for drinking water supplies - Geosmin, MIB (Methylisoborneol)
- DOC (Dissolved organic carbon)-river reach scale (related to primary productivity and fish production)
- DO (Dissolved oxygen) & fish kills -important but local
- Salinity- environmental but also for desalinisation plants and on shore gas: salinity as a waste product. Electrical conductivity
- Nutrients
- pH (acidity) (e.g. acid mine drainage)
- Stratification (water temperature and DO).

3.1.7 Disease related

- Pathogens
- Selected diseases of key aquaculture species: origin and spreading direction
- Discharge from aquaculture farms: either legal, illegal or potentially carrying pathogens
- Raw and treated sewage effluents. Note that under some circumstances the plumes of effluent can be traced into receiving water using earth observation (either Optical or TIR methods)

3.1.8 Micropollutants

- Cyanotoxins i.e. from blue green algae
- Other toxins (e.g. PoP's=Persistent Organic Pollutants)
- Pesticides
- Pharmaceutical products
- Heavy metals.

3.1.9 Supplementary notes on in-situ measurements

Some specific comments were provided related to in-situ instrumentation and data. Although various aspects of in-situ instrumentation have already been discussed there were specific remarks and requests made by the workshop participants and we summarise these here:

- Consider the value of point in-situ data to trigger tasking of imagery in following overpasses
- The use of sensor networks to extend the observations possible with satellite data (other variables)
- The need for on ground sensors for toxicity and for species knowledge
- The value that AquaWatch Australia could offer in reducing the number of staff field days
- In-situ monitoring; Setting up in-situ spectral sensors-feed into AquaWatch Australia (integration of existing sensor networks). See Website Water Quality Australia for issues
- Citizen science – playing an increasing role in acquiring all sort of data (apps: Living Australia; EyeOnWater Australia, etc.,)
- Validation of satellite/drone data with in-situ sampling needs clear guidelines
- The cost in time and effort to maintain and calibrate sensors in remote and hard-to-get to areas
- Augmented satellite sensor data helps with calibration, synchronisation
- Sensor biofouling issues - can these be mitigated? Aquaculture would like instruments in each pond-costs are currently prohibitive.

Next, we present a synthesis of results that go from what could and should be measured to why this information is relevant and how it will be used. From the workshop responses we identified the following categories of use of data and information:

- Aquatic ecosystem processes
- Regulatory and ecosystem management drivers
- Extreme events

- Change and trend detection
- Hindcasting, now-casting and forecasting
  Analytics
- Ease of access to the data and information; trust and reliability; accounting and compliance.

3.2 Aquatic ecosystem processes

In the previous section the end-users and stakeholders defined the direct measurable (in-situ, in-air or from space) variables or variables that were most relevant for water ecosystem management. The reason many of these variables are required is to gain insight into processes.

Here we summarise the processes of interest provided by the workshop participants focusing on inland, estuarine, and coastal waters mostly and some additional information on the Great Barrier Reef. Please be mindful that this reflects the participants views, i.e., represents a subset, focussed on needs in Australia.

The inland water ecosystems of interest mentioned by the workshop participants are riverine, lacustrine or riparian; perennial or ephemeral; wetlands, floodplains, river reaches, lakes, reservoirs, or man-made ponds (aquaculture, drinking water, farm dams). The processes that are of interest to understand are broadly understanding status and change in aquatic ecosystem health — and their social, economic, or cultural impacts:

- Movement of fish and macroinvertebrates
- Sediment and nutrient (particular and dissolved) load from e.g. catchment run-off, erosion
- Nutrient bound in sediments (internal loading, e.g. phosphorus driving eutrophication)
- Influence of agricultural and other catchment activities on inland waters: e.g. erosion issues, extensive grazing lands, fertilizers, pesticides, and leakage from septic tanks
- Linkage with catchment processes which lead to water quality problems
- Blackwater events leading to low dissolved oxygen, fish kills and challenges for water treatment processes
- Inland algal blooms: smothering macro-algae, cyanobacteria blooms with a range of issues: low dissolved oxygen, toxin production, taste, and odour problems. Extent and transport of blooms
- Pesticides and other anthropogenic substances (e.g. PAHs, PFAS)
- Water release from reservoirs, e.g. low DO and cold-water pollution
- Longitudinal and latitudinal connectivity of water ways
- Surface-groundwater interactions.

Naturally many of the inland water processes have flow-on effects on estuarine and coastal aquatic ecosystems. Thus, there will be overlap across these systems. The coastal to marine systems discussed were coastal receiving waters (specifically the GBR which is affected by significant nutrient and pesticide inputs from catchment run-off). Here we summarise the more specific coastal and marine processes discussed:

- Movement of fish, macroinvertebrates (also in the intertidal zone)
- Origin and fate of coastal algal blooms
- Changes in mangrove forests
- Understanding how nitrogen affects coastal and marine ecosystems
- Shallow water and benthic system, monitoring over time
- Understanding how sediments (from catchments and resuspended sediment) along the coast impact seagrass & other habitat features across wet and dry seasons and their monitoring in rough sea conditions
- Understanding how coastal developments affect sediments and erosion
- Understanding how salinity from desalinisation plants impact seagrass & other habitat features
- Understanding how freshwater quantity and quality affect coastal and GBR reef waters across wet and dry seasons
- Impact of DOC/blackwater events on marine life

- Submarine discharge of freshwater
- Ballast water pollution
- Oil spills.

3.3 Regulatory and ecosystem management drivers

Government at all levels provide regulatory drivers for water related information from the Commonwealth to the states to regional and local council levels. This is reflected in issues such as evaluation of management policies and actions, and compliance. Many of the actions and activities that were raised at the workshops were focused on having a better ability to:

- Support catchment management authorities
- Measure impacts of industry
- Drive behavioural change
- Assess the impact of management change
- Support economic development, recreational use, tourism, biodiversity and fairness of water use, public confidence (education)
- Evaluate of environmental baselines
- Audit and monitor compliance of measures designed to reduce the impacts of water abstraction, nutrients, and pesticides etc.
- Manage water resources and ecosystems including securing high-quality water at the local, regional, national and international scale.
- Determine who is holding and using water? e.g. assessing water resources on private land; particularly around amount of water stored in dams and in water systems.
- Ensure fairness and transparency of access
- Impact public perception and policy action
- Detect changes in the health of water bodies (natural or by pollution) that could compromise economic activity
- Support innovations in freshwater and marine interventions.

3.3.1 Implications for AquaWatch Australia design

AquaWatch Australia can provide aquatic ecosystem accounting information and environmental reporting for both national and international accounting purposes.

Some of these uses are: National Natural Capital Accounts (NCA) and the international System of Economic Environmental Accounting (SEEA). Natural capital accounts are defined as the assets that nature provides, that up to now have been potentially unsustainably exploited by industry, but which provide a service that is currently unrecognised. In the AquaWatch Australia case, these are related to aquatic ecosystems such as wetlands, rivers, creeks, farm dams, lakes, floodplains, seagrass fields, corals, etc.

These accounting methods allow systems to be developed to provide the financial incentives to reduce use and impacts on environmental assets. Natural capital accounting also requires reporting. Some of these reporting mechanisms (in addition to NCA and SEEA) are:

- State based State of the Environment reporting.
- National State of the Environment reporting.
- United Nations led Sustainable Development Goal reporting.

In general, the workshop participants identified a high demand for information on overall water body health, including management of ecosystems and eutrophication studies. Some specific uses for AquaWatch Australia type information related to ecosystem management were also provided:

- Evaluating the effectiveness of environmental flows
- Use for early intervention (modelling and forecasting) on an ongoing basis
- Ability to mitigate harmful algal blooms, e.g. in rivers by flushing/diluting
- Ability to improve selection of monitoring locations and variables

- Understand the influence of wind, currents and flow on bloom development as best seen from satellite (or airborne); helps with configuring offtakes in water treatment plants (protect drinking water) and reservoirs (avoid downstream seeding)
- Remote detection of mixing events in lakes and reservoirs
- Assess the impact of dredging projects using several images within a season.

Aquaculture was mentioned by multiple participants as a rapidly developing area requiring the information that AquaWatch Australia could provide:

- Site suitability assessment for aquaculture development including factors such as:
    - Assessing accessibility, water quality, temperature, salinity, pH, water exchange rate, existing aquaculture, and other activity
    - Detecting disease vectors
    - For prawn aquaculture-coastal areas 1 ha ponds; 1 to 1.5 m deep; to be kept turbid
    - Detect changes in the health of water bodies (due to natural or aquaculture causes) that could compromise economic activity
    - Prawn aquaculture: nitrates, ammonia, toxic algae; DO and pH; Management issue play at 1-3 days; prediction is important
- Potential role in ongoing functioning of aquaculture installations once developed, such as:
    - Ongoing water quality monitoring, forecasting of water quality impacts etc.

Multiple participants reiterated the necessity to also include the remote observation of catchment and land-use processes in the AquaWatch Australia portfolio as primary drivers of change in water quality. Land use/catchment issues that affect the health and condition of aquatic ecosystems include:

- Evaluating and managing overland flows (and surface-groundwater coupling): “Where is the water going?”
- Informing land-use planning decisions
- Need to predict and prepare for management of impacts on water quality from controlled and uncontrolled bushfire events
- Secure crops, minimise environmental impacts, expand the industry
- Land-based Earth observation methods are being used in natural resource management
- Improving nutrient/water management in cropping-detecting nutrient or water stress
- Acid Mine Drainage (AMD) can affect (very) small streams. Can also occur in natural systems. Acid mine drainage observation needs NIR to Shortwave Infrared (SWIR) 900-2500 nm coverage from Earth observation
- Mining below the water table (e.g. Pilbara) -massive draining of water => deposited elsewhere
- Acid sulphate soils and their effects on water quality.

3.4 Implications for AquaWatch Australia data processing

Because of the nature of regulatory drivers, the following overall criteria were identified as important:

- Metrics should be based on scientific method, auditable and verifiable
- Requires open-source approach to tools and data.

Previously we defined what is measurable, the resultant information that feeds into the ecosystem processes and drivers that need to be understood in order to be managed by water management agencies and other regulatory authorities. Now we need to consider the ways in which the spatially and temporally explicit AquaWatch system-derived data and information could be generated.

There are four to five types of information provision and use that each have (varying) consequences on the AquaWatch Australia data processing and information infrastructure, these are: Near real time decision making, extreme events, change and trend detection and modelling for hind-casting, now-casting and forecasting. An additional type of information could be accounting and compliance: aspects of this are covered in further sections.

A relevant aspect of in-situ data, airborne data and satellite data is the frequency of measurements. In-situ instrumentation is becoming more and more automated for many variables, thus allowing for high frequency data, with the drawback of measuring at a single location per instrument.

Airborne data can be obtained flexibly (especially from drones) but has limited spatial reach.

Data from Earth observing satellites can be high frequency with low spatial resolution from geostationary satellites (at 30.000 km altitude always positioned over the equator); higher spatial resolution but lower revisit times for Low Earth Orbit (LEO) satellites (e.g. Landsat and Sentinel-2 series are in a polar orbit around 500 to 800 km altitude). To improve Earth observation frequency, it was recommended in CEOS (2018) to consider a combination of geostationary orbit (GEO) and LEO) satellites; or alternatively have more LEO satellites.

The current plan for this AquaWatch Australia program is to design, build and launch two large suitable LEO satellites or more smaller LEO satellites (CDF study, 2021).

3.4.1 "Near Real Time" and "Early Warning" application areas

The end-users informed us that there are several situations where Near Real Time (NRT) data would be valuable for decision making and to provide early warning. NRT decision ready information needs to span large areas with high spatial resolution (resolve streams), but not necessarily at a daily frequency (is problem dependent). The time scale of operation is one day to hours. Note that these two previous statements contradict each other, and thus there are end-users/stakeholders with differing requirements.

Decision ready data needs to be made available directly to the operator in "understandable" terms and be guided by a prescribed ruleset. NRT decision processes implemented in AquaWatch Australia need to be linked to the relevant guidelines and implement theses as basic framework (e.g. Australian and New Zealand Guidelines for Fresh & Marine Water Quality). NRT decision ready information can have legal consequences.

Some examples provided by workshop participants are:

- Hydropower and energy management: assessing when and when not to use water for turbines: e.g. heavy suspended sediment loads can wear down the turbines
- Optimal timing of bulk water pumping and release: intake and release of bulk water from reservoirs
- Water treatment plants: Geosmin, MIB, CDOM and cyanotoxins need to be removed from surface water to make drinking water
- Tracking movement of blackwater and/or cyanobacteria blooms in relation to water offtake points. Needs high spatial resolution from satellite (river width) and upstream sensor network with specific capabilities (DO, DOC, cyanobacteria)
- Some reservoirs are used for recreational activities (fishing, boating, swimming) which need to be limited or closed under certain levels of cyanobacteria biomass (or toxins). These limits are specified in water quality guidelines by states and government. The time scale for effective warning needs to be better than a week to a day.

3.4.2 Extreme events

Predicting extreme events or managing the consequences of extreme events will impact the data processing infrastructure required. Essential criteria are near real-time delivery of data, including analysis, to the relevant authorities and organisations involved. In managing extreme events, a comprehensive level of detailed data is balanced against the need for time-critical and essential data required for early-stage assessment, e.g. a high degree of accuracy of about the concentration of variables, may not be needed, if it is made available in (near) real time.

Some of the extreme events that were mentioned during the workshops were:

- Consequences of blackwater events related to low DO (hypoxia/anoxia) and fish kills
- Timing and extent of fish kills
- Post bushfire consequences for water quality in rivers and receiving waters (increased sediment and thus nutrient loading, metals, etc.)
- Disaster mitigation: flooding, being pre-emptive (e.g. by understanding soil moisture saturation levels)
- Emergency management for flood mapping – distribution, flood damage assessment
- Early detection of nutrients and algal blooms
- Forecasting allows true early warning/risk mitigation. Is based on historical analysis which by itself is also useful for site assessment/application process
- Man-made pollution events and aftermath across all lakes (rapid deployment) e.g. oil and chemical spills
- Data driven forecasts using artificial intelligence (AI) and machine learning (ML) methods

3.4.3 Change & trend detection

Change and trend detection require valid, accurate long-term timeseries of information as subtle changes need to be recognised as early as possible indicating an ecosystem is being affected by stressors or recovering due to management interventions. Change detection can be as simple as comparing two images of seagrasses to see a change in seagrass cover. More complex (from an earth observation point of view) is e.g. to determine whether a change in seagrass species is happening.

Assessing long-term trends in eutrophication generally relies on assessing whether chlorophyll levels are changing in an aquatic ecosystem which requires well validated and calibrated data. Detecting climate change induced trends in e.g. a species distribution, is a clear case requiring many variables to be measured accurately over a long-time span. As catchment condition is a major contributor to the quality of the run-off and groundwater flowing into receiving waters, monitoring catchment condition and issues such as land - use changes are also important. Dense (in relation to the problem) in-situ sensor networks with high resolution data of multiple variables are necessary for this

Earth observation can also be used as a first flag for early detection of anomalies. In an historical context, Earth observation (going back to 1987) can highlight changes in phenology of ecosystem processes (e.g. distribution and timing of blooms)

3.4.4 Hindcasting, nowcasting & forecasting

To undertake forecasting, a water quality model is required. A fully integrated water quality model will need a catchment run-off model to provide it with the catchment inputs. A water quality model will need to be underpinned by a 1-D, 2-D or preferably a 3-D hydrodynamical model. An algal growth model needs these to be able to predict algal growth and distribution in space (depth and lateral). Such an integrated model can be parameterised and calibrated/validated with the use of in-situ data and archival satellite data (for Australia available from 1987 onwards). The demands on data availability increase when progressing from 1D (local situation, river flow) to 2D (flow with vertical stratification) to 3D (vertical and horizontal processes and distribution) models. Water quality models, e.g. algal growth models, need specific data on species composition, cell counts, nutrient availability, food web structure, etc. – such data are usually not measured continuously (if at all) or with high resolution – thus new sensor development is needed, e.g. in the form of hyperspectral cameras or new miniaturized technology (from lab to field instruments above and water and submerged).

There was considerable agreement that many end-users would like to see the water quality modelling extend as far as possible into the future to empower timely management decisions. Any prediction beyond 3 days would be excellent using fully assimilated data sources.

The use of water quality modelling and forecasting focused on the health of water bodies for different uses (e.g. domestic consumption, industrial production, agriculture, aquaculture, shipping, tourism, environmental use). Some specific uses were:

- Trophic status
- Coloured dissolved organic matter (CDOM)
- Resuspended sediment
- Stormwater effects on seagrasses
- Nitrogen dynamics
- Pesticides: is there a correlation with other variables to derive proxy maps
- Need for detection of threshold levels: not necessarily “accurate” modelling, e.g. to trigger supplementary water sampling at specific points.

Some examples of what agencies, utilities or industry would like to see:

- Water treatment utility scope: once a day (early): what the situation will be with respect to algal blooms. E.g. a modelling- based prediction for the next 3 days; 10 to 30 m spatial resolution would accord with water quality modelling scale and resolution; include variables such as chlorophyll, cyanobacterial concentration, and turbidity variables. Knowledge of when an algal bloom will end is also important. Others would like information on geosmin, MIB and CDOM (drinking water utilities)
- Benefits from correlation of imagery with in-situ sensors and use of ML/AI for predictive analysis in terms of operating cost for business. Specifically, reduced costs and effort for in-situ sampling and travel
- Ability to access places that are normally time consuming/expensive/risky to visit (e.g. in situations of flooding, remote areas)
- Being able to have early detection to mitigate the situation by distributing the chemicals that are needed to treat the outbreak and eliminate it early
- Baseline and impact environmental studies of new industrial developments in coastal areas
- Blue carbon/accounting focus on prediction
- Prediction of freshwater flooding for inland and coastal aquaculture (e.g. carrying potential pollutants or significantly reducing salinity)
- For the GBR, seeking an improvement on the resolutions of the eReefs models (1km and 4km). Integration with existing analytics networks. Integration of existing sensor networks of GBR data can be made available to assist with calibration and validation; even better if QLD Government could contribute end of catchment data, e.g. for better estimation of nutrient inflow from catchment runoff.

The workshop participants that have experience with modelling also contributed to more technical aspects that they would like to see incorporated:

- Significant benefits seen in linking and integrating in-situ and Earth observation (airborne and from space) data and integrated modelling
- Calibration of hydrodynamic models using satellite and in-situ information
- Use of data assimilation for hind/now/forecasting, validating models against hindcast, continuous updating of models with actual data from multiple sources. This will involve access to related data – e.g. weather forecasts, soil moisture history and prediction, risks of pollutants and/or diseases, natural processes such as overland flow, groundwater flow, river flow, runoff, currents. Water quality measurements (including laboratory analysis of water samples, e.g. algal cell counts, metal concentration, toxins, etc.,) in conjunction with quantity and flow
- Access to tools for water quality forecasting (daily updates at 5 to 50 m resolution), within 24 hours. Integration with the BOM Water Outlook tool (7 - 10 day short-term up to 3-month forecasting). Seasonal forecasting of blooms not so useful (seasonality is known, magnitude is hard to predict)
- For aquaculture: the focus is on short term forecasting for risk management. Knowing the in-situ state plus flow is important to aquaculture

- Develop understanding of what behaviour will change, on what timescales, and how to measure effectiveness.

3.5 Data access and quality of data

A significant amount of participants stressed the importance of ease of data and information access from AquaWatch Australia, e.g. government departments would like to see ease of ingestion of the data into departmental systems (formats etc) and that data should be made available via a querying system.

Generally, it was felt that the large volumes of data require tools to manage/select/choose relevant temporal and spatial subsets to ensure consistency in data quality and analysis.

Some aspects mentioned were:

- User interface/experience is important
- Comparability and interoperability to existing systems is important and thus metadata and standards for quality assurance are essential
- Existing systems make data readily available via on-line portals or via APIs
- Ease of access and suitability of data analytics tools
- Make a clear statement for AquaWatch Australia: that IP, data availability, model algorithms need to be open access
- Push to combine measurements to address issues earlier and more effectively: e.g. near real time dashboards for operational interventions
- Visualisation tools need to be optimised and /or customisable for specific uses
- Defining uncertainty (calibration accuracy) in measurements
- Calibration and validation are a key gain in AquaWatch Australia. For both satellite and models with the aim of assessing the accuracies of EO derived water quality.
- Ensure persistent data storage for AquaWatch Australia.
- Increasing data volumes from satellite/in-situ allows for AI/ML approaches.
- Integration of information from satellites/ drones/ in-situ sensors with other information.
- Near real-time data – streaming data continuously, extrapolating out with EO data.

For accounting and compliance many of the above criteria need to be met. Some additional comments were that the applied metrics need to be based on a scientifically traceable method that is auditable and verifiable. This requires an open-source approach to tools and data.

Globally there is now a strong push for Earth observation data to be made available as Analysis Ready Data (ARD). The International Committee on Earth Observing Satellites (CEOS) defines ARD as: "Analysis Ready Data are satellite data that have been processed to a minimum set of requirements and organized into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets". So, this is highly standardised which was another requirement from the end users.

End-users or value-adding industries still need to apply their own algorithms to ARD to get information. A new term is now being developed called Interpretation Ready Data (IRD) which is Earth observation data that has been processed right through to a spatio-temporal information product such as e.g. concentration development of blue green algal pigments, shallow water bathymetry or a eutrophication index.

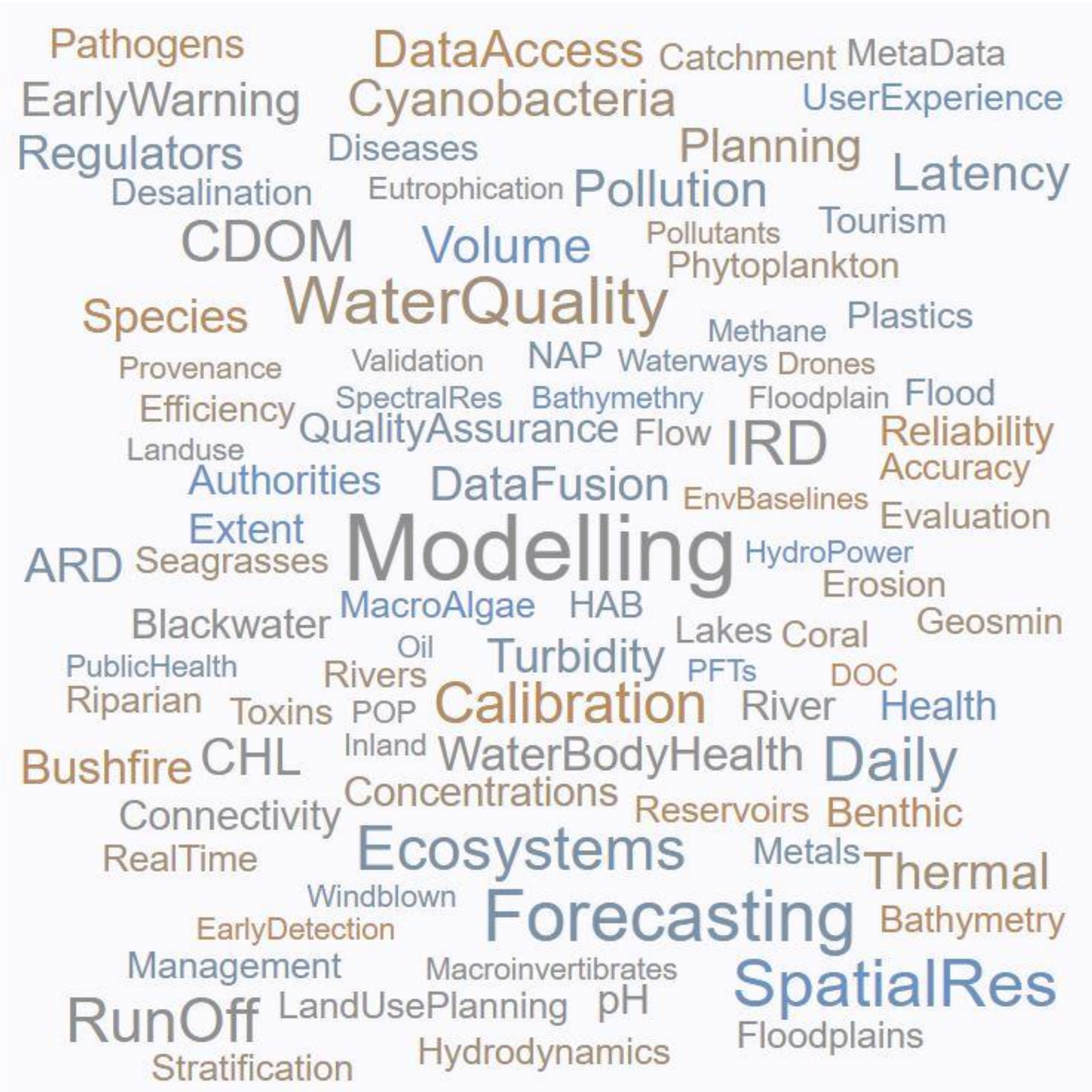
The workshop participants varied in their need for ARD or IRD based on their in-house capacity and capabilities. Many felt both ARD and IRD are needed with low latency and high reliability. Industry would like to take advantage of both aspects ARD and IRD. Visualisation (visualisation tools) was also considered important. Some participants with a scientific programming capability are satisfied with back-end access to Top of Atmosphere Earth observation data so they can do their own complete processing.

3.6 Word cloud

Given the wide range of end-users consulted, it is important to establish areas of commonality as well as individual sector needs. Several software-based methods were used to summarise some of the information collected. Although not clearly structured as the previous section it does give an instant overview of priorities.

The following word cloud represents the most used terms captured during the workshops. This simple technique highlights areas of common interest for the end users across all workshops.

Figure 3: Word Cloud Derived from End User Consultation Workshops



There was a lot of interest in remote detection of water biogeochemistry of water bodies and the ecosystem dynamics. These covered the range of what is possible to detect from satellite and in-situ sensing (and it is expected that AquaWatch Australia will be able to detect the vast majority of these).

There was also a strong interest in water extent and hydrodynamics— particularly the interconnection of water bodies. Modelling was mentioned most as it has an explanatory and predictive function which is of the highest relevance and functionality for water managers in general.

Across the groups there was a strong focus on overall system functionality. While ARD is commonly sought, there was a strong focus on acquiring high-level data products including IRD, Data Fusion, Machine Learning, Artificial Intelligence, Modelling and Forecasting. There was also a strong focus on the quality of data; it's providence, metadata, calibration, and accuracy.

3.7 Trade-offs

When we review the feedback from the workshop participants and look at the very broad range of requirements of potential AquaWatch end-users, there is a clear challenge for the AquaWatch program design to optimise the delicate balance between technical efficiency, breadth and depth and quality of data and short term versus long term impact and benefit.

Through this process our aim has been to develop the strongest possible business case for AquaWatch. This implies building an AquaWatch Australia system at a reasonable cost, but which satisfies the broadest possible range of end user requirements. As a system AquaWatch Australia will be unparalleled in terms of performance and functionality, but it won't be all things to all people. Design trade-offs are inevitable. Through the end-user consultation process there is **one major trade-off** that has emerged and that is the trade-off between "revisit time" (or how frequently a part of Australia is imaged by the EO satellites) and the ground resolution achievable by the EO satellites.

1) Higher ground resolution (e.g. pixels of a few meters) implies that the satellite imaging system has a small Field-Of-View (FOV)
2) Smaller FOV means less area is covered by each satellite overpass*
3) Smaller area covered by each satellite overpass means more overpasses are needed to cover Australia (i.e.: a lower revisit time).

Note: Assuming a LEO satellite. Other orbits have been discussed but are currently out of scope due to significantly higher costs involved.*

Naturally all AquaWatch Australia end-users would like higher ground resolution and shorter revisit times. In addition, the fact that many water bodies in Australia are quite narrow presses us towards the path of having high spatial resolution. But the impacts of potentially harmful algal blooms and other extreme events and the advantages of early detection in a range of AquaWatch Australia applications pushes us down the path of having short revisit times. We are continuing to evaluate this aspect of the system design. As it stands, we are aiming for a ground resolution of around 20m and a revisit time of a few days**.

*Note **: Assuming 2 AquaWatch Australia satellites.*

3.8 Computing infrastructure

One area where such trade-offs are unlikely to be necessary is in computing infrastructure. Our early investigations into computing infrastructure for the AquaWatch Australia Data Analytics subsystem have shown that cloud computing resources are, to a first order, suitable for our purposes.

Using existing cloud computing vendors, the project could access the amount of computer processing power and archiving space that would be needed to support our purposes. The processing pipeline and workflows can be as simple or as complicated as we need them to be.

In many ways AquaWatch Australia will be a software defined system. From our end-user consultation process, we identified a strong interest in the functionality supported, the data products produced, the access to data and metadata, the providence, reliability, and accuracy of data. There was a lot of interest in long term-archiving, the development of models, including AI and ML for forecasting.

The software that will define the system, including the Data Analytics Subsystem and the Control & Monitoring Subsystem, will be developed using evolutionary and iterative processes. This approach will help to ensure that:

- functionality delivered provides maximum benefit to end-users
- functional delivery starts to occur relatively early in the system roll-out
- early adopters can assess and feed-back

It is likely that a scaled agile framework will be used for software development.

3.9 In-Situ Sensor Network white paper

We are currently analysing the specifications and requirement of the AquaWatch Australia in-situ sensor network (See Malthus & Dekker, 2021). It is important to note that the AquaWatch in-situ sensor network is completely scalable and, theoretically, may incorporate any number of sensors, and can cope with yet to be developed sensors to measure with higher resolution and allow for new parameters

It may also incorporate any number of sensor variants (different sensors deployed to different locations) if they conform to a standard interface for control and monitoring, and data. This means that any desired sensor functionality can be designed into the AquaWatch system.

We expect the sensor network to be large, providing wide coverage of Australia and working with high availability in remote areas. Sensors are not necessarily cheap, easy to deploy, reliable or easy to maintain. There is a strong imperative to ensure that AquaWatch sensors address these issues. The AquaWatch Australia team is currently drafting an In-Situ Sensor Network white paper in which they start to determine the requirements (See Malthus & Dekker, 2021).

3.10 Technology Readiness Levels and staged roll-out

AquaWatch Australia will leverage the products/capabilities of component/service suppliers in the space industry. AquaWatch Australia will benefit from the improved maturity (and Technology Readiness Levels, or TRLs) of suppliers over the coming years. The performance and functionality of components that we purchase may exceed what we currently plan for, and that will have a positive impact on the overall system performance and functionality.

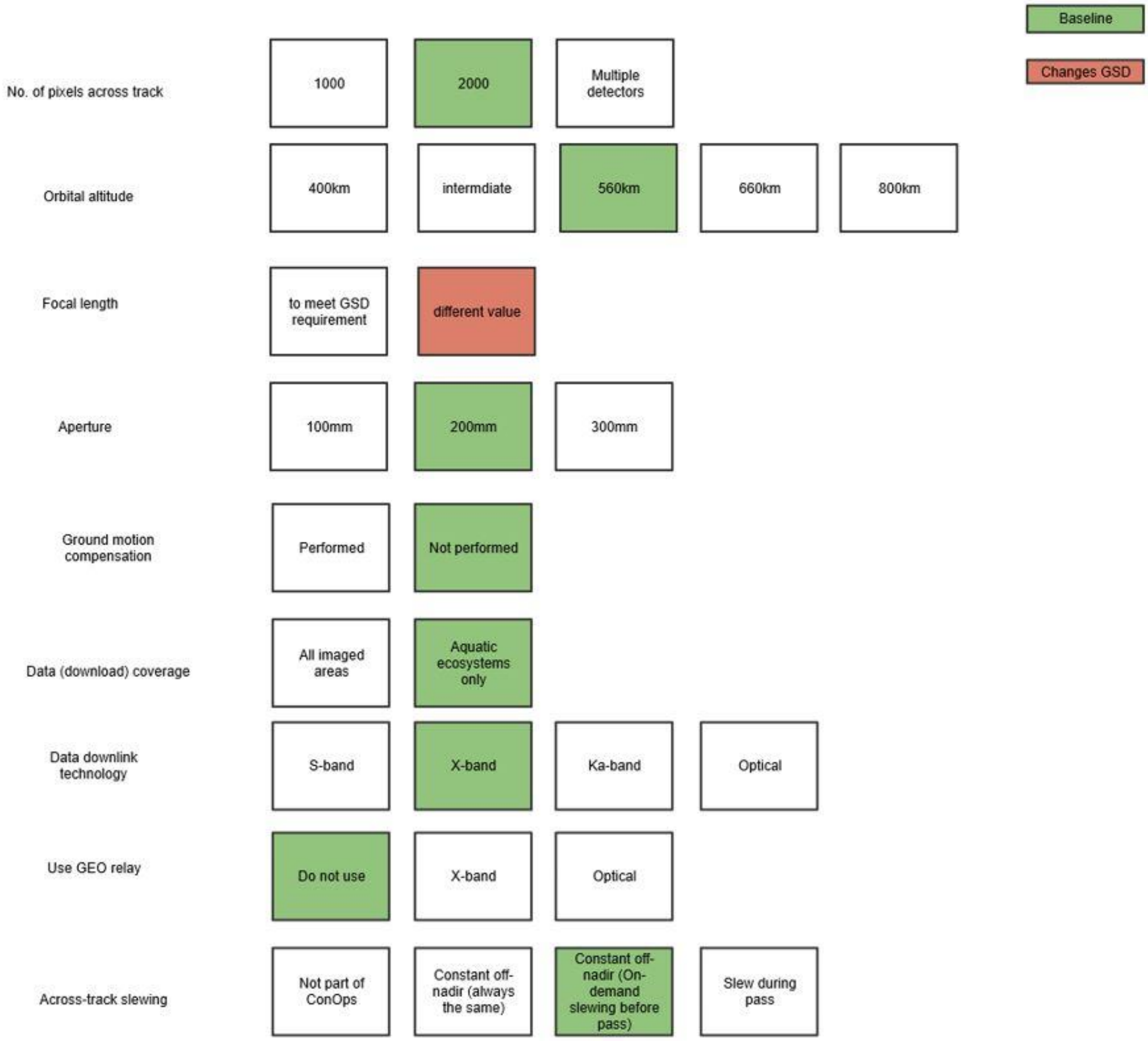
The AquaWatch Australia system architecture allows a staged roll-out (by having multiple satellites, a scalable sensor network and an evolutionary approach to software development). This aspect lowers the project risk, allows early science, and increases our opportunities to benefit from improving products and capabilities developed by global suppliers.

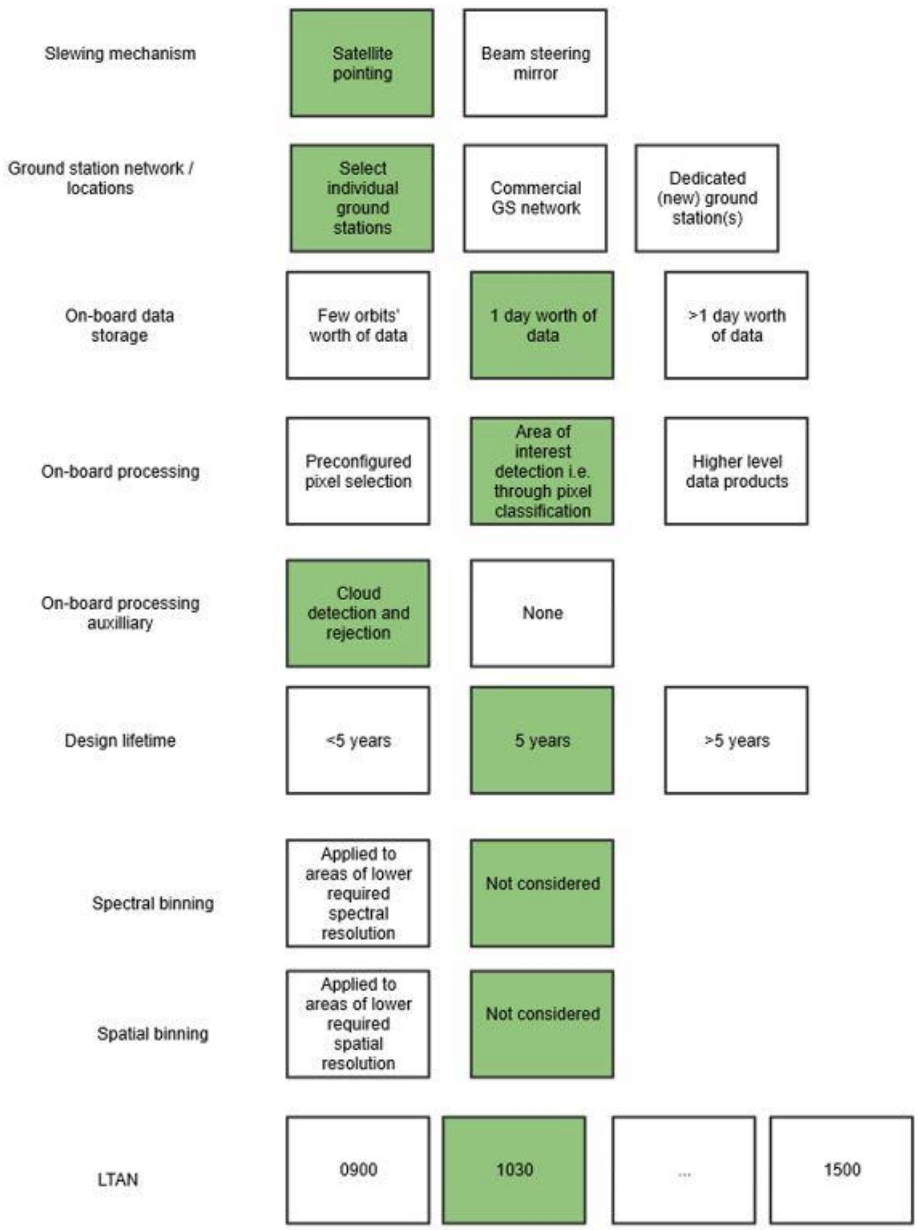
3.11 Initial Satellite System Requirements based on end-user consultation

The Level-1 Satellite System Requirements are the initial set of requirements, based on the outcomes of this initial end-user consultation process. They aim to express the high-level requirements of our AquaWatch end-users in terms of a system definition, based on a broad understanding of what is possible and feasible.

Within the AquaWatch concurrent design activity these Level-1 requirements were used to assess the system architecture, performance, and functionality, identify trade-offs, and initial cost and schedule estimates and risk profile (See CDF Study, 2021 for details). These satellite specifications will be used as a "baseline" from which to refine the architecture, specifications, and project planning.

Figure 4: Initial Outcome of the CDF Study (CDF Study, 2021) for AquaWatch Australia




Slewing mechanism
Satellite pointing
Beam steering mirror
Ground station network / locations
Select individual ground stations
Commercial GS network
Dedicated (new) ground station(s)
On-board data storage
Few orbits' worth of data
1 day worth of data
>1 day worth of data
On-board processing
Preconfigured pixel selection
Area of interest detection i.e. through pixel classification
Higher level data products
On-board processing auxilliary
Cloud detection and rejection
None
Design lifetime
<5 years
5 years
>5 years
Spectral binning
Applied to areas of lower required spectral resolution
Not considered
Spatial binning
Applied to areas of lower required spatial resolution
Not considered
LTAN
0900
1030
...
1500

4 Next Steps

4.1 Round 2 End-user consultation

There will be a second round of end-user consultation within the AquaWatch Australia Phase-0 project. This will provide feedback on the outcomes of the first-round consultation (reported here) and the concurrent design activity (reported separately) and the instrumentation green paper (Malthus & Dekker, 2021). It will invite further input for considerations based on the evolving system architecture.

There will be an increased emphasis on identifying the applications based on new expectations around ground resolution, spectral resolution, revisit time and dynamic range. There will also be an emphasis on articulating and quantifying the impact/benefits of the system.

4.2 AquaWatch Roadmap

AquaWatch will transition from “Phase-0” to “Phase-A” in Q3 2021.

Figure 5: AquaWatch Mission Phase Definitions

Phase 0	Mission Analysis and Identification
Phase A	Feasibility
Phase B	Preliminary Definition
Phase C	Detailed Definition
Phase D	Qualification and Production
Phase E	Launch and Operation
Phase F	Disposal

AquaWatch Phase-A:

- Will run over ~9 months
- Include refinement of the system design/system architecture
- Include detailed project planning against an increasingly solid business case
- Conclude a Preliminary Requirements Review (PRR)

System Requirements don’t need to be baselined until AquaWatch Phase-B, which features the System Requirements Review (SRR). Implicitly there will need to be an Engineering Change Process in place by that stage. This will place a moderate, but necessary, overhead on design changes derived from new or evolving user requirements.

4.3 Long term end-user engagement

Further end-user consultation will be done mainly via the AquaWatch Australia End-Users Advisory Group (EUAG). This will be the primary interface for engaging the broad end-user community. Within the EUAG we are seeking representation from a cross section of industry groups to provide a range of perspectives of issues and needs of their segment of the end-user community.

Throughout the project lifecycle there will be many other opportunities for end-user consultation:

- We will continue to liaise with our broad base of end- users via communications material and scientific outreach.
- The End-User Advisory Group (EUAG) will meet periodically and will provide input to the AquaWatch Steering Committee.

- We will continue to operate National AquaWatch Australia Science Advisory Team
- And the International AquaWatch Australia Science Advisory Team
- AquaWatch is expected to provide opportunities for both early and applied science. For EO Scientists and those who like to get hands-on with their data, there will be many chances to contribute to system validation and evaluation activities.

References

CEOS (2018): Dekker, A.G & Pinnel, N. (Eds) Feasibility Study for an Aquatic Ecosystem Earth Observing System. CEOS Report, CSIRO, Canberra, Australia

CDF Study (2021): Preliminary Concept Study for the Satellite Segment of AquaWatch Australia (2021), Australian National Concurrent Design Facility, UNSW, Canberra, Australia

IOCCG (2018) Greb, S, Dekker, A.G. and Binding, C. (eds) Earth Observations in Support of Global Water Quality Monitoring., IOCCG Report Series, No. 17, International Ocean Colour Coordinating Group, Dartmouth, Canada

Malthus, T.J., Dekker, A.G., Xiubin Q. and MacLeod, A. (2021) In Situ Sensor Networks - Strategy Green Paper. AquaWatch Project Report. CSIRO, Canberra, Australia.

Appendix A Notes from end-user workshop breakout groups

The series of AquaWatch Australia end-user consultation workshops, held in late 2020 and early 2021, aimed to solicit input from a broad base of AquaWatch Australia end-users. This included people from a wide range of industries and organisation types. The workshops attracted approximately 80 participants in total with each workshop attracting between 10 and 20 participants.

We held workshops for:

- **Water Science** (specialists in water quality research from academia, NGOs and CSIRO)
- **Planning & Environment** (including the Bureau-Of-Meteorology, Geoscience Australia, along with a range of state depts and peak bodies)
- **Water Utilities** (including water suppliers and the hydro-electric industry)
- **Primary Industries** (broad range of users from Agriculture and Aquaculture)
- **CSIRO Water Specialists** (targeting the broad base of expertise in water science and water use within CSIRO)

Within each of the 5 workshops we aimed to get representation from each state and each major industry (within the relevant category). The workshops included facilitated break out group discussions around a generalised set list of questions. The discussion sheet is included in Appendix B.1 and B.2.of this document.

Verbatim recording of the group discussions from each of the workshops are given here. These notes were used to write the end user requirements in the main document. As each breakout group discussion focused on different aspects, omitted some aspects, and added new topics we had to restructure and amalgamate this information considerably in the main text.

Water Science Workshop – Dec 2020

	Main interests, key challenges and opportunities	Key water quality variables of interest	Scale of importance, or benefit	Related issues to consider
Breakout 1+2 (T.Biswas/T. Malthus)	Shallow water and benthic system, monitoring over time Riverine and desert systems, riparian systems, river reach mapping Beginning to focus on reservoirs Blue carbon/accounting focus on prediction going forward Inland and coastal algal blooms, early warning tools, prediction systems Characterise water bodies Australia-wide Extreme events blackwater, bushfire impacts, extreme events). Surface/GW interactions Freshwater and coastal habitat loss due salinisation Aquatic movement of fish, macroinvertebrates Understanding current status (water quality, ecosystems, flora and fauna) Prediction of health of water bodies for different uses (e.g. domestic consumption, industrial production, agriculture, aquaculture, shipping, tourism)	Phytoplankton functional types Blackwater events DOC Dissolved oxygen PFTs to determine species contributing to algal blooms Coastal benthic vegetation Floodplain harvesting, water volume Suspended sediments, and where they settle/resuspend Submerged vegetation health, species det ection Light availability Connectivity in ephemeral systems / waterholes - low flow in rivers Pathogens Metals Geosmin (odour) Salinity	Calibration and validation a key gain. For both satellite and models Improved characterisation of error in satellite and model data Value of point in-situ data to trigger tasking of imagery in following overpasses Value of satellite and in-situ in assisting 3D modelling of water bodies Sensor network extends observations possible with satellite data (other variables) Increasing data volumes from satellite/in-situ allows for AI/ML approaches Near real time dashboards for operational interventions Blackwater events (large scale – km scale) – taken seriously by state agencies, related to DO/Fish kill impacts. DOC (small scale – river reach scale) – medium. Related to primary productivity and impacts on fish production Dissolved oxygen / fish kills – extremely important, but also very local Coastal benthic ecosystems (seagrass, aquaculture impacts) – important, improved methods to monitor and detect impacts is required Floodplain harvesting, water volume – moderate to important (NSW Govt). Important from regulators perspective. Remote detection useful. Suspended sediments, and where they settle/resuspend – low to medium. But can be important elsewhere (other than Australia) Submerged vegetation health, species detection – important – change detection, habitat quality perspective Securing high quality water, local, regional, national, international Biodiversity, agriculture (for every $ at the farm gate – 3.5x economic benefit)	Integration of information from satellites/sensors with other information. Water quality data availability – sparse and undiscoverable. Data availability from state and local agencies… Citizen science – playing an increasing role in making all sort of data (Living Australia) Visualisation – decision making/ ready information/ operational decision (general vs technical) Near real-time data – streaming data continuously, extrapolating out with EO data. Minimum latency period - between acquisition and availability of data. Data accessibility
Breakout 3 (T.Hoang)	Site suitability for aquaculture development: accessibility, water quality temperature, salinity, pH), water exchange rate, existing aquaculture and other activity. Ability to detect changes of the health of water bodies either naturally or by pollutions that could compromise economic activities (with particular interest in aquaculture)	Raw and treated sewage effluents Toxins e,g, PoPs, heavy metals Oil spill Sea water temperature Selected diseases of key aquaculture species: origin and spreading direction Discharge from aquaculture farms: either illegal or potentially carrying pathogens	Aquaculturalists always seeking new sites, considerable investment required to establish, success directly related to site suitability over long term. Aquaculture systems also a potential pollution source – need to forecast capacity of resources.	Access to related data – e.g. weather forecast risks of pollutants and/or diseases, natural processes such as river flow, runoff, currents. Flooding for inland and coastal aquaculture (significantly reducing salinity or carrying potential pollutants Industrial new development in coastal areas

Breakout 4 (A.Dekker)	Marine WQ Coastal WQ & Processes, GBR, River & lake health & hydropower In-situ monitoring Detecting climate change trends Identifying hotspots-event based Consequences of bushfires and aftermath across all lakes (rapid deployment) Monitor land use changes in river catchments (intensification of use) Coral bleaching, monitoring/mapping of seagrasses, macro-algae, Nutrient species	Tropic status Terrestrial CDOM vs coastal CDOM Macro/micro plastics - distinguish plastic at surface vs below surface		Access to the well-structured information from the AquaWatch is key for researchers The large volumes of data require tools to manage/select/choose relevant temporal and spatial subsets- some want to make it end user friendly! Possible to standardise is important. Others just want the easy back-end access.

Planning and Environment Workshop – Dec 2020

	Main interests, key challenges and opportunities	Key water quality variables of interest	Scale of importance, or benefit	Related issues to consider
Breakout 1 (Dan.?)	Need to satisfy Gov regulators, utilities, catchment authorities. Sediments and erosion around coastal developments.	High demand for params on overall water body health, including mgmt. of ecosystems and eutrophication studies. Optical (turbidity), biological, salinity, pesticides, pathogens, pharmaceutical products. Tools for water quality forecasting. Seek daily updates, and 5-50m spatial resolution. Meta data & standards for quality assurance.	Evaluation of environmental baselines. Evaluation of mgmt. policies and actions, and compliance.	Combined in-situ and EO imagery is attractive. Rich, multi-source data sets. Great benefits from integration of existing sensor networks. Seek “interpretation ready” rather than “analysis ready data” Water quality measurements in conjunction with quantity and flow. Near real-time availability of data. < 24h Integration with BOM Water Outlook tool (10 day, up to 3-month, forecasting).
Breakout 2 (K. Joehnk)	Informing public health and water body condition; land use planning. Disaster mitigation: flooding, being pre-emptive; bushfires and WQ Water level (flow), EC, pH, suspended sediments, nutrient run-off, water extent, HAB, floodplain harvesting extent of problem, detect low concentrations of (toxic) algae, bathymetry, latency,	Spatial resolution (20/5/1m) to determine influences on catchment. Detection of toxic algae for oyster harvesting. Suspended sediment detection capability. Comparability and interoperability to existing systems is important. User interface/experience is important, defining uncertainty (calibration accuracy) in measurements. Frequency (5/1/0.1 days). I.e. Daily. High dynamic range comparable to sentinel 2. Species pigments (algal signature/functional types). Spectral resolution supporting thermal sensing.	water use regulation health of GBR related to nutrient run-off support economic development, tourism, public confidence (education) use for early intervention (modelling and forecasting) on an ongoing basis generate standardized reporting (on different levels, state … SDG) Informing land-use planning decisions	Latency on analysis ready and decision ready data is important. Knowledge of when a algal bloom will end is also important. Develop understand of what behaviour will change, on what timescales, and how to measure effectiveness. Possible combination of GEO and LEO satellites should be considered. now/forecasting, validating models against hindcast, continuous updating of models with actual data,
Breakout 3 (A.Dekker)	C’wealth (govt regulators) provides oversight; refer to tech w.gr’s. Toxicant trigger values ANZWQ guidelines. WA DEWR- like to augment in-situ using EO: turbidity phytoplankton communities & Chl. TSS also. Effects of desalination plants on aquatic environment. Can we detect salinity and density effects on environment?. Seagrass & Macro-algae mapping. Setting up in-situ spectral sensors-feed into AW (integration of existing sensor networks). See Website Water Quality Australia for issues. Need for near real time extreme event monitoring: does not need to be accurate	Modelling hydrodynamics, using bathymetry for port development. As well as ecological information: trends in seagrass recovery; algal blooms. DEWR has buoys with sensors. Do monthly reporting for port development. Would be good to have in-situ measurements of toxicity of blooms. Ground res (30/10/5m). Revisit daily. Concentrations of compounds 0 to 3 mg/l Chl; 3-10 and 10-20		In WA DEWR is deploying spectral sensors at the moment. DEWR would like advise on deployment. Having the analysis and interpretation ready maps is essential. Would like to access; pre-processed data for possible experts to work on was well.

Breakout 4 (T. Malthus)	Measuring water quantity, connectivity of waterways (needing spatial resolution). systems supported by ground or surface waters. Pollution events and sediment loads. Marine focus, accurate information on water quantity, catchment loads and concentrations. RS of water quality across GBR –exposure maps, condition and trend. Chlorophyll and NAP. A key question is how much resuspension of sediment occurs across wet and dry seasons. Suspect a lot of resuspension occurring during dry seasons – a combination of wind, wave and tidal effects. Monitoring small waterways. Understanding accuracy (calibration and quality assurance)	Temperature, pigments, water body detection (extent) at a fine scale (m); Riparian zone extent and health. Exposure mapping categorises water type (in the GBR) –Chl and NAP – standard water quality variables. Profile of the water body – where is the data coming from? Stratification interests. Algal speciation (harmful vs benign) concentrations, HABs in recreational water bodies. If lidar available, broader floodplain mapping would be useful. Also strong interest in water resources on private land (dams… etc). Seagrass systems (total extent, patchiness/density), coral habitat monitoring Bathymetry, Salinity, DO Resolution for GBR is not very high (100 m) Otherwise 10m ground res is useful. Better than sentinel 2 is preferred. Revisit daily, but cloud cover is an issue. Pigment absorption features, including chl but also others for PFT's. Scattering, for sediment. Thermal. Salinity (NIR?) CDOM/blue wavelengths.		To reconcile against current datasets (validating models) suitable and gap filling. Support management in the catchment (catchment authorities); innovations in marine interventions. For GBR, seeking an improvement on the resolutions of the eReefs models (1km and 4km) Ease of access to the data and information. Ease of ingestion of the data into departmental systems (formats etc). Integration with existing analytics networks. Integration of existing sensor networks GBR data can be made available to assist with cal-val; even better if QLD Govt could contribute end of catchment data. Keen to see in-situ network located near existing stations to provide continuity of time series. Existing systems make data readily available via on-line portals. Both ARD and IRD needed with low latency and high reliability. Trees hanging over waterways is a potential challenge (can lidar be incorporated into the satellite system to detect this?).

Water Utilities Workshop – Dec 2020

	Main interests, key challenges and opportunities	Key water quality variables of interest	Scale of importance, or benefit	Related issues to consider
Breakout 1 (K.Joehnk)	WQ problems: algal blooms, sediments, organics Linkage with catchment processes which lead to WQ problems Sediment run-off after bushfires Fire spotting Linking data and modelling, take snapshots in time, drones could be useful Faster response time to problems Learning aspects from satellite imagery, e.g. wind influence on bloom development not seen from ground but from satellite; helps configuring offtakes in WTP Linkages between events from a catchment perspective, e.g. erosion event à WQ	Blooms Methane production Particle size, algae vs cyanobacteria, Resolution of vertical structure in water column needs in-situ instrumentation Turbidity data for model calibration Species detection, broad groups would be sufficient and keep high temporal/spatial resolution – a grab sample will be sufficient for a specific location to get species	State of Env. Reporting can be based on a few images with low resolution, but policy is different to operation Long period of data can help in model calibration, reduce uncertainty Uncertainty of model output Reducing number of field days/limited staff Early warning on a larger scale what local sampling might not pick up Calibration of hydrodynamic model using satellite information; data assimilation Need for detection of threshold levels to trigger supplementary water sampling at specific points (not "accurate" modelling)	Validation of satellite/drone data with in-situ sampling needs clear guidelines Good meteorological data are crucial to keep model uncertainty low Need data available at different levels of sophistication, ARD, IRD Industry would like to take advantage of both aspects ARD and IRD From an industry point of view AquaWatch need to supply a clear message that satellites are not the only part of the system, in-situ data are equally important, as is model software Make clear statement: IP, data availability, model algorithms need to be open access
Breakout 2 (A.Dekker)	Concentration of geosmin is the key issue-this is at low concentrations. At high cyano concentration toxins etc become an issue=health issues. Bulk water pumping and release: intake and release of bulk water from reservoirs: can we track movement of black water and /or cyano affected waters to raw water pipelines/ or SWTPs. Width e.g. 30 m (Murray)?	Cyanobacterial Earth observation: in-situ spectrometers (above water). Windblown effects scums; Early warning systems! Temperature useful. Detect Seiching etc. ensure HD model representativity. How well do the CDOM sensors work- need to remove organic matter (disinfection by-products); same for by-product algae. Also, CDOM effects on seagrasses. Resuspended sediment and stormwater sediments affecting seagrasses.	Water treatment utility scope: once a day (early) what the situation will be re algal blooms. E.g. a modelling- based prediction next 3 days 10 to 30 m spatial resolution would accord with water quality modelling scale and resolution: chl, cyano conc and turbidity variables.	Push to combine measurements to address issues earlier and more effectively. Bias for the provenance of the information (i.e. imagery dates/registration => swathe width) and support coordination across agencies. Additional sensing (and EO) is valuable for refining the existing models, particularly at (or outside) the jurisdictional boundaries. Also the visiting & calibrating sensors in remote and hard-to-get to areas.
Breakout 3 (A.Macleod)	Understanding sediments and how sediments along the coast impact sea grasses & habitat - particularly around the impact of desal plants. Early warning systems for monitoring quality of living streams (i.e. a developed urban drain to promote co-use of ecosystems + urban areas). Interested in algal and organic contaminants. Would need high resolution (e.g. 5m) to be able to monitor these.	Differentiation between sediments and algae. i.e. what's organic and what's inorganic[1] BF: Being able to differentiate algal blooms and cyanobacteria would be useful too. KR: Is it possible to detect salinity in some way[2]? Is there ability to detect plastic content of water[3]? Is there potential for the EO satellites to detect acidification[4]?	Would like updates several images within a season e.g. to assess the impact of dredging projects. Benefits from correlation of imagery with in-situ sensors, and ML/AI for predictive analysis in terms of operating cost for business. Specifically, reduced sampling and travel. Ability to access places that are normally time consuming/expensive/risky to visit (e.g. flooding, areas under native title). Being able to have early detection to mitigate the situation by distributing the chemicals that are needed to treat the outbreak and eliminate it early.	

Primary Industries Workshop – Feb 2020

	Main interests, key challenges and opportunities	Key water quality variables of interest	Scale of importance, or benefit	Related issues to consider
Breakout 1 (K. Joehnk)	Evaluation of policies. Water management and ecosystems. Water temp and pollution. Fish breeding. Need for early detection. Ability of businesses to access and use data. Openness of data. Who is holding and using water? Water flow. Address needs of agriculture, aquaculture, indigenous and environmental groups.	Blackwater, nutrients, algal blooms, pathogens, suspended solids, water temperature, HAB, cost of monitoring, cost of data. Water temperature. Volume and interconnectedness of water systems. High spatial resolution. Ability to do early detection. Atmospheric correction. Consistency in data quality, availability and analysis. Need all suitable metadata. Persistent data storage.	Particularly around amount of water stored in dams and in water systems. Fairness and transparency of access. Impacting public perception and policy action.	Ease of access and suitability of data analytics tools. Supporting machine learning. Calibrating satellite data with in-situ measurements. Fill gaps in existing models. Desire to integrate existing in-situ sensor networks. Compliance needs rigour in system. Quality and maintenance of data is important. Tend to focus on short term forecasting for risk management. Knowing the in-situ state plus flow is important to aquaculture. Visualisation tools need to be optimised.
Breakout 2 (A)	Early detection of nutrients and algal blooms. Timing of fish kills. Processes for mitigation/remediation. Freshwater flows and hydrodynamics. Particularly into estuaries. Algal species. Submarine freshwater discharge. Detection of aquatic macrophyte extent. Environment release dams.	Nutrients and algal blooms. Dimensions of water bodies from many kilometres down to 10m. Water storages. Sediment. Blackwater events. DO and EC needed in-situ. Sources and fates of sediments. Water temperature & effects on native species. Temperature and DO Stratification.	Evaluating the effectiveness of environmental flows. Ability to mitigate HAPS by flushing/diluting. Ability to improve monitoring locations. Evaluating and managing overland flows... where is volume going. Remote detection of roll-over event in storage mixing.	Use EO as first flag for early detection of anomalies. Helps to improve monitoring locations. Also, early detection allows flushing to mitigate the impact of HABs. Desire to integrate existing in-situ sensor networks. Data compatibility, interoperability with existing data analytics systems and provision of interpretation ready data is wanted.
Breakout 3 (T.Malthus)	Natural capital accounts (NCA) – the focus. Defined as the asset that nature provides that up to now have been exploited by industry with that service currently unrecognised and potentially exploited unsustainably. Rivers, creeks, farm dams, lakes. Support biodiversity and fairness of water use. Measure impacts of industry. Drive behavioural change. Assessing the impact of changes implemented. Access to suitable new Aquaculture production sites. Where to locate new farms. Difficult to assess impacts in advance. Diseases can transport from one farm to another.	Blue green algae, and blackwater. Water flow. Nutrients. Hydrodynamics and interconnectedness. Long term changes and impacts of climate change. Sediment and dissolved oxygen. Pathogens. Wastewater and pollution movements around aquaculture farms. Near real-time measurements, and forecasting. Estimates of pollution and NO3 fluxes. Detection pollutants, flooding run-off, point sources. Temperature, salinity, turbidity, currents, pollutants, run off. Higher resolution and lower revisit freq. for primary industries. (e.g. < 10m accuracy but 5 days revisit OK)	Identifying new aquaculture sites. Early detection of HABs. Better ability to support NCAs. Aquaculture in shared use areas Allowing the systems to be developed to provide the financial incentives to reduce use. Secure crops, minimise environmental impacts, expand the industry. Metrics are based on scientific method, auditable and verifiable. Requires open-source approach to tools and data.	Determining impacts of new developments and interdependencies between aquaculture farms and other industries. Natural disasters – prediction, but historical analysis is also useful for site assessment/application process. Awareness of the environmental impacts of farming practices – sedimentation, eutrophication on the site and surrounds. Forecasting allows true early warning/risk mitigation. Implies AI and ML. Must make the data access user friendly. ARD and IRD wanted. Visualisation tools needed.

CSIRO Water Community Workshop – Feb 2020

	Main interests, key challenges and opportunities	Key water quality variables of interest	Scale of importance, or benefit	Related issues to consider
Breakout 1 (K. Joehnk)	Species detection, toxic strains, shifts in composition. Agricultural water usage. Emergency management for flood mapping – distribution, soil moisture; real-time delivery of data including analysis); equivalent specifications of satellite monitoring for their research areas (vegetation) commercial opportunities: flood damage, retaining ecosystem health requiring knowledge of watering; cyanotoxins in drinking water, recreational use, water supplies; direct water use for farmers, food source and quality for higher trophic levels (cyanobacteria), blackwater, fish kills. Water run-off from land use.	high special resolution <10m, cyanobacteria, blackwater, fish kills, water temperature, stratification, mixing, TSS loads, sediments, nutrients, coral reef health, chlorophyl in vegetation, fluorescence in vegetation near water. Approx. 10M ground resolution. Revisit time ~ daily for best chance at modelling bloom dynamics. Spectra of interest 350-1200nM. Spectral resolution ~ 10nM	Safety of drinking water Fish kills – biodiversity, aquaculture and recreation Toxins (why and when) Blackwater TSS and sediments	Need on ground sensors for toxicity and for species knowledge. Detection/modelling of where blooms occur will help with sensor deployment. Changes in population composition can be addressed with high revisit allowed by satellites. Continental coverage. Calibration and known accuracy is important. Augmented satellite sensor data helps with calibration, synchronisation. Data should be made available via a querying system. Forecasting need hindcasting bit resolved first. Nowcasting to observe changes in bloom. Forecasting time scale: a view days to weekly. seasonal forecasting of blooms not so useful (seasonality is known, magnitude is hard to predict)

Breakout 2 (A.Dekker)	Prawn Aquaculture-coastal areas 1 ha ponds; 1 to 1.5 m deep; kept turbid Agricultural: influence ag activity on WQ: 3 pollutants: sediment, nutrient bound to sediments, dissolved forms of N and pesticide residues; sediment bound P drives eutrophication, N affects marine ecosystems. Variability on (suitable) incoming water supplies. Acid Mine Drainage (AMD) can affect (very) small streams. Can also occur in natural systems acid Sulphate Soils- water conditions in tailings ponds (1 * 1 km). Mining below the water table (e.g. Pilbara) -massive draining of water => deposited elsewhere. On shore gas: water salinity an issue (is processed to remove salinity). Greenhouse gases big issue: CSIRO sensing gas in-situ. Erosion issues extensive grazing lands	Prawn Aquaculture: Nitrates, ammonia, toxic algae; DO and pH; Management issue play at 1-3 days; prediction is important Acid mine drainage (caused by acidic rocks oxidising & minerals) => needs spectral range extended from 900-2500 nm. For vegetation VIS-NIR-SWIR important. Estimating organic content TSM. TSM is visible => useful for PR. Better understanding flooding on edges of water ways. 5 to 10m great; 2 to 3 m even better. Approx. 10M ground resolution for mining / tailings dam applications.	Auditing and compliance the impacts of nutrients and pesticides etc. Land-based EO is being used in NRM management. Queensland; Improving nutrient/water management in cropping-detecting nutrient/water stress	Monitoring soil carbon (ref carbon farming-sequestration, depletion of soil carbon), vegetation. The future ESA hyperspectral mission CHIME is focusing in this area. For sensors - biofouling issues -can we mitigate? Aquaculture would like instrument sin each pond- costs are prohibitive now. Vicarious calibration of Earth radiance/reflectance is important. Interest in water quality modelling (hindcasting, nowcasting, forecasting)? N, Pesticides: looking at correlations with EO variables, data-assimilation. Any prediction beyond 3 days would be excellent using full assimilated data sources. Seek both ARD and IRD.

Appendix B End-user consultation workshop discussion sheet

The SmartSat CRC and CSIRO are committed to the health, safety and welfare of staff, partners, stakeholders and the broader environment. We are passionate about creating an inclusive workplace that promotes and values Diversity, Excellence & Impact, Innovation & Agility, Collaboration, and Integrity and we strive to constantly demonstrate these values through our behaviours.

1) With regards to water bodies and water quality, what are some of the key issues, challenges and opportunities that you (or your industry) are facing?

2) With regards to water bodies and water quality, what are some of the things you would like to detect?

3) What is the importance, or benefit, of being able to detect these things?

4) What functionality or performance measures of AquaWatch are most important, or useful to your industry?

5) What are the ways that Earth Observation data be combined with in-situ sensor data most effectively for your application?

6) Would you like to see existing in-situ sensor networks integrated into an AquaWatch system?

7) What kinds of data products would you like AquaWatch to provide (e.g. any considerations WRT format & presentation of data; the usefulness of raw data, post-processed data, analysis ready data, decision-ready data; considerations around data access and data archiving).

Appendix B.2 End-user consultation quantitative AquaWatch variable/requirement table

Variable/Requirement	Still Useful	Preferred	Stretch Goal	Notes, considerations and trade-offs
EO Satellite: Ground resolution				
EO Satellite: Orbital revisit time				
EO Satellite: Radiance levels / Dynamic Range				
EO Satellite: Compounds/Spectra of interest				
EO Satellite: Spectral resolution				
EO Satellite: Swathe or instantaneous FOV				
In-Situ Sensor Network: Sensor type and functionality				
In-Situ Sensor Network: Location and quantity				
Data Analytics: Pre-Processing and calibration functions				
Data Analytics: Post-Processing and processing pipeline functions				
Other				

These are difficult questions which are likely to have answers that are not clear cut. Information provided here does not need to be complete or accurate. In each case a best guess is more useful than no answer.

Appendix C Workshop participants and external stakeholders

The following list gives the names and sectors of organisations engaged throughout AquaWatch Australia Phase-0. There are ~140 organisations on this list.

Many attended the AquaWatch Australia Introductory Webcast (Sept. 2020) where we introduced the AquaWatch Australia Survey (October 2020). Most of these organisations were invited to participate in the End User Consultation workshops and good, representative cross section of them did.

Label	Sector
Australian Institute of Machine Learning	Academic
Adelaide University Ecology and Environment Department	Academic
Institute for Photonics and Advanced Sensing	Academic
Institute for Marine and Antarctic Studies	Academic
Curtin University	Academic
University of NSW	Academic
Australian National University	Academic
University of Queensland	Academic
Swinburne University	Academic
Bureau of Meteorology	Commonwealth Gov
Department of Agriculture, Water and Environment	Commonwealth Gov
Department of Industry, Science, Energy and Resources	Commonwealth Gov
Murray Darling Basin Authority	Commonwealth Gov
Geoscience Australia	Commonwealth Gov
Department of Infrastructure, Cities, Regional Development and Communications	Commonwealth Gov
Australian Geospatial-Intelligence Organisation	Commonwealth Gov
Integrated Marine Observing System	Commonwealth Gov
Great Barrier Reef Marine Park Authority	Commonwealth Gov
SmartSat CRC	Commonwealth Gov
Australian Space Agency	Commonwealth Gov
Australian Geospatial Intelligence Agency	Commonwealth Gov
Defence Science & Technology Group	Commonwealth Gov
Australian Centre for International Agriculture	Commonwealth Gov
Australian Centre for International Agricultural Research	Commonwealth Gov
Department of Prime Minister and Cabinet	Commonwealth Gov
Office of the Chief Scientist	Commonwealth Gov
Myriota	Space Industry
Saber Astronautics	Space Industry

Sitael	Space Industry
Inovor	Space Industry
BAE Systems	Space Industry
Ozius	Space Industry
Flurosat	Space Industry
Earthspace	Space Industry
Gilmour Aerospace	Space Industry
Cosine	Space Industry
Leonardo	Space Industry
Surrey Sat	Space Industry
Frontier SI	Industry
SatDek	Space Industry
Murray Regional Tourism	Industry
Yumbah Aquaculture	Industry
Digital Content Analysis Ltd	Industry
Alluvium	Industry
Rivers and Wetlands	Industry
Minderoo Group Pty Ltd	Industry
Hydro Tasmania	Industry
Coffey International Development	Industry
Sydney Water	Industry
TasWater	Industry
Austral Fisheries	Industry
Wine Australia	Industry
Fisheries Research and Development Corporation	Industry
Melbourne Water	Industry
SE Water	Industry
City West Water	Industry
Western Water	Industry
Yarra Valley Water	Industry
Central Gippsland Water	Industry
Grampians Wimmera Mallee Water	Industry
Hunter Water	Industry
Coliban Water	Industry
Goulburn-Murray Water	Industry
NT Power & Water	Industry
SEQ Water	Industry
Barwon Water	Industry
Icon Water	Industry

Central Highlands Water	Industry
Veolia	Industry
Wannon Water	Industry
BHP	Industry
DCAT	Industry
Tassal	Industry
Huon	Industry
Humpty Doo	Industry
Fusion Farming	Industry
Precision Pastoral	Industry
National Farmers Federation	Industry
Cotton Research and Development	Industry
AgriFutures	Industry
Canegrowers	Industry
Ricegrowers	Industry
Cotton Australia	Industry
Consolidated Pastoral Company	Industry
Meat and Livestock Australia	Industry
Great Barrier Reef Foundation	NGO
Earth Observation Australia	NGO
Northern Basin Aboriginal Nations	NGO
Ngarrindjeri Regional Authority	NGO
Derwent Estuary Program	NGO
Queensland Water Directorate	NGO
NSW Water Directorate	NGO
NSW Smart Sensor Network	NGO
Mackay-Whitsunday-Isaac Healthy Rivers to Reef Partnership	NGO
Defence Materials Teaming Centre	NGO
Hobart City Council	Local Gov
City of Launceston Council	Local Gov
Kingborough Council	Local Gov
Cairns Council	Local Gov
Orange Council	Local Gov
Goulburn Valley Water	Local Gov
Water Research Australia	Research Inst
Defence Innovation Partnership	Research Inst
Goyder Institute	Research Inst

Tasmanian Institute of Agriculture	Research Inst
Environmental Protection Agency Tasmania	State Gov
Office of the Coordinator-General (TAS)	State Gov
Department of Premier and Cabinet (TAS)	State Gov
Department of Primary Industries, Parks, Water and Env (TAS)	State Gov
TAS Water	State Gov
Department of State Growth (TAS)	State Gov
Department of Primary Industries (NSW)	State Gov
Natural Resources Access Regulator (NSW)	State Gov
Water NSW	State Gov
Defence NSW	State Gov
Department of Planning, Industry and Environment (NSW)	State Gov
Chief Scientist (NSW)	State Gov
Department of Environment, Parks and Water Security (NT)	Territory Gov
Department of the Chief Minister and Cabinet (NT)	Territory Gov
Department of Trade, Business and Innovation (NT)	Territory Gov
Department of Resources (QLD)	State Gov
Department of Environment and Science (QLD)	State Gov
Department of Natural Resources, Mines and Energy (QLD)	State Gov
Department of Environment and Water (SA)	State Gov
Chief Scientist (SA)	State Gov
South Australian Space Industry Centre	State Gov
Environmental Protection Agency Victoria	State Gov
Victorian Environmental Water Holder	State Gov
Department of Environment, Land, Water and Planning (VIC)	State Gov
Goulburn Broken Catchment Management Authority (VIC)	State Gov
Office of the Victorian Lead Scientist	State Gov
Commissioner for Sustainability and the Environment (ACT)	Territory Gov
Environment, Planning and Sustainable Development Directorate (ACT)	Territory Gov
South Australian Research and Development Institute	State Gov
SA Water	State Gov
WA Water Corp	State Gov
Chief Scientist (WA)	State Gov
Western Australian Government	State Gov
Department of Water and Environmental Regulation (WA)	State Gov

Appendix C Acronyms

AI	-	Artificial Intelligence
AMD	-	Acid Mine Drainage
ARD	-	Analysis Ready Data
BGA	-	Blue Green Algae
BoM	-	Bureau of Meteorology
CDF	-	Concurrent Design Facility
CDOM	-	Coloured Dissolved Organic Matter
CHL	-	Chlorophyll-a
CYP	-	Cyanobacteria or Cyanophycocyanin
CSIRO	-	Commonwealth Scientific Industrial Research Organisation
CEOS	-	Committee on Earth Observing Satellites
DO	-	Dissolved Oxygen
EO	-	Earth Observation
ESA	-	European Space Agency
EUAG	-	End User Advisory Group
FOV	-	Field Of View
GA	-	Geoscience Australia
GBR	-	Great Barrier Reef
GEO	-	Geo Synchronous Satellite
HAB	-	Harmful Algal Bloom
IP	-	Intellectual Property
IRD	-	Interpretation Ready Data
LEO	-	Low Earth Orbit Satellite
LIDAR	-	Light Detection and Ranging
MDB	-	Murray Darling Basin
MIR	-	Mid Infrared wavelengths
ML	-	Machine Learning
NCA	-	National Capital Accounts
NGO	-	National Governmental Organisation
NIR	-	Nearby Infrared wavelengths
NRT	-	Near Real Time
POP	-	Persistent Organic Pollutant
SD	-	Secchi Disk Depth
SEEA	-	System of Economic Environmental Accounting
SWIR	-	Short Wave Infra-Red

TSM	-	Total Suspended Matter
TURB	-	Turbidity
VIS	-	Visible
WQ	-	Water Quality
WRT	-	With Regards To

As Australia's national science agency and innovation catalyst, CSIRO is solving the greatest challenges through innovative science and technology.

CSIRO. Unlocking a better future for everyone.

Contact us

1300 363 400

+61 3 9545 2176

csiroenquiries@csiro.au

csiro.au

For further information

AquaWatch Australia Mission

Dr Alex Held

AquaWatch@csiro.au

USER INFORMED INDUSTRY DRIVEN RESEARCH POWERED

SMARTSAT
COOPERATIVE RESEARCH CENTRE

Australia's Premier Space Research Centre

Australian Government
Department of Industry, Science and Resources

AusIndustry
Cooperative Research Centres Program

SmartSat CRC Head Office:
Lot Fourteen, Level 2, McEwin Building
North Terrace, Adelaide, SA

info@smartsatcrc.com
smartsatcrc.com