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TECHNICAL REPORT AQW-3

Preliminary In Situ Sensor Networks Strategy Green Paper

(PRELIMINARY REPORT)

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AquaWatch Australia Mission

In Situ Sensor Networks - Strategy Green Paper

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Summary of intent

This green paper is intended to stimulate discussions in the conceptualisation and planning of the AquaWatch Australia Mission in situ sensor network. The paper identifies the broad roles that the network will play in the mission and identifies a potential pathway for a cost-effective approach based on the Internet of Things. Some of the key issues and challenges to be addressed are also identified as are potential opportunities for technological innovation.

We invite AquaWatch International and National Science Committee discussion, comment and contributions on the proposed in situ sensor network plan. After this process the concept will become a white paper for wider distribution.

The AquaWatch Australia mission

To overcome the lack of a comprehensive, monitoring system for Australia’s fresh- and coastal waters, the AquaWatch Australia mission proposes the establishment of an integrated ground-to-space national monitoring platform for Australia by 2026. This will be achieved by the integration of three components: specially designed satellite sensors, 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. Working with partners to deliver the innovation required, the AquaWatch Australia mission will deliver timely information to water agencies, local communities and industry and commercial water users, as well as enable decision makers to support industry, manage human or animal health impacts and better manage ecosystem health. The mission is seen as partnership between government, industry and research and is designed to grow Australia’s space and environmental monitoring industries whilst ensuring sustainable environmental outcomes.

In situ networks

The aim of this white paper is to draft strategic directions for the AquaWatch Australia Mission in situ sensor network for internal and external partners. This will be part of the overall sensor strategy that may be adopted.

The engagement process envisaged is as follows:

1. CSIRO experts in sensors and associated technologies. Relevant expertise and transferable learnings reside in Data61 (AI/ML, IoT), NCMI, O&A, Minerals (new Autonomous Sensing Future Science Platform - FSP), A&F (Digiscape, nutrient detection, automated data QA/QC).
2. National experts (including the AquaWatch National Science Advisory Group) in sensors and associated technologies, including the SmartSat CRC.
3. AquaWatch International Science Advisory Group.

There is a continuing and increasing need for water quality information from across Australia's inland and coastal systems, but current data are of limited availability and traditional sampling approaches are both costly and impart a delay to the availability of that information for any action to be initiated. In situ sensor networks are a cost-efficient means to monitor water quality, particularly in remote basins. It is also recognised that Australia's in situ water quality networks are sparse and disjointed due to increasing costs and declining resources to support monitoring programs. Deployments may be short-lived as monitoring priorities change over time. Access to the data from such current in situ sensor systems is sometimes patchy.

The approach to sensor networks for the AquaWatch Australia mission is to leverage on existing monitoring infrastructure and augment these with new sensor packages to extend geographical coverage and frequency and to broaden the water quality parameters to be measured. The network is seen as having value in its own right and is thus to be designed in a way that is independent from the successful delivery of the satellite components of the AquaWatch mission.

Key aims will focus on 1) a sensor network that is cost-effective to construct and operate, easy to maintain; 2) from which the data obtained is robust and credible and offers information appropriate for decision making; 3) access to the data is both open and timely delivered, and 4) synergy with airborne and space borne platforms is high.

In situ monitoring and its utility for AquaWatch

In situ monitoring will address different requirements for the AquaWatch Australia mission, each requiring potentially different sensor capabilities. The challenge in implementing this component of the AquaWatch Mission will be in ensuring sufficient sensors are deployed to satisfy each role. This section summarises these different roles of a) satellite geophysical signal calibration and validation; b) satellite water quality product validation and c) extending to water quality parameters that cannot be measured by remote sensing.

1. Satellite calibration and validation

It is envisaged that AquaWatch satellite sensor data may be provided to end users as Analysis Ready Data (Level 1 – surface reflectance), or Interpretation Ready Data (Level 2 - data products and higher). *Vicarious calibration* and *validation*, involving independent surface-based observations, provide the means for independent verification of these output products and to provide estimates of uncertainties in the data products produced. Additionally, there will be a need for ongoing validation of the satellite raw radiances (vicarious calibration) to track sensor degradation in space. Sensor observations required include above surface radiance/reflectance, aerosol optical properties (and other meteorological data), in situ optical characteristics (in water light absorption, scattering, attenuation and backscattering).

Australia already has some existing satellite calibration and validation facilities along with best practice, largely developed via national research infrastructure initiatives (e.g. IMOS, TERN). Leveraging off these existing satellite calibration and validation facilities, and integrated into the AusCalVal proposal[1], we propose to develop a small network of in situ measurement and monitoring stations (Table 1) is proposed to cover a range of water types (coastal and inland) and different water and aerosol types. These stations may be further augmented with sensors to deliver measurements relevant to the other requirements of the AquaWatch sensor network outlined below. Measurement of atmospheric optical properties can also be extended using the AeroSpan network of sensors.

Table 1. Potential sites for AquaWatch Australia mission satellite calibration and validation

RECOMMENDED SITES	WATER TYPE	EXISTING (YES/NO)	MEASUREMENT VARIABLES	COST
Lucinda Jetty Coastal Observatory	Optically complex coastal waters	Yes	Above-water surface hyperspectral reflectance Aerosol optical properties Conductivity Temperature Dissolved oxygen Algal pigments Turbidity CDOM Particulate/dissolved spectral absorption and attenuation Total backscattering Weather parameters Total suspended matter	IMOS/CSIRO funded, $300k annual maintenance and lab costs. $1M establishment costs
Rottnest Island (MarONet)	Blue coastal waters	Installation in 2022, operational 2023	Above-water surface hyperspectral reflectance Aerosol optical properties	~US$10M
Lake Argyle site	Blue inland water	No	Above-water surface reflectance Aerosol optical properties In situ water quality variables	na

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[1] AusCalVal 2021. Establishing Australia as a global leader in delivering quality assured satellite earth observation data. An initiative of the Australian Earth Observation community. 27 May 2021. (https://frontiersi.com.au/auscalval/)

RECOMMENDED SITES	WATER TYPE	EXISTING (YES/NO)	MEASUREMENT VARIABLES	COST
Cotter Dam	Dark water target	No	Above-water surface reflectance Aerosol optical properties In situ water quality parameters	na

2. Direct satellite product validation

In situ sensors capable of providing estimations of water quality parameters directly measurable by satellite sensing will be required to be geographically dispersed across the Australian continent. Such a network is required for the verification of satellite data products (i.e. interpretation ready data) and validation of the of algorithms used to derive the data products. Critical satellite data products will include estimated pigment concentrations (chlorophyll and cyanobacterial pigments), suspended sediment, CDOM, turbidity/Secchi disk transparency/vertical attenuation of downwelling irradiance, freshwater macrophytes, bathymetry and substratum cover reflectance. The measurement of these water quality and benthic parameters also is required for parameterisation and validation of models developed as part of the activities in the data analytics component of the AquaWatch Australia mission. For some parameters periodic verification of the measures by the sensors may be required via laboratory analysis of water samples.

Table 2. Water quality variables and methods for direct satellite product validation

WATER QUALITY PARAMETER	MEASUREMENT RANGE REQUIRED (END USER DEFINED, UNITS)	LIMIT OF DETECTION	SENSOR OPTIONS (POTENTIAL APPROACHES)	LABORATORY METHOD	VALUE OF THE MEASUREMENT, COMMENT
Surface reflectance	400 – 800 nm <= 5 nm interval 0 – 50%	2%	Above surface spectroradiometer Autonomous in situ spectroradiometers	Possible determination of particulate absorption	Direct calibration against satellite, algorithm development, surface estimation of other water quality parameters, phytoplankton functional type
Water colour	21 colour Forel Ule scale	Within 1 colour class	Above water camera (mobile phone app such as Eye on Water Australia)	Spectrophotometric	Assessment of colour using Forel-Ule scale Citizen science capability
Chlorophyll	0 – 1000 mg Chl m^{-3}	1 mg m^{-3}	Above surface spectroradiometer In situ fluorometer	HPLC or similar extraction method (spectrophotometric)	Assessment of phytoplankton biomass and primary productivity; part of carbon budgets fluxes To measure development of eutrophication and measures to combat it, Trophic status
Phyco-biliproteins (cyano-phycocyanin and phycoerythrin)	0-1000 ug m^{-3}	na	Above surface spectroradiometer In situ fluorometer	HPLC or similar extraction method; (spectrophotometric)	Indication of cyanobacterial biomass; part of carbon budgets fluxes To measure development of eutrophication and measures to combat it; also to access level of potentially harmful algal blooms

WATER QUALITY PARAMETER	MEASUREMENT RANGE REQUIRED (END USER DEFINED, UNITS)	LIMIT OF DETECTION	SENSOR OPTIONS (POTENTIAL APPROACHES)	LABORATORY METHOD	VALUE OF THE MEASUREMENT, COMMENT
CDOM	Absorption at 400-440 nm 0.01-10 m^{-1}	0.01 m^{-1}	Above surface spectroradiometer In situ fluorometer	Spectrophotometric: Long pathlength absorption of filtered water	Level of tannins that discolour water and that need to be removed for drinking water purposes; part of carbon budgets fluxes, potential link to dissolved organic carbon
Turbidity	Scatter at ~550 nm Nephelometric units	2 NTU	Turbidity sensor Optical, e.g. Above surface spectroradiometer	Turbidity meter; (spectrophotometric)	Simple measure, related to combination of phytoplankton biomass, sediment concentrations and water clarity NTU units need translation into backscattering characteristics or attenuation
Transparency	Depth (m)	10 cm	Secchi Disk PAR sensor chain	na	Simple measure of water clarity using simple tools Citizen science capability
Vertical attenuation of diffuse downwelling irradiance (kd*)	Units: m^{-1}	0.01 m^{-1}	Chains of PAR or spectral sensors	na	Exact determination of vertical spectral distribution and quantity of light available for photosynthesis in the water column and at the benthos
Total suspended matter	Units: 0-300 g m^{-3}	0.1 mg m^{-3}	Turbidity sensor Optical, e.g. Above surface spectroradiometer	Gravimetric analysis of filtered samples Seston dry weight split into organic and inorganic fractions	Understand erosion rates; sediment transport rates, sedimentation rates (especially in reservoirs); wears down turbines in hydro-electric energy systems

3. Extending water quality parameters not measured by satellite

For the three components of the AquaWatch Australia mission (satellite, in situ network and data analytics) to be most relevant to water quality agencies and other end users, a range of other key water quality parameters will need to be measured which **are not able to be directly determined by optical remote sensing**. Similarly, measurements may need to be made at different levels in the water column to determine vertical stratification in water quality parameters and to assist in the assessment of 3D structure as determined from models. These parameters may not be measured at all sites but may be deployed where it best suits end user's needs.

Table 3. Extended water quality parameters for sensor networks (to be completed…)

WATER QUALITY PARAMETER	MEASUREMENT RANGE REQUIRED (END USER DEFINED) UNITS	LIMIT OF DETECTION	SENSOR OPTIONS (POTENTIAL APPROACHES	LABORATORY METHOD	VALUE OF THE MEASUREMENT, COMMENT
Temperature	0 – 40 °C	0.2 °C	Thermocouple chain	na	Thermal stratification, water circulation, flow regime
Dissolved Oxygen	mg l^{-1} Percent saturation	0.2 mg l^{-1}	DO electrode	DO electrode Winkler titration	Habitability of water to life Product of in situ photosynthesis Consumed in respiration - link to oxygen demand and depletion, fish kill events, blackwater events Link to temperature, altitude, salinity
Electrical conductivity	Units: mho/cm (Siemens)	2 umhos/cm	Conductivity electrode	Conductivity electrode	Measure of the amount of salts (ions) in the water Related to salinity Value for drinking, irrigation water quality
pH	0-14 pH units	0.1 pH units	pH electrode Colorimetric test kits/strip	pH electrode	Measure of water acidity/alkalinity Habitability of water to life Drinking water quality Buffering capacity of the water
Salinity			Electrical conductivity	Electrical conductivity Total dissolved solids	Measure of the amount of dissolved particles and ions in water Drinking/irrigation water quality in freshwaters Link to evaporation processes Link to soil salinity
Stage height	Height (m)	1 cm	Level recorders Camera observations of stage height post, local landmark		Related to water discharge Citizen science capability
Wind direction and speed	m sec^{-1} Degrees bearing	10 degrees	Anemometer	Na Potentially from nearby weather records	Informs mixing and surface bloom dispersal
Algal cell counts and identification	Phytoplankton species and class	Key classes: Cyanobacteria Dinoflagellates Diatoms	In situ fluorometer Above surface spectroradiometer (links to phytoplankton functional types)	Microscopic identification and enumeration Biovolume calculation	Direct link to WHO drinking and recreational use water quality guidelines

WATER QUALITY PARAMETER	MEASUREMENT RANGE REQUIRED (END USER DEFINED) UNITS	LIMIT OF DETECTION	SENSOR OPTIONS (POTENTIAL APPROACHES	LABORATORY METHOD	VALUE OF THE MEASUREMENT, COMMENT
Nitrate/nitrite	mg l^{-1}	0.05 mg l^{-1}	Optical (UV) Reagent based microfluidics	Reagent based colorimetric approaches Nitrate/nitrate Total Nitrogen (Kjeldahl digestion and colorimetry) Ion chromatography	Key nutrient available for plant growth (nitrate) Nitrite link to human health (methemoglobinemia) Link to terrestrial pollution sources/eutrophication Key challenge is: low limits of detection to meet those observed in natural waters, potentially labour intensive
Phosphate	mg l^{-1}	0.05 mg l^{-1}	Reagent based Microfluidics	Colorimetric analysis Soluble reactive phosphorus (PO_4^-) Total phosphorus (Kjeldahl digestion and colorimetry) Ion chromatography	Key form of nutrient phosphorus available for plant growth Link to terrestrial pollution sources/eutrophication Key challenge is: low limits of detection to meet those observed in natural waters, potentially labour intensive
Toxins			Rapid in-field toxin tests/reagents	Toxin tests/reagents	
Heavy metals	Cadmium Copper Lead Zinc Etc…		??	Solid phase extraction Gas chromatography/ Mass spectrometry (GC/MS)	Measures of water toxicity at high concentrations Potential to cause adverse effects in aquatic organisms when elevated Link to drinking water quality standards/human health Biproducts of mining and other industrial activity Potential to accumulate in waterbody sediments
Organic micropollutants	ug l^{-1}			Solid phase extraction GC/MS High resolution mass spectrometry	Indication of industrial, urban pollution, shipping Characterized by their persistence, bioaccumulation, toxicity in aquatic ecosystems Needs a prioritized list of key pollutants to focus on
Pesticides and herbicides	ug l^{-1}	~0.05 ug l^{-1}	ELISA kits (colorimetric method)	Solid phase extraction Gas chromatography/ Mass spectrometry (GC/MS) ELISA kits	Indication of agricultural, urban pollution

WATER QUALITY PARAMETER	MEASUREMENT RANGE REQUIRED (END USER DEFINED) UNITS	LIMIT OF DETECTION	SENSOR OPTIONS (POTENTIAL APPROACHES	LABORATORY METHOD	VALUE OF THE MEASUREMENT, COMMENT
				2D fluorescence correlation spectroscopy	
E.coli			Rapid assessment not available? High density microarrays? Possibility for ecogenomics (DNA/RNA extraction)	Selective cell culture Biochemical methods Molecular methods Laboratory qPCR methods	Indication of industrial, urban pollution, shipping Link to disease, human and animal health Molecular methods have greater sensitivity, faster in analysis
ecoGenomics			In situ samplers In situ analysers	Laboratory qPCR methods	Identification of: Presence of pathogens Biodiversity Potential for bloom toxicity Invasive species
Oil detection, hydrocarbon detection			Multichannel fluorometers, particle analysers to detect dissolved and suspended oil components in water In-line VOC analysis Infrared spectroscopy	Gas chromatography SAR based satellite detection of oil and oil movement	Indication of industrial, urban pollution, shipping Degree of pollution and movement

Internet of Things (IoT) sensor networks

Internet of Things (IoT) networks employ wireless communications across 5G, fixed aerial, long range (LoRa), or satellite networks to collect and monitor data from dispersed sensors and to provide remote control of the sensors themselves. Often those monitoring and control elements are provided by AI/ML-based software components. Smarts allows for dynamic control in real time to control, for example, sampling frequency and limits to the duty cycle.

Low-cost sensors are essential to realise the concept of IoT, to provide ubiquitous, autonomous sensing in both spatial and temporal domains, and that is cheap, portable and fast in response time. Current suitable Commercial-Off-the-Shelf (COtS) sensors are expensive and poorly adapted to IoT technologies and thus are economically unviable for large scale adoption for water quality management at scale; low-cost sensors suitable for IoT adoption are still largely in the research domain.

A new suite of devices will be needed to deliver an economically viable approach to be embedded in platforms suitable for IoT adoption. As with current COtS sensors, such new sensors will need to deliver adequate specificity, sensitivity and reliability when integrated into a network of measurement modes. Realisation in an Australian-wide water quality monitoring network for the number of sensor nodes that is envisaged will require a considerable degree of innovation in the sensors used, and potentially in how they are deployed (fixed, or on moving platforms (ships of opportunity, UAV's, remotely operated vehicles, robotics). Other key goals include their ease of calibration and low frequency of maintenance (self-cleaning/self-calibrating).

New sensors will need to be innovatively constructed for IoT systems that are characterised by resource constraints: in communication capabilities, energy, processing capabilities and limited data storage. Each of these constraints will influence sensor design, operation mode and sampling rate, on-board processing and type and rate of communication.

Similarly, key elements and challenges in an IoT water quality sensor network that will need to be overcome include (in relative order of importance):

- Robustness
- Reliability and maintainability
- Availability
- Interoperability and flexibility
- Unit cost (manufacture and deployment)

Other challenges that are more solvable include:

- Integration
- Scalability
- QA/QC
- Standards and protocols
- Security
- Development of robust AI/ML approaches

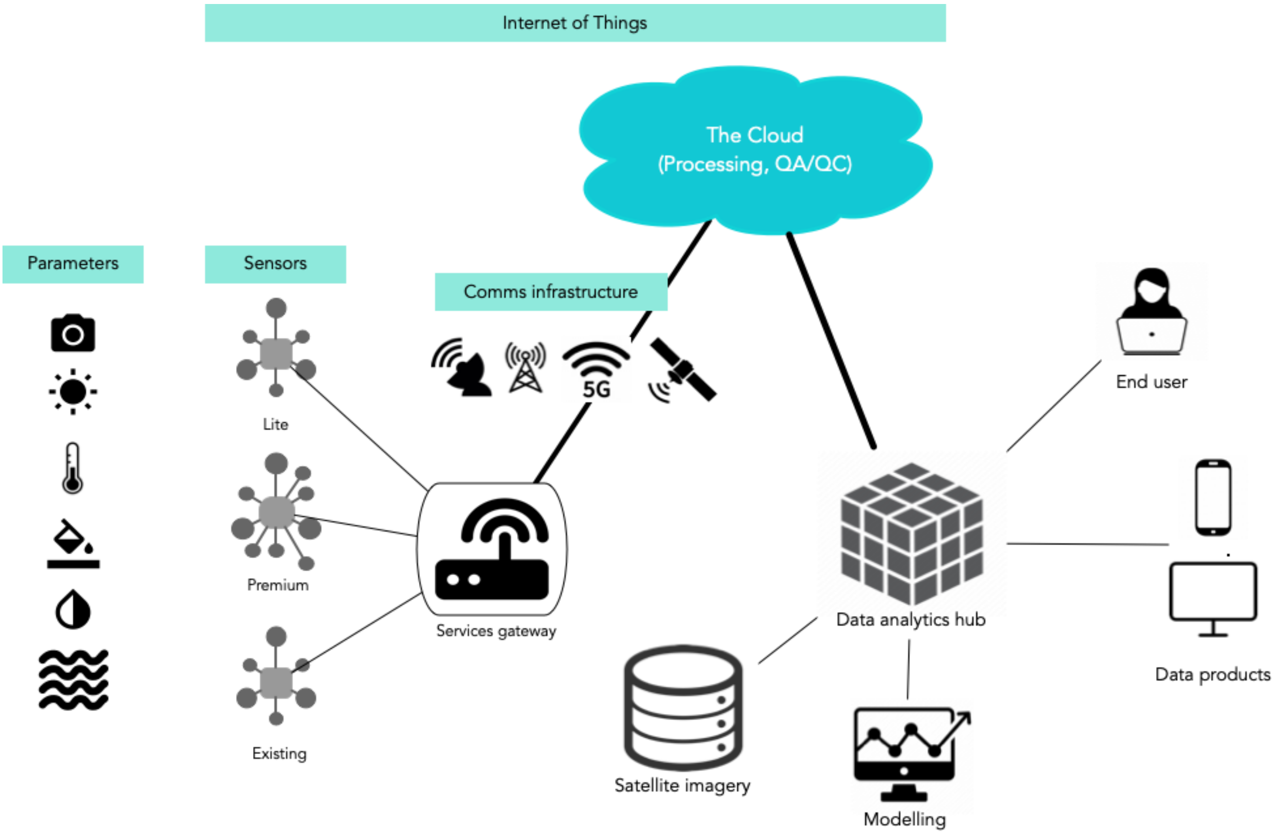
Energy efficiency and data storage and transmission may be the most important and challenging matters in a dynamic IoT network along with their setting up and maintaining. A focus on energy harvesting, its storage and optimisation/management will be required to minimise the size and hence cost, of any photovoltaics required. Smart operations may include either time-based or event-driven architectures.

While still in its relative infancy, in the future IoT networks will be self-organising, self-managing and self-configuring but the risk of their proliferation in the longer term is the fragmentation of the IoT solutions themselves. In the context of the AquaWatch Australia mission project it is proposed that an IoT solution to the in-situ sensor package is pursued with development in terms of three perspectives:

- **Sensors** – development of robust but cost-effective sensor solutions for different water quality parameters, as well as platforms for their prolonged deployment (e.g. fixed stations, buoys, etc.).

- **Platforms** - comprising the data logger, data storage, power supply, remote control, onboard data processing and data telemetry.
- **Software** - comprising data management and storage, embedded QA/QC, variable quantification and smart data analytics, and dashboard, alert and report generation.

Proposed solution



Proposed sensor package solution

To meet AquaWatch Australia mission in situ sensor network objectives, it is proposed that two newly engineered autonomously operating devices are developed:

- “Lite” - integrating simplified HydraSpectra surface reflectance, temperature, CHL, CPC, CPE, CDOM, Kd, Secchi Disk transparency, turbidity, salinity, conductivity, pH, DO; with IoT capability only
- "Premium" - integrating HydraSpectra surface reflectance, temperature, turbidity, salinity, CHL, CPC, CPE, CDOM, Kd, Secchi Disk transparency conductivity, pH, DO, Nitrogen, depth, Phosphorus; with IOT and 4G connectivity options. Innovation could be detection using novel methods for heavy metals, organic micropollutants, bacterial contamination etc.

Key sensor considerations will be cost, limits of detection, precision and functional range to track abnormal water quality events. Engineering will need to include the need for remote operations, powering options, communication requirements and security/privacy procedures. Thus, sensor network establishment costs will need to include the non-recurring engineering (NRE) to design the sensors and associated platforms (could be contracted), satellite and 4G/5G data delivery, other operating establishment costs, development of the data delivery platform and ongoing compute infrastructure service (AWS, Azure etc.).

Annual operational costs will need to include data management (QA/QC), compute infrastructure, in-field device maintenance, central operating, management labour and management and science oversight.

Operational requirements/considerations:

Other operational requirements required include:

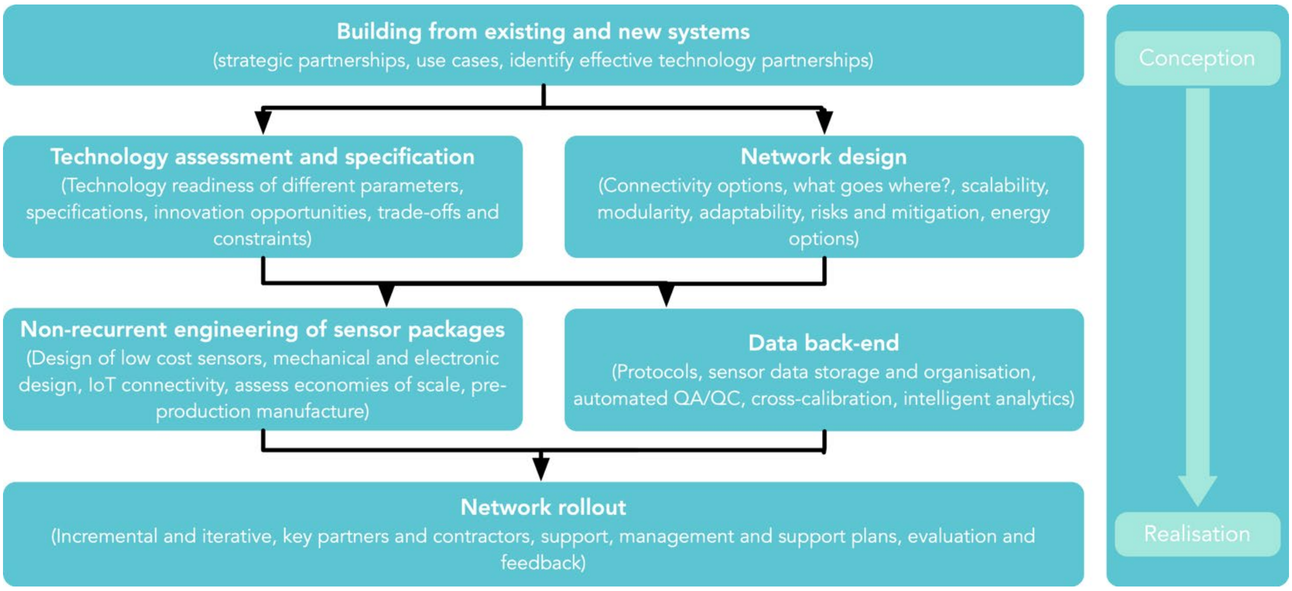
- **Selection and establishment of the network of sites** to be instrumented. Earth observation data and hydrodynamical modelling can provide optimal location and distribution.
- **Scalability** of the network – the network is proposed to be a modular one such that sensor packages may be added and withdrawn, and that new services can be added with ease to enable network extensibility. Extensibility may also include the **development of a mobile app** enabling reporting via a concerned citizens network.
- **Extreme events** – the installations will need to resiliently withstand extremes of flow and flood.
- The need for a high level of **data interoperability**. The adoption of an open data policy is proposed, using open formats and protocols where data storage and access employs a cloud-based model that is, within the available budget, scalable to meet storage and processing requirements. To potentially suit the concerns of some collaborating agencies, an option to restrict (via encryption) access to potentially sensitive data may also be included.
- To the point that it is possible, there will be a need for a **standardised set of protocols covering installation, calibration, operating practices and laboratory and data analytics.** These would ideally be developed in collaboration with key stakeholders to ensure strict implementation. There may be a large diversity of instrumentation deployed. A series of inter-laboratory calibration tests would also ensure inter-laboratory comparability.
- **Long-term viability**.

Associated technologies and roles for innovation

There will be a key role for innovation in development of sensors, communications and in intelligent systems for autonomy, data integration and data analysis, to meet the goals of the AquaWatch Australia mission. These innovations will be tied with wider Australian initiatives driving the development of sensors and will draw on co-support from other funding agencies such as the SmartSat Cooperative Research Centre, and state-based groups such as the NSW Smart Sensing Network. Key foci for innovation may include:

- **Communication technologies**: the use of combined broadband (4G/5G/6G) and Internet of Things (IoT) communication to enable high bandwidth and ubiquitous communication to both receive sensor data and enable wireless remote control of sensors across the Australian continent. The potential to include satellite-based data processing on IoT
- **Next generation cheap and accurate water quality sensors,** suited for prolonged operation dispersed across the harsh Australian environment, and with the goals of improved power efficiency, increased autonomy, miniaturisation, high frequency observing, low maintenance, low need for calibration or self-calibration, and on-board intelligent processing,
- Development of **intelligent data integration** systems with increased decision making, exploiting the rapid advances and sophistication of AI/ML.
- **Next gen sensing** covering:
    - The measurement of **water quantity** (amount and flow) in the environment.
    - The development of **next generation underwater optics sensors** for determination of inherent optical properties which provide the link between remotely sensed algorithms and water quality parameters and hence to data assimilation.
    - Bathymetry and bottom reflectance
    - Underwater acoustics – underwater profilers, depth, flow (Doppler)
    - Low-cost tethered underwater for broadscale shallow marine water survey (e.g. CSIRO Vertigo3 glider);
    - Underwater high resolution multispectral imaging (e.g. CSIRO Coryceaus underwater multispectral camera for automated marine habitat assessment)
    - Automated sampling technologies (e.g. CSIRO Khong and STAN automated DNA samplers and associated technologies).
- **Improved sensor coatings** for marine and freshwater use such as the **non-toxic low-fouling surfaces** showing considerable promise developed by CSIRO's Manufacturing Business Unit.
- Alternatives to temperature, salinity and monitoring using Raman techniques. (e.g. at Macquarie University). Possible depth profiling.
- The development of biosensors and related technologies for the assessment of toxins.

Proposed pathway forward



Project phases in detail:

1. **Building from existing and new systems**
    - Build a strategic partnership with key stakeholders - establishment of key partnerships, key stakeholders (e.g. with water utilities, state governments, IMOS for existing marine deployments, TERN, NSSN, industry...)
    - Development of potential use cases to focus on (e.g. algal blooms, turbidity events)
    - Assessment of current in situ infrastructure for water quality monitoring, review of existing regional water quality monitoring networks in Australia and globally
    - Who owns and operates it?
    - Where is it located? Why is it located there?
    - What is being monitored and how are data transferred?
    - What is the data used for and how is it being analysed?
    - How widely is the data and results being disseminated?
    - What is the willingness of the operator to release water quality data to the AquaWatch Australia mission?
    - Ease of incorporation into an AquaWatch Australia mission wireless sensor network
    - How can the existing and proposed new node(s) be augmented?
    - Learnings from the AquaWatch pilot projects (e.g. differences between freshwater and marine deployments)
    - Identify effective technology partners

2. **Technology assessment and specification**
    - Work with key stakeholders to provide different application scenarios, informed by the AquaWatch end user analysis
    - A review of water quality detection methods, picking likely winners for IoT devices
    - Assessment of technology readiness

- Definitive statements around limits of detection and measurement ranges
- Aiming for common set of measurements
- Exploration of the scope to which existing sensors can be re-engineered into an IoT compatible and low-cost format
- Trade-offs and constraints
- Energy and comms efficiencies
- Development and evaluation of protocol standardization process

3. **Non-recurrent engineering of sensor package**
    - Design of the low-cost sensors
    - Mechanical design updates (Design for Manufacture, Design for Environment, Design for Assembly, Design for Test).
    - Electronic design updates (Integration of 4G and Satellite IOT radio, Design for Manufacture, Design for Test)
    - Design of IoT connectivity and protocols
    - Focused on autonomy
    - Assessment of economies of scale, optimise unit cost
    - Pre-production manufacture, roll-out and verification

4. **Designing the network**
    - Review of the approaches that can be taken (e.g. 5G, fixed aerial, LoRa, or satellite networks). What's feasible for Australia?
    - What new systems can be used to enhance existing network elements?
    - Focus on scalability, adaptability and modularity
    - Risks and mitigation
    - Methods to optimize sensor placement - what criteria will be used to locate them? How many sensors do we need?
    - Energy: powering the network

5. **The data back-end**
    - These tools can be developed in an agile evolutionary environment which is advantageous in terms of early results and managing risks
    - Review of current approaches to sensor data storage and organisation
    - Comms protocols
    - Automated QA and QC of data streams
    - Intelligent 'fault finding' - cross calibration etc.
    - Data protocols and organisation
    - The compute and storage backbone
    - Design of intelligent analytics tools
    - Optimised integration into the AquaWatch Data Analytics component, for incorporation with satellite data and for visualisation

6. **Network rollout**
    - The IOT sensor network allows an incremental and iterative approach to roll out, which is beneficial in terms of getting results early and for managing the overall project risk
    - Establishment of key partners and contractors
    - Collect simultaneous supportive sensor measurement and lab sample analysis for cal/val.
    - Management plan
    - Maintenance plan
    - Support plan
    - Costing plan
    - Ensure strict implementation of standard operating protocols
    - Evaluation and feedback

Benefits and distinctive features

The approach outlined here confers a number of key benefits over the existing dispersed approach to water quality sensing in Australia, and to the AquaWatch Australia mission itself in seeing the in-situ sensor networks component developed and implemented. These benefits include:

- Builds credibility by working closely with stakeholders
- A large-scale sensor network with national coverage
- Potential to develop regional/global models
- Integration with EO data products and modelling outputs
- Standardized and streamlined operating protocols to ensure data quality
- Automated data QA/QC, including the use of AI/ML tools
- Smart data analytics for enhanced analyte quantification and classification
- Dashboard with interactive visualization
- Report generation function for informed decision making
- Backed by CSIRO's R&D strength and background IP
- Build credibility of the mission through working closely with stakeholders in multiple representative pilot projects in Australia.
- A large scale and living testbed that allows for the deployment, testing, cross-comparison and validation of various sensing technologies
- Potentially breaks the bottleneck for new technology adoption at scale

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